AN INTERACTIVE ENERGY DESIGN AND SIMULATION TOOL FOR BUILDING DESIGNERS

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ABSTRACT

This paper discusses a detailed building energy simulation model that has been made available to the building designer through a graphic user interface. The simulation model uses hourly energy calculations driven by an hourly weather data generator. Capabilities of the simulation portion include: monthly energy loads and utility bill predictions, peak load analysis, demand charge evaluations, life-cycle cost: analysis, and floating space temperature prediction for comfort analysis in passive designs.

The visual interface program is written to operate under the Windows environment, thus allowing the user to freely choose the sequence of events in describing -the building and its energy parameters. This visual interface consists of a mouse-operated drawing tool as well as custom-designed pop-down screens that permit: the user to rapidly access standardized data bases. These data bases are populated with default values describing wall, roof, and window assemblies, occupancy schedules, lighting and HVAC systems and schedules, temperature profiles, and economic parameters.

This tool permits iterative inputs, results examination, and changes in the building design without leaving the Windows environment. It has the ability to help the building designer with new building designs as well as retrofit designs, and can be useful for pre-checking the building design for code compliance. Detailed simulations also allow for examination of energy savings from daylighting, alternative building envelope designs, thermal envelope insulation, and efficient HVAC systems.

INTRODUCTION

The amount of energy consumed by a building is governed largely by the building's form and thermal characteristics. Thus, it is actually the building designer who has the primary control over the building's energy use (Meyer 1983). To avoid major flaws of the design that might not be discovered until the later stage of the design process, building designers need to include the evaluations of the building's energy early in the design process. Unfortunately, many of the currently available energy analysis tools are not oriented toward building designers. The typical tool requires a very detailed description of the building as well as the mechanical systems — neither of which are available in the earlier stages of a design process (Clarke 1989, Degelman and Kim 1991). In addition, many of these tools lack effective visualization capabilities. As a result, building designers find it burdensome to include energy considerations in the design process, and so energy analyses are regularly delayed until after the building has been completely designed (Huang et al. 1992).

In an attempt to remedy this situation, the authors have developed a visually oriented energy simulation tool intended for building designers. Although this tool uses detailed hourly energy calculations, the user inputs are simple and are kept to a minimum. The weather data generator of this program is directly accessible from the energy simulation package and thus eliminates the need to rely on outside sources for weather tapes — a common problem that plagues many other energy simulation packages (Degelman 1991). The visual interface program, which is written to operate under the Windows environment on microcomputers, allows the user to be in full control of the sequence of steps for describing the building, accessing the databases, running the energy simulation, and reviewing the outputs (Degelman and Soebarto 1994). Quick turn around allows the designer to effectively evaluate the building's energy use and change the building design or properties to meet an energy target while the design is still in its infant stages.

FUNDAMENTAL CONCEPTS

The development of ENER-WIN was based on the recognition of several simple premises. The first of these is that building designers often have to make design decisions with very little detailed information available to them (Lawson 1990). The second is that the earlier information can be made available, the better the chance of having a successful and economical design. Third, the simpler the information and the easier it is to access, the higher the likelihood that it will be utilized.

Recognizing these premises, the ENER-WIN software was developed to have fast access to databases, short run times, and preliminary building and system default descriptors. Then, to make the program easy to use, it was designed with a convenient user-oriented interface program that connects the user to the energy simulation program and the databases.

SOFTWARE MODULES

The ENER-WIN software has been built from several modules — an interface module, a weather data filing and retrieving module, a sketching module, and an energy simulation module. Because it is important to provide the building designer with an easy-to-use tool, the interface module was written in a way that it would allow the sequence of program operations to be at the discretion of the user while examining a building. Visual Basic (by Microsoft), that runs under the Windows environment, was selected for the programming language for the interface module. Visual Basic is an *event-driven* and *object-oriented* programming language. Its visual interface permits the user to quickly input and modify the data, and to rapidly execute the simulation program and access the standardized databases.

The other three modules had originally been developed as stand-alone programs, so they were left in their original languages, and are called and executed by the interface module. The weather data generator was written in FORTRAN-77, while the weather filer and retriever was written in Quick Basic. The sketching program was written in C, and the energy simulation program was written in FORTRAN-77. The content of the databases as well as the tabular reports are written in ASCII text formats. In the final step, Visual Basic is used again to produce several graphical output screens. The linkages between the modules in ENER-WIN are shown in Figure 1.

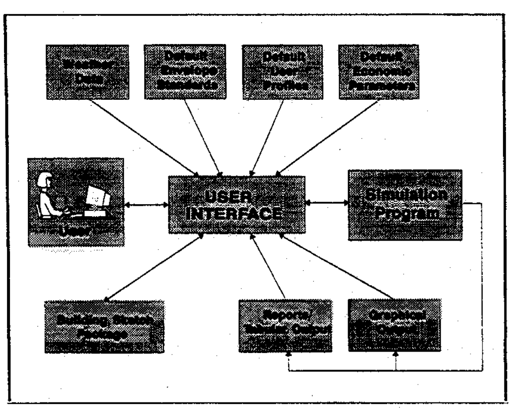

Fig. 1. Conceptual linkage of ENER-WIN modules.

GENERAL OPERATIONAL OVERVIEW

There are only 3 types of basic inputs that are required by the ENER-WIN program in order to simulate a building: (1) the building type, (2) the building's location, and (3) the building's geometrical data. After a building type has been selected from the menu selections, numerous default data will be brought automatically into the program [Fig. 2]. These default data include economics parameters, number of occupied days and holidays, typical occupancy and hot water usage schedules, lighting and HVAC systems and schedules, temperature settings, and other typical parameters for the selected building type.

The building location will be entered by selecting the city name from the weather database, and the geometric data can be entered by sketching the building zones. Once the weather data and the building geometry have been input, and the user is willing to accept the default data given by the program, the energy simulation program can be executed. To optimize the building energy use or to analyze other design alternatives, the user is then encouraged to change any of the building parameters that needs to be modified, using the breakdown of the energy simulation results as the guidance. Some alternatives may include the use of daylight, efficient building envelope designs, efficient thermal envelope insulations, and efficient HVAC systems.

WEATHER DATA SEQUENCES AND OPTIONS

Weather data generation is done hour-by-hour, producing the variables of dry-bulb temperature, dewpoint temperature, wind speed, sun angles, cloud cover fraction, direct insolation, and diffuse insolation. Luminous values used for daylighting computations are derived from the thermal radiation by use of a luminous efficacy algorithm. Equations

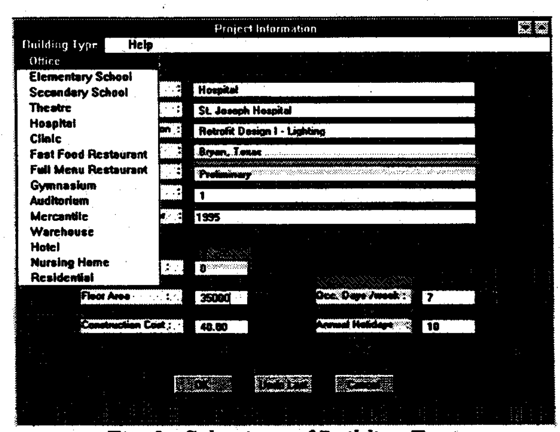

Fig. 2. Selections of Building Types

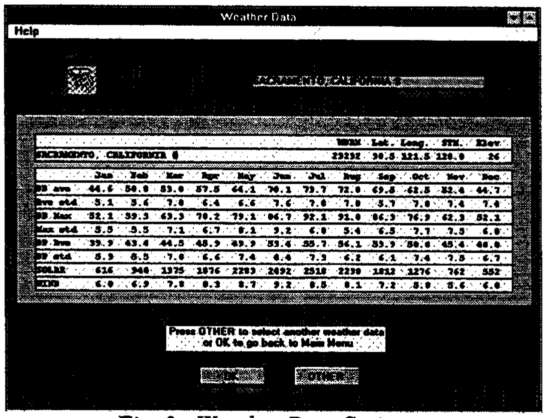

Fig. 3. Weather Data Summary

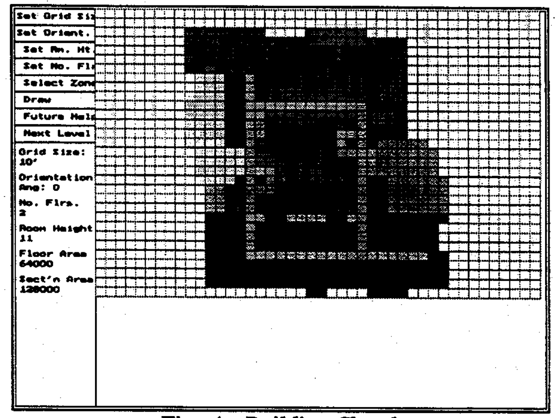
Fig. 4. Building Sketch

used in the weather simulation model and data compression techniques as well as details on sun angle and radiation calculations are described in separate publications (Degelman 1991, 1990, 1970). Input to the model comes from statistical summaries of monthly means and standard deviations derived from the National Solar Radiation Data Base from 1961 through 1990. Currently, the weather database contains around 239 U.S. cities and 40 foreign sites. Figure 3 shows the summary of the weather data that will be presented in one of the ENER-WIN interface screen.

The program permits various simulation run periods to facilitate different simulation objectives. When only a quick estimation is needed — as is the case when the building designer wants to explore several building designs — a one-week-per-month simulation is sufficient. On the other hand, a full-month simulation is recommended when sizing the HVAC equipment. A full-month simulation will perform the simulation for all 8670 hours in a year. Table 1 shows an example of the variations in the predicted annual energy consumption in an office building when using different simulation lengths.

Table 1.
Results of Simulations of Different Lengths for a 4-Story Office Building

Wks/ month	Energy use Btu/sq.ft.yr.	Energy cost $/sq.ft.	Total Present Worth $/sq.ft.	Run Time (sec)*	Degree Days (H/C)
1	102.0	0.67	63.39	33	3107 / 1127
2	102.4	0.69	63.63	54	2997 / 1034
3	103.5	0.72	64.91	75	2960 / 1042
4	103.5	0.72	64.49	105	2956 / 1031

* Computer was an Intel 486/DX4-100 Mhz running under Windows 3.11

BUILDING DESCRIPTION METHODS

A. Sketching Interface

ENER-WIN uses a simple sketching program that allows the user to sketch the building's HVAC zones and specify the geometrical parameters, such as, the number of floors in the building, the floor-to-floor heights, and the building orientation (Degelman and Huang 1993). The user can specify up to 10 zones on every floor. Zones are simply represented in plan by different colors [Fig. 4]. After the sketching process is complete, a drawing processor will analyze the geometrical conditions, and automatically add the floor and the roof areas to the building. A very important capability of this processor is that it is able to analyze how the walls are shaded by adjoining and outside structures.

B. Zone Processing.

ENER-WIN will analyze the inputs given by the drawing processor and put the data into the Zone Description screen for every zone [Fig. 5]. The software automatically collects the building envelope sizes and orientations that "belong" to each zone. The only geometrical parameters that have to be added manually are the window sizes and any additional shading devices such as overhangs and light shelves. In addition, non-geometrical parameters, such as the wall, roof, and window materials, can be specified either by accepting the default envelope materials, modifying the thermal properties of the default materials, or simply adding new envelope materials to the envelope materials catalogs.

For each zone, the program maintains a catalog of floor area, ceiling height, interior mass, annual use schedules, lighting type, mechanical system type, heating fuel for space and hot water, economizer ventilation, and daylighting dimmers. Peak values for occupancy, hot water use, ventilation, lighting, and equipment are also specified and linked to their respective schedule numbers. Modifications of these schedules can be done through the built-in user profile catalogs.

C. Input of Reference Catalogs

Envelope Materials Cataloging permits any wall, roof, or glazing assembly to be specified and entered in a simple, numbered catalog. Each assembly is defined by its name, thickness, thermal conductivity, thermal capacitance, density, and absorptivity of the outside surface to solar radiation. Glazing assemblies require input of overall thermal conductance, thermal radiation transmissivity, emissivity, and luminous transmissivity. Cost per unit area is also required if life-cycle costing is to be performed. The ENER-WIN program presents tables of default opaque and glazed assemblies for the user's selection. Figure 6 shows the wall assemblies catalog in ENER-WIN.

User Profile Cataloging permits the user to specify up to 50 different daily profiles defining the hourly occupancy, hot water usage, lighting and appliance loads, ventilation rates, normal summer and winter temperature settings (including setbacks), and holiday summer and winter temperature setbacks. ENER-WIN provides a default set of profiles based on the building type selected. However, as the design becomes more detailed, these values may easily be modified according to the activity type in a particular zone. New profiles can also be added and stored for later reference and use.

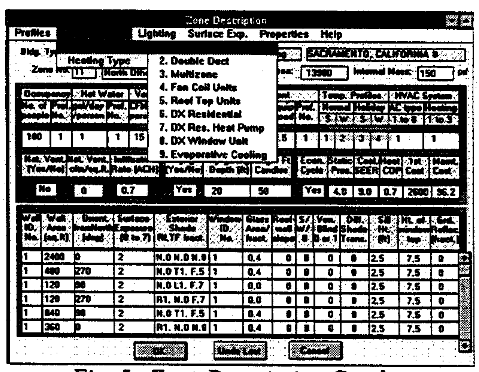

Fig. 5. Zone Description Catalog

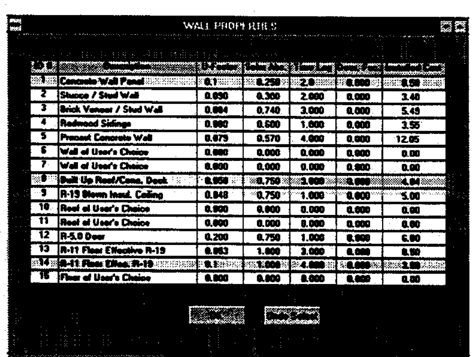

Fig. 6. Wall Material Catalog

ENERGY SIMULATION PROCEDURES

Load Calculations, System Simulations, and Energy Summations are performed simultaneously each hour, beginning at 1:00 a.m. on January 1 and ending at 12:00 a.m. on January 1 of the next year. Heat transfer through walls and roofs are handled by a transient heat balance technique based on sol-air temperature, time lag, and decrement factor (Degelman 1990).

The instantaneous conducted gains react to the history of exterior weather conditions and the actual interior temperature, which is constantly changing within its dead band range. The zone temperature changes are not assumed to cause a load until the upper or lower limit of the dead band is exceeded. At that point the conditioning equipment is turned on in response to the amount of load present. Convective gains are translated into loads immediately, while the radiative gains are delayed by weighting factors for each source of heat. The absorbed radiative gains are re-released later into the space at a rate governed by convective heat transfer coefficients and the temperature differential between the internal mass and the zone temperature. The interior thermal mass, therefore, plays an important role in the response of these internal temperature movements. This is unlike some other hourly simulation models which may fix the interior temperature while calculating loads and then run a second systems simulation cycle in order to determine the energy usage.

Daylighting algorithms are based on a modified Daylight Factor method wherein the source of daylight incident on the glass is calculated from an efficacy equation which converts the incident thermal radiation to luminous radiation (Gillette and Treado 1985). Based on the availability of daylight, a dimmer control is assumed to lower the electric for lights accordingly.

The software contains a data base of prototypical system types which are assumed to be able to handle the loads when they occur. Initially, the system is sized based on the peak load conditions in the hottest and coldest months. As the simulation proceeds, the system may be resized if a higher load is encountered at some other time of the year. The energy calculations are based on default system efficiencies, typically the Seasonal Energy Efficiency Ratio (SEER) and Coefficient of Performance (COP) values, which the user may change during the input stage.

The program also has the capability of simulating the floating space temperature for comfort analyses in passively heated and cooled buildings. The results

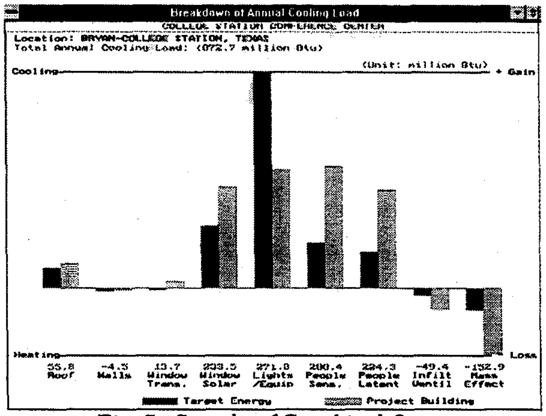

Fig. 7. Sample of Graphical Output

include the hourly space temperatures and Mean Radiant Temperatures (MRT's) over the 24 hours of a day for several seasons throughout the year. A comfort evaluation is made and is expressed in terms of "discomfort degree-hours", which is the weighted sum of temperatures outside the ASHRAE thermal comfort zone.

PROGRAM OUTPUT

Output from ENER-WIN is available in both tabular and graphic forms. During the design process, the user will normally want to gain a more qualitative evaluation in graphical forms that quickly shows the problems to the user [Fig. 7]. Later a higher level of detail may be desired by viewing the tabular results. The tabular results will consist of the following outputs: breakdown of monthly energy loads and utility bill predictions, energy savings from utilizing daylight, peak load analyses, demand charge evaluations, 24-hour energy use profiles, and life-cycle cost of the building in terms of the present.

The Life-Cycle Cost Prediction is the final step in the program procedures. First costs for the building are computed by the program based on the unit costs of walls, windows, and roofs from the assemblies catalog. Additional first costs include the lighting system and the mechanical system. A "Present Worth" analysis is then performed on the future recurring costs of fuel, electric, and maintenance. These calculations are based on fuel price escalation rates and opportunity interest rates.

EXAMPLE PROJECT

The simulation model has been applied to the renovation of a conference center to recommend the most effective strategy for reducing the building's utility bills. Several alternatives to be investigated included upgrading the ceiling insulation to R-27, introducing roof-top multi-zone gas-heat HVAC units, and introducing an energy management system. The result showed that the combination of these three alternatives was actually the best solution. With this, it was predicted that about 30 percent of the previous electric bill could be saved.

Historical records for the conference center's energy use were obtained for a two-year period preceeding the renovation. After the renovation, the energy performance has been recorded for about 3 years. The recorded results show that the annual electric use has actually been reduced by 38 percent. The most recent records have confirmed that the savings continue and are fairly close to that predicted by the simulation.

Figure 8 shows the recorded monthly electric consumption from the year prior to the renovation and the year following the renovation. For comparison purposes, the energy use predicted by the ENER-WIN software is shown by month for the year following the renovation. The fact that the weather data used by the software was for a 30-year average and was not adjusted for the "actual" year of weather made little difference in the model's ability to reasonably predict the effects of the renovation.

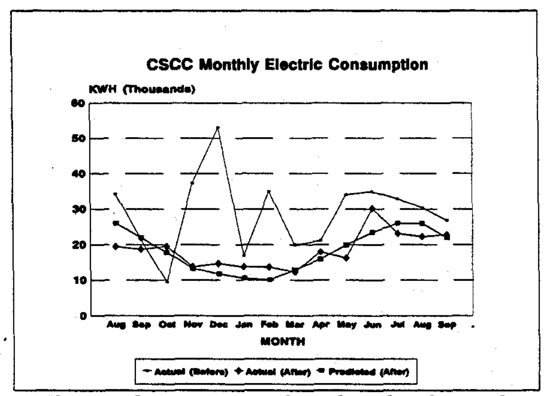

Fig. 8. Comparisons of Predicted and Actual Monthly Energy Use

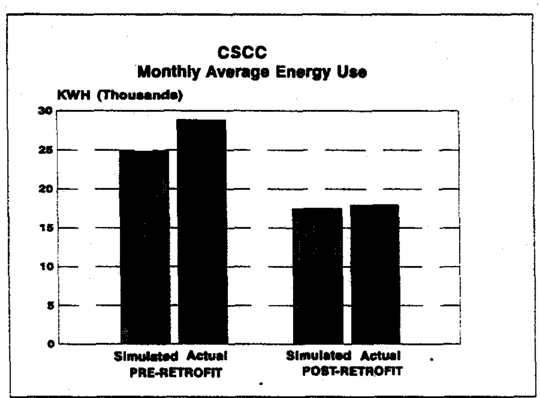

Fig. 9. Comparisons of Simulated and Actual Overall Energy Use

Figure 9 shows the overall electric energy use from pre- and post-retrofit periods compared to that simulated. The pre-retrofit simulation was not calibrated to the actual utility records, but close agreement was still maintained between the post-retrofit measured data and that predicted by the software model.

CONCLUSIONS

An interactive visual design and energy simulation tool has been developed to provide building designers with an easy-to-use tool that can be used during the design process, either for new buildings or retrofits. The program may also be used later for checking for energy code compliance. Several information databases enable the program to function in the "energy advisor" role in a way that will help assure the design's compliance with local energy codes.

To make the program more useful for retrofit designs, the authors are currently developing an automation method for disaggregating the energy consumption components in an existing building and then calibrating the computer-predicted values to the real building's utility data. This automation tool will be linked to the current energy analysis program, and the whole package will help to identify current energy problems in existing buildings, as well as defining new solutions to improve the energy performance of the buildings.

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