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A Methodology for Computer-Aided Design of Passive Solar Direct Gain Buildings

Eraclis Akhniotis

A Thesis

in

The Centre for Building Studies

Presented in Partial Fulfilment of the Requirements
for the Degree of Master of Applied Science at
Concordia University
Montréal, Québec, Canada

June 1992

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ABSTRACT

A Methodology for Computer-Aided Design of Passive Solar Direct Gain Buildings

Eraclis Akhniotis

The performance of a passive solar direct gain building depends on the design of its envelope, which requires appropriate selection of design variables with respect to window, wall and thermal mass characteristics. Decisions concerning these variables are usually first considered during preliminary design and are finalized during the detailed design stage. This design process involves synthesis and analysis and depends on both qualitative and quantitative knowledge. However, due to lack of easy to use yet accurate analysis tools, designers do not usually check the product of design synthesis with rigorous analyses. Their decisions are based primarily on previous experience.

The present study aims to improve the passive solar design process with a methodology and a computer program for both design synthesis and analysis. This program, named "Passive Solar Designer" (PSD), which is intended to be a design assistant, is comprised of several modules: the energy analysis program BEEP, a knowledge-based system, databases and a hypertext all running simultaneously in a synergic manner in a flexible graphical user interface.

Knowledge-based system techniques are used to establish a design control mechanism, to facilitate the information processing and assist the designer decision making throughout the design process. The knowledge base consists of design heuristics which can provide acceptable defaults for design variables at the initial design stages.

Heuristics are also used for the evaluation of the design alternatives. A hybrid knowledge representation methodology is implemented using objects, rules, demons and methods. These are also utilized to establish a versatile overall design process control mechanism, which is based on the principles of the developed methodology. The information flow between the different components is controlled by rules. Interface characteristics are also represented in the knowledge base by demons and methods.

The program developed (PSD), takes into account energy and comfort indices and can support a systematic iterative process of design alternative generation. A guiding principle during the design alternative generation is successive improvement. Minimum energy consumption, effective solar energy utilization, minimum equipment size and comfort maintenance are the primary considerations in design alternative evaluation. The design process is also facilitated by on-line databases, a hypertext and other programs.

PSD is a prototype of the concept of a combined knowledge-based-algorithmic system for passive solar design. It supports synthesis and analysis and also traces and explains analysis results. Furthermore, it demonstrates the advantages of an integrated algorithmic-knowledge-based system approach. Two case studies typical for two different climatic regions (cold and temperate climates) are presented with results to demonstrate the methodology.

To Gnosia and Alexandros

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CHAPTER 1

INTRODUCTION

1.1 Background

For many years the impact of design decisions on the overall performance of buildings had not been adequately considered. Due to increased cost of energy and the prospect for future energy shortages building designers now investigate ways to improve the performance of the building envelope in order to reduce heat losses and excess heat gains. Renewable sources of energy are also exploited in order to reduce the dependency on the use of fossil fuels. This is feasible since only a small amount of the solar energy reaching our planet, if properly utilized, could significantly reduce energy consumption in buildings [Carter and Villiers, 1985].

Passive solar design deals with utilization of solar energy in order to reduce auxiliary energy costs while at the same time maintaining comfortable indoor conditions. This process involves synthesis and analysis which depend on both quantitative and qualitative knowledge. Qualitative, experiential knowledge is what we often call "rules of thumb" or heuristics. This type of knowledge is acquired over time, usually through years of experience. The other type is quantitative knowledge, which is derived from scientific theory or empirical knowledge which is gained from experiments.

Synthesis is the creative part of design. During synthesis the designer usually generates various design alternatives which are feasible solutions within design constraints. The performance of the product of synthesis must be verified using analysis. During analysis the various performance characteristics are calculated and tested against

the evaluation criteria which are set at the beginning of design. In such an iterative process of generating-testing various design options the designer eventually selects an optimal (most promising) solution which is then further developed and finally implemented.

During the conceptual design stages, decisions concern the determination of the building orientation and space allocation at the level of the general layout. For this kind of decisions, qualitative knowledge can be used while quantitative knowledge is not necessarily required. However, later on during the preliminary and detailed design stages, more specific decisions are taken with respect to the type, location and size of the direct gain windows (defined as windows with high solar gains-generally near south-facing), the thermal storage mass amount and location as well as the optimum amount of insulation. These decisions affect significant parameters such as sizing of heating/cooling equipment, auxiliary heating and cooling loads (dollar value) and thermal comfort indices (PMV, PPD) of the indoor environment. In this case, qualitative knowledge is not adequate; quantitative knowledge and accurate analysis techniques are indispensable to carry out design.

1.2 Motivation

Decisions during the preliminary design stages of a passive solar building affect significantly the building thermal behaviour. Despite the need to use accurate means, especially during these design phases, designers often take decisions intuitively, based on previous experience and using rules of thumb. They rarely conduct detailed and accurate analyses to test the product of synthesis. This is mainly due to lack of user-friendly, easy to use analysis tools which can rapidly analyze and compare design alternatives without

sacrificing accuracy. Thus, incomplete and inaccurate designs are often adopted for further consideration (documentation & implementation), which subsequently result in building operation problems, high energy losses and discomfort due to high room temperature swings.

Conventional algorithmic computer programs can be used to support the well-formalized aspects of the passive solar building design process. Knowledge-Based Expert System (KBES) techniques offer the capability to fill the gap between the 'creative' and 'checking' aspects of this process. KBES can handle declarative knowledge and information which is usually needed at the most ill-defined stages of the design process, while traditional algorithmic programs cannot. Therefore, a combined knowledge-based-algorithmic system could support both the creative and analytical aspects of the passive solar design process.

The detailed Building Energy and Environment Program (BEEP) [Athienitis, 1988] can be used as the algorithmic module of such an integrated system. The thermal storage mass effect on the building dynamic response is accurately modelled by BEEP which can also evaluate accurately the solar radiation transmission and distribution in a room at any orientation and time of the year. In combination with heuristics and a design control mechanism, BEEP could support a systematic process of generation and evaluation of passive solar building design alternatives during the preliminary and detailed design stages.

1.3 Objectives

The main objectives of this thesis are the following:

1. To combine existing algorithmic computer programs with knowledge-based

techniques in a design tool, which will aid the process of systematic synthesis and analysis for the generation of different design options in order to decide the window area, location and type, the thermal mass amount and location, as well as the optimum R-value of a passive solar building.

2. To establish an intelligent, flexible, user-friendly system for passive solar design, which will accommodate a building thermal analysis program, a knowledge-base, a hypertext and a database with a Graphical User Interface. This system will be the basis for the development of an integrated methodology for passive solar analysis and design.

3. To develop a Hypertext-based system, which will provide design on-line guidelines and assist designers in implementing the main concepts and strategies of Passive Solar Design.

1.4 Organization of the thesis

Chapter 2 includes a literature review. The nature and definition of building design are discussed along with current building design thermal environment issues. Passive solar design considerations are also discussed in this chapter with more information related to passive solar direct gain buildings. Computer-aided building design and new trends in computing, with more emphasis on knowledge-based expert systems and object-oriented programming, are also described with some of their applications in building design.

In chapter 3 a model of a combined knowledge-based-algorithmic approach in passive solar design is described. This chapter also includes requirements for an effective

design tool and selection criteria for an appropriate environment to implement such a system.

Chapter 4 presents the prototype design assistant "Passive Solar Designer". The main features of the different system components are also described. Typical knowledge representation structures used in the system are explained. Description of the design methodology is also included.

Chapter 5 presents two typical case studies using Passive Solar Designer. Validation issues are also discussed.

Chapter 6 includes conclusions based on this study and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Building Design Issues

2.1.1 Definition

The conflicting nature, intuition and complexity involved in 'Design', are enough to justify the variety of definitions applied to it in the literature. Some of them, as reported by Kalay [1989], refer to 'design' as:

- " The performance of a very complicated act of faith" (Jones, 1966).
- " The process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative) in which the basic sciences, mathematics, and engineering are applied to convert resources optimally to meet a stated objective" (Application Board for Engineering and Technology, 1985).
- " Goal-directed, problem solving activity" (Archer, 1965).

Design is a process leading to the definition of a physical form that achieves a certain predefined set of performance criteria [Garrava et al., 1990]. Design is also perceived as "an integrative activity and decision-making process involving a variety of areas of decision, including human, functional, economic and physical" [Manning, 1984]. Other definitions describe 'design' as an iterative process in which the sequence of operations depends on the experience, knowledge and imagination of the designer [Logcher, 1970].

From the building engineer point of view [Bédard, 1989], design is considered as '...the engineering activity that proceeds systematically through several steps towards the

development of an overall best solution (optimum) by satisfying numerous constraints, criteria and objectives".

2.1.2 Design process model

The most important features of the architectural and engineering design process are shown in schematic form in figure 2.1. The first subprocess, that of 'Definition', refers to the recognition of need and to a thorough specification of what is to be designed. It takes into account a variety of areas of decision, including human, functional, economic and physical from which constraints are normally drawn and all of which influence the overall project expenditures [Bédard 1989, Manning 1984]. The 'Synthesis-Analysis' subprocesses of the model, stand for the creative organization of the different building components or subsystems (Synthesis) and the performance evaluation (Analysis) based on design criteria set earlier. This process is highly iterative since the product of 'Synthesis' may finally be modified, improved and re-analyzed until all components and subsystems are optimized to form an overall system. Documentation is the process of preparing the final detailed drawings and specifications sufficient for the construction of the building.

2.1.3 Design stages

In engineering the design process is described as a series of time related events or stages, namely: (a) Conceptual, (b) Preliminary and (c) Detailed design stage.

The conceptual stage is the domain of brainstorming. This is typically practised in group settings, where the participants are encouraged to contribute ideas without control and without the need to rationalize them [Kalay, 1989]. During this stage the

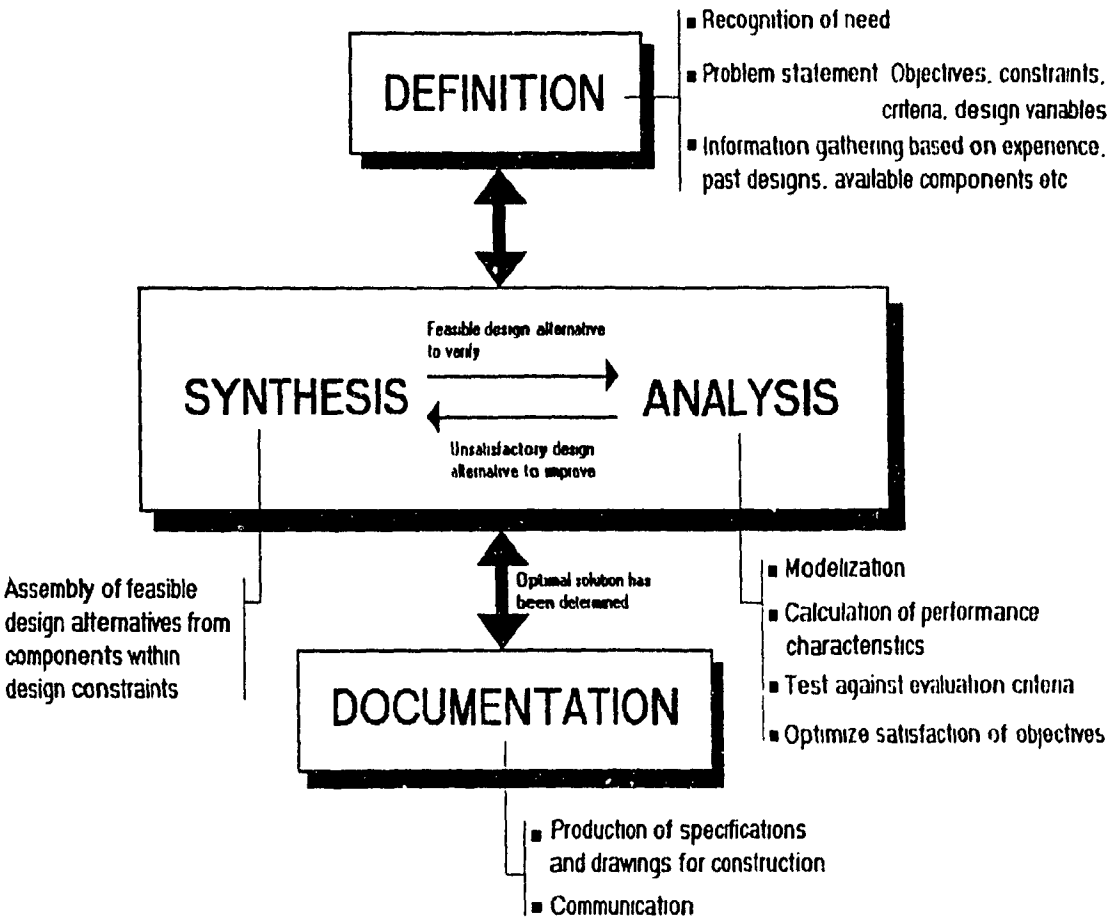


Fig. 2.1 Model of building design process [Bédard and Gowri, 1990]

designer establishes his/her line of thinking and starts generating design descriptions from functional and behavioral requirements. The main objective at the conceptual design stage is to generate many potential design alternatives (DA). These DAs must take into account fundamental elements of the problem, like the interaction between the different building systems and subsystems, the basic human needs and specific environmental conditions in order to achieve total building performance. An evaluation of all the alternatives is usually performed so as to select the more promising ones for the next stage.

The next stage is the preliminary design stage. The solutions generated at the conceptual stage are quantified and the overall best solution is selected for the detailed design stage. The detailed design stage is characterized by complete engineering description of the design alternative selected at the previous stage. Everything is thoroughly evaluated; plans and specifications are prepared for the procurement and construction phase of the project life-cycle.

2.1.4 Common problems in Building Design

- *Fragmentation.* Building Design is traditionally characterized by participation of different professionals who come from different backgrounds and their education is based on different philosophies. The lack of proper coordination among them results to what is called "horizontal fragmentation". This in combination with the "vertical fragmentation", which occurs between project phases, e.g. planning, design and construction, misses important opportunities for improved project performance [Howard et al. 1989, Stahl 1983].

Fragmentation is characterized as a common agent behind problems that develop during the design-construction phases, or malfunctions that appear only later during

operation [Bédard et al., 1991].

- *Complexity*. The present state of building design is also characterized by growing complexity of the buildings themselves. 'Intelligent Buildings' incorporate automated systems for HVAC controls, lighting, fire-safety, security, electrical power etc. Consequently the use of such systems increases the complexity of the processes leading to the design, construction and management of buildings [Fitzgerald, 1990].

- *Codes - Owner requirements*. New, more detailed requirements are reflected by design codes and standards concerning safety, energy efficiency, environmental and health aspects. Generally there is increased demand for buildings that are more responsive to the user needs. In addition to all these demands there is a pressure from the owners for flexibility and minimum life-cycle cost along with as early as possible completion of the project. These lead to an 'Information & Requirements explosion'.

Under the pressure to complete design in a very narrow time schedule, designers are often unable to consider more than one or two design alternatives. Thus the likelihood that the final design is the best that could be achieved, is diminished and hence the initial aims for an energy-efficient, aesthetically pleasing, less costly design, are usually not realized.

- *Designer resources allocation*: During design the activity that absorbs the most resources and time, is the one which deals with the preparation of the final construction drawings and specifications. However, this has the least impact on the building eventual operating and maintenance costs. The opportunity for greatest savings occurs after programming and during the earliest concept trial stage. It diminishes rapidly once design concept is selected and detailed design gets underway [Hanscomb, 1990].

- *Lack of Integrated Approach in Design*. A very common pitfall in building

design is to overemphasize only some of the building systems on the other expense, which are generally "fitted" into a preconceived arrangement [Howard et al. 1989, Bédard 1989]. Due to the lack of integrated approaches in building design, system interferences cannot be predicted because each one of them is designed separately, most of the times by different firms. Such inconsistencies are most likely to be found during construction. This leads to disputes, claims, costly changes, poorer construction quality and delayed occupancy of the building.

2.1.5 Potential improvements.

Significant technological improvements gave the opportunity to mobilize computers in new, challenging roles in design. Computers as powerful data processors can be considered to be effective promoters of integration. Recent computing developments in Object Oriented Programming, symbolic processing and natural-language interface, offer new forms of communication that can break the information impasse common in current computing applications [Bédard et al., 1991].

Various approaches have introduced the use of Knowledge-Based System techniques, which can handle and integrate the scarce and fragmented multidisciplinary expertise in automated, interactive, design assistants. This is a breakthrough in the way design is currently performed, because designers will be able to focus on the most important aspects of building design, overall building performance and life-cycle costs. This means that more efficient ways of utilizing materials, of allocating space, of creating building envelopes and of ensuring appropriate internal ambiences and climates will be employed. In the same manner, better ways which could achieve greater functional, economic and energy efficiency for which knowledge is available, will be considered.

2.2 Passive Solar Building Design

2.2.1 Introduction

Passive solar design concerns the determination of the most suitable passive systems and components and the appropriate use of the climatic and environmental factors in order to minimize energy usage by effective utilization of solar energy. The main common characteristic of these systems is that thermal energy transfer into and out of buildings, into and out of thermal energy storage and around a conditioned space, occurs naturally through conduction, convection and radiation [US Dept of Energy, 1980]. The primary objective in the thermal design and analysis of a passive solar building is to achieve high savings in energy consumption through maximum utilization of solar gains, while at the same time preventing frequent room overheating [Athienitis, 1985].

During the thermal analysis and design of a passive solar building, it is necessary to evaluate heating or cooling loads and room temperature fluctuations with given weather data such as solar radiation and ambient temperature. Moreover, it is desirable to evaluate the building response under extreme weather conditions for many design options, each time changing only a few of the building parameters, until an optimum response is obtained. Thus, it is desirable to have efficient simulation and design tools which can be used for routine passive solar analysis.

2.2.2 Passive Systems

Various passive systems have been developed through many years of experiencing the building behaviour in different climatic conditions which provide means for more effective utilization of solar energy. A passive solar heating or cooling system, as

mentioned before, is one in which the thermal energy flow is by natural means. These natural energy flows are the most important, and controlled auxiliary heating becomes less significant than in thin-walled buildings, in which intermittent heating is required to respond to sudden changes in weather [Athienitis, 1985]. The three functions of any solar heating system are collection of the solar energy, storage of the energy as heat and distribution of the heat throughout the building when needed.

There are three major design approaches being used to passive solar heating. These approaches can generally be separated into the following categories based on their main characteristics [Balcomb 1978, Mazria 1979, US Dept of Energy 1980]:

Category 1. Direct Gain

- South wall or clerestory windows
- Shading overhangs for summer
- Internal thermal storage mass

Category 2. Indirect Gain

- Thermal storage wall
- Thermal storage roof
- Solar greenhouse
- Thermosifoning collectors

Category 3. Isolated Gain

- Indirect gain situation in which there is a major separation by either distance or insulation between the thermal storage and conditioned space.

2.2.3 Direct gain systems

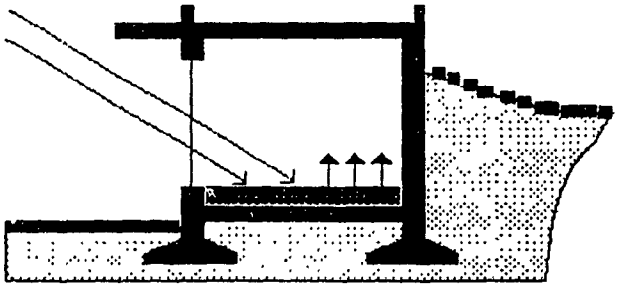
Direct gain is the most popular passive solar design approach, due to simplicity,

effectiveness and relatively low cost. This type of passive system is characterized by large south-facing glazing areas that allow solar radiation to enter the living space directly (fig. 2.2). These solar gains serve either to meet part of the current heating needs or are stored in the building mass to meet heating needs that arise later [Balcomb et al., 1982].

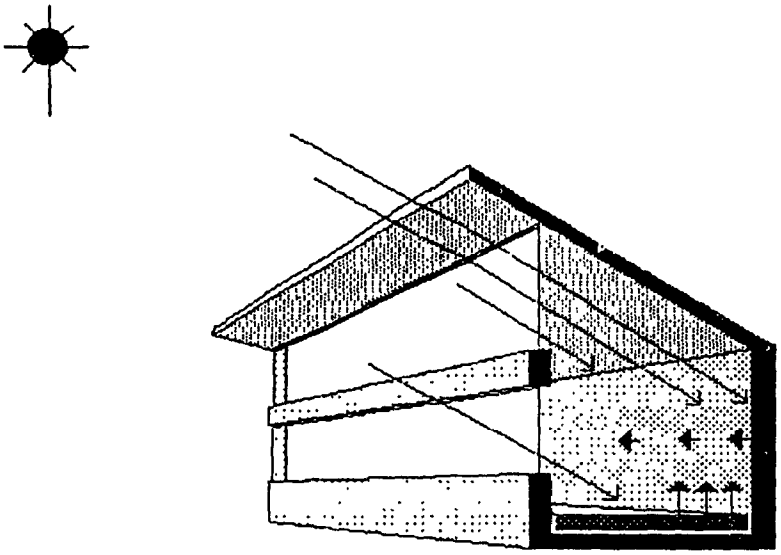
Based on this approach, the building is usually extended along the east-west axis, providing many windows on the south-facing wall for maximum solar exposure. The sunlight penetrates through those windows into the house and due to the "greenhouse effect" heat is trapped. Actually the window glass admits solar shortwave radiation into the room, but when it strikes surfaces they absorb it and, in turn, emit heat (long-wave radiation) that the glass will not transmit back outside. Usually two glazing layers are mounted in direct gain apertures. A single glazing is undesirable because of the large heat losses that are allowed. In very cold climates, triple glazing may also be used to control heat losses.

There are often some significant drawbacks of direct gain systems related to space overheating, early in spring or autumn. In early spring or autumn, heating may often be required, and the south-facing windows transmit high solar gains due to the relatively low solar altitudes; however the outside temperature can be high during the daytime, potentially causing significant overheating. This is usually due to improper sizing of the direct gain window area and inappropriate selection of window type, thermal storage mass materials, amount and location. Energy dumped (cooling) in the heating season is significant if the direct gain building is nonmassive. Also heat losses through an aperture whose effectiveness is impaired by insufficient thermal mass, can exceed useful solar gains [Athienitis, 1985].

The effectiveness of thermal storage mass in direct gain buildings depends on its



Solar Window



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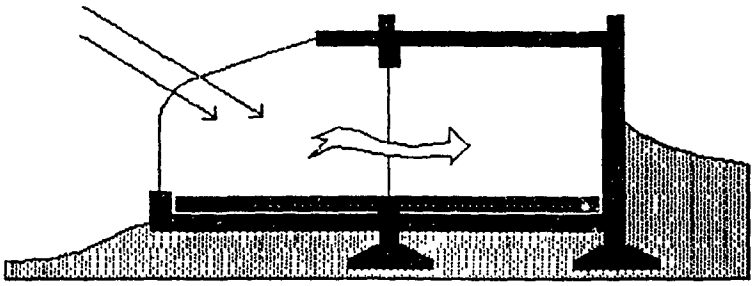


Greenhouse - Sunroom

Fig. 2.2 Direct gain systems

thickness, surface area and thermal properties (volumetric heat capacity and thermal conductivity). The location of the thermal mass in a direct gain room is also very important and affects the amount of transmitted solar radiation absorbed by each room interior surface. The absorbed radiation is a function of the following parameters [Athienitis and Stylianou, 1991]:

1. Mass location
2. Mass solar absorptance
3. Absorptance of the other surfaces
4. Room and window geometry
5. Latitude
6. Time of the year

The best materials for efficient thermal storage capabilities are those that can store large quantities of heat (high heat capacity) and that can readily transport heat from the mass surface to the mass interior for storage and back again to the surface to meet the building heat load (high thermal conductivity) [Balcomb et al., 1982].

Significant objectives in the design of a passive solar direct gain building is to select the area and characteristics of the direct gain windows, and the thermal mass properties and its distribution in order to prevent frequent overheating while at the same time achieving savings in energy consumption. As for all buildings, the amount of insulation is also an important parameter to be selected; in passive solar buildings thermal storage mass should be placed on the room-side of the insulation. In order to meet these objectives the designer should perform many cycles of synthesis and analysis to investigate through different design alternatives the possibilities for an optimum building response.

This process requires a flexible, yet detailed and accurate program to perform the analysis part of design. For the synthetic part, since it is not suited to a pure algorithmic description, a Knowledge-Based System can incorporate sufficient information and knowledge to support the designer. Several performance indices are involved in this process. Important indices implemented in the methodology in design alternative evaluation, are described below.

2.2.4 Important performance indices

The operative temperature is approximately equal to the average of air and mean radiant temperature and its swing is related to the storage effectiveness of the thermal mass in a direct gain room. Results from sensitivity analysis [Athienitis et al, 1987] indicate how thermal mass properties affect comfort. For a difference of 0.6 kJ/kg/K in the mass specific heat capacity, there are ranges of the magnitude of 6.5 °C in the operative temperature maxima for a sunny day. Also the effect of mass thermal conductivity on room operative temperature is significant. For thin mass layers the value of the conductivity is important while the reverse is true as the amount of mass increases. Therefore, both properties should be important factors in the selection of thermal mass materials. The operative temperature swing should be calculated for clear days when potentially high solar gains may result in higher indoor temperature fluctuations and overheating. In this case passive analysis, i.e. assuming no energy dumping, is adequate for the purpose of optimizing the building performance [Athienitis et al., 1986].

The ΔTsolar index [Balcomb et al., 1982], is the net increase of the room mean temperature above ambient temperature due to solar gains, and can be used to determine the optimum amount of insulation and window area and type. For this purpose,

alternatively the auxiliary heating loads can also be computed on a clear winter day, until the desired energy savings are achieved. These indices show also how effectively the solar energy is used to heat the building.

In sizing the heating/cooling equipment, the peak heating/cooling loads must be calculated usually for extreme weather conditions. The mean radiant temperature (MRT) along with other environmental variables (air temperature, air velocity, relative humidity) and personal variables (clothing thermal insulation, metabolism) is necessary in determining the occupant's thermal sensation indices PMV and PPD in the building. The PMV index (Predicted Mean Vote) predicts the mean response of a large group of people based on a thermal sensation scale with a range of values between +3 (hot) and -3 (cold) with 0 (neutral) as the optimum value. The PPD (Predicted Percentage of Dissatisfied) index accounts for the acceptability of a thermal environment by its occupants and should not exceed 20% for an acceptable thermal environment [ASHRAE, 1981].

These are primarily the indices that are taken into account during the generation and evaluation of various design options of a passive solar direct gain building.

2.3 Computer-Aided Building Design (CABD)

The last decade has been a period of innovation and expansion for Computer-Aided Design and the related technologies of Computer-Aided Drafting and Manufacturing. Various computer software have been developed to provide assistance in analysis, design, drafting, project management, cost and quantity estimation. Computers make these processes faster and easier. The variety and the decreasing cost of software and hardware, make them available to a large number of professionals.

Some important benefits which result from the use of computers are reflected in

improved work quality, improved control and productivity, significant time savings, speed and greater accuracy in analysis and calculations. With respect to drafting, drawings are "standardized" and more understandable, and control and implementation of engineering changes is significantly improved.

Most of the efforts reported so far, have been concentrated on the use of computers as tools for solving numerical problems and drafting. The impact of computers in creative aspects of building design has been marginal. Computers in architectural design have been used primarily in drafting [Kalay, 1985]. The creative process of design synthesis is not significantly supported by the existing CAD tools. However, recently computers are increasingly being accepted as potential tools for creative design. This is due to increased capabilities offered by relatively new computing techniques and environments that are described below.

2.4 New Trends in Computing

Two software techniques have a major impact on the current computing environment and most probably will have even more in the future:

- Object Oriented Programming (OOP) and
- Knowledge-Based Expert Systems (KBES).

Their main characteristic is the methodology used to tackle problems not really susceptible to solution using conventional techniques and languages (e.g. FORTRAN). Following is a description of the main features of these two trends, along with new designer-machine interface characteristics.

2.4.1 Object-Oriented Programming (OOP)

Object-Oriented Programming is one of the major new programming methodologies that had recently emerged from the research environment. The 80s will probably be known as the decade that launched the object-oriented era of computation. OOP can be considered as a style of programming which eliminates the separation between data and procedures. The principle is that the proper place to describe the procedures available for manipulating particular data, is with that data, not in a separately defined procedure [MacRandal, 1988]. This programming style can be applied in almost any language, though obviously it is easier in those languages that were designed to provide direct support for it, e.g. Smalltalk-80, Flavours, Ada, C++, Objective-C etc.

The notion of 'Object-Oriented' as perceived by Cox [1990] evolves around an attempt to "...change the way we view software, shifting our emphasis to the objects we build rather than the processes we use to build them. Thus software is made as tangible and as amenable to common sense manipulation as are the everyday objects".

The difference between conventional procedural programming languages and OOP is that the former require a global, logical hierarchical thinking and have mainly a process-centric view. In contrast, the concept of Object-Oriented Programming is easy to grasp due to the localized, anthropomorphic, object-centered thinking required.

There are different opinions on how radical is the change in current software capabilities by introducing OOP techniques and languages and what is their impact on computing. Duff and Howard [1990] believe that generally because OOP principles localize information and logic are simply less complex. They also believe that OOP is just the next step in the evolution of structured programming, while in many discussions about methodologies, OOP is portrayed as a revolution that can replace the earlier structured

techniques [Cox 1987, Yourdon 1990].

However, it is general belief that the benefits of OOP are significant because its concepts and tools are enabling technologies that allow real-world problems to be expressed easily and naturally. Moreover, just to exemplify a measure of difference, after adopting an object-oriented style of programming, instead of conventional styles, significant code reductions were achieved of the magnitude of 40 percent [Khoshafian and Abnous, 1990].

The prevailing concepts and features that characterize OOP languages and distinguish them from traditional programming are 'Encapsulation' and 'Inheritance' [Cox 1990, Duff and Howard 1990]. They are described below along with the main object characteristics.

• **Object** is called the encapsulation of data and procedures. Usually, but not necessarily, this object represents a physical entity, e.g. building, facade, window etc. However, it may also represent abstract or pseudo-physical objects such as radiation, thermal resistance etc. The object holds the data representing the object in whatever format is convenient for it and contains a collection of permitted manipulations that may be applied to this data (methods).

• **Class** can be thought of as an object template which can be used to produce several similar objects. Most Object-Oriented languages provide a mechanism for describing 'objects' as 'instances' of a generic class.

• **Encapsulation** is the foundation of the whole approach and is generally used to describe an object's protection of its private data from outside access. All access to this data is handled by procedures (methods) that were put there to mediate it. Nothing external to the object is allowed access to internal data (fig. 2.3) [Gibson 1990, Cox

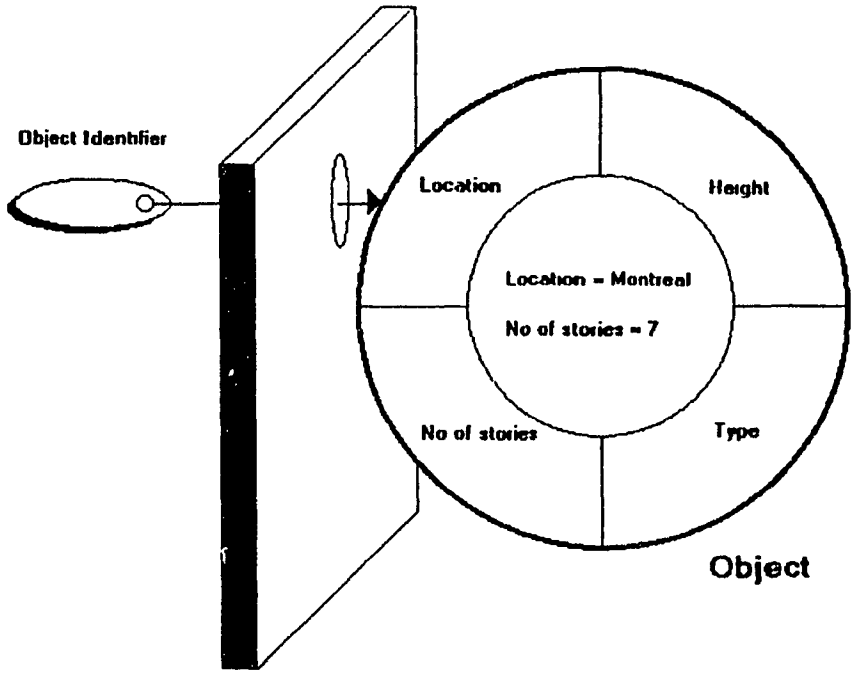


Fig. 2.3 Encapsulation in Object-Oriented Programming

1990].

• **Inheritance** denotes the ability of an object to derive its data and functionality automatically from another object. It is the more innovative part of the approach because it is not provided by conventional languages. Inheritance is a tool for organizing, building and using reusable classes of objects as descendants of existing ones. Classes are organized into a hierarchy of superclasses and subclasses. A subclass inherits all the methods, data structures and class variables that were possessed by its superclass.

2.4.2 New Designer-Machine Interface

With regard to a general attempt for integrating the methods and procedures involved in building design, important step is the development of graphical user interfaces (GUI) for existing tools. This will not only facilitate the information transfer but also it will provide easy access to computer packages that are difficult to use though indispensable for a successful design.

Around the 70's user interfaces were of little concern. Today graphical user interfaces are quite different. As much as 75% of the logic of windows-based, mouse-driven, icon-oriented systems, is associated with the user interface [Yourdon, 1990]. The invention of the mouse and other devices to control, monitor and display information (eg. windowing systems), was the beginning of the development of more intuitive and easy-to-use computer environments [Khoshafian and Abnous, 1990]. The idea of 'The Desktop Metaphor' has brought the computer closer to the natural environment of the end-user. This concept initiated most of the research for object-oriented interfaces.

Nowadays, Object Orientation provides to the user the means to create documents composed of different objects such as text, graphics and images. Based on the most recent

advances, a user-interface can be quickly developed graphically by selecting, placing and resizing user-interface objects. In the near future GUIs will play a dominant role in the industry making computers, and thus knowledge, accessible to a broader audience. An example of GUI is that of the Microsoft Windows environment of DOS (available only on 80386 systems or higher) which exhibits the Object-Oriented paradigm. One of its most important features is the multitasking capability offered to the designer/user.

2.4.3 Knowledge-Based Expert Systems (KBES)

2.4.3.1 General

Expert System technology is the branch of the Artificial Intelligence field that deals with emulation of the human thought process in computers. Recalling description by Feigenbaum, "Expert System is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution". The knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners of the field. Knowledge-Based Expert Systems use symbolic logic and heuristics in order to find solutions efficiently in a narrow problem area [Waterman, 1986].

In recent years, Knowledge-Based Expert Systems have received considerable attention among professional and academic groups. The attention can be attributed to the advertisement of a few relatively successful expert systems and the great potential for the development of more successful applications. Before, interest in expert systems was limited because of difficulties in their development since complex programming languages

and mainframe computers were required [Baker, 1988]. However, the introduction of a new generation of software, Expert System Shells that run on a PC, provided a simple, yet powerful tool for expert system development.

A shell is an expert system with the domain specific knowledge removed. Expert System shells concentrate mainly on the programming needs for building Knowledge-Based Expert Systems and provide an integrated set of tools to allow multiple paradigms in the same program [Ramamoorthy et al., 1987]. Nowadays the use of shells has been widespread. Increased cost and time requirements for an expert system development and domain expert-knowledge engineer communication difficulties are overcome with the use of expert system shells. By using a shell the number of participants for an expert system development can be limited to the domain expert, who also undertakes the role of the knowledge engineer, and the user.

The capability of KBES techniques to describe and tackle problems which require declarative knowledge manipulation, contributed to their successful implementation in a variety of areas. They have been applied in finance, geology, medicine and so on. Research and recent applications in areas related to buildings such as Architectural Design [Radford and Gero, 1985], Structural Design [Maher, 1988], Project Management [Alkass and Harris, 1991], HVAC Systems Design and Configuration [Fazio et al , 1989a] etc., prove that KBES can be successfully used during the design process.

2.4.3.2 Main characteristics of KBES

The knowledge of a KBES consists of "facts" and "heuristics". The facts constitute a body of information that is widely shared, publicly available and generally agreed upon by experts in the field. The "heuristics" are mostly private rules of good judgment, that

characterize expert-level decision making in the field.

KBES can increase the availability of expert advice and the productivity as well. The separation of domain knowledge from the inference mechanism is an important advantage of KBES, especially when compared with conventional algorithmic programs. This feature enables KBES developers to update easily the knowledge base without reorganizing all the structure of the system. Although KBES are usually designed to function like human experts, they do not reduce the human decision making process to an algorithmic form [Valliere and Lee, 1988].

2.4.3.3 Components of a KBES

A KBES can contain from three to six components. Their relationship is shown in figure 2.4. There are three components which are contained in every KBES: the knowledge base, the context (working memory) and the inference mechanism. The heart of a KBES is its corpus of knowledge which resides in the knowledge base and is structured to support decision making [Waterman, 1986]. This knowledge is specific to the domain of the problem to be solved and can be classified into 'deep' (basic principles) and 'surface' (heuristics) knowledge with respect to how well it is established [Maher 1985, Parsaye and Chignell 1988].

The context is built dynamically each time a new problem is considered. It holds the problem specific information and reflects the current state of this problem. The Inference Mechanism (engine) contains the inference strategies and controls that an expert would use to manipulate the facts and rules (knowledge) while solving a problem. An expert system, depending on the capabilities of the development tool, may employ forward, backward chaining or a combination of them for a specific problem.

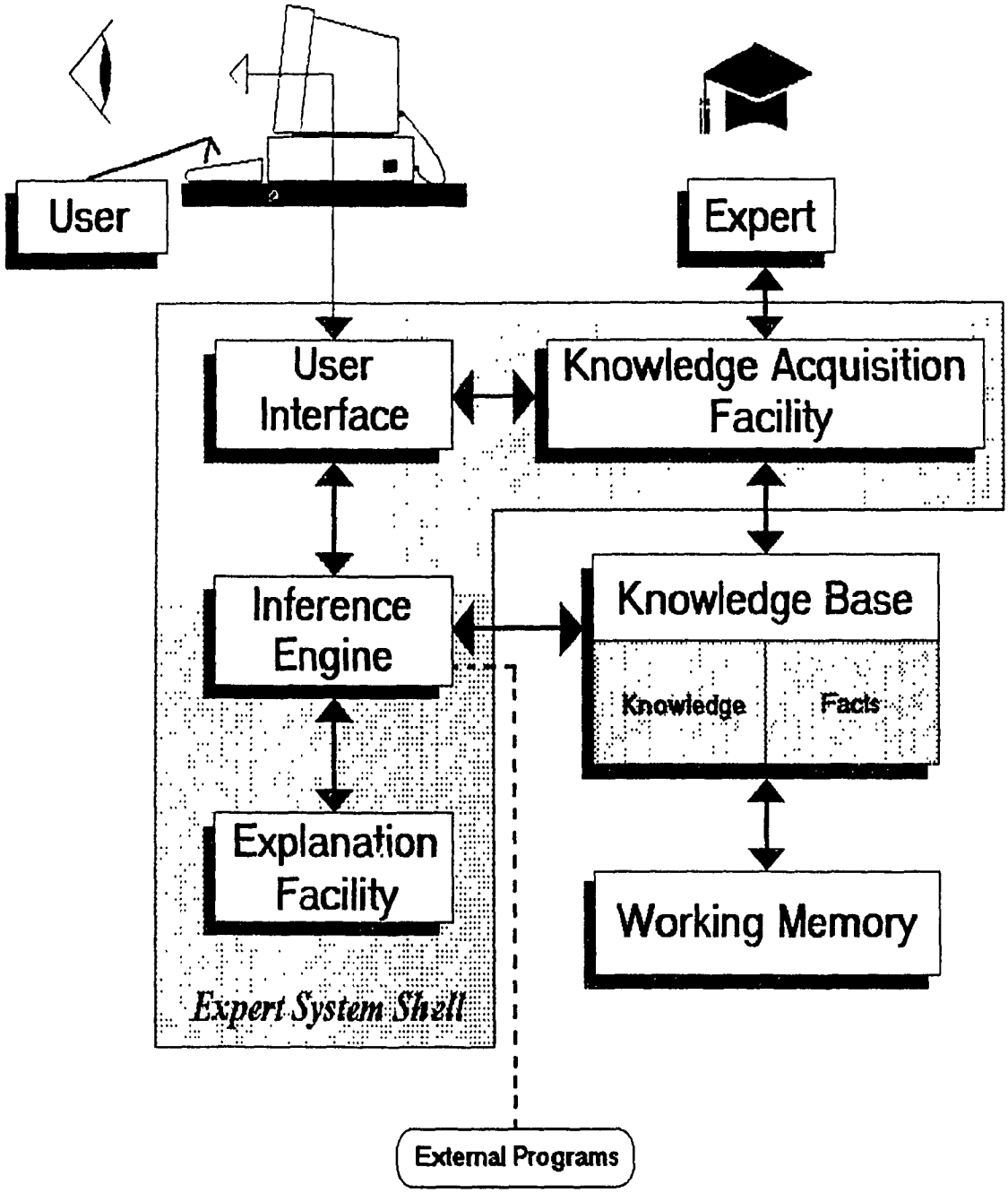


Fig. 2.4 Knowledge-Based Expert System components

The following components (subsystems and interfaces) are not necessarily part of every KBES. However, they are useful and should be incorporated in a final product.

Knowledge Acquisition module is the subsystem which serves as an interface between the expert(s) or knowledge engineer and the KBES. It provides means for entering knowledge in the knowledge base and revising this knowledge when necessary. The Explanatory Facility provides explanations of the inferences used by the expert system. The User Interface handles the interaction between the user and the system during a consultation. It facilitates the context definition and provides access to the functions that take place inside the system, in text or in a graphical manner.

2.5 KBES - Building Design

Existing detailed programs and techniques for energy efficient building design require large computer facilities and, more importantly, a fairly detailed description of a building so that they can carry out accurate evaluations of the performance of the building.

Simulation programs like DOE II [Curtis et al., 1984] and BLAST [Hittle, 1979], require constructing a model before subjecting it to analysis to derive its performance. Therefore most of the evaluation and analysis is accomplished in the development of the model prior to simulation. The designer expends considerable effort in producing a design before simulating its performance.

Optimization techniques address the issue of searching for the best design and is a powerful numerical technique provided the elements of the model have been identified a priori. A model of the artifact to be designed is implicitly embedded. Once the optimization process is involved, there is negligible user interaction, effectively isolating

the designer from the process of deciding values for the design variables [Tham et al., 1990].

Since most engineering design problems are not amenable to sequential processing (they deal with experience, judgement) and often require the use of design heuristics, knowledge-based techniques can be used to address these difficulties by enabling the representation of symbolic information. KBES for building design have been the subject of considerable research at many universities and research organizations. Recently, numerous papers describe approaches which aim to support or fully automate several processes during building design. Most of these approaches are in an experimental form and have not yet been used in practice. Applications more r ·d to passive and energy conscious building design are described below.

Shaviv and Peleg [1990] developed KB-CAAD, a knowledge-based system which aims to support the schematic-conceptual design of passive solar buildings by integrating a simple simulation model with a KBES. Another system for the whole energy design process of passive and conventional buildings is the Energy Design Technique (EDT) described by Hand and Higgs [1986]; its main advantage is that it bridges the gap between comprehensive thermal simulation tools, which demand detailed input and computation, and simplified methods which may lead to errors. Dry and Givoni [1986] developed an expert advisor for energy efficient design in hot-humid and hot-dry climates; this is an interactive system and provides information and recommendations associated with visuals. ENERGY EXPERT is another prototype expert system targeted at the schematic design phase of an architectural project [Bharati, 1990]. Its unique feature is the integration with AutoCAD™ to facilitate the input of building characteristics and to simultaneously create a database of attributes for a specific design. ENERGY EXPERT

uses an approximate method for evaluating the performance of a design. Rosenman and Gero [1989] developed SOLAREXPERT, an expert system for the passive solar design of single dwellings. An important characteristic of this system is the graphical input and output. Its current version considers direct gain through solar windows and the system's knowledge base contains only rules of thumb and experiential knowledge.

With the exception of KB-CAAD, none of the above approaches has incorporated any easy to implement yet detailed analysis technique to check the energy performance of a design proposal. The accuracy of a detailed, validated energy analysis program like BEEP and the capability to test the building performance while representing in detail the passive solar effects, is a unique characteristic of the present approach.

2.6 Discussion

There are tasks in building design which can be significantly facilitated with the use of computers. These tasks usually deal with extensive computations and data manipulation. Other tasks which involve creativity and imagination cannot be completely automated. Since the learning, the creative and the judgmental processes that comprise design remain the prerogative of humans [Garrava et al., 1990], the objective should not be to substitute designers, who managed for many years to tackle successfully design problems, but to support them. It is not necessary to fully automate the process of design to significantly improve design productivity and quality. It is more expedient to establish a design partnership between the designer and the computer using the capabilities of both. Therefore, there is a need for tools that can assist designers rather than fully automate the design process. The purpose of these tools would not be to perform an automatic design but to act as "intelligent" assistants [Zmeureanu and Fazio, 1990].

CHAPTER 3

AN INTEGRATED SOFTWARE APPROACH

3.1 General

The integration of KBES with conventional algorithmic programs in design, is among important trends in the application of expert system techniques [Pedersen, 1988]. The combination of algorithmic programs with KBES could be a possible solution to the problem of inefficient design tools. The principle of such an integrated software architecture is becoming increasingly important versus autonomous operation of task specific programs which conserve a fragmented design environment.

In a hybrid system experiential knowledge and engineering judgment can be represented using knowledge-based techniques and numerically intensive procedures using algorithmic programs. Traditional algorithmic software are used primarily for analysis and they can perform extensive data manipulations. However, they are often complicated and designers avoid using them. A mechanism is needed to make the analysis operations transparent to designers in order to effectively use them during design. This can be achieved by fusing algorithmic with knowledge-based tools, capable of supporting the preparation of input values needed for analysis, explaining the meaning of results obtained by analysis and providing advice when necessary during the design procedure.

3.2 Integrated KBES - Algorithmic approach

In passive solar and energy efficient building design, detailed conventional algorithmic programs have proved to be cumbersome in the iterative design process. This

is mainly due to their inability to manipulate heuristic and qualitative knowledge which is necessary to tackle design synthesis related problems. However, as mentioned above, they are very versatile and effective in numerical data manipulation that characterizes analysis. On the other hand KBES are not robust in numerical data manipulation, while they are very effective in declarative knowledge manipulation and handling of logical inferences and reasoning.

Therefore, despite their many differences (Table 3.1), expert system technologies and conventional programming can be combined to support good decisions throughout the whole building design process. This is important since the earlier analysis results are made available, the more impact they have on the final design. It is necessary to enable designers to make use of analysis tools not only at the final stages when almost everything has been determined and any changes are costly and time consuming. This can be achieved by using the developed design assistant which combines effectively the advantages of simulation and knowledge-based techniques and can be applied also at the preliminary design stages.

A model of the structure of an integrated, combined knowledge-based-algorithmic passive solar design system is illustrated in figure 3.1. During the design process Artificial Intelligence (AI) can assist the designer-decision maker in detailing and conducting simulation and assessing the validity and meaning of the results of simulation [Wright 1985, Adey and Trevelyan 1988]. At the beginning of design, information related to the building type and characteristics is provided by the designer who also specifies his objectives and preferences with respect to the final design features. Monitoring of the whole design process, useful recommendations for the various steps in design and possible corrective actions are provided to the designer as well as the rationale behind any

CONVENTIONAL PROGRAM	EXPERT SYSTEM
Algorithms	Heuristics
Effective manipulation of large databases	Effective manipulation of large knowledge bases
Numerical treatment	Symbolic treatment
Sequential	Interactive
Complete / rigid	Incomplete / flexible
Run - time explanations impossible	Run - time explanations desirable and achievable
Representation and use of data	Representation and use of knowledge
Knowledge and control integrated	Knowledge and control separated
Static decision process	Dynamic decision making
Oriented towards numerical processing	Oriented towards symbolic processing

Table 3.1 Expert Systems vs Conventional programs

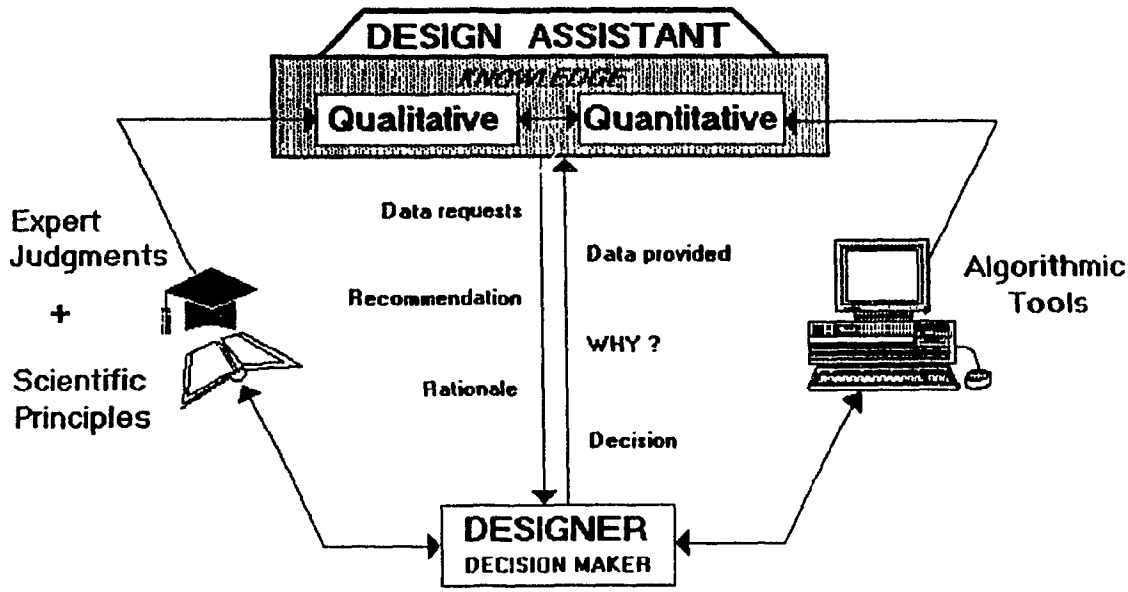


Fig. 3.1 Combined knowledge-based-algorithmic design system

suggestions. The designer interacts with the system and is guided to a successful conclusion and decision.

A discussion on final design tool features, development tool selection criteria and characteristics follows.

3.3 Design Tool Requirements

Detailed tools developed for design are usually difficult to use because they are are complicated, requiring many input data and running time. In order to effectively support design, a design tool should fulfil some important requirements [Mathews and Richards, 1989]:

- It should be applicable to a wide range of buildings.
- The input data should be kept to essentials and should be readily available to the building designer.
- The preparation of the input should not take more than one hour and the output should be visual.
- Generally a design tool should be a user-friendly program using language familiar to the designer and not scientific phrases.

Moreover design tools should be easy to update in order to incorporate more knowledge and information when required, without the need to modify all the structure and program code. They should also be 'self-descriptive' [Uzel and Button, 1987] providing explanations and reasoning about their requirements, limitations etc. when asked by the designer. An idea of what the designer knows, doesn't know and is trying to accomplish is also useful so as to complement his/her knowledge by additional information, or avoid asking questions irrelevant to the designer background [Shapiro and

Geller, 1987].

For architectural design tools the information presented to the designer should be of the architectural form [Brown, 1990]. This could be facilitated with a graphical user interface which is useful part of any design tool [Rosenman, 1990].

3.4 Selection of a Development Tool

KBES development tools could be used to implement the integrated system architecture based on the methodology. Currently a variety of KBES development tools exist which provide different capabilities. These capabilities differ significantly depending on the type(s) of inference mechanism(s) offered, the knowledge representation methodology, integration facilities with other software and characteristics of the developer and user interface.

In order to satisfy the previously described requirements with respect to the characteristics of the final design tool, the developer has to select an appropriate development package. The following criteria were considered in the development tool selection:

• **Expert System shell:** The non-availability of suitable tools for the development of a KBES is overcome. Expert System shells provide environments that do not require the effort which is needed in order to learn and use symbolic programming languages like LISP or PROLOG. Therefore, the development of a KBES could be undertaken also by domain experts who are not necessarily programmers. The structure of the domain knowledge can be accomplished faster using a shell, as compared to programming languages, without the need to build the system inference mechanism and interface from scratch.

• **Software Integration:** The development tool should provide 'bridges' i.e. integration capabilities with other programs [Ignizio, 1991]. Even if KBES development tools have the advantage of symbolic processing, desired features for applications in engineering design include also basic computational capabilities and interface to databases, in order to retrieve or store information, and external programs which can carry out extensive numerical computations.

• **Multitasking:** Simultaneous running of different applications with exchange of information is among the necessary capabilities of the development tool operating environment. Since there is a need for integrating software which have to run at the same time sharing the memory capacity of the computer, this feature is among the primary considerations.

• **Knowledge representation methodology:** Among different knowledge representation techniques that have been developed, like semantic networks, production rules, frames, objects and logic [Waterman 1986, Harmon and King 1985, Parsaye and Chignell 1988], the most widely implemented are based on production rules and frames or objects. Rules are useful in representing heuristic knowledge while objects can effectively model knowledge in a hierarchical manner, taxonomies, more closely to the way humans use to organize information about the world. There are systems which combine both rules and objects thus providing a hybrid knowledge representation schema offering more flexibility for the development of a KBES.

The nature of the problem at hand is important criterion in the selection of an appropriate knowledge representation schema. For formation problems, like design, object-oriented code (or hybrid object-oriented systems) offer some distinct advantages [Allen, 1986]. One of the major advantages is that by integrating frames/objects and production

rules into a single unified representation facility, the organizational and expressive power of OOP is made available to domain experts [Fikes and Kehler, 1985]. As compared with rule-based systems, a hybrid knowledge-based system environment (supporting frames and rules) is considered more appropriate for a design tool [Bédard and Ravi, 1991]. Therefore the selected development tool should support a hybrid knowledge representation technique combining frames or objects with production rules.

• **Debugging facilities:** Sufficient debugging facilities should be provided by the development tool in order to facilitate the knowledge engineering process. Tracing of the steps the inference mechanism follows during a session and graphical representation of the knowledge offered by some tools, are very helpful during the system development process.

• **User interface:** The possibility to develop a user-friendly interface providing explanatory information and reasoning without much programming efforts, is considered important for a successful system. A graphical environment was also desired in order to enhance the designer-machine interface.

3.5 Development Tool - Implementation Issues

LEVEL5 OBJECT was selected for the system development because it met all the above requirements. LEVEL5 OBJECT provides many features such as rules, Object-Attribute-Value triplets, use of inheritance and other Object-Oriented Programming characteristics useful for the knowledge representation. Hypermedia handling (including text and bit-mapped images), string manipulation, on-screen page scrolling are also useful for the interface development.

An 80386 personal computer has been used with Microsoft Windows™ (version

3.0) multitasking operating environment. It was the fact that LEVEL5 OBJECT runs under Microsoft Windows™ that made it a perfect fit for the developed system. The Windows operating environment added more indispensable capabilities by allowing several programs running concurrently (multitasking). For example, it was necessary for the system to run the energy analysis module BEEP, which is the core algorithmic program, simultaneously with the Knowledge-Based System and other procedural programs and Windows applications. Thus, Windows and LEVEL5 OBJECT provided an integrated environment.

Another advantage of LEVEL5 OBJECT is that it makes extensive use of the Windows library of display design tools (such as pushbuttons, check lists, dialog boxes) and includes a powerful programming environment for rule-based expert system development, with multiple inference strategies and capability of their combination in an application.

A major advantage of the development tool was the high level of integration between expert system, hypermedia, Windows and external (DOS applications) components. For example, any topic within the system can contain text, hypermedia and procedural or rule-based statements. Thus, from a development point of view the tool provided also a vehicle for an effective rapid prototyping of the system. More information on the development tool can be found in Appendix A.

CHAPTER 4

PASSIVE SOLAR DESIGNER - THE DESIGN ASSISTANT

4.1 Introduction

The current prototype implementation of Passive Solar Designer (PSD) aims at the successive improvement of design alternatives by taking into account performance attributes relating to energy efficiency, occupant comfort and sizing of auxiliary heating/cooling equipment. The architecture of Passive Solar Designer is presented in this chapter with description of the different system components and other programming issues. The design procedure proposed in the methodology is also described.

4.2 Components of Passive Solar Designer

PSD includes several modules which are organized in a graphical user interface (GUI) with multitasking and interact with each other during the design process. The communication links between these modules are illustrated in figure 4.1. These links establish constant information flow among the different programs and databases, controlled by a mechanism developed as part of the KBES.

4.2.1 Energy Analysis Module - BEEP

The initial steps for system development were concerned with the structure of the interface which would bridge the Knowledge-Based System module with the main algorithmic program, BEEP. Therefore, first a link was created between LEVEL5 OBJECT and BEEP. The communication between BEEP and PSD is performed through

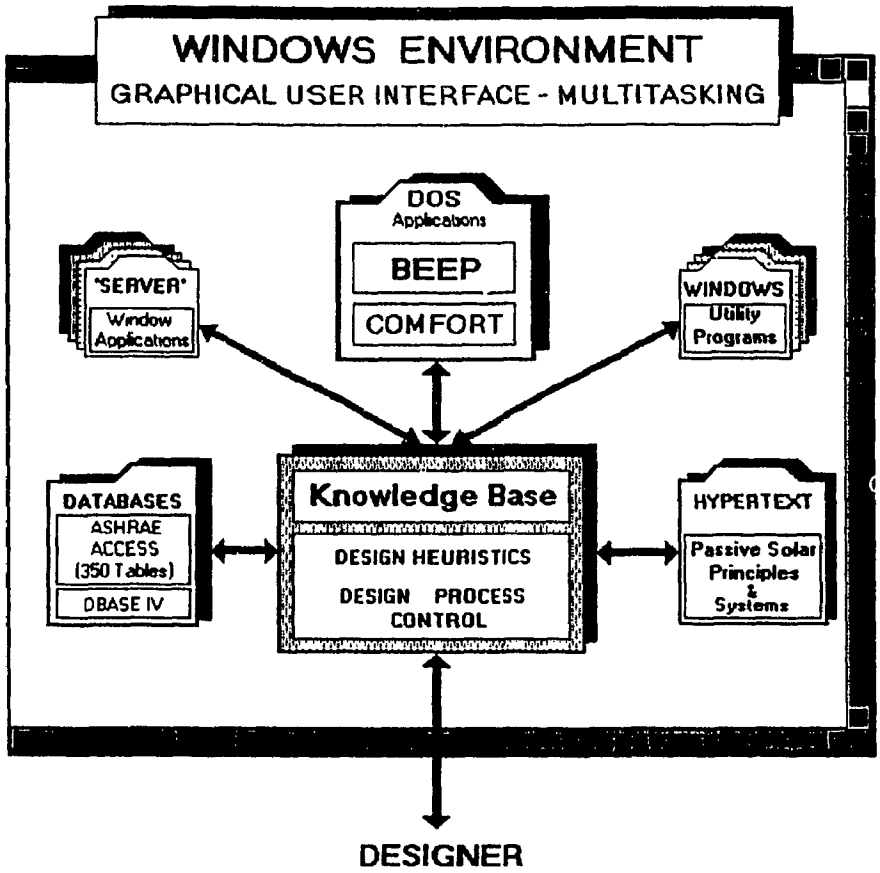


Fig. 4.1 Integrated system architecture

data exchange from files.

With respect to the input values required by BEEP, the system provides to the designer explanatory information about each of these values (fig.4.2). At run-time, this information can be accessed by selecting the appropriate item from a special display (fig.4.3). From this display the designer can also access the ASHRAE ACCESS database [ASHRAE, 1989], the Graph-2 program, to plot graphs from BEEP results, and the hypertext "Design Guidelines" module.

BEEP models accurately the solar effects, the natural energy flows and the heat storage and release process together with the temperature swings associated with it. The primary capabilities of BEEP are described below [Athienitis et al., 1986]:

• Distributed elements such as thermal storage mass are modelled as twoport network elements without the need for discretization.

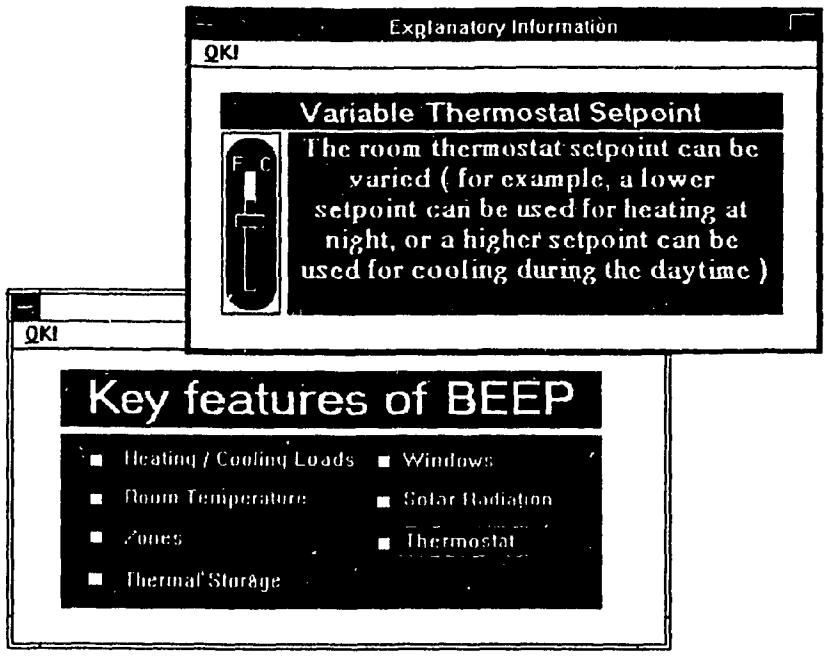
• Room interior radiant heat exchanges (infrared) among the room interior surfaces are modelled in detail (separate from convection), the radiation exchange factors being calculated exactly; the only major approximation made is linearization.

• A time-varying conductance such as that corresponding to a window with night insulation is modelled accurately.

• The solar radiation absorbed by each room interior surface is calculated. This is important in determining the effects of the thermal storage mass location and solar absorptance on direct gain room performance.

• The room mean radiant temperature is determined accurately; the effects of surface longwave emissivity are included and the operative temperature is calculated.

• On/off auxiliary heating is modelled by means of an iterative technique; proportional control being linear, is modelled directly



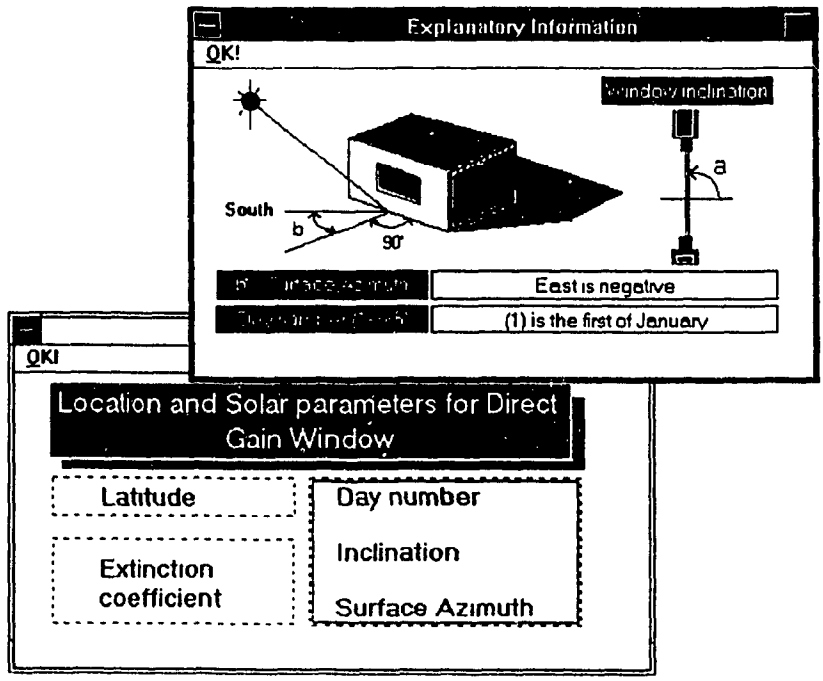


Fig. 4.2 Typical explanations for input values required by BEEP

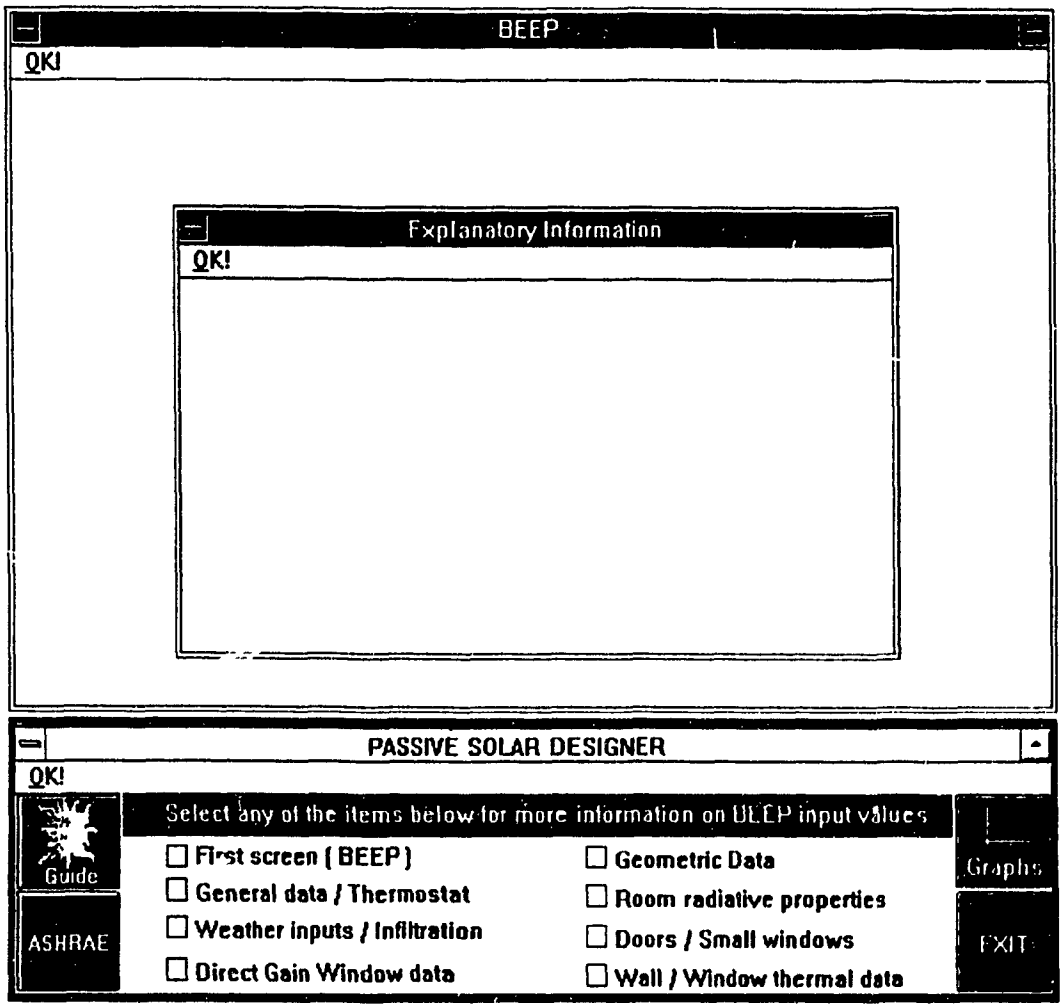


Fig. 4.3 Reference display

BEEP takes also into account (optionally) internal loads generated by occupants and equipment in a building. This is important especially in the case of office buildings where these loads are often significant and auxiliary cooling is required in the building core even during winter.

At run-time, BEEP is called from LEVEL5 in order to perform analysis when the designer needs to investigate the performance of a specific design alternative. The required input is provided by the designer and after results are obtained, values needed by other modules for the calculation of other indices (eg. PMV, PPD) are transferred through LEVEL5.

BEEP requires only a minimum number of weather inputs: the daily clearness index (which is used to generate a half-sinusoid model for solar radiation), the mean ambient temperature, and its range. Other input values required concern direct gain window data and more specific information (geometry, thermal characteristics) for the components of the zone under consideration. BEEP calculates accurately the hourly heating and cooling loads for a design day and determines the room temperature dynamic response with or without auxiliary heating/cooling. It also determines accurately the solar radiation transmitted through a window for any orientation and its absorption by each room interior surface.

4.2.2 Comfort Evaluation Module

The second algorithmic module of the system [Zmeureanu, 1991] is used for the calculation of the comfort indices PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied), which predict the thermal sensation of people in a zone based on Fanger's model [ASHRAE, 1981]. The required input includes environmental variables

(air temperature, MRT, RH, air velocity) and personal variables (metabolism, thermal insulation of clothing, work which is done by occupants). PMV and PPD are the output values. Appendix B includes more information on comfort indices.

4.2.3 Databases - ASHRAE ACCESS

The ASHRAE ACCESS database which contains about 350 tables and theory from the ASHRAE Handbook of Fundamentals [ASHRAE, 1989] can also be accessed on-line by the designer. This facilitates further the design process since the designer can extract material properties and other required information from within the system without leaving the KBES environment, thus saving considerable time, and ensuring continuity in the design process.

Other database files store information related to thermal characteristics of building materials, and weather data for different locations.

4.2.4 Hypertext - "Design Guidelines"

The hypermedia facilities provided by LEVEL5 OBJECT were used to develop "Design Guidelines" which is the hypertext module of the system. 'Hypertext' is a term that describes nonlinear text applications. These applications incorporate the capability for the end user to move through a body of text in a point-to-point, self directed manner. Unlike traditional text applications, such as a book, where the user proceeds in a linear, incremental fashion, hypertext applications allow the user to pursue information in a relatively random fashion depending on ones needs.

As classical hypertext applications "Design Guidelines" consists of a series of windows (screens of information), text and graphics that are associated with each other

by links to other displays. This application makes use of LEVEL5 hypermedia tools (such as hyperregions) and takes full advantage of the display items provided, especially pictureboxes, pushbuttons and textboxes. The final result is a highly graphical environment which accommodates useful explanatory images associated with passive solar design principles and design guidelines.

Figure 4.4 shows an example of a typical display from the hypertext module. Information is structured in 45 different displays which are organized in such a way that can be easily explored by the designer (fig.4.5). LEVEL5 OBJECT has the capability through the 'CHAIN' command to link different KNB files, and thus access to "Design Guidelines" is easy for reference during design.

4.2.5 Other incorporated programs

GETSTR is a windows application called by the system to facilitate the transfer of information from BEEP output files. In LEVEL5 OBJECT Windows applications are called 'SERVER' programs and they can either be 'activated' or 'established' by calls from LEVEL5 applications. GETSTR is called via the 'ESTABLISH' command and becomes memory resident in order to repeatedly exchange information with LEVEL5.

NOTEPAD is a text editor which runs with Windows.This program is activated when the designer wants to obtain the full output from BEEP which is stored in ASCII files. This output is saved for each design alternative.

4.2.6 KBES - Design Control Platform

The controlling/coordinating module of the system is written in LEVEL5 OBJECT and while running the system is in continuous contact with the designer

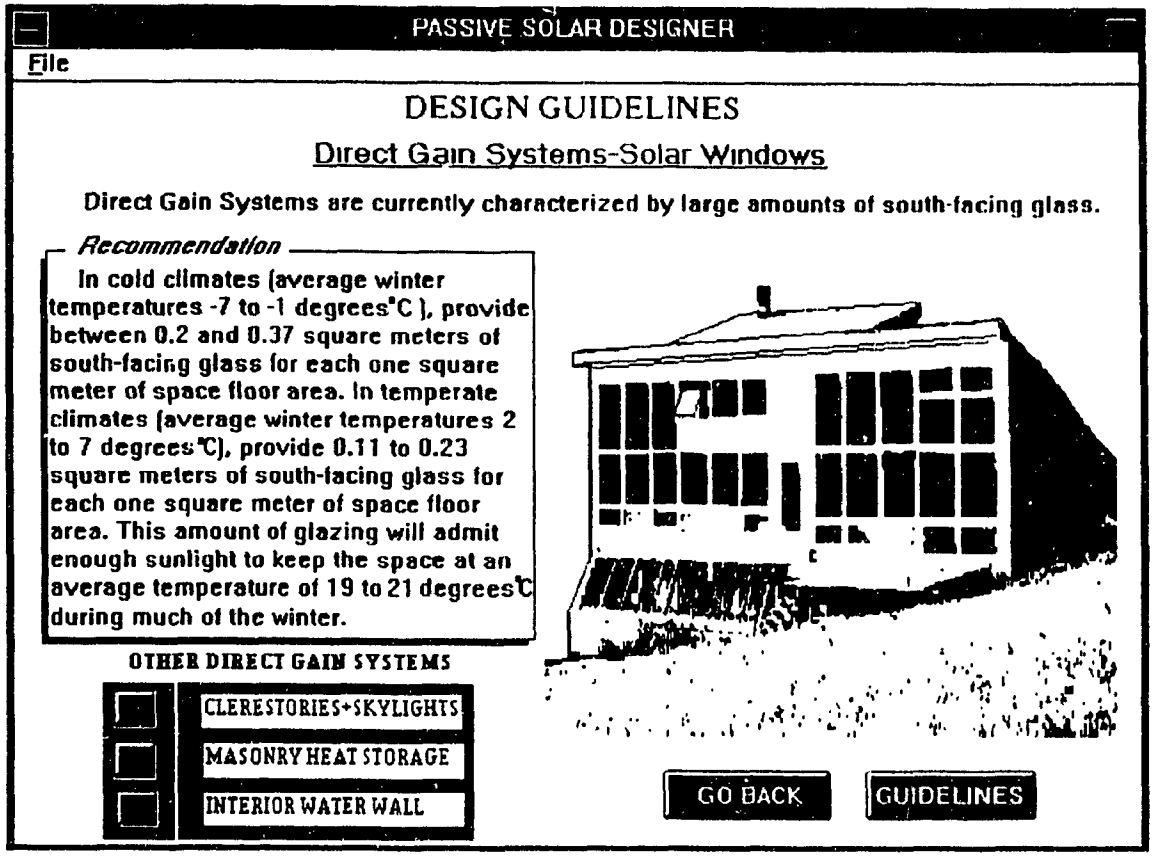


Fig. 4.4 Typical display from "Design Guidelines" hypertext

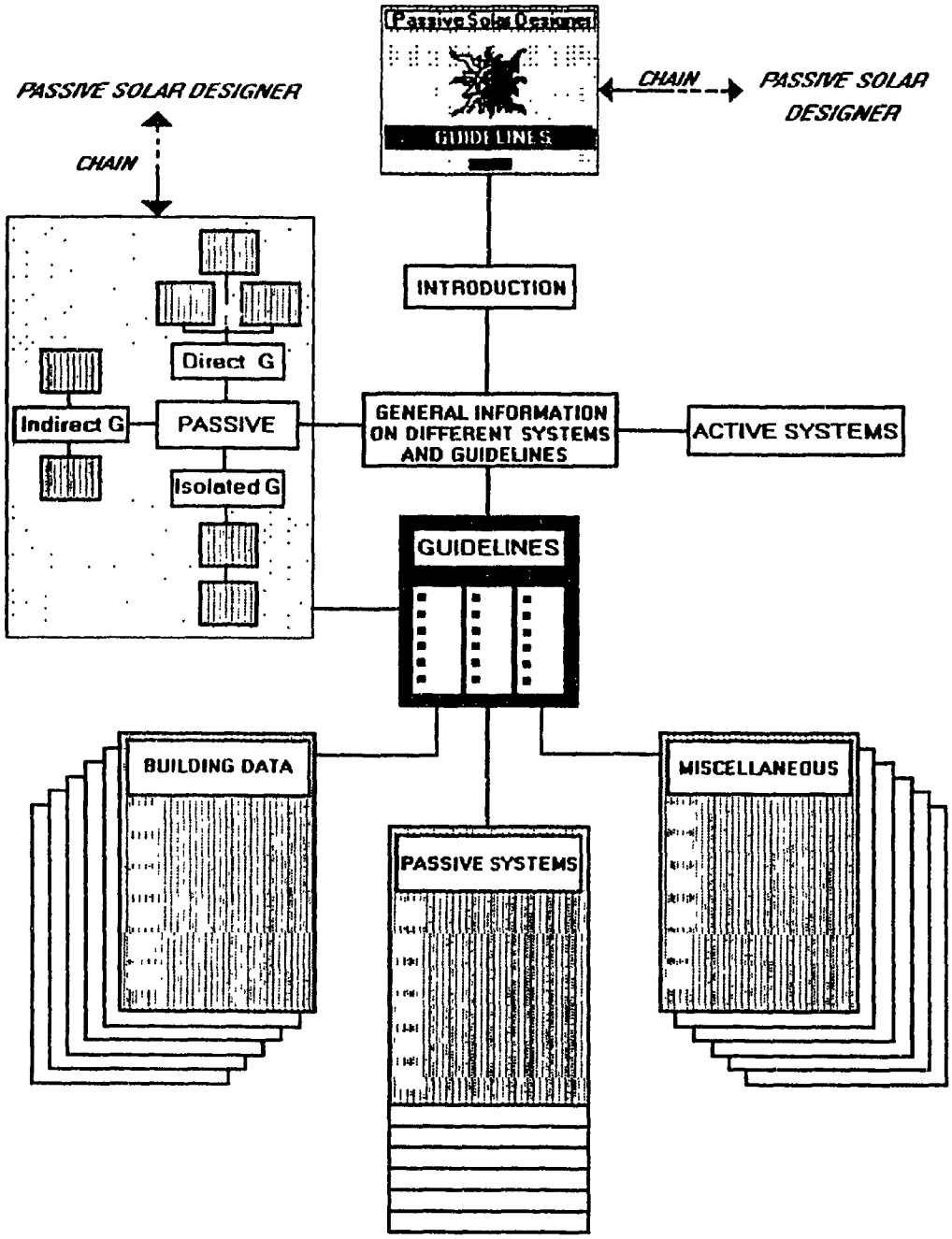


Fig. 4.5 Structure of the hypertext module

(fig.4.6). Its knowledge base accommodates the design heuristics acquired mainly from the literature (Mazria 1979, Balcomb et al. 1982, Givoni 1991, ASHRAE 1980, CHBA 1989). Information regarding the design process and interface characteristics is also included. The basis for the structure of all this information in the shell is the 'Class'. Various design objects such as "direct gain window" etc, are represented by Classes. A Class is the template of an object and is used to produce multiple instances of the object.

Characteristics of each object, like window area, number of glazings etc, are represented by attributes which have their own type, name and properties that specify the way the inference mechanism will treat them at run-time. The actual values of each object obtained during a consultation are held by the object's 'Instances' which inherit the characteristics (structure and behaviour) of the object. For example an instance of the 'direct gain window' Class stores in its attributes, such as "orientation", "glazing area" etc. values that are input by the designer or calculated by the system. Figure 4.7 shows the structure of an object declaration, the 'Zone Design Alternative' Class (ZoneDA). During design the system generates dynamically instances of this Class, which encapsulate the object structure and hold the actual values of the Class in its attributes. Each Class has a name and properties that specify for example whether it inherits the characteristics of any other Class or Classes, if it is sourced from a database or whether it has a single instance.

Inferential knowledge is represented in the form of rules and methods (procedural attachments) to attributes. Backward chaining rules and forward chaining demons describe the operational logic, rules of thumb and cause-and-effect relationships needed to make decisions and trigger certain events or actions during a session. Methods establish procedures for determining values; they are blocks of developer-defined procedural

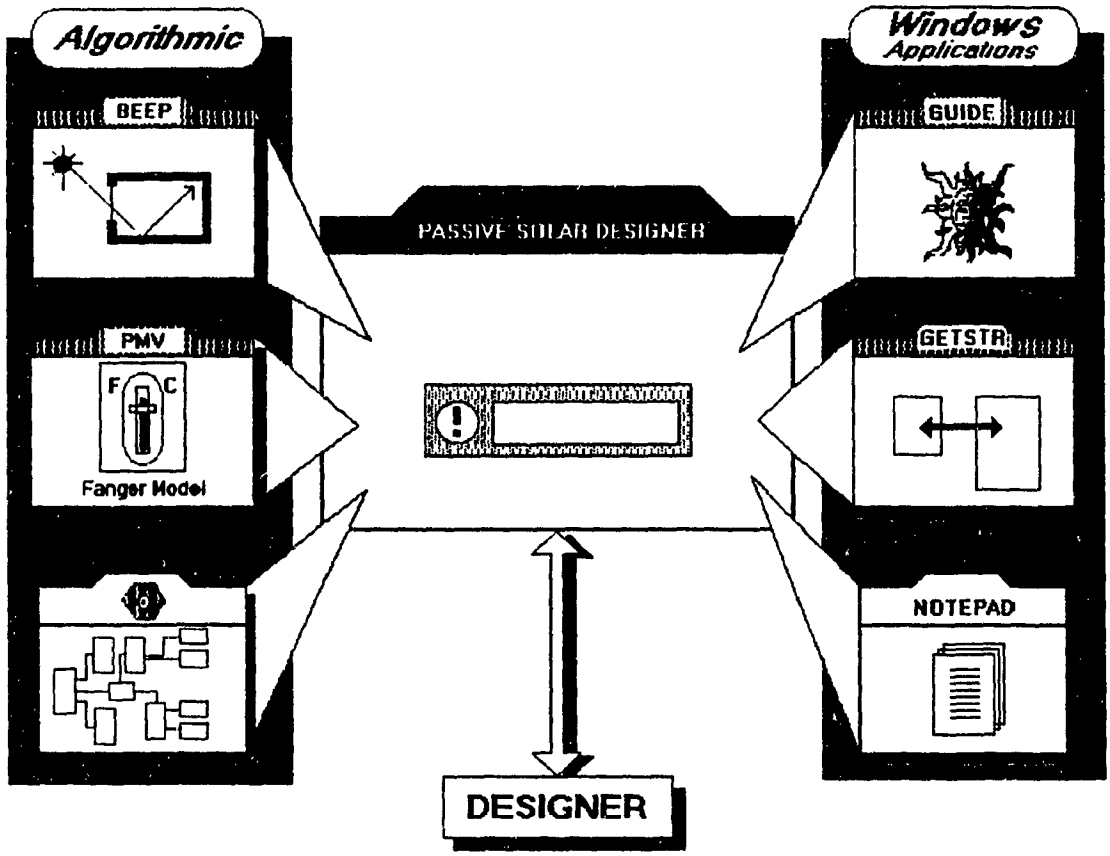


Fig. 4.6 Coordinating module

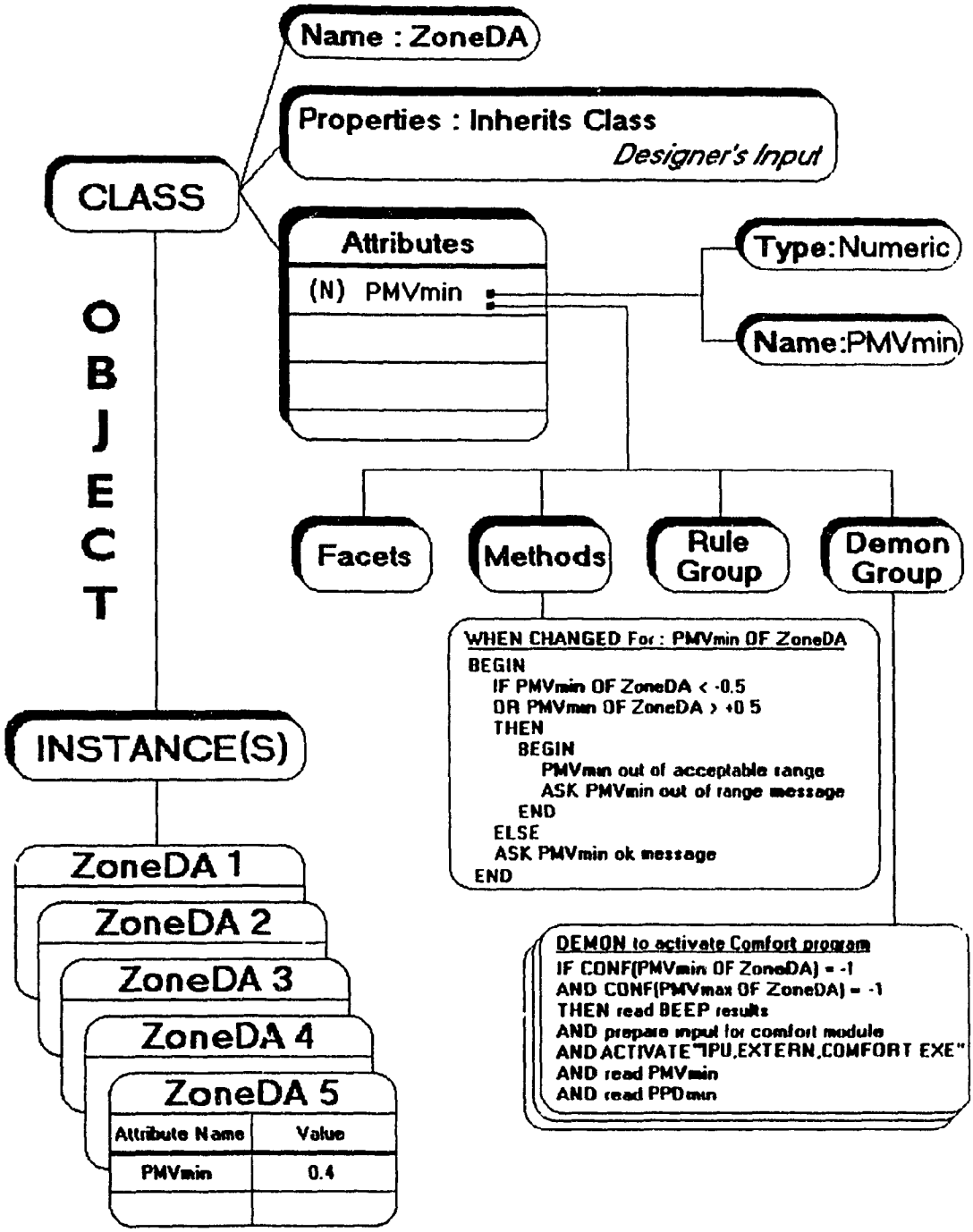


Fig. 4.7 Object structure in Passive Solar Designer

statements that are executed when the value of an attribute changes (When Changed Methods) or when a value is needed (When Needed Methods).

Example rules

The following rule is a backward chaining one, tested by the backward chaining inference engine in the path towards the agenda goal 'Uo OF ASHRAE' which is the overall thermal transmittance value required by ASHRAE Standard [ASHRAE 1980].

RULE for Ufloor

IF type OF Building IS type A_1

OR type OF Building IS type A_2

OR type OF Building IS type B

AND slab on grade OF Floor

AND slab is heated OF Floor

AND ddays OF Building > 0

AND ddays OF Building < 10500

THEN Ufloor OF ASHRAE := $-(2.38 * 10^{4}) *$ ddays OF Building + 0.45

An example forward chaining rule (demon) is given below. It is tested after results from BEEP are obtained. If the conditions of the antecedent (IF part) are satisfied, ie. if the operative temperature on a clear day exceeds the maximum specified by the designer, then the demon fires and the 'simple' attribute 'overheating' gets a value of 'True' while appropriate recommendations are selected from a 'string' array attribute called 'Recommendations', and are shown to the designer in order to assist in overcoming the problem.

DEMON for overheating

IF operative temperature [1] OF ZoneDA > operative temperature OF Designer's Input

THEN overheating := TRUE

```
AND text OF Recommendation textbox := Recommendation [1]
AND ASK Recommendation display
```

Recommendation [1]: "*Problem :* Overheating is likely to occur! *Recommendation :* Increase mass on interior surfaces that absorb much transmitted solar radiation OR reduce the window area".

Example Methods

A typical 'When Needed Method' is the following:

```
WHEN NEEDED METHOD For: Uo OF ASHRAE
BEGIN
        Uo OF ASHRAE := (ASHRAE.Uwall * Wall.area + ASHRAE.Ufloor * Floor.area +
        ASHRAE.Uroof * Roof.area) / envelope area OF Building
        ASK Wall section display
END
```

It is tested in the same backward chaining path as the rule described above, during the inference mechanism search for a value associated with the 'Uo OF ASHRAE' ie the maximum envelope thermal transmittance value specified by ASHRAE. Since the individual envelope component U_values are required to calculate Uo, this method will force the inference engine to find values for all the U_values from other sources eg. rules, databases, by querying the designer etc. In this case information needed is stored in backward chaining rules.

The method shown in figure 4.8 is used after the completion of a design alternative in order to compare the performance attributes of two successive design alternatives. The 'FIND <class name> AS <alias name>,<class name> AS <alias name>' command [Info. Builders, 1990], creates two temporary views of the same class instances in order to make comparisons between them. Then the system selects, based on the

WHEN CHANGED For : Compare successive design alternatives

```
WHEN CHANGED
 BEGIN
  FIND ZoneDA AS view 1, ZoneDA AS view 2
   WHERE  view 1.DA no = DA number
     AND view 2.DA no = DA number - 1
   WHEN FOUND
    MAKE Match
     WITH Temp swing1 := view 1.Temp swing
     WITH Temp swing2 := view 2.Temp swing
     WITH AuxHL1 := view 1.AuxHL[ 1]
     WITH AuxHL2 := view 2.AuxHL[ 1]
     WITH Peak Load1 := view 1.Peak Load[ 2]
     WITH Peak Load2 := view 2.Peak Load[ 2]
  FIND END
  IF Match.Temp swing1 > Match.Temp swing2 THEN
   Temp swing higher OF Recommendations := TRUE
  ELSE
   BEGIN
    IF Match.Temp swing1 < Match.Temp swing2 THEN
     Temp swing lower OF Recommendations := TRUE
   END
  IF Match.AuxHL1 > Match.AuxHL2 THEN
   AuxHL higher OF Recommendations := TRUE
  ELSE
   BEGIN
    IF Match.AuxHL1 < Match.AuxHL2 THEN
     AuxHL lower OF Recommendations := TRUE
   END
  IF Match.Peak Load1 > Match.Peak Load2 THEN
   Peak Load higher OF Recommendations := TRUE
  ELSE
   BEGIN
    IF Match.Peak Load1 < Match.Peak Load2 THEN
     Peak Load lower OF Recommendations := TRUE
   END
 END
```

Fig. 4.8 Example "When Changed" method in Passive Solar Designer

comparison, the last two design alternatives and generates dynamically an instance of the CLASS 'Match' so as to store values of important attributes (operative temperature swing, auxiliary heating load, peak load) from the selected design alternatives . These values are compared by the system and finally recommendations are provided. The recommendations are specified in demons as the one described above which have as antecedents conclusions obtained in the comparative process initiated by the Method (e.g. Temp swing higher OF Recommendations := TRUE). Among the conflict set of demons, one executes and the associated conclusion (recommendation) is chosen and shown to the designer.

Various constraints from codes and standards are also incorporated in the controlling/coordinating module which are of the symbolic or numerical format and specify acceptable values or range of values for important attributes (e.g. -0.5=<PMV<=+0.5).

The role of each of the system modules and their interaction during the design process, is discussed further in the following description of the design alternative generation and evaluation process.

4.3 The User Interface

The user interface is a very important part of any computer-based design tool which is often underestimated by developers. Systems which may be technically complete and well-organized, sometimes lack an interface for effective designer-machine interaction.

It is important during the design process to keep the designer updated. Since, as mentioned before, design is an iterative process, frequent feedback is provided to the designer from analyses in order to keep him/her aware of the impact of any decisions.

Graphics are used when they can be an appropriate and effective communication medium especially if it is easier to show an idea than to describe it.

The development of the interface for the design assistant was accomplished by utilizing the tools offered by the development environment. An interactive GUI was developed which provides explanations throughout the whole design process regarding input variables required by the different modules, the system output and the design procedure itself. Help is also available with respect to the acceptable range of important input values, as well as type checking and input validation. The user interface enables the designer to update, add or delete information from the databases. This is possible using the object-oriented database management features of LEVEL5 OBJECT.

Figure 4.9 illustrates some of the tasks involved in the development of the GUI. Drawings or other graphical information were integrated in the system while program information files (PIF) specified how programs that are not Windows applications, run with Windows. These files also specify program running priorities (foreground/background) and memory allocation among the various applications in PSD.

4.4 Software Metrics

The current prototype of PSD was developed in three stages. During the first stage a communication link was established between BEEF and the KBES. During the second stage knowledge required at the initial stages of design was acquired and structured in the knowledge base. Also the system platform and interface were expanded in order to accommodate the rest of the modules. A predominant issue during this and the third stage was the implementation of the design procedure and the control mechanism. The most important performance variables are used by the mechanism during design alternative

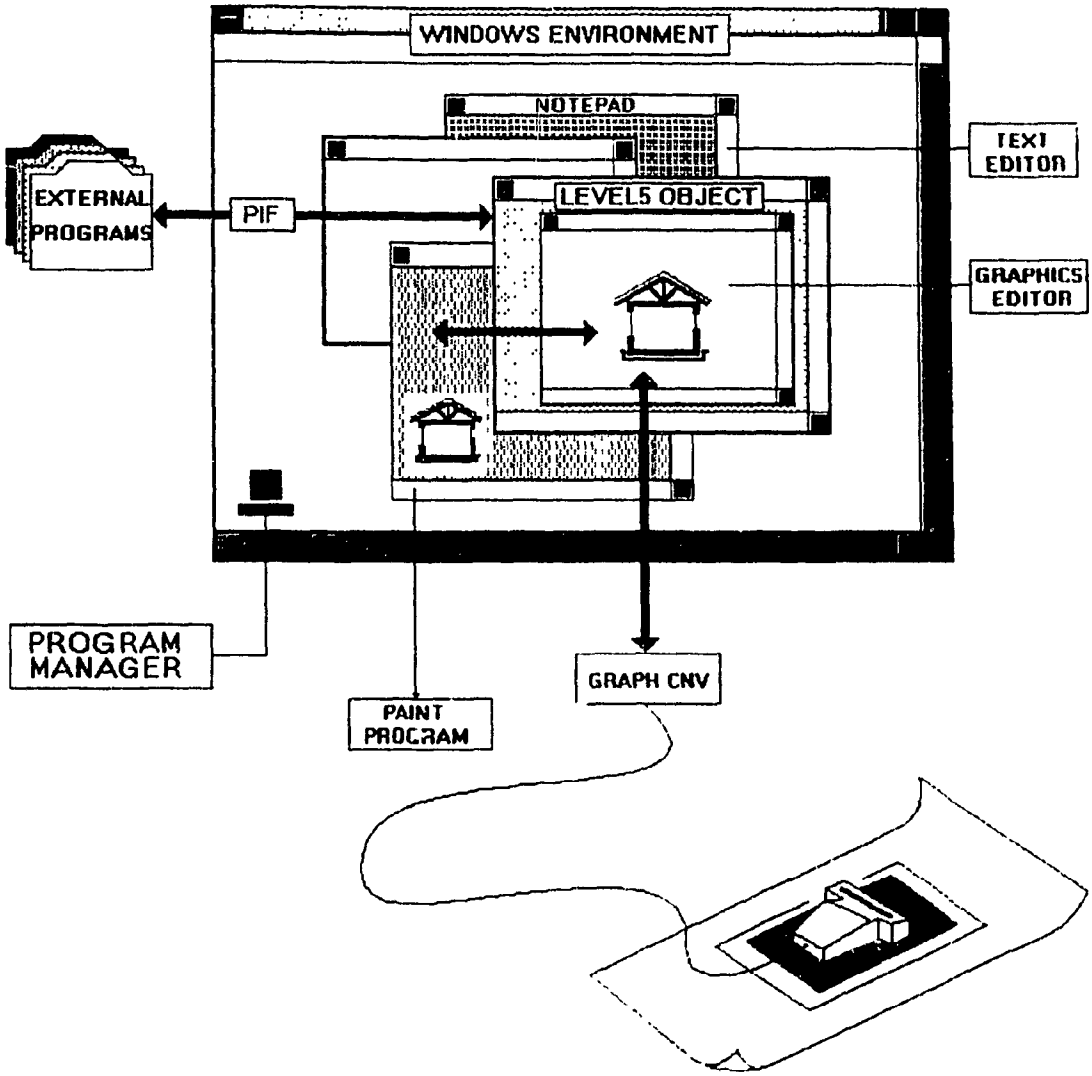


Fig. 4.9 Tasks involved in graphical user interface development

generation and evaluation.

The knowledge-based module, as mentioned above, includes the design heuristics and information regarding the design process control and interface characteristics. This information is represented by 'rules' and 'methods' which are grouped in different categories based on their purpose and use during design. These categories are described below (See Appendix C for typical rules and methods):

- Start design (provide initial values - acceptable defaults)
- Design process control and interface characteristics

  Explanations

  Bridges with other programs

  Access to databases

  Organization of displays / information transfer

  Numerical calculations
- Code / Standards compliance checking
- Recommendation for possible corrective actions

4.5 Design with "PASSIVE SOLAR DESIGNER"

4.5.1 Generation of Design Alternatives

Passive Solar Designer supports an iterative system-user cooperative procedure of design alternative generation and evaluation. The main principle of its operation is the improvement in performance of successive design alternatives. Design alternatives, typically consist of different building zone arrangements, building envelope component materials and properties, their dimensions and location in the zone. The generation of

design alternatives is performed step-by-step by generating-testing-improving an alternative (fig.4.10). This design process has the advantage that the designer experiences immediately the impacts of his decisions. The basic unit which is considered each time is the "zone" and is assumed to be isothermal for load calculations.

At the beginning of a consultation the designer specifies the type and location of the building, the type of climate and constraints regarding the maximum allowable direct gain window area and wall thickness. The next step is the selection of a zone in order to test its performance. It is important, in order to save time and reduce the number of synthesis-analysis cycles, to provide best default input values [Shaviv and Kalay, 1990]. Therefore, the system provides initial values (acceptable defaults) for the window area, number of glazings and thermal mass surface area. These values are selected based on information repository in the knowledge-base (rules of thumb). The system provides also support for the appropriate initial selection of the building envelope components thermal resistance values. For this purpose ASHRAE Standards provisions are encoded in the form of rules. These rules are tested to verify whether the overall envelope thermal transmittance value is within the acceptable ASHRAE ranges.

When the synthetic part is completed (i.e. sizing and selection of materials for the envelope components and mass), analysis is performed for a design day. From the results obtained from analysis, the MRT and air temperature are used as input in the comfort evaluation module. The KBES controls the overall exchange of information, data retrieval from the databases and execution of algorithmic modules when needed.

A design alternative for a zone is completed when three important cases have been considered:

Case 1. The zone performance is checked on a relatively clear winter day

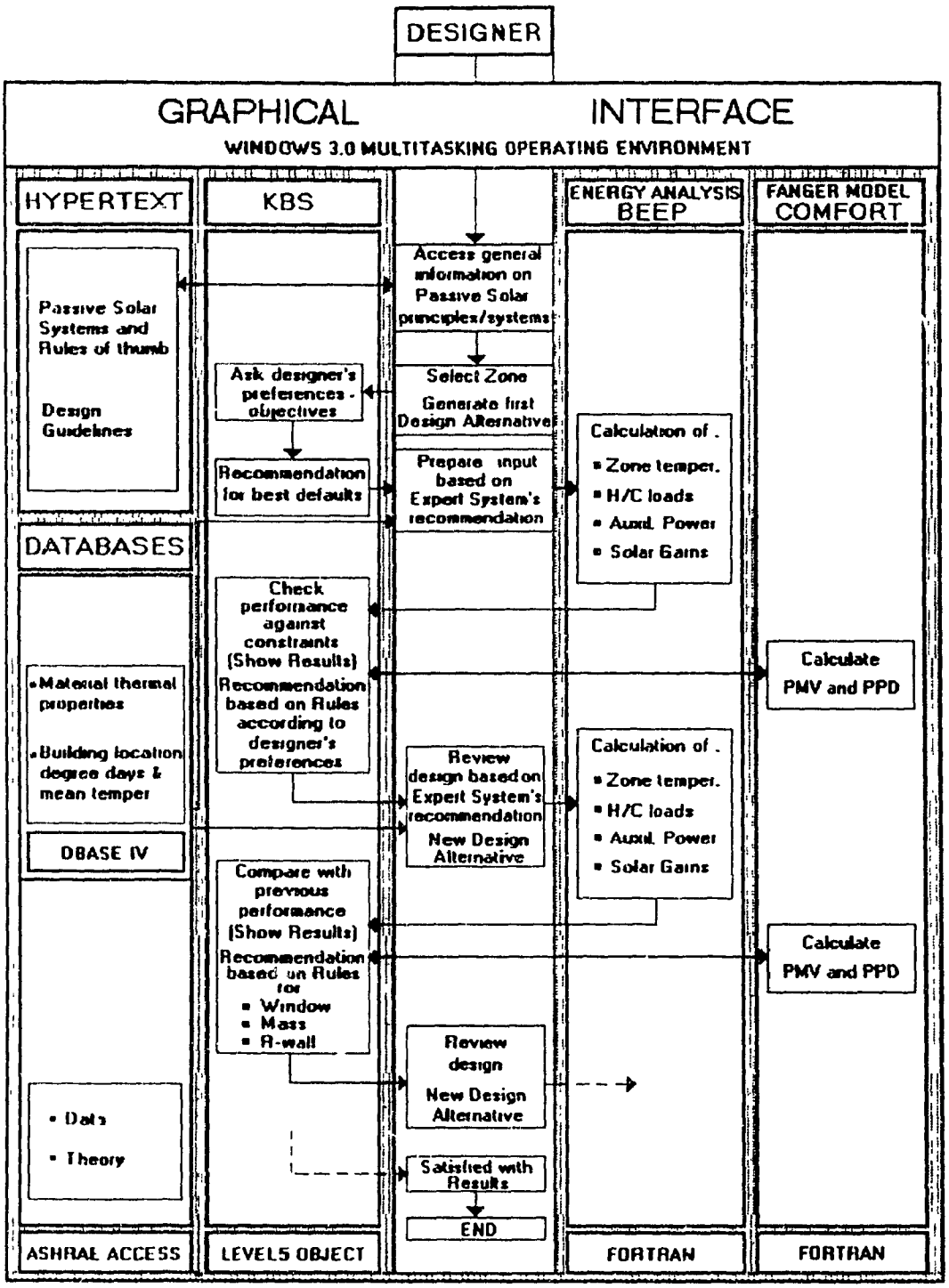


Fig. 4.10 Flowchart of the design process with Passive Solar Designer

(KT=0.7) assuming no auxiliary heating/cooling. The objective of this analysis is to investigate the thermal storage effectiveness of the zone thermal mass distributed along the inner surfaces. When the type is not appropriate or the amount of mass is not sufficient (eg. in a lightweight structure) significant temperature fluctuations occur, often with overheating. The important performance parameter in this case is the operative temperature swing.

Case 2. The zone performance is checked on a relatively clear winter day with heating. With the results obtained the designer can check how effectively the solar energy is utilized within the zone by considering the auxiliary load. Therefore, between two successive design alternatives the best is the one which eliminates the possibility of auxiliary cooling load (which is needed when overheating occurs) and has the lowest auxiliary heating load.

Case 3. The zone performance is checked on a cold cloudy winter day with auxiliary heating/cooling. This case is considered in order to investigate the effect of the thermal mass on the size of equipment. The parameter of interest is the peak heating load.

For each case the system displays graphically the portion of solar radiation that is absorbed by each room interior surface (fig.4.11). This barchart representation of the absorbed solar radiation within a zone is updated dynamically depending on BEEP results. This information helps the designer to decide about the distribution of the thermal storage mass in the room interior. At the instance of constraint violation, for example if the PMV/PPD values exceed the allowable by ASHRAE range, the system informs the designer.

Results for all the values of interest are accumulated by the system in a table along with important input variables and are shown to the designer (fig.4.12) with

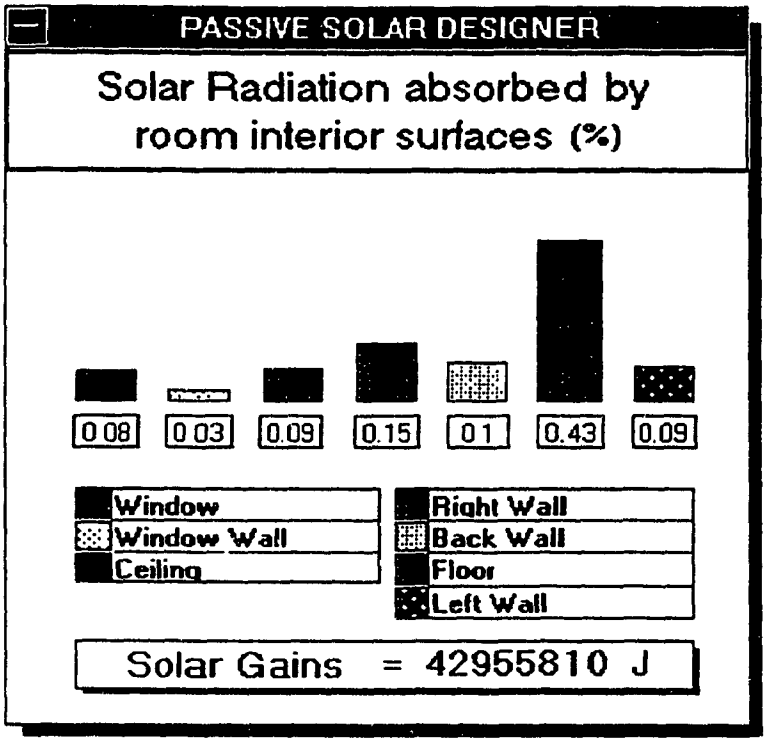


Fig. 4.11 Dynamic display of solar radiation absorbed by each room interior surface for a particular design alternative

OVERALL RESULTS

INPUT								OUTPUT								
DA #	KT	Set-back (°C)	INFL ach	# Glaz.	Window area m^2	R of walls (RSI)	R of Shutters (RSI)	Peak Load (W)	Total Heat Load (MJ)	Toper (°C)		Solar Gain (MJ)	PMV		PPD	
										Min	Max		Min	Max	Min	Max
1	0.7		0.5	2	5.2	2.462	0			6.8	31.2	75.5	6.7	1.8	100	69
	0.7	0						2254.2	96.7	18.3	28.7	75.5	-2.6	0.9	95	24
	0.2	0						2288.6	121.9	18.5	20.1	6.1	2.5	2	94	79
2	0.7		0.5	2	5.2	2.462	0.3			7	32.4	75.5	-6.7	2.2	100	87
	0.7	0						2089.7	89.3	18.5	28.9	75.5	2.5	1	94	26
	0.2	0						2124.3	113.1	18.7	20.2	6.1	2.5	2	93	79
3	0.7		0.5	2	5.2	4.35	0.3			7.5	33.2	75.5	6.5	2.5	100	94
	0.7	0						1985.3	83.5	18.6	29	75.5	-2.5	1	93	28
	0.2	0						2000.5	103.8	18.8	20.3	6.1	2.4	2	92	77

Explain | Generate New Zone | Generate New Alternative | Quit

PASSIVE SOLAR DESIGNER

Overheating occurs!

> **Select thermal storage materials with higher specific heat capacitance.**

> **If you use a thin mass layer (2-3 cm) select materials with lower conductivity.**

Fig. 4.12 Results for three design alternatives with recommendations

recommendations for possible improvements. In order to provide recommendations the system evaluates the different building design options according to a relative basis and using the heuristics.

If the designer is not satisfied with the results, he/she can improve the zone performance by developing another design alternative taking into account the recommendations provided by the system. In this case the system generates dynamically a new design alternative which is an instance of the design alternative (ZoneDA) Class. The new instance can store all the information and results for the zone performance that will be obtained from the new synthesis-analysis cycle. This can be repeated to examine the performance of various design alternatives until the designer is satisfied with the overall results. Such an iterative process for testing and refinement is essential in design.

CHAPTER 5

CASE STUDIES

5.1 General

In this chapter implementation of PSD for two case studies is presented. These case studies also serve as a validation of the methodology.

Validation of a computer program in general is a test done to determine whether it meets the requirements for which it was designed. Test cases are usually collected against which the system performance is checked. The performance of PSD can be tested analyzing typical case studies and comparing the results with the original design proposals. Two examples were selected which are representative of two different climatic regions. The first is a typical example of a single family residential building in Montréal (cold climate, latitude 45°). The second one considered is for a single family residential building in Cyprus (temperate climate, latitude 35°). The construction types of both buildings are typical for the regions selected.

The following important performance attributes were selected as the basis for the comparisons:

(a) Thermal resistance of exterior walls

(b) Total auxiliary heating loads

(c) Peak loads

(d) Operative temperature swing

(e) ΔTsolar.

5.2 Case Study 1

The first example deals with a direct gain zone in a single-family residential building in the area of Montréal (Latitude 45°). The zone layout, cross section and exterior wall detail are illustrated in figure 5.1. The building is of a wood frame with brick on the exterior walls, and interior partitions of plasterboard on wood frame. Figure 5.2 presents results from five design alternatives. A south facing zone (6 x 7.5)m^2 in area is considered with a large direct gain window and small window areas on the west wall which do not have significant solar gains as compared to the large window. A typical wall section of the original design is shown in figure 5.3a.

The results represent the most important performance attributes discussed earlier, and can help the designer to initiate the right action in order to improve the zone performance. For each design alternative analysis is performed for three different cases (clear day, KT=0.7 without auxiliary heating or cooling, clear day, KT=0.7 with aux.heating/cooling and cloudy day, KT=0.2 with aux.heating/cooling).

For each case the system informs the designer about the consequences of his decisions on the thermal sensation indices PMV and PPD. The meaning and significance of these indices are explained by the system at the beginning of design. It depends on the designer to decide whether values obtained for PMV and PPD will be restrictive in the design alternative evaluation. If so, the ranges for their values as specified by ASHRAE will be constraints to be met. For both the presented case studies, the economic impact of a DA as well as the elimination of overheating were the prevailing constraints. Better results for PMV and PPD could have been achieved by giving priority to improvement in comfort, as opposed to reduction in auxiliary heating loads and size of equipment.

For the first three design alternatives there is no additional thermal storage mass

in the zone. Since the construction is lightweight, high temperature swings occur for all the three alternatives. The first DA includes carpet on the floor (but no night insulation for the window). The 2nd alternative shows that when night insulation is used, there is a reduction in both auxiliary heating load and peak load. This is due to better window performance and thus lower heat losses during the night. The third design alternative, demonstrates the contribution of a better insulated exterior wall (fig.5.3b) to an improved performance of the envelope, causing another reduction in auxiliary heating loads and peak load. The operative temperature swing for clear days (KT=0.7) is for all three cases high. For the third design alternative auxiliary cooling is needed which indicates that overheating occurs. This occurs due to the lack of sufficient thermal storage mass which could otherwise store energy and stabilize the thermal environment of the zone.

Results from design alternative 4 show that thermal mass can significantly reduce the auxiliary heating load on clear days (KT=0.7). This mass is concrete on the floor with density d=2100 kg/m^3, conductivity k=1.7 W/m/C and specific heat capacity c=800 J/kg/C and an additional layer of plasterboard on the interior surface of the walls. There is also reduction in the temperature swing for a clear day and reduction in peak load for both clear and cloudy days as compared with the previous alternatives. These results could justify a higher initial investment on a structure which incorporates storage mass since this will pay-off during the life-cycle of the building For the fifth design alternative, a relatively small reduction in window area causes a reduction of peak load and auxiliary heating load on a cold cloudy day, while there is a slight increase of their values on a clear day.

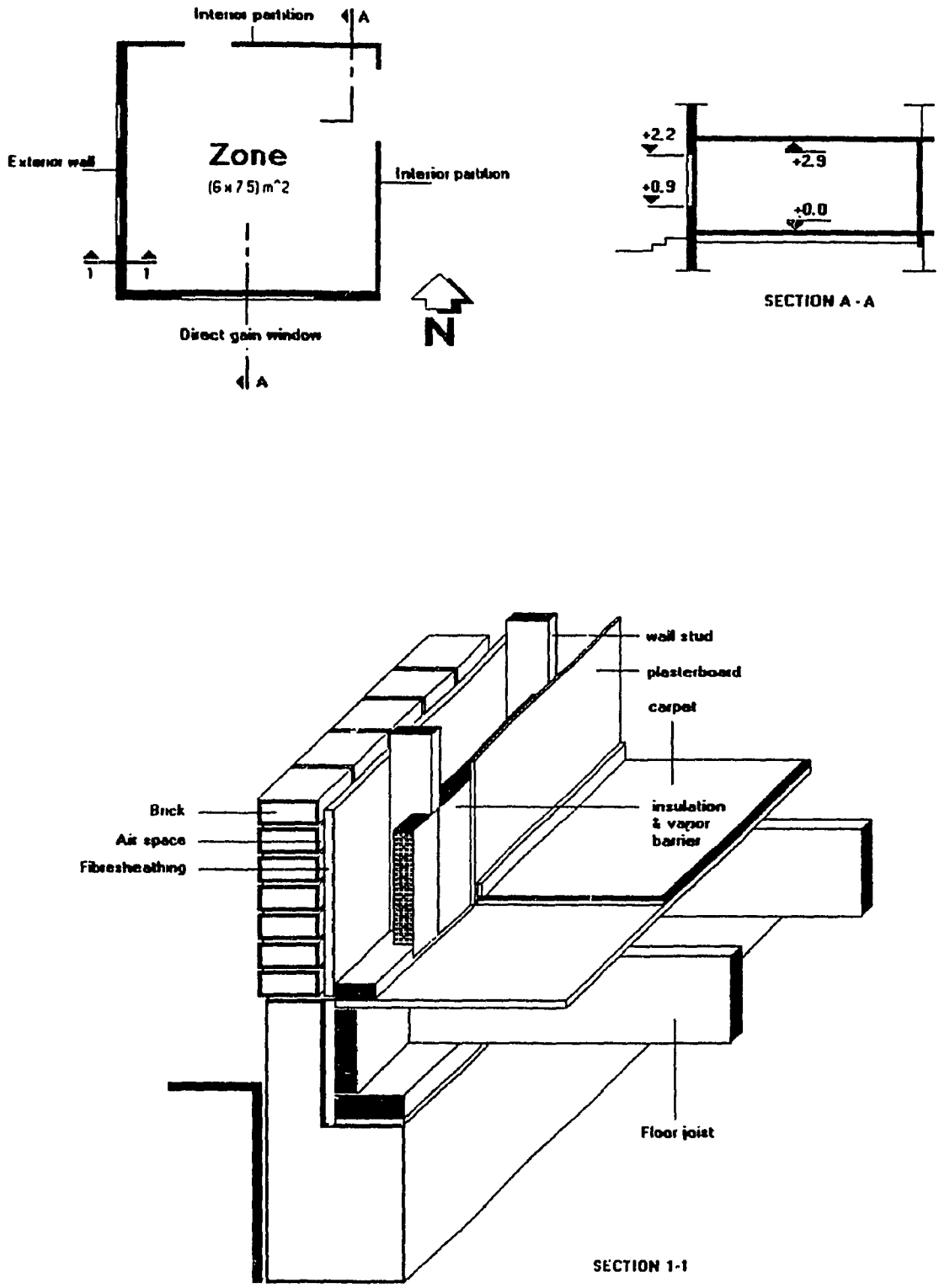


Fig. 5.1 Case study 1. Single family residential building in the area of Montréal

INPUT								OUTPUT								
DA #	KT	Set-back (°C)	INFL. ach	# Glaz	Window area m^2	R of walls (RSI)	R of Shutters (RSI)	Peak Load (W)	Total Heat.Load (MJ)	Top (°C)		Solar Gain (MJ)	PMV		PPD	
										Min	Max		Min	Max	Min	Max
1	0.7		0.5	2	5.2	2.462	0			6.8	31.2	75.5	6.7	1.8	100	69
	0.7	0						2254.2	96.7	18.3	28.7	75.5	-2.6	0.9	95	24
	0.2	0						2288.6	121.9	18.5	20.1	6.1	2.5	-2	94	79
2	0.7		0.5	2	5.2	2.462	0.3			7	32.4	75.5	-6.7	2.2	100	87
	0.7	0						2089.7	89.3	18.5	28.9	75.5	2.5	1	94	26
	0.2	0						2124.3	113.1	18.7	20.2	6.1	2.5	2	93	79
3	0.7		0.5	2	5.2	4.35	0.3			7.5	33.2	75.5	6.5	2.5	100	94
	0.7	0						1985.3	83.5	18.6	29	75.5	2.5	1	93	28
	0.2	0						2000.5	103.8	18.8	20.3	6.1	2.4	-2	92	77
4	0.7		0.5	2	5.2	4.35	0.3			13.4	21.8	75.2	-4.4	1.4	100	50
	0.7	0						1467.2	56	19.2	23.9	75.2	2.3	0.7	89	16
	0.2	0						1734.1	103.7	19.1	20	6.1	2.3	2	90	81
5	0.7		0.5	2	3.9	4.35	0.3			13.2	20.4	56.7	4.5	-1.9	100	76
	0.7	0						1509.9	61.2	19.3	22.7	56.7	2.2	-1.1	88	33
	0.2	0						1689.9	100.3	19.1	20	4.6	2.3	2	90	80

Explain | Generate New Zone | Generate New Alternative | Quit

Fig. 5.2 Case study 1. Summary results for five design alternatives

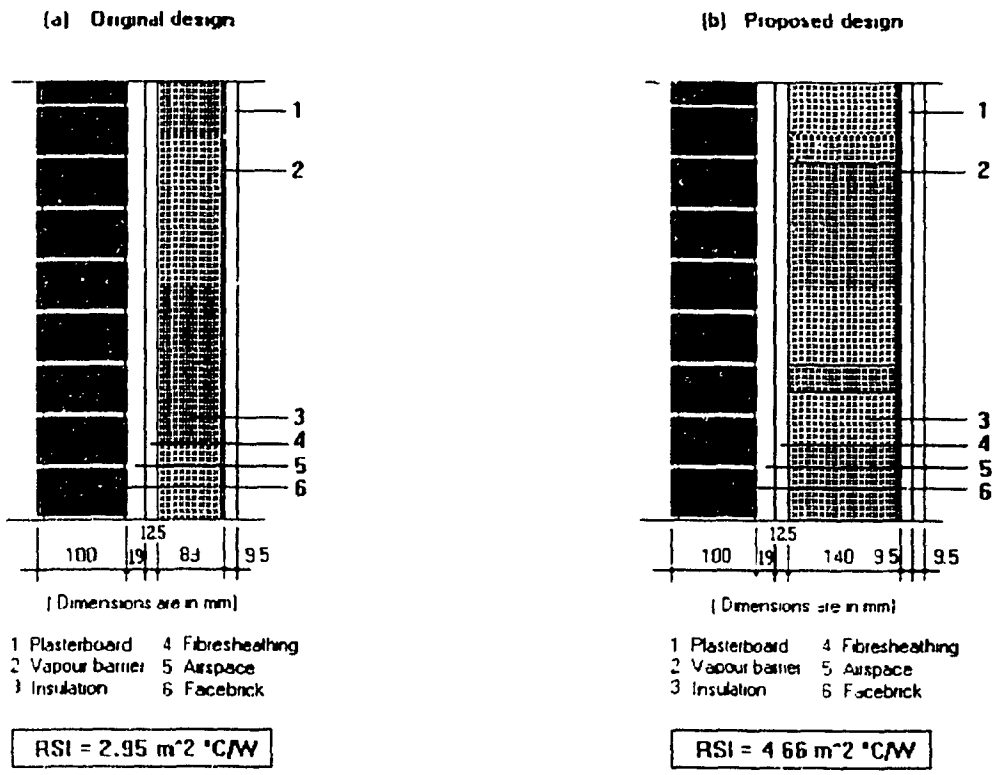


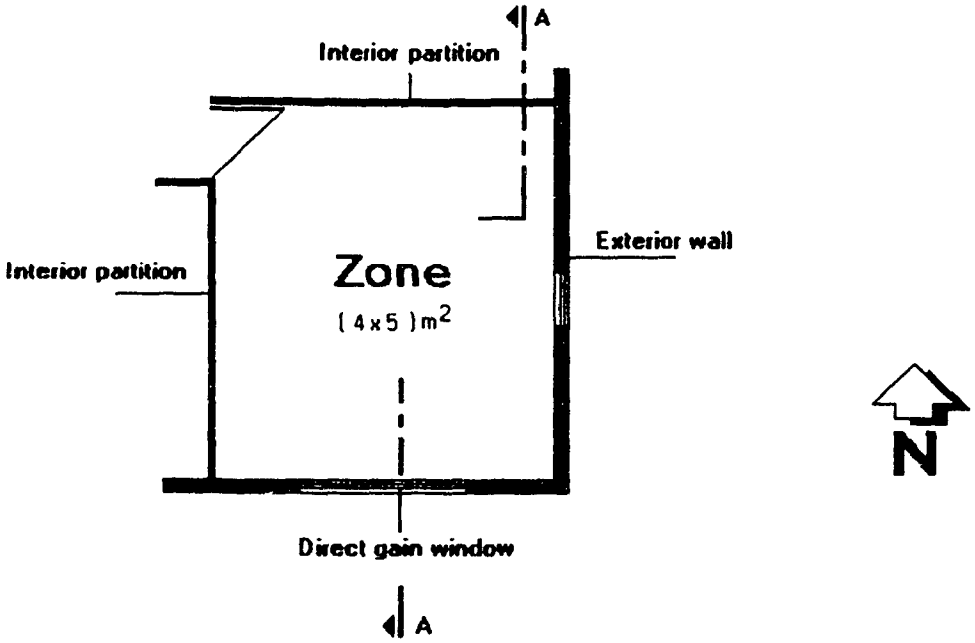
Fig. 5.3 Case study 1. Typical exterior wall details

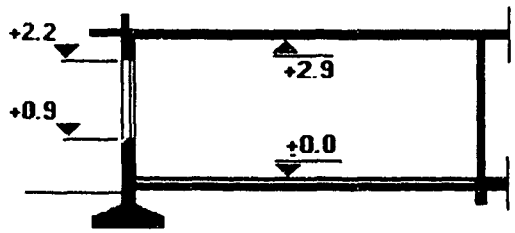
5.3 Case Study 2

The second example investigates the performance of a single-family dwelling in a temperate climate (latitude=35°), with hot summers and relatively cold winters (fig.5.4) It is a concrete structure with brick exterior (fig.5.5a) and interior walls of thickness 0.25m and 0.14m respectively.

Results from a typical zone are shown in figure 5.6. The first design alternative considers exterior walls without any insulation, as in the original design, single glazing for the south facing direct gain glass sliding doors and carpet on floor (without extra thermal mass). The absence of significant thermal mass results in a high temperature swing and the single window pane and uninsulated exterior walls cause considerable heat losses which are reduced in design alternatives 2 and 3. Despite these reductions, in both design alternatives 1 and 2 there is indication of overheating which means that thermal mass must be used to store the excess energy for use at night. Design alternative #3 considers an increase in mass of 0.12m concrete on the floor, without carpet which otherwise acts as an insulating layer [Balcomb et al., 1982]. The result is a reduction in operative temperature swing, auxiliary heating load and peak load for a clear day (KT=0.7).

Night insulation also has a positive effect as shown in design alternative #4. It causes a reduction in the peak load and auxiliary heating load for both clear and cloudy days. Increase of the wall resistance in design alternative #5 (fig.5.5b), contributes to a significant reduction in the peak load and auxiliary heating load for clear and cloudy days. Decrease of the window area in design alternative #6 results in a reduction of the peak heating load for KT=0.2, while there is an increase in the auxiliary heating load and peak load for KT=0.7.





SECTION A - A

Fig. 5.4 Case study 2. Single family residential building in Cyprus (latitude 35°)

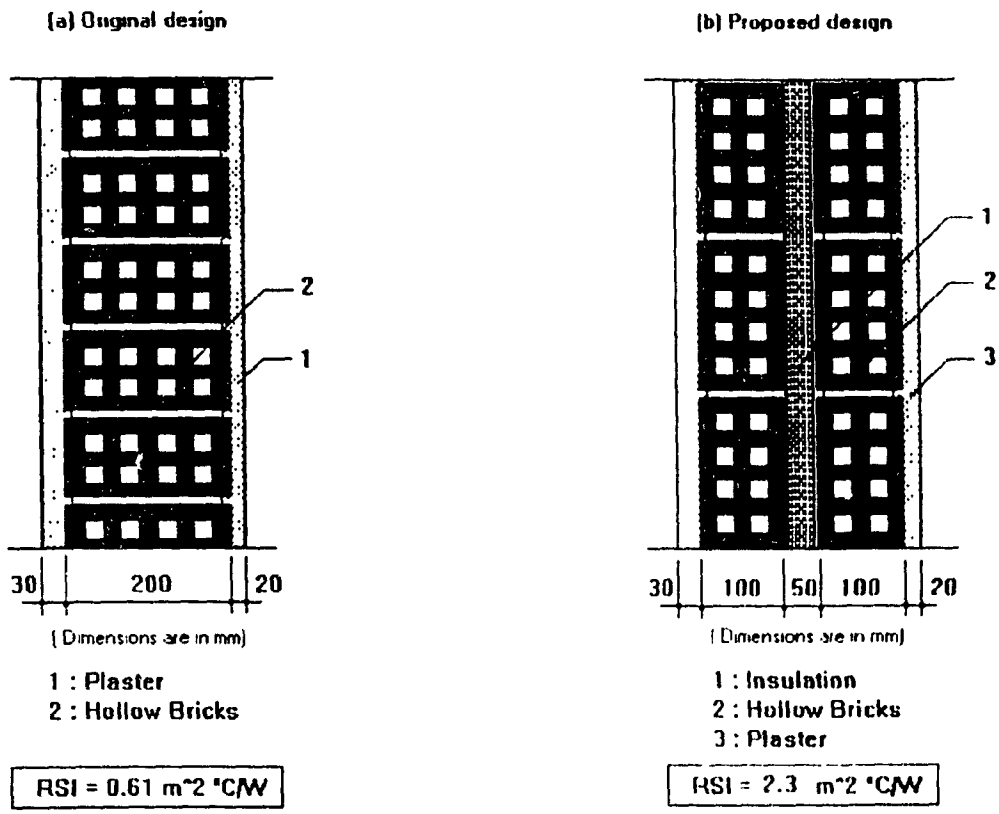


Fig. 5.5 Case study 2. Typical exterior wall details

INPUT								OUTPUT								
DA #	KT	Set-back (°C)	INFL ach	# Glaz	Window area m^2	R of walls (RSI)	R of Shutters (RSI)	Peak Load (W)	Total Heat Load (MJ)	Toper (°C)		Solar Gain (MJ)	PMV		PPD	
										Min	Max		Min	Max	Min	Max
1	0.7		0.5	1	4.2	0.5	0			5.8	33.1	75.6	7	2.4	100	93
	0.7	0						1520.5	64.1	17.1	28.9	75.6	2.9	1	99	26
	0.2	0						1652	90.7	17.1	19.3	8.7	2.9	2.2	98	87
2	0.7		0.5	2	4.2	0.5	0			6.1	32.6	63.5	6.9	2.3	100	89
	0.7	0						1385	58.1	17.4	28.7	63.5	2.8	0.9	98	24
	0.2	0						1516.2	83	17.4	19.4	7	2.8	-2.2	98	87
3	0.7		0.5	2	4.2	0.5	0			9.8	21.8	63.5	-7.5	-2.4	100	91
	0.7	0						1291.3	52	17.7	23.6	63.5	3.9	1.6	99	58
	0.2	0						1526.4	93.6	17.3	18.9	7	-4.1	3.5	100	99
4	0.7		0.5	2	4.2	0.5	0.3			9.7	22.2	63.5	-7.5	2.2	100	86
	0.7	0						1248.5	50.1	17.9	24.1	63.5	3.9	1.4	99	47
	0.2	0						1486.1	92.2	17.4	18.9	7	-4	-3.5	100	99
5	0.7		0.5	2	4.2	2.2	0.3			18.9	23.1	63.5	-3.6	-1.8	99	70
	0.7	0						2261	44	19.9	23.5	63.5	3.2	1.6	99	61
	0.2	0						758.4	51.4	18.8	19.3	7	3.6	3.4	99	99
6	0.7		0.5	2	3.36	2.2	0.3			17.6	21.1	50.8	4.2	2.7	100	97
	0.7	0						342.2	9.2	19.6	22.3	50.8	3.2	2.2	99	84
	0.2	0						745.4	51.3	18.8	19.3	5.6	-3.5	-3.4	99	99

Explain | Generate New Zone | Generate New Alternative | Quit

Fig. 5.6 Case study 2. Summary results for six design alternatives

5.4 Discussion

A significant improvement of the important performance attributes has been achieved in both case studies. The system supported successfully the iterative design procedure. PSD assisted in design synthesis by providing initial values for important design variables. Guidance with respect to the necessary steps to be followed during design was also provided. Access to data and explanatory information required during the synthetic part of the design process was achieved easily from within the system. The algorithmic components of PSD, BEEP and comfort evaluation module, tested the generated design alternatives. Analysis results were available immediately and helped to identify the impact of design decisions. In the case of unsatisfactory performance the system provided recommendations in order to overcome the problem.

PERFORMANCE ATTRIBUTE	Improved using Design Assistant	Original Design	ASHRAE Requirements
Wall Thermal Resistance ($m^2 \cdot °C / W$)	4.66	2.95	1.11
Auxiliary Heating Load (MJ)	61.2	96.7	–
Peak Load (W)	1689	2288	–
Operative Temperature swing (°C)	7.2	24.4	–
ΔT solar (°C)	27.6	27.0	–

Table 5.1 Case study 1. Comparison of performance attributes

PERFORMANCE ATTRIBUTE	Improved using Design Assistant	Original Design
Wall Thermal Resistance ($m^2.°C/W$)	2.30	0.61
Roof Thermal Resistance ($m^2.°C/W$)	2.23	0.41
Auxiliary Heating Load (MJ)	4.40	64.10
Peak Load (W)	758	1652
Operative Temperature swing (°C)	4.20	27.30
ΔT solar (°C)	15.05	14.20

Table 5.2 Case study 2. Comparison of performance attributes

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

A computer method for passive solar design of direct gain buildings has been developed. It is based on a combined knowledge-based-algorithmic approach and can be used for both synthesis and analysis processes at the preliminary and detailed design stages. This method was implemented in PSD, a computer program that integrates a KBES, algorithmic programs, databases and a hypertext with a GUI in a multitasking operating environment. PSD takes advantage of important characteristics of KBES, OOP techniques and existing procedural algorithmic programs. Manipulation of declarative knowledge needed for design synthesis, offered by KBES and a flexible, modular knowledge representation methodology offered by OOP are combined in PSD with procedural programs that provide versatile data manipulation required in analysis.

PSD proves that difficulties associated with the use of traditional algorithmic programs in design, can be overcome when they are part of a combined system where knowledge-based and algorithmic components complement each other. Based on this principle, PSD provides guidance to the designer in order to start design with an acceptable proposal, and progressively improve it through design synthesis and analysis.

The integration of Building Energy and Environment Program (BEEP), the KBES, the databases and the hypertext "Design Guidelines" with a GUI provides an overall effective, simple to use and user-friendly tool for passive solar design. During the design process, on-line access to various databases and the hypertext, immediate feedback from analysis performed by BEEP and recommendations provided by the KBES, enable the

designer to reach fast a feasible design solution.

The combined KB-algorithmic methodology implemented in PSD contributes to a general effort undertaken at the Centre for Building Studies. This effort aims to improve the processes involved in building design by integrating tools and expertise from different disciplines in order to counteract fragmentation and realize a more effective and productive integrated building design environment.

The significance of this research is summarized as follows:

- Implementation of the principle of a combined knowledge-based-algorithmic program for passive solar design synthesis and analysis, using a KBES shell with hybrid knowledge representation schema (objects and rules) in a multitasking operating environment.
- Application of qualitative knowledge to aid in design synthesis.
- Utilization of quantitative knowledge and traditional algorithmic tools in an iterative manner during the design process, providing immediate feedback with analysis results.
- Integration of a GUI, databases and a hypertext system with the knowledge-based and algorithmic modules providing on-line assistance and ensuring continuity of operations during the design process.

6.1 Extensions of the current work

The main objective of this research was to develop a computer method for passive solar design which combines both synthesis and analysis by utilizing algorithmic and knowledge-based software in a multitasking environment. The design framework and the

overall system platform have been established. There are still issues to be considered for further system improvement.

- **Knowledge base.** More heuristic knowledge is needed to enhance the system capabilities regarding the final recommendations that are provided to the designer. Currently recommendations are given based on a comparative evaluation of the different design alternatives. Extensive sensitivity analyses using BEEP could make possible the establishment of more design heuristics.

- **Envelope details database.** A database with 'standard' building envelope details, common in various regions could be build up in order to be provided at the initial design stages. This would be useful in the case the designer is not familiar with materials used and construction practice in a specific region. These details could also take into account issues related to material and structural compatibilities, possibility of condensation, durability, fire resistance etc.

- **Life-cycle cost.** A rigorous method for measuring the economic consequences of alternatives is necessary. Among the various methods described in the literature [Ruegg and Marshall, 1990] the life-cycle cost (LCC) method is a straight forward and simple way that can be used to make cost-effective choices among different design alternatives. Required parameters to calculate LCC is the sum of total construction, operation and maintenance, repair and replacement and energy costs all discounted to present value.

- **Integration with other systems.** Since the integration of different design tools in the overall design of buildings is increasingly becoming an important issue [Case et al. 1990, Amor et al. 1990, Bédard et al. 1991], the possibility of integrating Passive Solar Designer with tools which can be used for the design of other building subsystems should be investigated. Integration with systems developed at the Centre for Building

Studies [Fazio and Gowri 1990, Bédard and Ravi 1991] would enable the development of tools that can support the building design process from a multidisciplinary point of view.

- **BEEP - Windows application.** In order to take full advantage of the multitasking Windows operating environment and facilitate the communication between BEEP and the KBES, the effort for the development of a Windows version of BEEP would be justified. In such a case BEEP would be perfectly 'masked' by the intelligent front-end in LEVEL5. The information exchange would be direct and the participation of the designer in the preparation of the input would be minimized to the very basics.

- **Learning Expert System.** A very effective design assistant would be a 'learning' system which interactively would get information from the designer about decisions taken and the steps followed in solving a problem. This information would be represented in rules thus establishing a dynamic knowledge base. Cases with conflicting information would be possibly resolved by asking the designer or by comparing with previous cases stored in a database.

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APPENDIX A

DEVELOPMENT TOOL FEATURES

LEVEL5 OBJECT - Tool Features

LEVEL5 OBJECT is an application development tool that incorporates both expert system and hypermedia technologies. Its entire design is object-oriented. The editor, visual windowing system, displays, database interfaces, inference engines, knowledge bases, devices, files and timers are all treated as objects. All these components are referred to as 'system classes' which have associated building tools that automate much of the application development process.

Classes. A class is a standard definition for a given type of object which can be used or tailored to suit a particular instance of that object. System classes control much of the behaviour in applications written in LEVEL5 OBJECT and along with rules (rules, demons) and methods account for all procedural knowledge representation. These predefined object classes are useful templates for development of new object classes without the need to construct them from scratch. This is one of the main principles and advantages of Object Oriented Programming techniques.

Instances. The actual values of a class are held by its instances. A developer can also define new classes, according to the needs of a specific application, in order to represent any physical or abstract objects. All these objects can benefit from the advantages of the inheritance property provided by LEVEL5 OBJECT which tremendously facilitates a system development reducing the amount of data input and manipulation.

Methods. For complex applications LEVEL5 OBJECT provides the capability of using alternative structures over rules which could easily describe relations among simple facts. These structures are called 'methods' and simplify design by eliminating the need

to develop complex sets of rules. 'Methods' are attached to object attributes and are invoked when an attribute's value is needed or changes in the session context.

Parallel inferencing processing. A very important advantage provided by LEVEL5 OBJECT is what is called 'parallel inferencing processing' [Information Builders, 1990]. Both forward and backward chaining inferencing techniques is possible to be used within a single knowledge base. For example, a system can start using backward chaining, goal-driven approach and change during the process to a forward chaining, data-driven model. This feature offers significant flexibility for a system dynamic response to new situations and needs that arise during a session.

Hypermedia. LEVEL5 OBJECT can easily link hypermedia to object attributes whose activities can cause events or actions to occur within system classes such as firing of demons etc.

LEVEL5 OBJECT provides different editors the developer interacts with building expert system components.

Object editor. The object editor is the place where the various classes, system or user defined ones, are created, organized and edited.

Rule editor. The rule editor is accessed independently or from the object editor when an attribute is selected to be referred in a rule, demon or method.

Display editor. The display editor provides a variety of display items such as textbox, valuebox, pushbutton, checkbox etc. which can be used for the development of interactive, graphical displays.

In terms of knowledge visualization and tracing facilities, LEVEL5 OBJECT offers various tools the developer can use to monitor the system development and for debugging purposes.

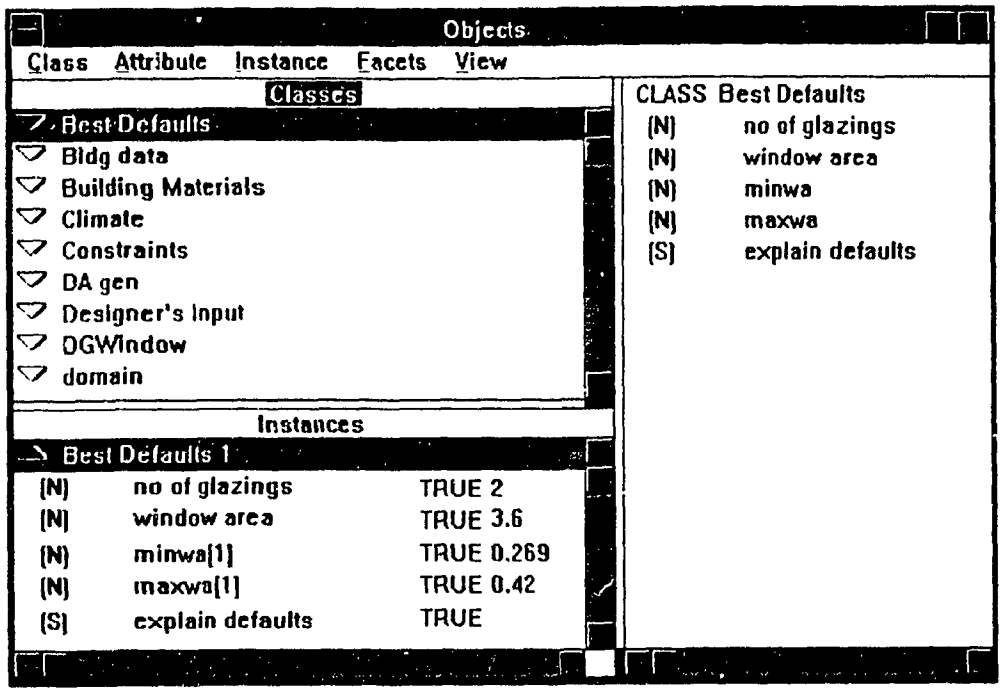
Knowledge tree. This is a kind of flowchart where the basic system components (rules/demons, facts, displays, goals) are represented with icons which can launch the related editor when selected.

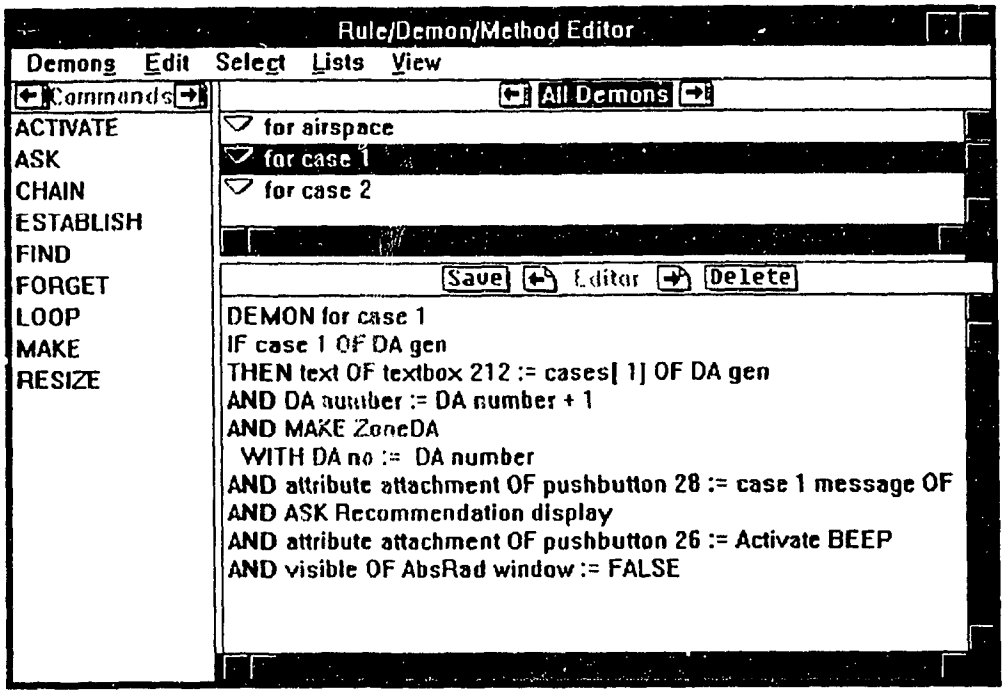
Values list. The 'values list' accommodates all the system attributes with their associated values, initial, default or assigned during the session.

History. Another useful device is the 'history' which records in a logging file selectively all or part of the steps the session follows.

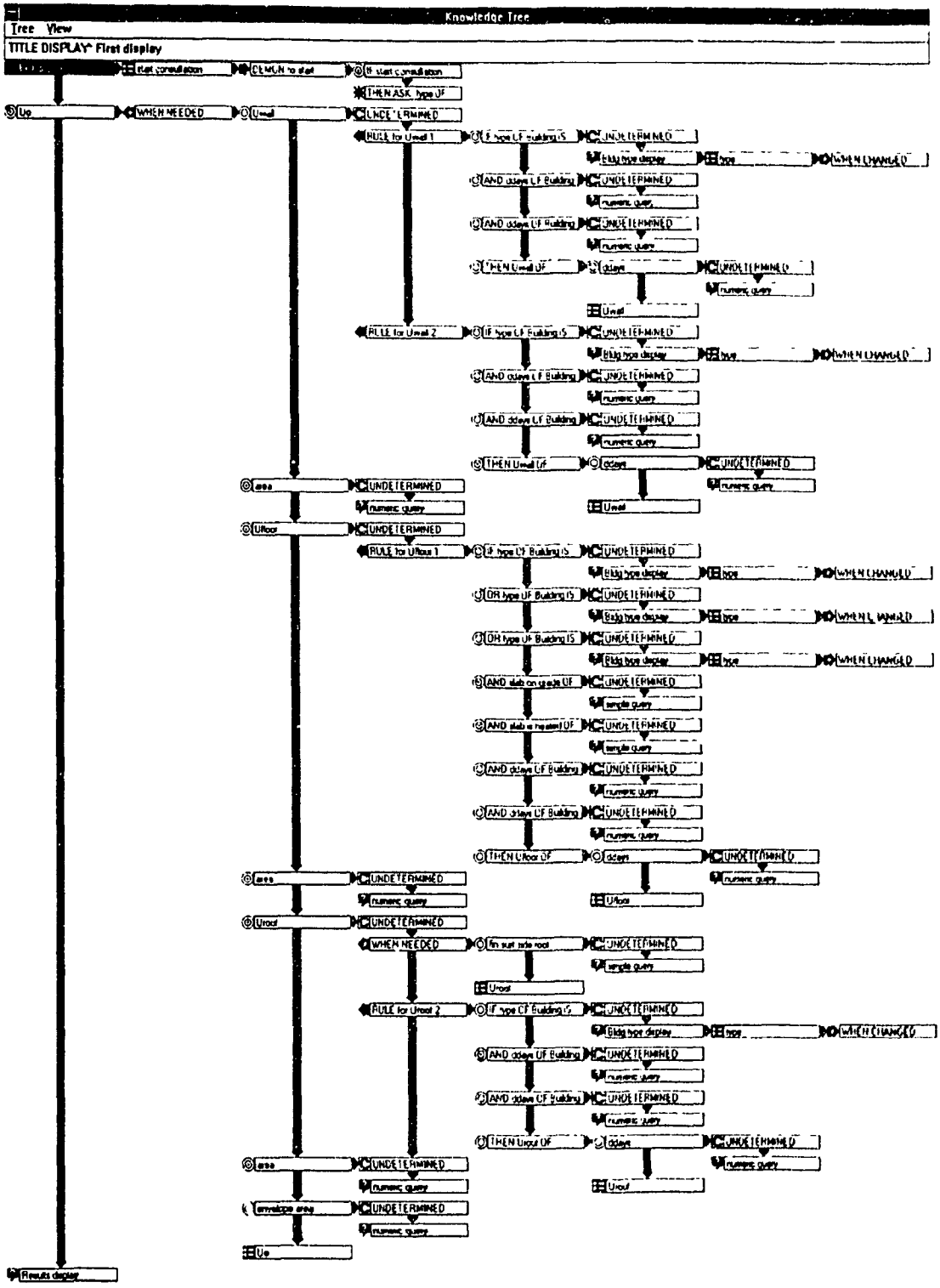
Session monitor. The 'session monitor' is another tracing tool and helps to visualize step-by-step the whole execution of a knowledge base session and see exactly what the inference engine is doing.

LEVEL5 OBJECT offers also an object-oriented database management interface and can integrate knowledge bases with database files. It treats different databases as objects integrating them completely in the object-based knowledge representation environment.





Object and Rule editors in LEVEL5 OBJECT



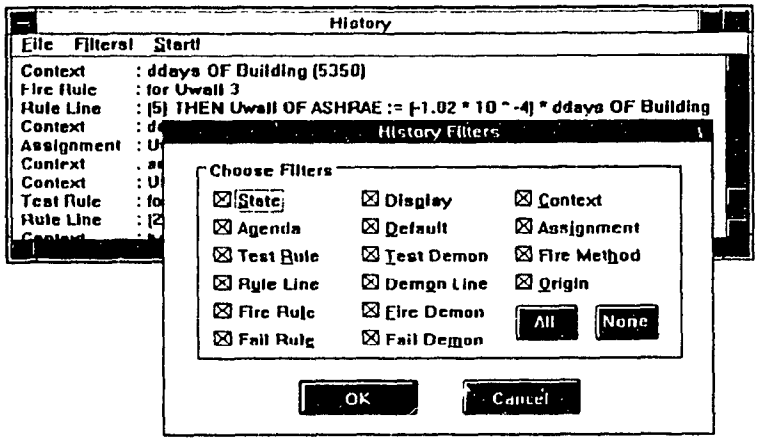
Knowledge Tree

Values List

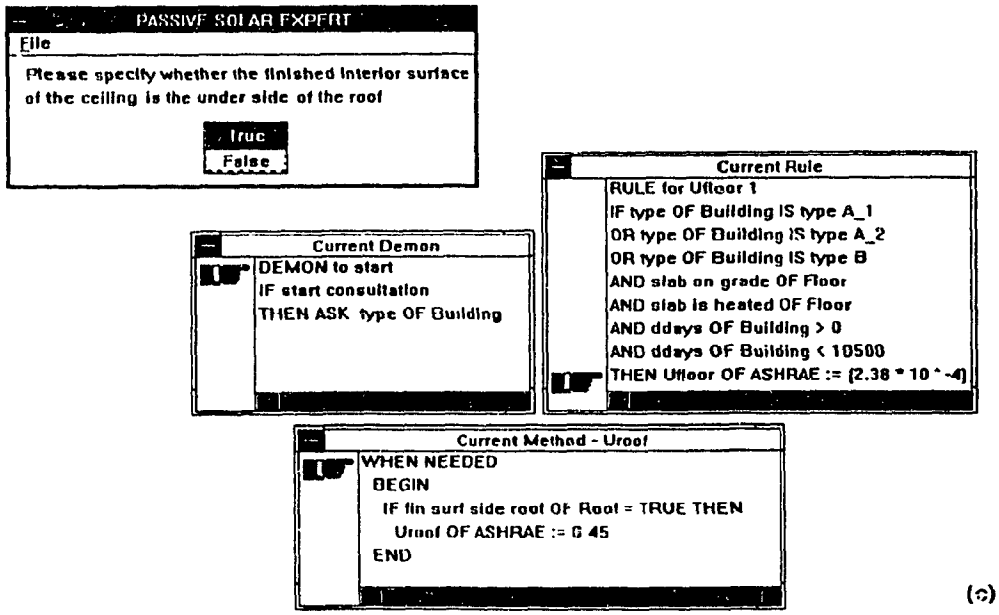
View

Value	CF	Attribute Name	Facets
0.8043	100	Uwall OF ASHRAE1 ISA ASHRAE (N)	S
0.792	100	Ufloor OF ASHRAE1 ISA ASHRAE (N)	S
0.45	100	Uroof OF ASHRAE1 ISA ASHRAE (N)	S, WN
0.669520	100	Uo OF ASHRAE1 ISA ASHRAE (N)	S, WN.
type A_1	100	type OF Building1 ISA Building (C)	WC, Q
5350	100	ddays OF Building1 ISA Building (N)	
1360	100	envelope area OF Building1 ISA Building (N)	
	UNDETERM	number of stories OF Building1 ISA Building (N)	
Montreal	100	selected name OF location 1 ISA dB3 location (Str)	WC
facebrick	100	name OF material ISA dB3 material (Str)	S
0.13	100	conductivi OF material ISA dB3 material (N)	S
20	100	cost OF material ISA dB3 material (N)	S
True	100	ask wall layer material (S)	WC
5	100	I (N)	
True	100	start consultation (S)	WC
True	100	ask roof layer material (S)	WC

(a)



(b)



(c)

Tracing Facilities in LEVEL5 OBJECT

APPENDIX B

THERMAL COMFORT MODEL

Thermal Comfort Model

One of the objectives in the design of a Passive Solar building is to maintain comfort. Comfort in general is the feeling of well-being. Thermal comfort is defined as that condition of mind which expresses satisfaction with the thermal environment. A person feels comfortably when the body temperature is maintained within a pretty narrow range, that of about 4°C temperature difference between the deep body temperature (≈37°C) and that of the skin (≈33°C).

Our thermoregulatory system is the mechanism responsible to maintain a balanced situation in our body. This is mainly achieved by carefully dissipating the generated by metabolism heat to the various organs or to our extremes, in order to keep the necessary temperature by often passing heat to the environment. As we know, the human body is kept in an equilibrium by basically transferring part of the generated heat to the outside; so we simply need cooling rather than heating. This is actually one of the main purposes of installing an HVAC system in a building, to control the heat loss of its occupants to the building environment thus maintaining thermal comfort.

The whole procedure of heat generation and dissipation to the immediate surroundings is quite complicated since heat is not uniformly generated, nor uniformly dissipated [ASHRAE, 1989]. Despite this complexity various researchers have modelled this process based on different assumptions, in order to provide means to "measure" the thermal sensation of people.

Extensive investigations and experiments involving numerous subjects have resulted in some methods for predicting the degree of thermal discomfort of people exposed to a still thermal environment [Hensen, 1990]. One of the most well-known and

widely accepted methods is Fanger's "Comfort Equation" and the practical concepts of "Predicted Mean Vote" (PMV) and "Predicted Percentage of Dissatisfied" (PPD). Other approaches are the "Two-Node model of human thermoregulation" developed by J.B.Pierce, a model developed by the CSTB laboratory which also considers factors that cause local discomfort, a model developed by Stolwjik known as the "25-Node model" and a model by Wemer which deals with cold and warm effects on the way heat is generated and dissipated.

The wide acceptability of Fanger's model is based on the straightforward concepts of PMV and PPD which provide an easy way to determine whether a specific indoor environment satisfies the requirements for thermal comfort.

The PMV index predicts the mean response of a large group of people according to the following thermal sensation scale:

+3	:	hot
+2	:	warm
+1	:	slightly warm
0	:	neutral
-1	:	slightly cool
-2	:	cool
-3	:	cold

Since for technical or economical reasons a thermal environment which will provide optimal thermal comfort is not always possible, it is often of value to quantify the degree of discomfort.

The other index accounting for the acceptability of a thermal environment is the PPD, which indicates the predicted percentage of dissatisfied people. Recommended

ranges for both PMV and PPD could be applied only for moderate thermal environments. An acceptable thermal environment is one with Predicted Mean Vote within the range -0.5=<PMV<=+0.5 ; with respect to the Predicted Percentage of Dissatisfied, this should not exceed 10%.

During the design of a Passive Solar Direct Gain building it is useful to have a prediction of the comfort indices discussed above. Since there is often the problem of overheating which results in uncomfortable conditions, the designer should take into account this possibility in the decision concerning the appropriate location and amount of thermal mass as well as window area, location and type.

APPENDIX C

TYPICAL RULES, DEMONS, METHODS IN PSD

Design process control and interface

DEMON for design step 1

```
IF case 1 OF DA gen
THEN text OF textbox 212 := cases[1] OF DA gen
AND DA number := DA number + 1
AND MAKE ZoneDA
  WITH DA no :=  DA number
AND attribute attachment OF pushbutton 28 := case 1 message OF DA gen
AND ASK Recommendation display
AND attribute attachment OF pushbutton 26 := Activate BEEP
AND visible OF AbsRad window := FALSE
```

WHEN CHANGED For: MRT

```
    BEGIN
      IF Calculate PMVmax OF Evaluation = TRUE THEN
        Calculate PMVmax OF Evaluation := FALSE
      action OF CFINPUT IS open new := TRUE
      CFINPUT.write line :=TO STRING(PMV group 1.AM)
      CFINPUT.write line :=TO STRING(PMV group 1.ET)
      CFINPUT.write line :=TO STRING(PMV group 1.CLI)
      CFINPUT.write line :=TO STRING(PMV group 1.TA)
      CFINPUT.write line :=TO STRING(PMV group 1.v)
      CFINPUT.write line :=TO STRING(PMV group 1.RH)
      CFINPUT.write line :=TO STRING(PMV group1.MRT)
      action OF CFINPUT IS close := TRUE
      activate comfort module OF PMV group := TRUE
    END
```

DEMON to limit layer number

```
IF Layer number OF Layer info 1 <= 0
OR Layer number OF Layer info 1 > Number of layers OF Layer info 1
THEN variable text OF message 5 :=TO STRING( Number of layers OF Layer info 1)
AND ASK message 5
```

RULE for Uwall

```
ASK  number of stories OF Building
IF type OF Building IS type B
AND number of stories OF Building > 3
AND ddays OF Building > 0
AND ddays OF Building <= 4450
THEN Uwall OF ASHRAE := (-2.35 * 10 ^ -4) * ddays OF Building + 2.7
```

Initial values - Start design

```
DEMON for thermal mass
IF  CONF(WINarea OF Designer's Input) <> -1
THEN output OF initial values window := Thermal mass display
AND min mass surf area OF Best Defaults := WINarea OF Designer's Input * 6

WHEN CHANGED For: Window area
    BEGIN
      IF type OF Climate IS cold THEN
        BEGIN
          IF night insulation OF DGWindow = TRUE THEN
            BEGIN
              FOR  (ww :=  1 TO  3)
                BEGIN
                  IF Toutmean OF Climate > Tout[ ww] OF Best Defaults AND Toutmean OF Climate <
                     Tout[ww + 1] OF Best Defaults
                  THEN
                    BEGIN
                      DGWindow.minwinarea := (((Best Defaults.minwa[ ww + 1] - Best Defaults.minwa[
                      ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best Defaults.Tout[ ww + 1]
                      - Best Defaults.Tout[ ww]) + Best Defaults.minwa[ ww]) * Zone.area
                      DGWindow.maxwinarea := (((Best Defaults.maxwa[ ww + 1] - Best Defaults.maxwa[
                      ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best Defaults.Tout[ ww + 1]
                      - Best Defaults.Tout[ ww]) + Best Defaults.maxwa[ ww]) * Zone.area
                    END
                END
            END
          ELSE
            BEGIN
              IF night insulation OF DGWindow = FALSE THEN
                BEGIN
                  IF Toutmean OF Climate < Tout[ 2] OF Best Defaults THEN
                    BEGIN
                      DGWindow.minwinarea := (((Best Defaults.minwa[ 3] - Best Defaults.minwa[ 2]) *
                      (Climate.Toutmean - Best Defaults.Tout[ 2])) / (Best Defaults.Tout[ 3] - Best
                      Defaults.Tout[ 2]) + Best Defaults.minwa[ 2]) * Zone.area
                      DGWindow.maxwinarea := (((Best Defaults.maxwa[ 3] - Best Defaults.maxwa[ 2]) *
                      (Climate.Toutmean - Best Defaults.Tout[ 2])) / (Best Defaults.Tout[ 3] - Best
                      Defaults.Tout[ 2]) + Best Defaults.maxwa[ 2]) * Zone.area
                    END
                  ELSE
                    BEGIN
                      FOR  (ww :=  2 TO  3)
                        BEGIN
                          IF Toutmean OF Climate > Tout[ ww] OF Best Defaults AND Toutmean OF Climate
                             < Tout[ww + 1] OF Best Defaults
                          THEN
                            BEGIN
                              DGWindow.minwinarea := (((Best Defaults.minwa[ ww + 1] - Best
                              Defaults.minwa[ ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best
                              Defaults.Tout[ ww + 1] - Best Defaults.Tout[ ww]) + Best Defaults.minwa[ ww])
                              * Zone.area
                              DGWindow.maxwinarea := (((Best Defaults.maxwa[ ww + 1] - Best
```

```
                Defaults.maxwa[ ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best
                Defaults.Tout[ ww + 1] - Best Defaults.Tout[ ww]) + Best Defaults.maxwa[ ww])
                * Zone.area
              END
            END
          END
        END
      END
    END
  ELSE
    BEGIN
      IF type OF Climate IS temperate THEN
        BEGIN
          IF Toutmean OF Climate < Tout[ 5] OF Best Defaults THEN
            BEGIN
              minwinarea OF DGWindow := minwa[ 5] OF Best Defaults * area OF Zone
              maxwinarea OF DGWindow := maxwa[ 5] OF Best Defaults * area OF Zone
            END
          ELSE
            BEGIN
              IF Toutmean OF Climate > Tout[ 7] OF Best Defaults THEN
                BEGIN
                  minwinarea OF DGWindow := minwa[ 7] OF Best Defaults * area OF Zone
                  maxwinarea OF DGWindow := maxwa[ 7] OF Best Defaults * area OF Zone
                END
              ELSE
                BEGIN
                  FOR (ww := 5 TO 6)
                    BEGIN
                      IF Toutmean OF Climate > Tout[ ww] OF Best Defaults AND Toutmean OF Climate
                        < Tout[ww + 1] OF Best Defaults
                      THEN
                        BEGIN
                          DGWindow.minwinarea := (((Best Defaults.minwa[ ww + 1] - Best
                          Defaults.minwa[ ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best
                          Defaults.Tout[ ww + 1] - Best Defaults.Tout[ ww]) + Best Defaults.minwa[ ww])
                          * Zone.area
                          DGWindow.maxwinarea := (((Best Defaults.maxwa[ ww + 1] - Best
                          Defaults.maxwa[ ww]) * (Climate.Toutmean - Best Defaults.Tout[ ww])) / (Best
                          Defaults.Tout[ ww + 1] - Best Defaults.Tout[ ww]) + Best Defaults.maxwa[ ww])
                          * Zone.area
                        END
                    END
                END
            END
        END
      END
    END
  IF DGWindow.minwinarea > DGWindow.maxallowarea THEN
    BEGIN
      CONF(DGWindow.minwinarea) := -1
    END
  IF DGWindow.maxwinarea > DGWindow.maxallowarea THEN
    BEGIN
      DGWindow.maxwin..rea := DGWindow.maxallowarea   END   END
```

Recommendations

DEMON to check for overheating
IF Topmax[1] OF ZoneDA > Tmax OF Constraints
THEN overheating OF Evaluation := TRUE

DEMON to check ΔTsolar
IF ΔTsolar < ΔTsolar previous
AND PMV not satisfactory
THEN ASK Recommendation display
AND text OF Recomtextbox 2 := "Improve the window thermal performance. Use night insulation to reduce heat losses"

DEMON for overheating 1
IF overheating OF Evaluation
OR Temp swing higher OF Evaluation
AND fl mass thickness OF Designer's Input < 0.2
AND fl mass conductivity OF Designer's Input >= 1.7
THEN increase floor mass thickness OF Recommendations
AND text OF Recomtextbox := RecomText[1] OF Recommendations
AND FORGET Match

DEMON to propose step1
IF case 1 message OF DA gen
THEN ASK message case 1
"Check the zone performance on a relatively clear winter day (KT=0.7) assuming no energy dumping (No aux. heating/cooling)"

Establish Bridges

DEMON to activate comfort module
IF activate comfort module OF PMV group
THEN ACTIVATE "IPU,EXTERN,D:\iraclis\COMFORT.EXE"
AND ASK stop message
AND FORGET activate comfort module OF PMV group
AND PMV available OF PMV group := TRUE

Explanatory Information

DEMON to explain case 1
IF follow case 1
THEN text OF design step := "At this stage the passive zone response will be evaluated. Important variable is the temperature swing which indicates how effective is the thermal mass"

APPENDIX D

TYPICAL DISPLAYS FROM "PASSIVE SOLAR DESIGNER"

File QKI

PASSIVE SOLAR DESIGNER

How the System Works

The system in the following steps will assist you in order to achieve a good building thermal performance.

Refer to the 'template' at the bottom of the screen to find explanatory information for most of the input variables of 'BEEP' program.

During the generation of a DA the system will check the performance

CONTINUE...

PASSIVE SOLAR DESIGNER

QKI

Guide

ASHRAE

Select any of the items below for more information on BEEP input values

- ☐ First screen (BEEP)
- ☐ General data / Thermostat
- ☐ Weather inputs / Infiltration
- ☐ Direct Gain Window data
- ☐ Geometric Data
- ☐ Room radiative properties
- ☐ Doors / Small windows
- ☐ Wall / Window thermal data

Graphs

EXIT

PASSIVE SOLAR DESIGNER

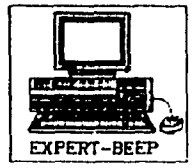
File QKI

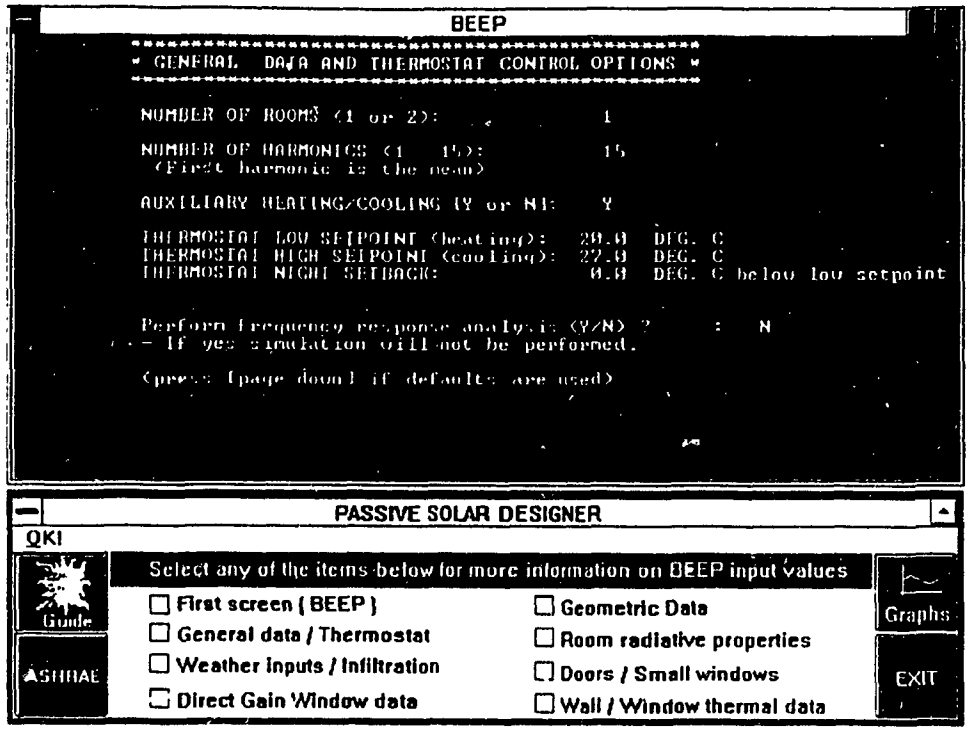
System Components

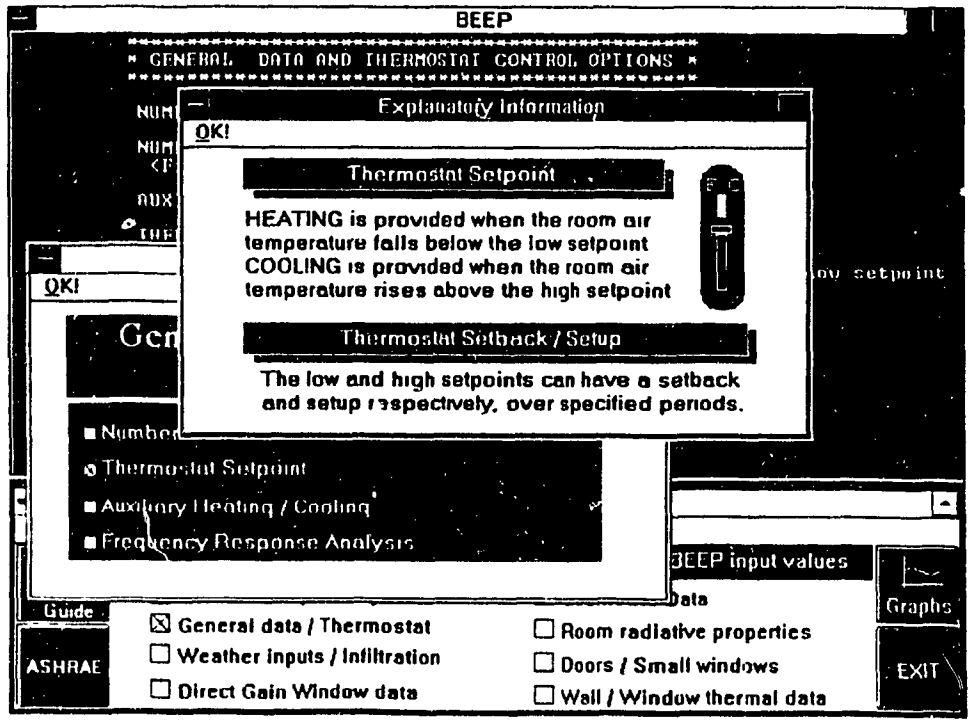
Click on the icons on the right to get information for each system's module

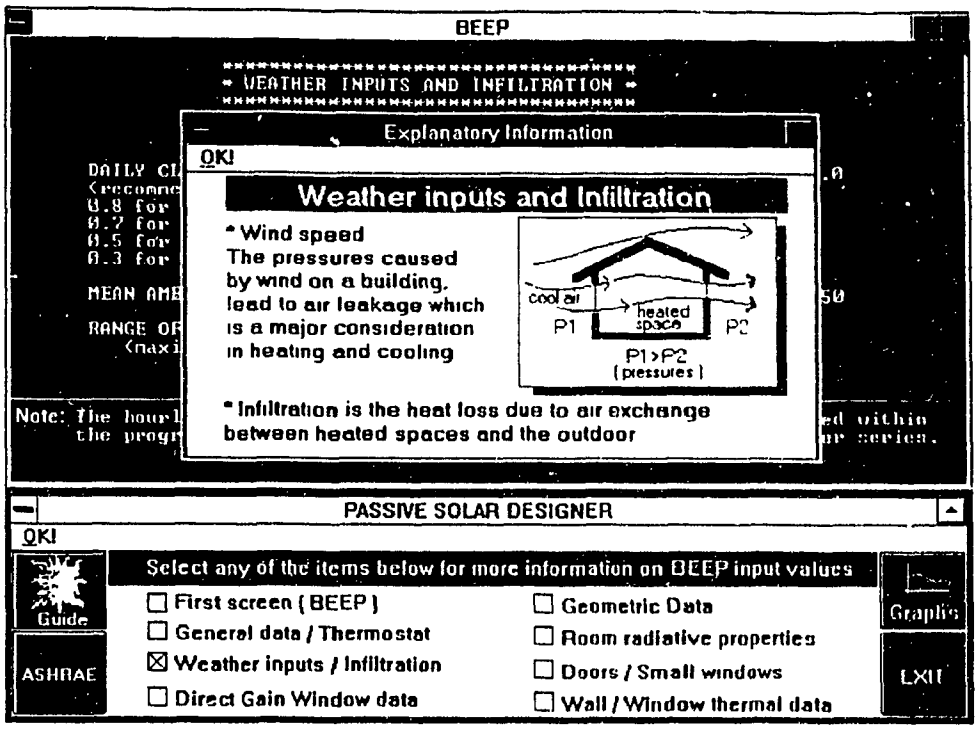
DESIGN GUIDELINES
This is the Hypertext module of the system which provides useful information describing Passive Solar Systems and design principles

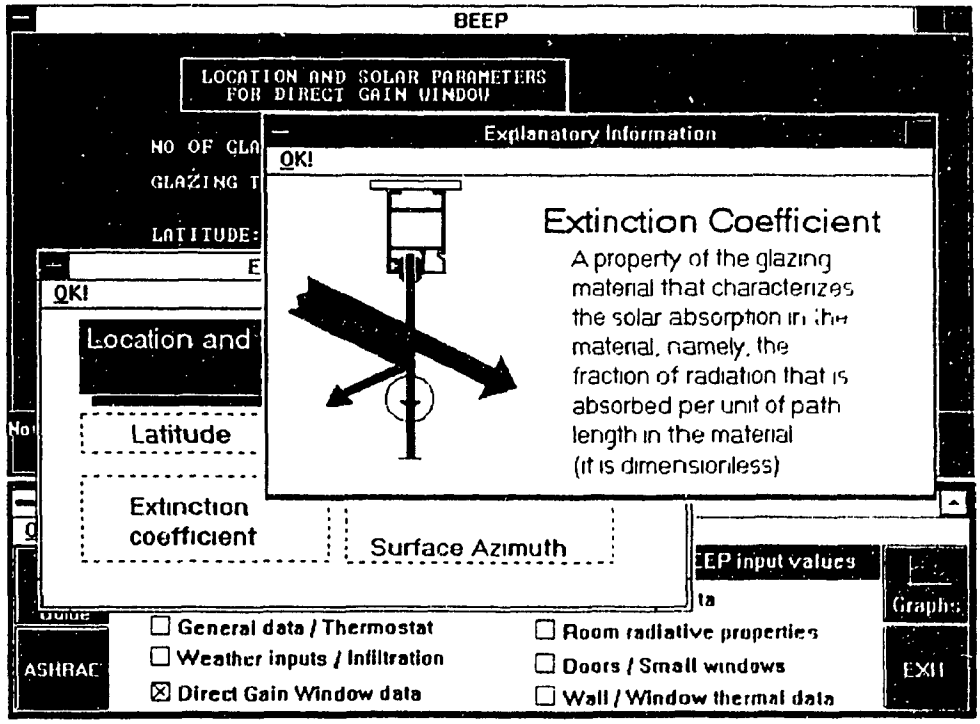
Run the GUIDELINES Module

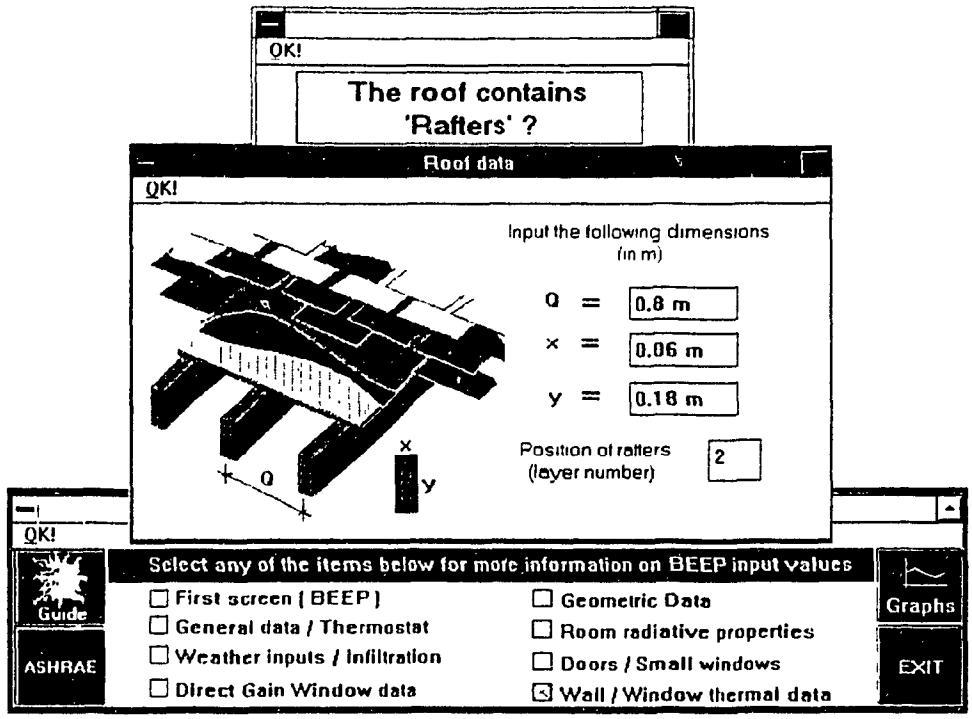


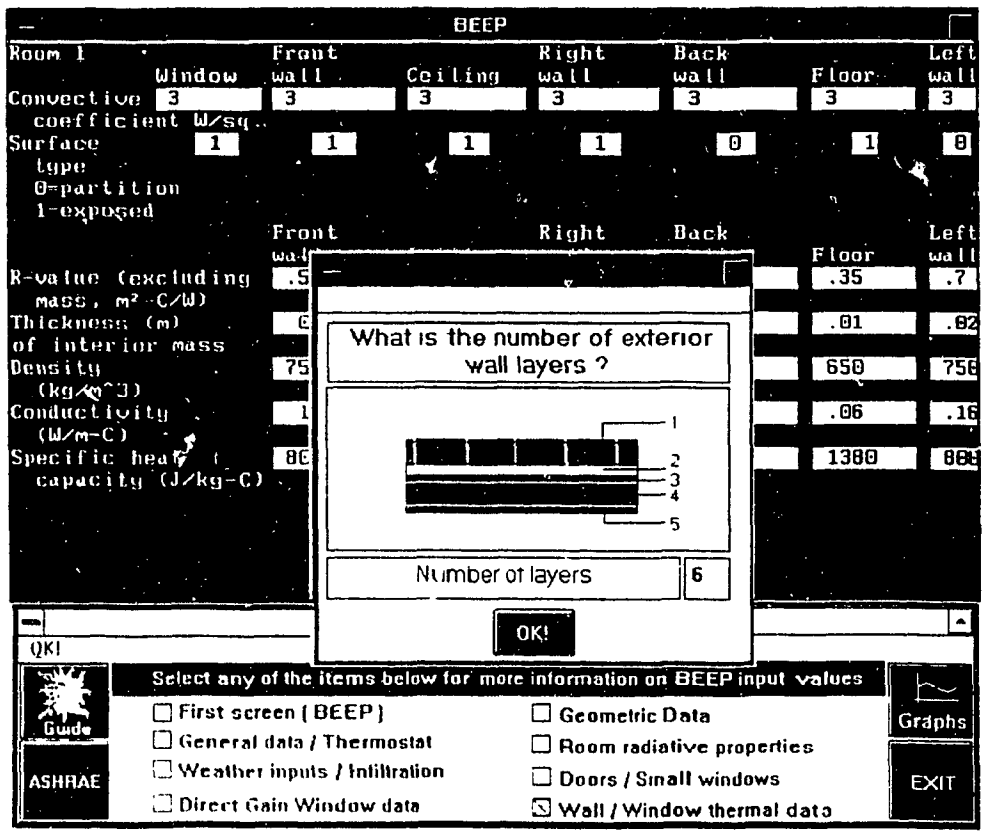

BEEP
* GENERAL DATA AND THERMOSTAT CONTROL OPTIONS *
NUMBER OF ROOMS (1 or 2): 1
NUMBER OF HARMONICS (1 15): 15
(First harmonic is the mean)
AUXILIARY HEATING/COOLING (Y or N): Y
THERMOSTAT LOW SETPOINT (heating): 20.0 DEG. C
THERMOSTAT HIGH SETPOINT (cooling): 27.0 DEG. C
THERMOSTAT NIGHT SETBACK: 0.0 DEG. C below low setpoint
Perform frequency response analysis (Y/N) ? : N
- If yes simulation will not be performed.
(press [page down] if defaults are used)
PASSIVE SOLAR DESIGNER
OK!
Select any of the items below for more information on BEEP input values
Guide
First screen (BEEP)
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Geometric Data
Room radiative properties
Doors / Small windows
Wall / Window thermal data
Graphs
ASHRAE
EXIT


BEEP
* GENERAL DATA AND THERMOSTAT CONTROL OPTIONS *
Explanatory Information
OK!
Thermostat Setpoint
HEATING is provided when the room air temperature falls below the low setpoint
COOLING is provided when the room air temperature rises above the high setpoint
Thermostat Setback / Setup
The low and high setpoints can have a setback and setup respectively, over specified periods.
Thermostat Setpoint
Auxiliary Heating / Cooling
Frequency Response Analysis
BEEP input values
Guide
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Room radiative properties
Doors / Small windows
Wall / Window thermal data
Graphs
ASHRAE
EXIT


BEEP
* WEATHER INPUTS AND INFILTRATION *
Explanatory Information
OK!
Weather inputs and Infiltration
* Wind speed
The pressures caused by wind on a building, lead to air leakage which is a major consideration in heating and cooling
cool air
heated space
P1
P2
P1>P2
(pressures)
* Infiltration is the heat loss due to air exchange between heated spaces and the outdoor
PASSIVE SOLAR DESIGNER
OK!
Select any of the items below for more information on BEEP input values
Guide
Graphics
ASHRAE
EXIT
First screen (BEEP)
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Geometric Data
Room radiative properties
Doors / Small windows
Wall / Window thermal data


BEEP
LOCATION AND SOLAR PARAMETERS FOR DIRECT GAIN WINDOW
Explanatory Information
OK!
Extinction Coefficient
A property of the glazing material that characterizes the solar absorption in the material, namely, the fraction of radiation that is absorbed per unit of path length in the material (it is dimensionless)
Location and
Latitude
Extinction coefficient
Surface Azimuth
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Room radiative properties
Doors / Small windows
Wall / Window thermal data
ASHRAE
EXIT


OK!
The roof contains 'Rafters' ?
Roof data
OK!
Input the following dimensions (in m)
Q = 0.8 m
x = 0.06 m
y = 0.18 m
Position of rafters (layer number)
2
Q
x
y
OK!
Select any of the items below for more information on BEEP input values
Guide
Graphs
ASHRAE
EXIT
First screen (BEEP)
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Geometric Data
Room radiative properties
Doors / Small windows
Wall / Window thermal data

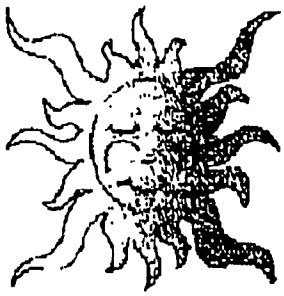

BEEP
Room 1
Window
Front wall
Ceiling
Right wall
Back wall
Floor
Left wall
Convective coefficient W/sq..
Surface type
0=partition
1-exposed
R-value (excluding mass, m² -C/W)
Thickness (m) of interior mass
Density (kg/m^3)
Conductivity (W/m-C)
Specific heat capacity (J/kg-C)
What is the number of exterior wall layers ?
1
2
3
4
5
Number of layers
6
OK!
OK!
Select any of the items below for more information on BEEP input values
Guide
Graphs
ASHRAE
EXIT
First screen (BEEP)
General data / Thermostat
Weather inputs / Infiltration
Direct Gain Window data
Geometric Data
Room radiative properties
Doors / Small windows
Wall / Window thermal data

PASSIVE SYSTEMS-DESIGN GUIDELINES

File

Passive Solar Designer

> Design Guidelines <



A Hypertext Design Assistant for Passive Solar Buildings

START

PASSIVE SOLAR DESIGNER

File

DESIGN GUIDELINES

Building Location

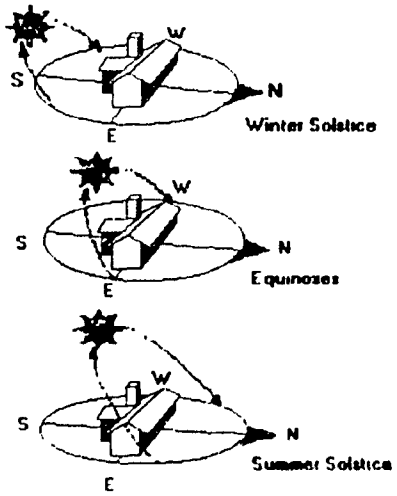
Buildings blocked from exposure to the low winter sun between the hours of 9:00 am and 3:00 pm, cannot make direct use of the solar energy for heating.

Recommendation

To take advantage of the sun in climates where heating is needed during the winter, find the areas on the site that receive the most sun during the hours of maximum solar radiation (9:00 am to 3:00 pm).

Placing the building in the northern portion of the sunny area will:

* Ensure that the outdoor areas and gardens placed to the south will have adequate winter sun, and
* Help minimize the possibility of shading the building in the future by off-site developments.



GO BACK GUIDELINES

PASSIVE SOLAR DESIGNER

File

DESIGN GUIDELINES

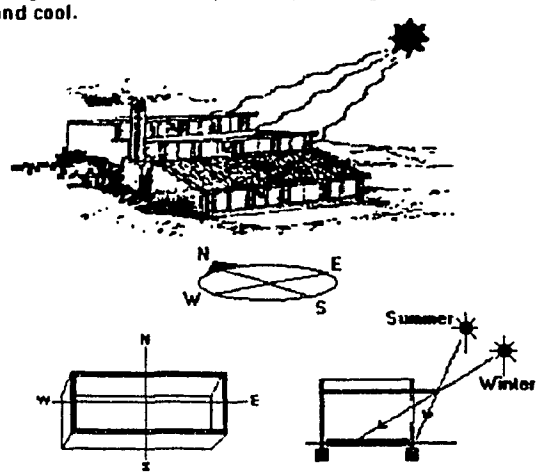
Building Shape + Orientation

Buildings shaped without regard for the sun impact, require large amounts of energy to heat and cool.

Recommendation

When deciding on the rough shape of a building, it is necessary to think about admitting sunlight into the building. A building elongated along the east-west axis, will expose more surface area to the south during the winter, for the collection of solar radiation.

This is also the most efficient shape in all climates, for minimizing heating requirements in the winter and cooling in the summer.



GO BACK | GUIDELINES

PASSIVE SOLAR DESIGNER

File

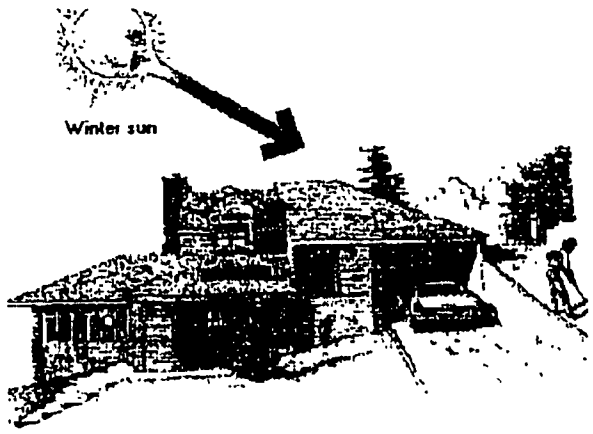
DESIGN GUIDELINES

North Side

The north side of a building is the coldest, darkest and usually the least used side, because it receives no direct sunlight all winter.

Recommendation:

Shape the building so that its north side slopes toward the ground.When possible build into the side of a south-facing slope and/or berm earth against the north face of a building, to minimize the amount of exposed north wall. As the height of the north wall is reduced, the shadow cast by the building in winter is shortened. Use a light-coloured wall (or nearby structure) to the north of the building to reflect sunlight into the north-facing rooms and outdoor spaces.



GO BACK | GUIDELINES

PASSIVE SOLAR DESIGNER

File

DESIGN GUIDELINES

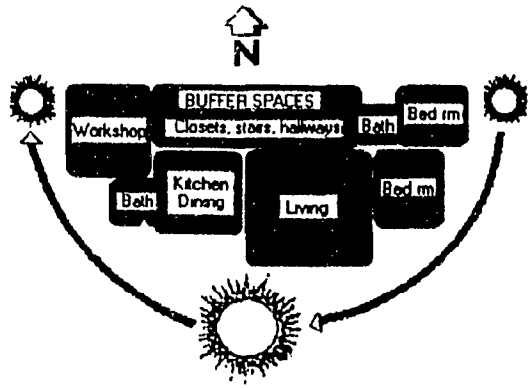
Location of Indoor Spaces

A space that does not utilize sunlight for heating during the winter months, will use proportionally more conventional energy than on which does.

Recommendation

Interior spaces can be supplied with much of their heating and lighting requirements, by placing them along the south face of the building, thus capturing the sun energy during different times of the day. Place rooms to the south-east south and southwest according to their requirements for sunlight.

Those spaces having minimal heating and lighting requirements such as corridors, closets, laundry rooms and garages, when placed along the north face of the building, will serve as a buffer between the heated spaces and the colder north face.



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Window Location

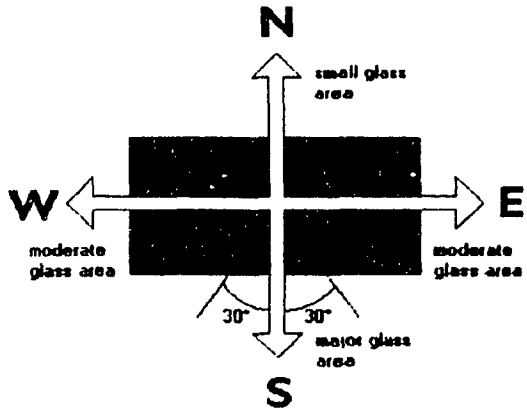
One of the largest single factors affecting building energy consumption, is the location and size of windows. Windows placed without consideration for the amount of energy they admit, will usually be an energy drain on the building

Recommendation:

Locate major window openings to the southeast, south and southwest according to the internal requirements of each space.

On the east, west and especially the north side of the building, keep window areas small and use double glass.

When possible, recess windows to reduce heat loss.



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DIRECT GAIN SYSTEMS

The concept of DIRECT GAIN is the most popular design approach to passive solar heating, due to its simplicity and perceived low cost.By using south facing windows or clerestory windows the actual living space is directly heated by sunlight.Shading overhangs can be used to avoid overheating during the summer.When the space is used as a solar collector, it must also contain a method for absorbing and storing enough daytime heat for cold winter nights.This is achieved by providing sufficient internal mass for heat storage, which also decreases temperature swings to acceptable levels.This storage mass, must be strategically located in the space.The floor and/or walls or roofs, must be constructed of materials capable of storing heat.The most common materials used for heat storage are masonry and water.

<For more details on materials, see 'GUIDELINES' Group2.2>

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DIRECT GAIN SYSTEMS

MASONRY HEAT STORAGE

Masonry thermal heat storage materials, include concrete, concrete block, brick, stone and adobe either individually or in various combinations.Typically, at least one-half to two-thirds of the total surface area in a space, is constructed of thick masonry.

INTERIOR WATER WALL

Water storage is usually contained in only one wall of a space.The water wall is located in the space in such a way, that direct sunlight strikes it for most of the day.Materials commonly used to construct the wall, are plastic or metal containers.

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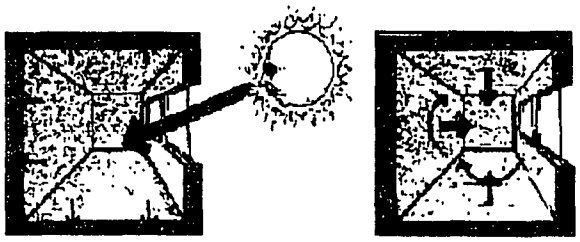
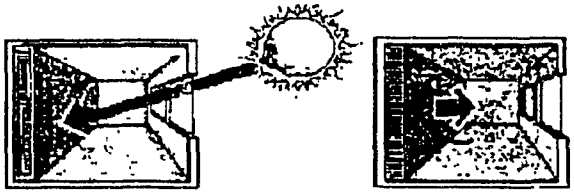


DAY NIGHT

MASONRY HEAT STORAGE



DAY NIGHT

INTERIOR WATER WALL

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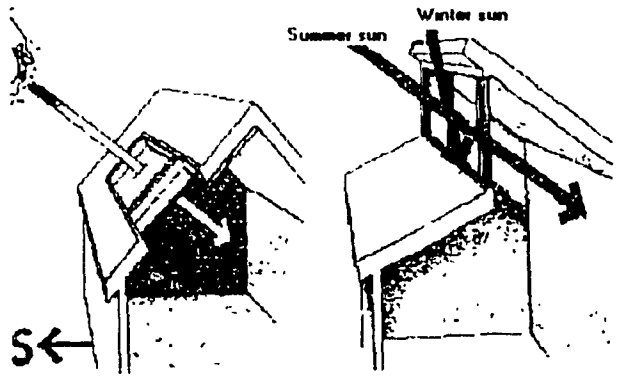
Direct Gain Systems-Clerestories+Skylights

There are many situations when admitting direct sunlight through south-facing windows is not feasible or desirable.

Recommendation:

Another method for admitting sunlight into a space, is through the roof.Use either south-facing clerestories or skylights, to distribute sunlight over a space or to direct it to a particular interior surface.

Make the ceiling of the clerestory a light colour and apply shading devices to both clerestories and skylights for summer sun control



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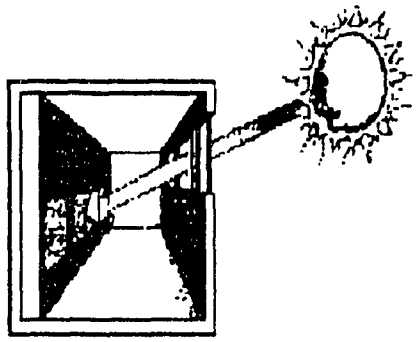
Direct Gain Systems-Masonry Heat Storage

The storage and control of heat in a masonry building, is the major problem confronting the designer of a Direct Gain System.

Recommendation.

To minimize indoor temperature fluctuations, construct interior walls and floors of masonry with a minimum of 10 cm in thickness. Diffuse direct sunlight over the surface area of the masonry by using a translucent glazing material, by placing a number of small windows so that they admit sunlight in patches, or by reflecting direct sunlight off a light-coloured interior surface first, thus diffusing it throughout the space.Use the following guidelines for selecting interior surface colours and finishes:

1. Choose a dark colour for masonry floors
2. Masonry walls can be any colour
3. Paint all lightweight construction a light colour
4. Avoid direct sunlight on dark-coloured masonry
5. Do not use wall-to-wall carpeting over masonry floors



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Appropriate Materials

More energy is consumed in the construction of a building than will be used in many years of operation.

Recommendation:

In building construction, use mostly biogradable and low energy-consuming materials which are locally produced.For thermal mass and bulk materials use adobe, soil-cement, brick, stone, concrete and water in containers; for finish materials use wood, plywood and gypsum board.Use the following materials only in small quantities or when they have been recycled: steel panels for containers, rolled steel sections, aluminum and plastics.

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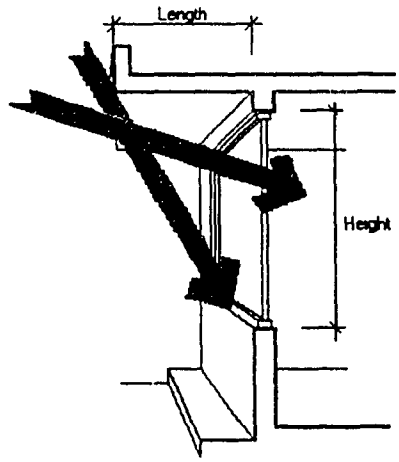
Shading Devices

Large south-facing glass areas, sized to admit maximum solar gain in winter, will also admit solar gain in summer when it is not needed.

Recommendation:

Shade south glazing with a horizontal overhang located above the glazing and equal in length with roughly one-fourth the height of the opening in southern latitudes (36°NL) and one-half the height of the opening in northern latitudes (48°NL).



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Choosing the System

What is the best Passive Solar System to use?

Recommendation:

Each system has specific design limitations and opportunities.Choose a particular system, that satisfies most of the design requirements you generate for each space. Remember that different systems can be used for different spaces, or systems can be combined to heat one space.

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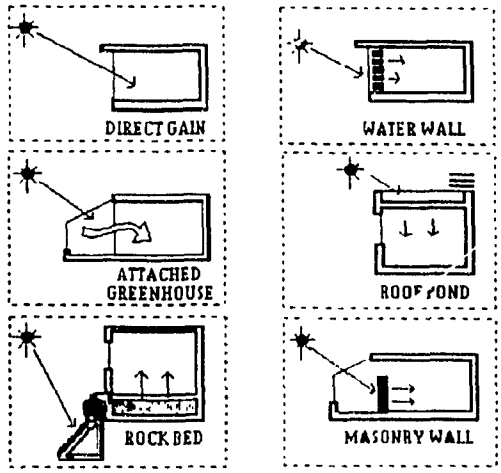

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Combining Systems

It is very likely that a combination of passive systems will be used to heat a space. However, sizing procedures are usually only given for individual systems.

Recommendation:

When sizing a combination of systems, adjust the procedures given in the patterns referring to the sizing of each of the combined systems. For the same amount of heating, each 1 sq m of direct gain glazing equals 2 sq m of thermal storage wall or equals 3 sq m of greenhouse common wall area.

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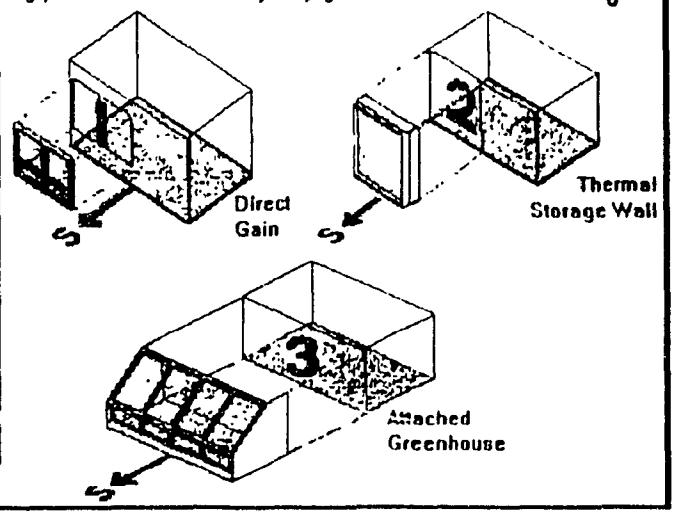

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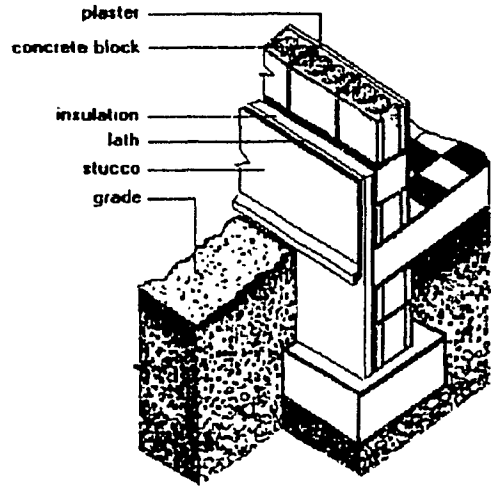
Insulation on the Outside

While good at storing heat, a masonry exterior wall used as a heat storage medium within a space will also readily pass this heat to the outside.

Recommendation:

When using a masonry wall (exposed to the exterior) for heat storage, place insulation on the outside of the wall. Also, at the perimeter of foundation walls apply approximately 0.7 to 1m of 5 cm rigid waterproof insulation below grade. This will prevent any heat stored in the walls and floor from being conducted rapidly to the outside.



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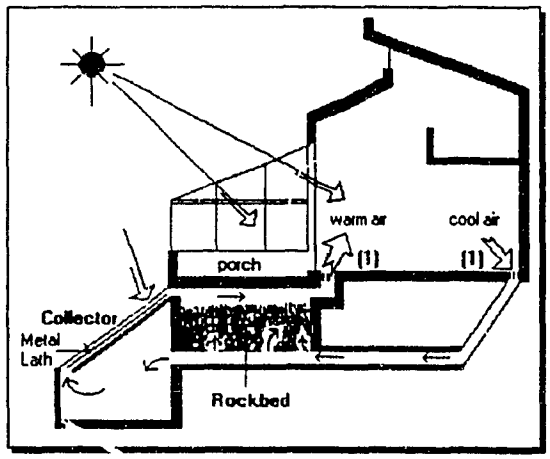
ISOLATED GAIN SYSTEMS

Based on the thermosifoning principle is the combination of a thermosifoning collector with a thermosifoning rockbed.

The air rises through the collector, becoming heated in the process. From there it travels through the rockbed located below the porch, or directly into the house through floor registers. Cooler air returns from the rockbed or the house to the collector.

The cooling effect of reverse air flow on winter nights is prevented by manual dampers (1) which also control the amount of heat rising into the house.



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