# AN INTELLIGENT FRONT END FOR BUILDING ENERGY SIMULATION ON MICROCOMPUTER ENVIRONMENT

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## ABSTRACT

This paper discusses recent efforts to develop an intelligent front end (IFE) for a building energy simulation model using a readily available expert system shell. Currently a number of dependable energy simulation models exist for the energy assessment of buildings. However, use of these simulation models involves one problem with respect to the data input process. Usually, detailed building energy simulation models require somewhat rigorous input information from users regardless of the design stage or application domain. Thus, utilizing databases and rulebases properly developed for intelligent input process, an IFE can be designed to interface between the user and a detailed building energy simulation model.

With this IFE approach, energy simulation models will be more easily accessible by building designers to test their design hypotheses during preliminary design stage. This also minimizes the involvement of the energy specialist at every stage of energy simulation. This study constitutes one step toward the development of integrated computer-aided building design (CABD) system, for which there is currently much effort being made by many different research sectors.

## INTRODUCTION

Currently, a number of dependable and well-known energy simulation models are available for the energy assessment of the building. Most of these building energy simulation models are simplified versions of mainframe analytical models originally developed for research purposes [Papamichael and Selkowitz 1990]. Thus, the input files required by such simulation models comprise of numbered fields, which has made understanding and developing the input data both difficult and error prone. Utilizing a building description language which has a certain syntax and grammar instead of formatted-field input file, was an important step toward a better user interface [Byrne 1990]. In spite of the adoption of building description language interpreter into the simulation model, such detailed simulation models are considered intricate to use due to the requirement of very rigorous input information about the building from users [Clarke et al. 1989]. Subsequently, many practicing architects regard the use of such simulation models as a tedious task that frequently requires the assistance of a building energy specialist during the design process. The unavailability of a detailed description of a building at the preliminary design stage also prevents building designers from adequately testing their design variables [Jog 1990]. Consequently, with such difficulties, final building designs do not usually reflect advanced energy concepts that are implemented in the detailed simulation models, and they have produced a large number of less energy- efficient buildings due to lack of detailed analysis with an energy simulation model [Degelman 1990].

This research aims to develop an intelligent front end for a building energy simulation model utilizing a readily available expert system shell (CLIPS). The program is still under development; however, the overall structure and its features will be discussed. Virtually, this IFE model can be applied to wide variety of building energy simulation models. In this research, ENERCALC (ENERgy CALCulations for buildings) [Degelman 1989] is modeled for the demonstration of its applicability. This intelligent front end system (ENERife) generates input information required for a simulation model intelligently and sends it to the simulation model as an input file under the MS-DOS environment. The system consists of a User Interface Module, a System Interface Controller, an Input File Generation Module, a General Database Handling Module, an Error Avoidance Handling Knowledge Base, and an Energy Advisor Knowledge Base.

## BACKGROUND

### Building Energy Simulation & Interface

Traditionally, building designers have utilized many disparate calculation techniques to quantify building energy performance during their design process. The professional handbooks abound with such techniques, regarded by many as the ultimate tools for design appraisal. A steady state U-value calculation is invoked to quantify envelope heat loss, and the degree-day method is still used to achieve an estimate of long-term energy requirements [Clarke 1988]. However, the model assumed in this method (steady-state unidirectional heat flow) hardly occurs in the real world.

From the mid 1970s, the frequency domain response factors, weighting factors, and energy balance technique were employed in building energy simulation modeling [LBL. 1979]. The predictive validity is increased substantially by these models; however, simulation models developed with this methodology require extremely detailed input data which are not always available to the building designer at a preliminary design stage. This point actually makes it difficult for building designers to take advantage of such advanced energy simulation models during the design process, even though those building designers are supposed to be the major users of building energy simulation models.

Several possible solutions have been suggested, i.e., input interfaces which attempt to minimize the occurrence of input errors [Barnaby 1989; Brown 1990; Clarke 1989; Quadrel and Kroner 1985; Schmitt 1987; Schuman et al. 1988], implementation of previously created input/output files for a detailed simulation model in a database [Huang et al. 1989], and graphical output analysis which can simplify mounds of output [Haberl et al. 1988; Jog 1990], etc. The most critical issue, however, is how to have the expertise of energy specialists made readily available to conventional building designers during their design process.

### Knowledge-based System

In spite of the rapid development of computing hardware systems, much less efforts have been placed into software engineering that could provide developmental diversity of application programs. In this regard, we must still wait until artificial intelligence (AI) matures. Recently, to solve ill-structured problems, it is frequently proposed that we utilize knowledge-based systems (KBS) from the field of artificial intelligence. It is still unknown whether the development of the AI area will provide the application software variety of intelligence that is required, since most research utilizing knowledge-based system is narrowed down to a specific domain. However, it is considered that such an approach is a natural consequence because computer is not only needed to add, subtract, multiply, and divide, but also to act human, to deal with symbolic, nonalgorithmic procedures [Wolfgram 1987].

In spite of the considerable attention attracted by the knowledge-based system in recent years, the knowledge-based system have been regarded as very high-cost artificial intelligence systems, because they have typically required sophisticated hardware/software resources (usually Lisp machines), so only a few Fortune 500 companies and the government could afford them [Wolfgram et al. 1987].

Recently, the Artificial Intelligence Section (AIS) at NASA/Johnson Space Center developed an expert system shell written in and integrated with the C language [Culbert 1989]. The 'C' Language Integrated Production System (CLIPS), available from COSMIC, the NASA software distribution center, is selected as the system prototypic environment. Since it is available for almost any hardware type and is available in source code form, CLIPS is becoming one of the most popular system shells for expert system development [Pohl et al. 1989]. The primary representation for CLIPS is a forward chaining, pattern matching and rule based methodology. The basic elements of CLIPS are fact-list, knowledge-base, and inference engine. Facts are very important since an expert system written in CLIPS is a data-driven program where the facts are the data that stimulate execution [Giarratano 1988].

## SYSTEM STRUCTURE

### Development

Input information for the energy simulation model must constitute the overall description of the building which is to be simulated, in terms of energy usage. The input information for ENERCALC consists of nine component modules, under four main elements: weather information, envelop material information, user profile information, and zone description [Degelman 1990].

There are two distinct approaches for the generation of input information in ENERife. With the help of the General Database Handling Module, a user can easily generate the initial part of building information description such as weather data, building material data, and typical building profile data. After that, the user can produce detailed building zone information either in conventional method (when detailed information is available or if the building is a post-design retrofit) or with Automated Information Generation Routines (e.g., preliminary design stage).

If the task is not a simple modification of an existing building, ENERife starts to collect primary information from the user. The primary information consists of fundamental building description such as, building location, floor area, envelop type, etc. In the collection process, the system collects information mainly from building databases based on the facts defined by the user. Through the checking routines, the system also conducts verification for the information at each module as well as inter-module verification for conflicting data. An input file for ENERCALC is then generated after the inter-module checking has been completed (Fig. 1).

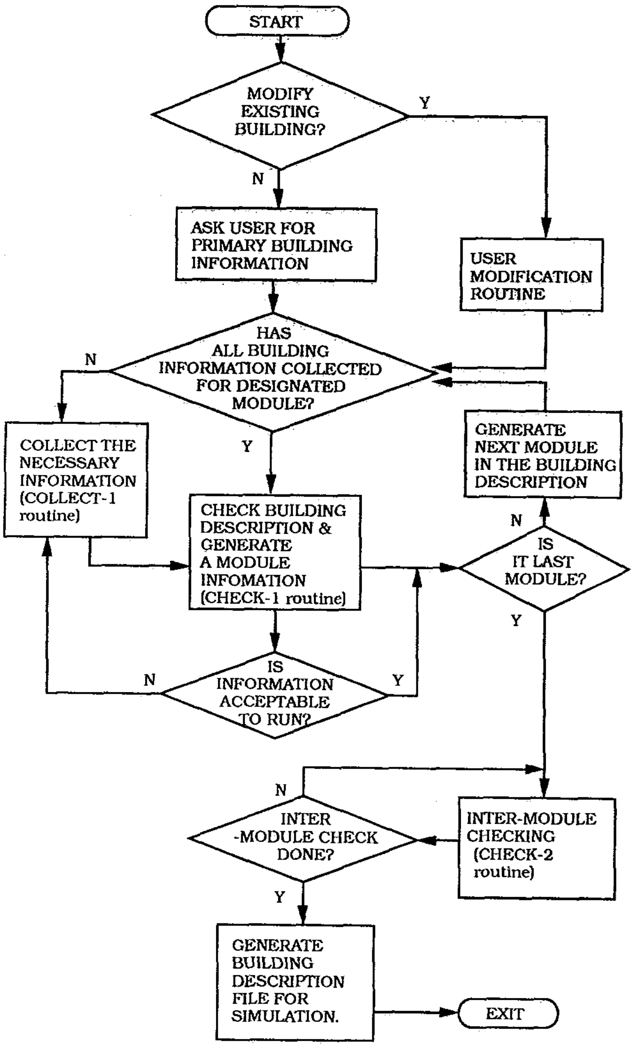

Figure 1. Flow chart describing logical analysis routines for ENERife.

System Interface Controller

Currently, this module controls interface between knowledge bases, user interface module, and input file generation module. As the system expands in the future, the role of this control system become also important to handle complicate manipulation between different knowledge bases. The implementation of a blackboard control system is being considered to accommodate such intricate manipulation.

I/O Handling Routines

Mainly, ENERife interfaces with standard text file for its I/O handling. Since CLIPS is capable of calling external routines written in C for use on both LHS (left-hand side) and RHS (right-hand side) of rules, the implementation of I/O handling modules developed in C is being considered.

User Interface Module. Through the user interface module, a user actually converses with the program and reviews generated information. This module employs a windowing and menu selection system on the screen like a conventional program interface. It is constructed with a menu tree (i.e., main menu and subsequent sub-menus) and several dialogue screens.

Input Information Generation Module. Input information for the simulation module is generated in plain ASCII text format for the simulation of the building. The component modules are: (1) project identification, (2) weather information, (3) economic information, (4) opaque envelop properties, (5) windows and skylight properties, (6) hourly profile information, (7) basic building description, (8) zone properties and identification, and (9) envelop component information.

| | | | | | | | | WBAN | Lat. | Long. | STM. | Elev |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUSTIN, TEXAS | | | | | | | | 13958 | 30.3 | 97.7 | 90.0 | 597 |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| DB ave | 49.7 | 53.3 | 59.5 | 68.6 | 75.2 | 81.6 | 84.6 | 84.7 | 78.9 | 70.1 | 59.1 | 52.3 |
| Ave std | 8.4 | 8.3 | 8.0 | 6.1 | 3.9 | 3.2 | 5.5 | 4.8 | 3.9 | 5.5 | 6.9 | 8.4 |
| DB Max | 60.0 | 63.8 | 70.7 | 79.0 | 85.2 | 91.7 | 95.4 | 95.9 | 89.4 | 81.3 | 70.2 | 63.0 |
| Max std | 9.7 | 9.4 | 8.8 | 6.1 | 4.5 | 3.6 | 4.4 | 3.3 | 4.4 | 4.7 | 6.7 | 8.7 |
| DP Ave | 38.0 | 42.0 | 45.0 | 55.0 | 64.0 | 68.0 | 69.0 | 68.0 | 65.0 | 56.0 | 46.0 | 41.0 |
| DP std | 9.1 | 8.9 | 8.4 | 6.1 | 4.2 | 3.4 | 4.9 | 4.0 | 4.1 | 5.1 | 6.8 | 8.5 |
| SOLAR | 865 | 1125 | 1429 | 1605 | 1834 | 2072 | 2106 | 1931 | 1606 | 1333 | 987 | 825 |
| WIND | 9.8 | 10.2 | 11.0 | 10.7 | 9.8 | 9.5 | 8.5 | 8.1 | 8.0 | 8.1 | 9.2 | 9.2 |

Figure 2. Sample statistical weather information for ENERCALC weather data.

### General Database Handling Module

Currently, this module handles the weather database, material database, profile database, and economic database. It can be easily extended to accommodate other databases. The structure of the building type database can be different from tabular information so that the handling is very complicated [Snyder and Chirica 1990]. However, to make the retrieval process easy in ENERife, the building type information is divided into two different databases at present, i.e., profile database and economic database.

Weather Database. At the moment, weather information for 194 major U.S. cities is available. ENERCALC has a unique hourly weather data generation routine [Degelman 1990; Degelman 1991]. The required basic information consists of the following weather statistics: (1) city name, latitude, longitude, local standard time meridian, and elevation above sea level, (2) monthly average dry-bulb temperatures, (3) standard deviations for monthly average dry-bulb temperatures, (4) monthly average maximum dry-bulb temperatures, (5) standard deviations for monthly average maximum dry-bulb temperatures, (6) monthly average dew-point temperatures, (7) standard deviations for monthly average dew-point temperatures, (8) monthly average daily horizontal insolation, and (9) monthly average wind speeds [Degelman and Kim 1990]. Each set of weather data can be retrieved easily by state names [Degelman 1990]. This database can be expanded by users with statistical information as mentioned above (Fig. 2).

Material Database. Currently, this database contains 76 different wall, roof, and glazing assemblies. Any specific wall, roof or glazing assembly can be added by the user. A separate database is under development utilizing each individual material with its thermal properties as a layer of construction in the assembly. With this method, variety of building envelop systems could be constructed easily by assembling layers of materials [ASHRAE. 1989].

Code/Standard Database. This database has not yet been realized in the program. Actually, development of this database involves a very complicated code-checking knowledge base and control strategies. The importance of this database and future implementation are indicated in a diagram (Fig. 3). This will be reported on after the completion of some future research project.

Building Type and Profile Database. The ENERife generates eight different daily usage profiles based on 14 generic building types: (1) building occupancy, (2) domestic hot water usage, (3) equipment operation, (4) lighting, (5) summer occupied temperatures, (6) winter occupied temperatures, (7) summer unoccupied temperatures, and (8) winter unoccupied temperatures.

### Error Avoidance Knowledge Base

The error avoidance knowledge base contains information about building configuration limits and bounds. For example, the sum of zone areas would never be permitted to exceed the total building floor area; nor would the area of glazing on a wall be permitted to exceed the total wall area. There are two types of error avoidance: the first type is denoted as the NP (not possible) set. The two previous statements are exemplary of this type error. The second error is denoted as the NL (not likely) set. In this case, the data depict logical bounds (e.g., percent glazing, type of mechanical system, and fan static pressures based on the building type selected).

The NP error set actually indicates a conflict in the input and a resolution must be made before the system will proceed. The NL set initiates a dialogue with the user and will proceed after the user's intent is verified by both sides.

### Energy Advisor Knowledge Base

This knowledge base is being developed utilizing several building energy guidelines and ASHRAE standards. Such building design guidelines provide prescribed input criteria to produce nominal building description in terms of energy usage. Proper implementation of appropriate rules has to be emphasized and the further expansion of this knowledge base will make the system behave more intelligently.

## **CONCLUSIONS**

ENERife can be identified as an application which involves primarily a data processing task requiring experience, rather than a creative thinking process. The system performs routine steps to handle major parts of the data. The remaining tasks require decisions based on experience or professional skill. ENERife may be found both as an expert assistant program used by the expert to process some already automated information, and also as an expert advisor system which is used by non-experts to increase their level of performance. The forward chaining inference engine is suitable for an accompanying application which processes data stream.

Further research will focus on the enhancement of each component module of present ENERife and development of an intelligent energy management system which will include both result recovery system and this IFE.

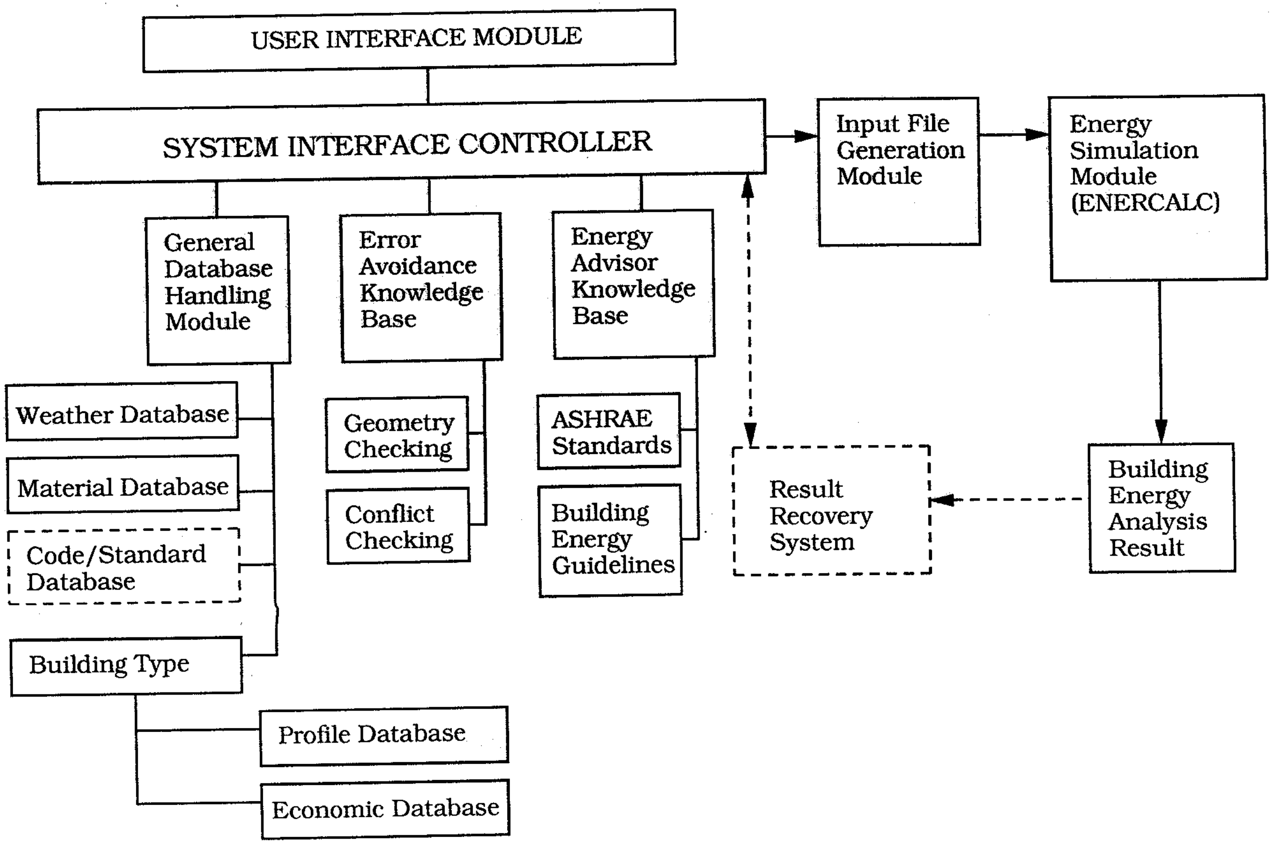

Figure 3. ENERife System Structure Diagram.

## ACKNOWLEDGEMENTS

Partial support for this research was provided by the Center for Energy and Mineral Resources of Texas A&M University. Another gratitude is extended to Dr. Joe A. Clarke of University of Strathclyde for letting authors have opportunity to review their recent workdone concerning IFE model.

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