Computer-Based Evaluation and Criticism for the Design of Energy-Efficient Buildings

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INTRODUCTION

Environmental comfort, economy and energy conservation are some of the major functional considerations in building thermal design. It has been estimated that more than 30 percent of the total energy resources in the United States are being used by buildings and a large portion of this is wasted. In recognition of this waste, many energy saving strategies and computer programs have been developed and vast knowledge has been generated and documented. Designers have become more sensitive to energy issues, but due to the complexity of this design problem, computer simulation programs such as BLAST (BLAST 1981) and DOE-2 (DOE 1980), have been required to analyze even simple buildings. This software is often complex, time-consuming and requires specialists to interpret. As a result, designers tend to avoid using simulation programs and rely on intuitive methods, guidelines, or prescriptive methods.

Recent research, making use of knowledge engineering, focuses on solutions which will encourage designers to utilize energy simulation within the design process (Shaviv et al. 1996); (Jog 1992); (Mayer et al. 1991); (Pohl et al. 1990); (Brown 1990). This research targets the first stages of design where the designer must make critical decisions. This is done by using extreme climate conditions for energy simulation and default values and general rules of thumb to cope with the problem of not having enough information to conduct thermal analysis (Hitchcock 1991). Although this approach, utilizing knowledge engineering, increases the designer's ability to manipulate different solution strategies early in the design, its method of using rules of thumb and its use of approximate simulation analysis tools makes it less suitable for aiding the designer in achieving building energy optimization. Approximation methods are also not suitable for dealing with cases that require specific solutions and are not helpful in identifying the location of thermal design problems. In addition, by utilizing the general guidelines as heuristic, these systems do not support advice regarding building thermal design for a unique design case problem.

This paper describes an intelligent computational system that aids in energy design optimization without the use of rules of thumb. The system has a Graphical User Interface combined with advanced Artificial Intelligence techniques to assist designers in optimizing the thermal performance of buildings. These provide an environment that aids designers in finding energy solutions for their specific designs. This was achieved by integrating a Graphical Interface, the Transfer Function Method (TFM) procedures and intelligent agents for problem detection and advice. This environment evaluates, critiques and aids in optimizing energy use and design in buildings.

SYSTEM DESCRIPTION

In addition to a graphical user interface, the system consists of three major components that are organized in an integrated framework. These components are: the databases, the simulation program and the intelligent agent, Figure 1.

The Databases

When a design problem is introduced using the graphical interface, the system accesses its database for the simulation procedures to take place. The system contains two types of databases: weather and standards database and building envelope database. The weather and standard database contains weather data including atmospheric and radiation data and ASHRAE standards (ASHRAE 1989). This database is accessed automatically according to the city and state name. The Building Envelope database contains wall, roof and room transfer function and weighting factors. This database was designed to allow the user to search for the best matching walls and roof based on the minimum attribute information that the user might have early in the design process by allowing best match capabilities and a variety of intelligent retrieval mechanisms (Malkawi et al. 1997). The goal was to integrate the extreme detail of wall and roof transfer function coefficients that are required to run the simulation with the existing framework of the system in a manner that could be quickly and easily manipulated. Through the system, the user can quickly retrieve the transfer functions for almost any combination of wall or roof materials. The database supports a

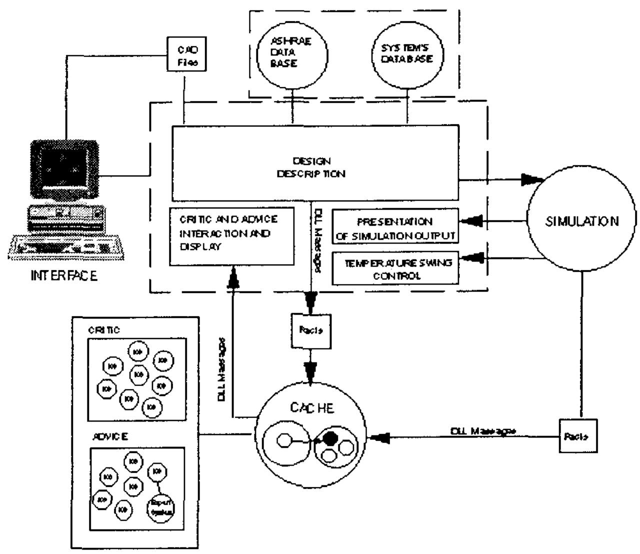

Fig. 1. The System Framework.

variety of search abilities that can be called by the interface of the system through Object Linking and Embedding (allows the creation of an "object" in the computer's memory which can be accessed by any software running on the computer). This facilitates ease of use by eliminating the need to switch between different software environments to retrieve the appropriate information. The database contains Weighting Factors (WF) data and Conduction Transfer Function (CTF) coefficients for a wide variety of walls, roofs, partitions, floors and ceilings (Falconer et al. 1993).

The Simulation Program

The simulation in this system uses the TFM (ASHRAE 1993) for analysis. All the TFM procedures have been fully implemented using Visual Basic. Visual Basic is an event-oriented graphical programming language that enables the creation of Windows applications by creating objects and manipulating their properties. The simulation provides the designer with a thermal evaluation of the proposed design. The simulation program is used to calculate the cooling and heating loads the building generates and to provide a passive and active interior temperature analysis based on heat extraction and floating temperature procedures (ASHRAE 1993).

The simulation of building thermal behavior in the system relies on the cooling load output generated from the individual building elements rather than the heat gain produced. In heating gain, only the individual element's amount of heat gain or loss contributing to the building are considered. On the other hand, through the use of weighting factors used in the TFM, the cooling load takes into consideration the building elements, space configuration and the delayed portion of cooling load interactions. This enables the reasoning process of the intelligent agents to determine the thermal problems considering time and interaction dependencies utilized in the TFM used for simulation.

When the simulation is complete, the designer has two options. The first option is to navigate through the results of the simulation. Several tools are provided to enhance the designer's ability to understand the design's thermal outcome. The user may use graphical tools that are custom designed to view the comparison between different loads and zones in the building or may use formatted numerical reports for a more detailed investigation. The second option the designer has is to request from the system a critique of the design and advice for optimizing thermal performance. At this stage the output of the simulation will be compared with the appropriate building energy standards and the result of compliance will be displayed showing the current design and the standard.

The Intelligent Agent

If the user sees that he or she needs to optimize the design to meet the standards, the intelligent agents use their expert sources to detect problem locations in the design. To do so, the expert sources will be provided with the design's spatial and structural components and its detailed thermal performance computed by the system.

The intelligent agents consist primarily of a module called the critic and a module called the advice. Both of these agents use the blackboard model supported by statistical reasoning as their framework, Figure 2. The Blackboard model provides a platform for multi-experts to be used for problem solving and to avoid possible conflicts among these experts while solving a problem. It resides in the intelligent agent's working memory (cache) which contains the facts about the design structural components and its detailed thermal performance computed by the system. The statistical reasoning (a reasoning technique that uses statistical measures in its representation) supports modeling the uncertainty that is present when predicting problems and giving advice for these problems. For example, at a given time a building's primary problem might be heating and cooling. One zone in this building might require only heating yet the worst problem in this zone might be glazing that produces cooling loads. In this case, without the use of the statistical reasoning, the system is uncertain if glazing is the worst problem in relation to that particular zone or to the building in general.

The control engine of the intelligent agents uses a combination of Artificial Intelligence techniques (e.g. backward and forward reasoning and backtracking) that allow the system to have the ability to provide specific expert advice for thermal problems (e.g. it can provide advice for what type of glass to use in the different windows in the building that will provide the best energy conservation measure) (Malkawi 1994).

If a problem is detected by the critic module, the designer has the opportunity to request an explanation from the system. In addition, the system asks the designer if suggestions for potential changes are required. For example, if the system's critic module found that the north glazing is the major contributor to thermal loss in a particular zone, the system will notify the user of that and provide him or her with the necessary information to understand the problem. The system will then ask the user if he or she needs advice on how to solve the problem. If the designer asks for these suggestions, the system's advice module uses the detected problems and its knowledge about the building itself to assign specific advice and suggestions to overcome the problems. These suggestions are oriented toward the designer's constraint emphasis. This is accomplished by acquiring feedback from the designer about his or her preferences within the process of the system's reasoning by prompting with questions. For example, the system will ask the user if natural lighting is important in his or her design or what color of glazing he or she prefers to use in the design. When a question is being asked by the system to accommodate the designer's needs and constraints, the designer has the ability to ask for justification. For example, the designer can ask the system "why are you asking me about natural lighting?" At this stage, explanations will be provided to the designer.

After the advice and suggestions for the detected problems have been provided for optimization, the designer can decide what changes to make to fit the proposed design and maintain the parameters that are believed to be essential for the design. The system keeps track of all the original design parameters. The user can change these parameters according to the advice given by the system and perform a second thermal design investigation to complete the optimization. The system provides navigation between the intelligent agents and the graphical and numerical presentations of the design simulation outcome. This facilitates an

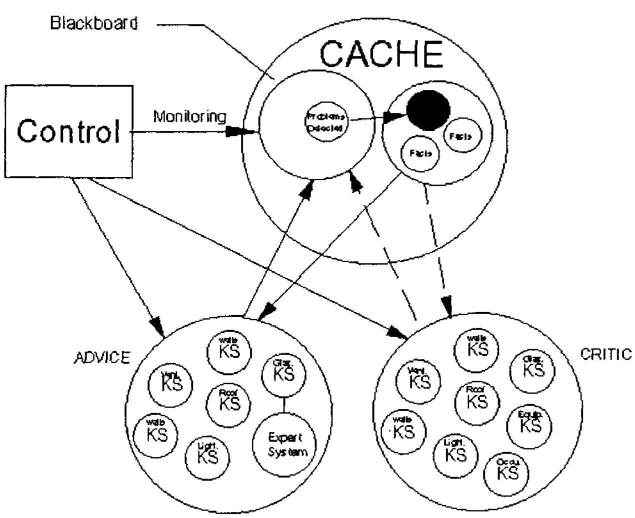

Fig. 2. The Intelligent Agent.

exploration environment where the designer might investigate the reasoning of the system not only by its explanation but also by navigating through the simulation outcome.

THE GRAPHICAL USER INTERFACE

The interface consists of 32 different screens organized in an intuitive, logical and nonlinear path. Each screen contains its own visual controls (e.g., check boxes, push buttons, etc.) that are used to accept the users input and commands. The interface is designed to accept input data files from CAD software and external databases. This enables the designer to specify the design problem in a CAD software and use the system discussed here to predict problems and acquire advice.

General Framework

The interface framework is organized around three primary screens: the problem definition, the design description and the advisor and presentation. These are briefly described below.

In the problem definition, the user defines the type of design being proposed (residential or commercial), the level of design (intermediate or final) and the kind of thermal design being investigated (passive or active). The design description screen provides a means for the formal description of the building and its surroundings to be specified. It is used to describe the building location and the weather models. In addition, this screen is the basis for branching to detailed building element descriptions. It also controls the building zone organization in relation to building description to maintain constant and logical input criteria, Figure 3.
The roof, lighting, equipment, occupants and ventilation are specified in separate screens that are branched from the design description. Each screen is used to describe the function for which it is assigned. Each screen provides zone access capabilities that allow zone navigation within that function. This in turn allows flexibility and minimizes the possibility of error.

The interface provides three alternative methods for the Transfer Functions (TF) to be specified for any wall or roof. The first method allows the specification to be automatic by choosing default values. The second method allows a user-friendly Graphical User Interface that constitutes a front-end for a wall and roof transfer function coefficient database to be invoked. It allows the user to quickly retrieve the transfer functions for almost any combination of wall or roof material values from the ASHRAE database. The third method allows inputting the TF values manually in case no values in the ASHRAE database are suitable for the materials used. These methods were provided to facilitate the performance of a range of detailed investigations based on the preciseness of TF for the specified materials used.

Finally, the advisor and presentation screen provides controls for launching the interior design temperature and humidity screens, the

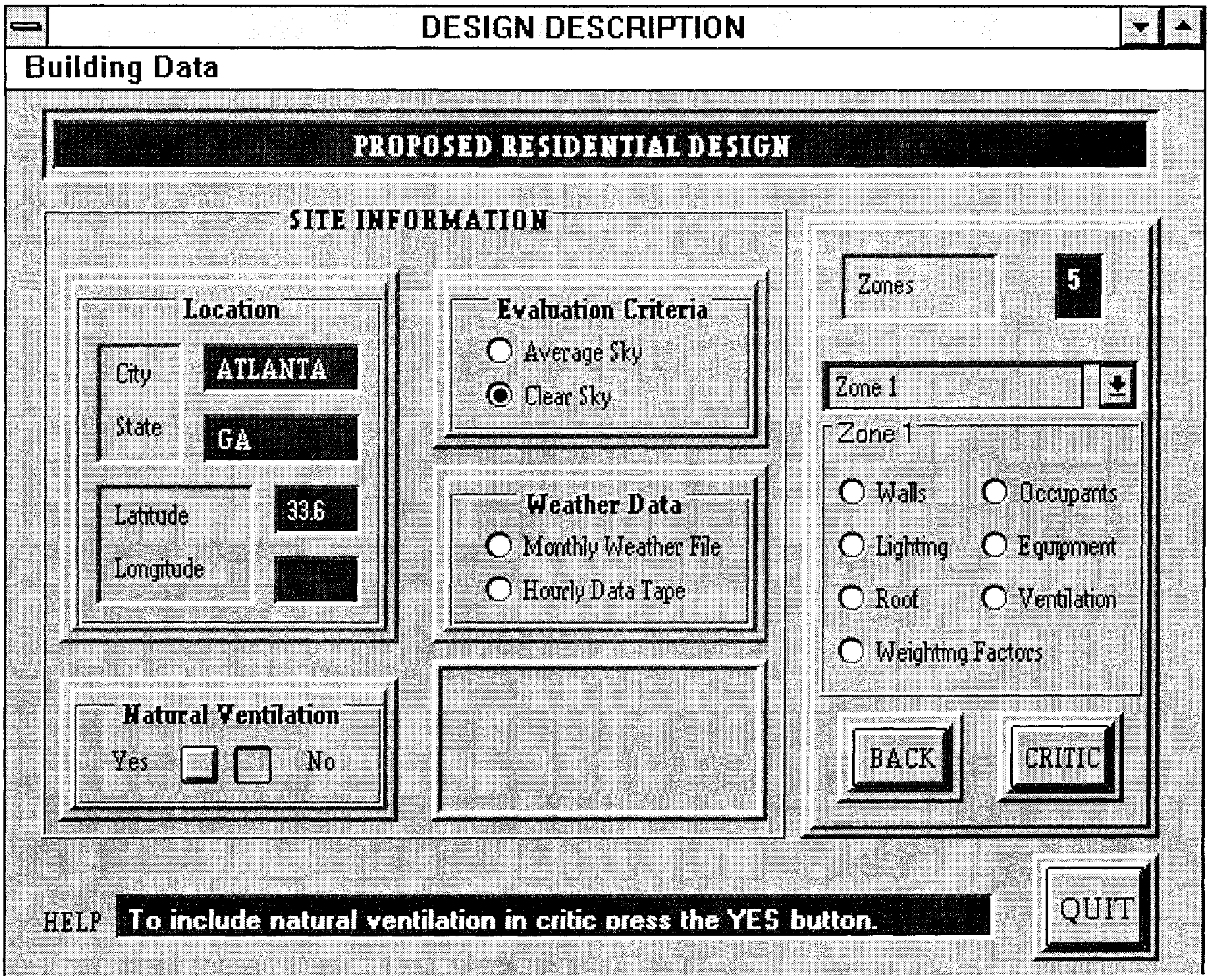

Fig. 3. The Design Description Screen.

detail thermal analysis reports and the interior passive temperature analysis screens. It also provides controls for starting the process of evaluation. It displays and controls the critic, advice, and the graphical analysis output, Figure 4.

The interior design temperature and humidity screen is used to define the temperature and humidity the designer targets. This screen allows the designer to input the goal interior temperature, setback and humidity for every month of the year.

The advisor and presentation screen provides access to screens displaying the detailed hourly reports for cooling and heating load consumption. These screens display an arranged thermal analysis output that is organized to provide comparisons between the different design components and the different zones. These screens provide detailed numerical thermal load comparisons and contain user oriented controls that allow flexible navigation between them.

The advisor and presentation screen also provides access to the hourly temperature analysis screen. This screen includes the tools necessary to investigate the building temperature performance for both passive and active analysis. In active analysis, the interface displays the amount of heating or cooling extraction in association with the interior temperature. For passive analysis the interface allows the designer to set maximum and minimum temperatures that the building is not allowed to exceed. The interface then displays hourly graphical and numerical temperature swings based on building construction type, Figure 5.

This facilitates monitoring the space floating temperature. These temperatures provide an easy to understand representation of the thermal behavior. In addition, it facilitates optimizing schedules for commercial buildings as well as investigating their potential use.

To enhance the understanding of the design thermal behavior, the advisor and presentation screen also provides controlled graphical presentation that allows a wide set of comparisons between building elements and zones for different time settings. These presentations are constructed in a way that provides the designer with visual tools to analyze thermal building design and to compare it, if necessary, to the advice and critic for better understanding of the problem and its solutions. These comparisons include:

1. Yearly cooling consumption for individual building elements
2. Yearly heating consumption for individual building elements
3. Yearly cost consumption by building element for individual building elements
4. Zone comparisons for both cooling and heating loads
5. Monthly comparisons for cooling and heating loads based on building elements
6. Yearly comparisons for all zones for heating and cooling separately and combined.

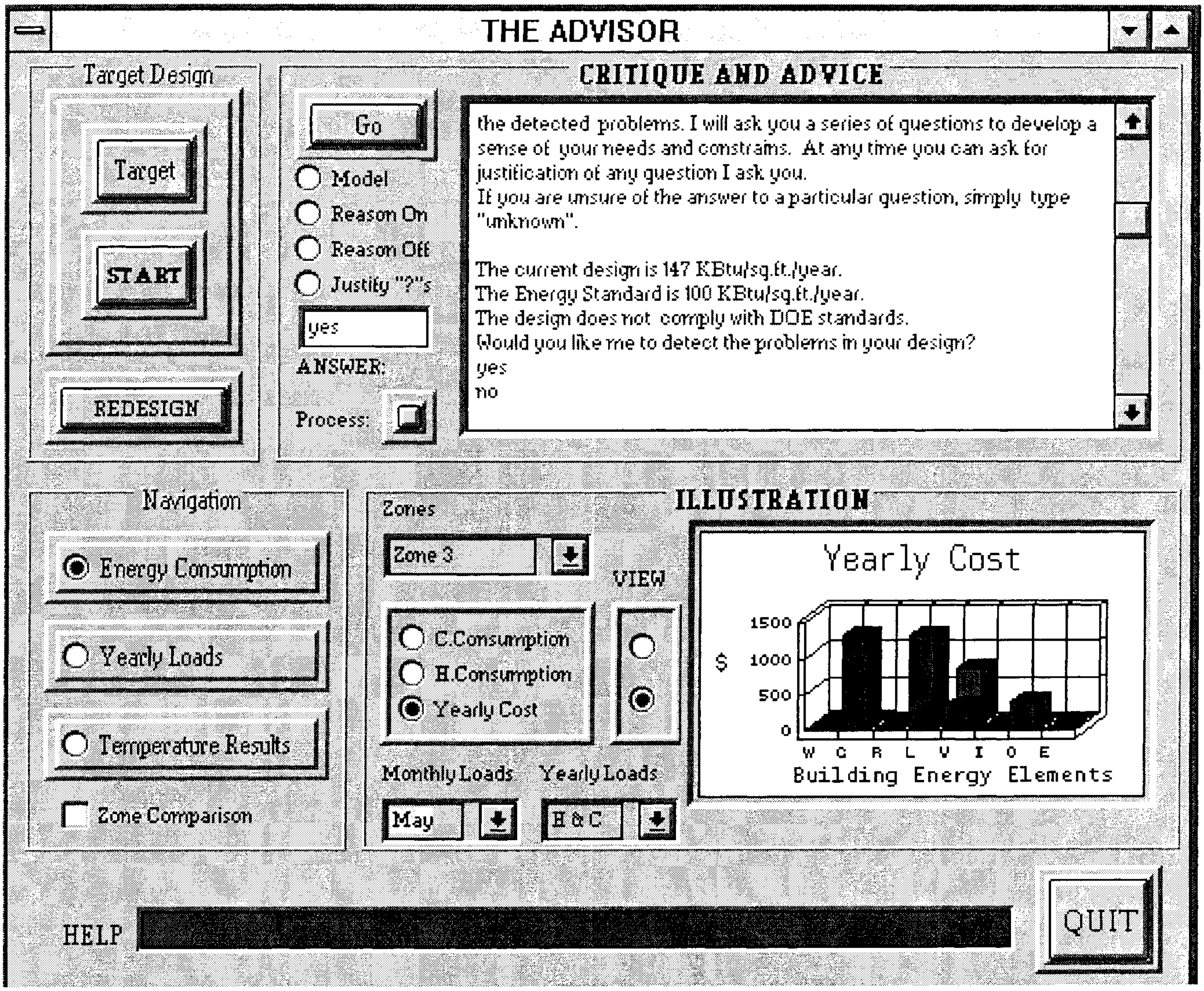

Fig. 4. The Advisor Screen

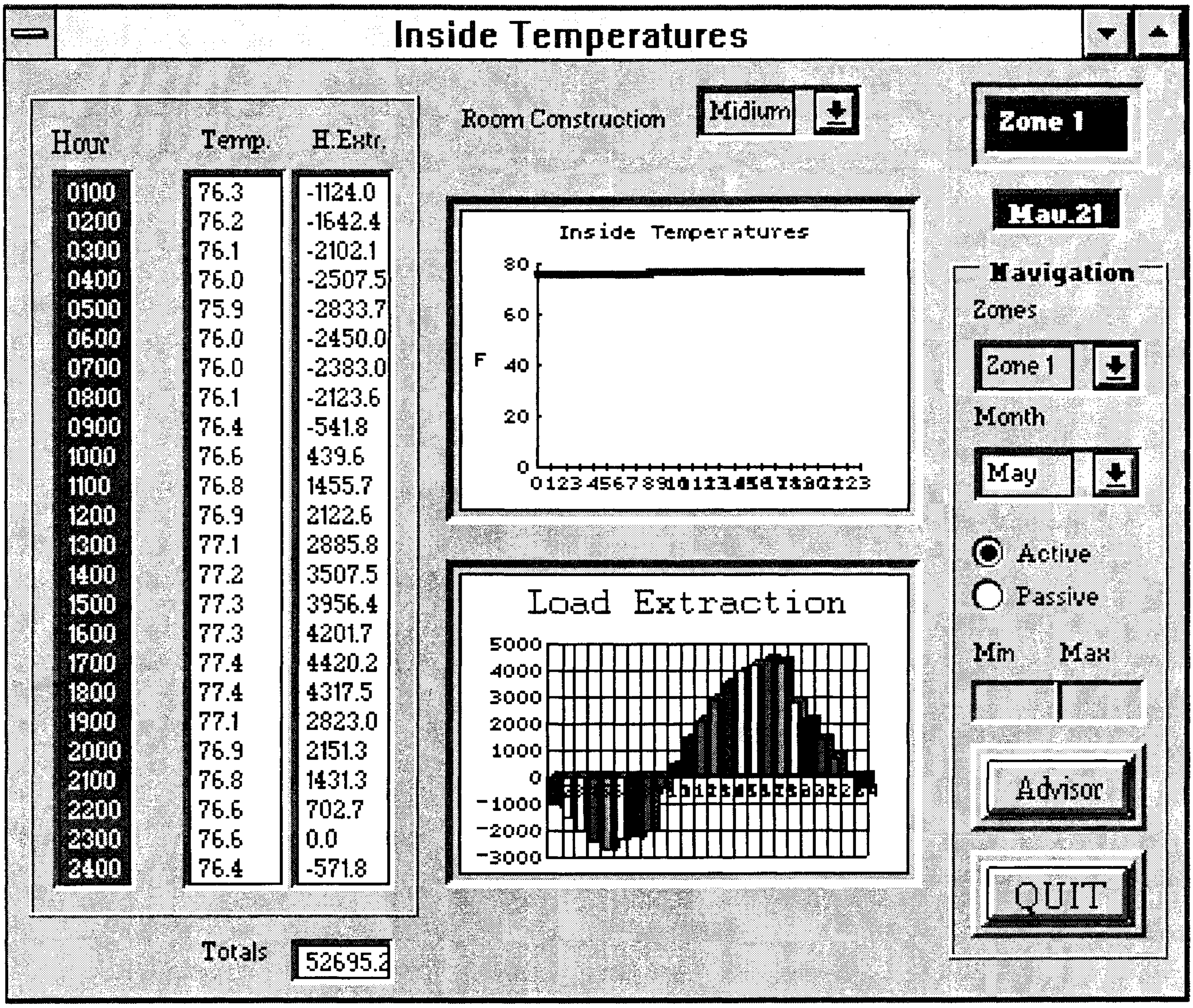

Fig. 5. The Hourly Temperature Analysis Screen

Finally, the advisor and presentation screen provides the display media and interaction controls with the intelligent agent. The interaction controls include initiating the process of reasoning, controlling the tracing ability, commanding the justification and responding to the critic and advice requests.

CONCLUSIONS

This system was developed to provide a flexible tool to propose design problems and to navigate and interact with the simulation output and its intelligent agents. The outcome is a system that allows the designer to evaluate the design ideas by providing criticism and advice through a variation of graphical oriented tools. The interface of the system enhances the user's ability to define the thermal design problem, start a detailed simulation, navigate the outcome, interact with the critic and advice and make alterations to the design for optimization. The interface provides flexible navigation that aids in problem definition and understanding and allows integration with other CAD software.

The system demonstrates the importance of a single integrated environment in developing design aid systems. It demonstrates the feasibility of developing tools that provide advice that are not based on rules of thumb while still being easy to use. It shows the potential of how new technology and advancement in AI techniques can be used to bring to the designers the knowledge needed to design energy efficient buildings. This will be done by providing them with intelligent assistance that provide logical criticism and advice and work with the designer throughout the design process. Through the integration of OLE technology and interface design, the system demonstrates the feasibility of conducting robust analysis without requiring the user to have an in-depth familiarity with complex simulation algorithms such as transfer functions. The system discussed is being used to educate designers on different aspects of thermal design. This includes thermal problem detection and optimization through organized exercises. Its associated conceptual framework provides the core for a larger implementation that is currently under development. The project attempts to expand the intelligent agents capabilities to provide advice by increasing the expertise the agents have and by utilizing and testing different AI techniques.

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