30. An Integrated KB-CAAD System for the Design of Solar and Low Energy Buildings

Edna Shaviv

Faculty of Architecture and Town Planning
Technion - Israel Institute of Technology
Haifa, Israel

Uriel J. Peleg

ACA-Architecture and Computer
Aids Ltd.
Ramat Gan, Israel.

A knowledge-based computer-aided architectural design system (KB-CAAD) for the design and evaluation of solar and low energy buildings is presented. The KB-CAAD system is based on the integration of knowledge-based and procedural simulation methods with any available CAAD system for building representation. The knowledge base contains the heuristic rules for the design of passive solar buildings. Whenever possible, the knowledge-base guides the designer through the decision making process. Yet, if the rules of thumb are not acceptable for the particular design problem, the KB-CAAD system guides the architect by using a procedural simulation model. We demonstrate by means of a case study, that not only does the KB-CAAD system lead to the design of better solar buildings, but that this process requires less time and labor than the process of building presentation by means of standard available CAAD systems.

Introduction

Different design tools for solar and low energy buildings were developed mainly since 1976 (SERI report 1980). These tools addressed different design stages. The first CAD tools to be developed were the comprehensive procedural simulations (deep knowledge). These tools were aimed for use on mainframes only and especially by researchers. Among the large simulations to be run on mainframes, we would like to mention the PASOLE simulation for passive solar design, developed by McFarland and used in Los Alamos National Laboratory (McFarland 1978) and TRNSYS for simulating the dynamic thermal behavior of active solar systems (Klein, et al. 1976). Other early examples of procedural simulation tools (that were aimed to be applied by researchers and designers) are BLAST (U.S Army 1977), ENERGY (Shaviv and Shaviv 1977), DEROB (Arumi 1979), ESP (Clark 1982), DOE-2 (LBL and LASL 1982), and SERIRES (Palmiter et al. 1982).

The cumbersome application of such heavy tools that run on mainframes led to the development of simplified procedural methods. These simplified methods were based on approximations, like steady-state assumption (ASHRAE 1972) and the correlations obtained from different detailed computer simulations. Typical examples are the “f-charts” method that was developed from the TRNSYS computer code (Beckman et al. 1977) and the SLR and LCR methods that are based on the PASOLE simulation tool (Balcomb et al. 1984).

Thus, the second approach to the design of solar and low energy buildings was based on simplified procedural methods and was not derived from first principles. It provides designers with an estimate of the expected thermal performance of different design alternatives. Shaviv

(1989) claimed that the simple expressions that were developed to be manually solved are in most cases too cumbersome for this purpose (particularly for architects). As a consequence special computer programs were developed to solve the so called manual analysis methods. These approximate CAAD tools require detailed data of the building's design parameters, much like the precise simulation tools do. The approximations differ from the precise tools in that they calculate energy consumption on an annual, monthly, or daily basis rather than hourly. The required climatological data for long time averages are naturally simpler than the hour by hour data. This advantage disappears when computers are used to perform the simulation. The storage requirements of hourly climatological data for each region seldom pose a problem even to small present day computers. We find that small computers can provide accurate simulations at modest cost and efficiently.

Looking back at the years 1976 to 1984, the rational behind the mentioned above approach is well understood. It was imaginary to predict that a time will come when architects will use the computer like a 6B pencil. Yet, few architects and researchers, that entered the field of CAAD at the early 70’s, believed in the use of computers as tools for energy conscious designs. Such ideas were presented in CAD conferences by Clark, Greenberg and Shaviv (Pikes 1978). In 1977, Shaviv and Shaviv (1977, 1978a,b) suggested a simulation model called ENERGY, which run on a personal computer and could be used easily by architects. This model was based on interactive handling of the building data, using essentially a questionnaire expressed in daily architectural terminology. This approach can be contrasted with the non friendly thermal network physical presentation models, like the PASOLE code. The ENERGY model presented by Shaviv and Shaviv was planed for simple and easy use during the early schematic design stage. But as personal computers were rare at that time, the suggested approach seemed remote from reality.

The use of accurate CAD design tools seems to many people today more realistic. The above philosophy was advocated by Klein in the address he delivered when he was honored with the Abbot award for ‘significant contribution to the field of solar energy’ (Ases annual meeting, Denver, CO., 1988). Klein got the award for the development and implementation of the "f-chart" design method for sizing solar heating systems and his contribution in the development of TRNSYS computer code. In his speech he mentioned the fact that the "f-chart" was an important design tool when it was developed, as designers did not have at that time access to personal computers of the today power. Yet, he was not sure that he would have suggested this method today.

The third approach, first suggested by Balcomb et al. (1984), is based on rules of thumb and acquired experience (wide knowledge). This approach was the latest to be developed, as it required the accumulation of knowledge and expertise. The heuristic rules provide designers with generalized appraisal of their choice of building orientation, geometry (massing), and choice of site treatments. The input required by this model is approximate and coarse compared to the input required by the procedural model. The knowledge-based evaluation model can therefore be applied at the early formative stages of the design process, where the impact of design choices on the energy performance of the building is more significant than choices made in later design phases (Shaviv 1977, Maher and Fenves 1985, Kalay et al. 1987, Schmitt 1987, Shaviv and Kalay 1990). Examples of early CAD tools based on this approach include an expert system developed by Gero and Coyne (1984), a design tool developed at CMU (Schmitt 1987), ARCADE (Antony 1987), and an expert system developed by Bharati (1990).

The early knowledge-based design tools for gross evaluation of thermal properties of design alternatives have the advantage that they don't require a full description of the building, and avoid the complication of preparing such detailed data. Yet, they suffer from the inherent over simplicity of rules of thumb, which do not provide deep knowledge and are based on previously examined standard cases. Recently, we find new attempts to develop advanced knowledge-based energy conscious design tools based on integration with deep knowledge. Some of these works were presented in the ASHRAE symposium 'Artificial Intelligence in Building Design: Progress and Promise' (Pohl et al. 1990, Shaviv and Peleg 1990, Brown 1990, Tham et al. 1990, Papamichael and Selkowittz 1990).

Evaluation and Prediction at the Schematic-Conceptual Design Stage

The solar characteristics of passive solar and low energy buildings are determined at the schematic design stage. Therefore, the need for a good design tool during the conception stages is evident.

The procedural simulation CAAD tools provide an accurate evaluation of the predicted energy consumption and performance of a buildings. These tools require a detailed description of the building, which are not always known at the schematic stage. As a result, the usual practice is to use at this stage simple rules of thumb and approximate methods and leave the accurate evaluation, using more complex simulation tools, to the final design stage.

Few problems arise: First, rules of thumb do not always lead to a correct solution because they are based on and relate to standard cases that were examined previously. Therefore, they may give incorrect recommendations for new innovative designs, which deviate substantially from the standard and frequent case. Second, major drawbacks may be discovered when accurate simulations of the building are carried out at the final design stage. Usually it is practically too late to draw new conclusion and introduce drastic changes.

In the same way that it is laborious to use simulation models at the early design stages, it is complicated to represent visually the building by applying any presently available 2D or 3D CAAD system. The reason being the cumbersome and tedious process of the introduction of the building's geometrical data. As a result most architects tend not to use these systems during the conceptual design stage but merely during the documentation of the final project.

The above difficulties call the need for a different and new computer-aided architectural design approach to handle the schematic sketch and evaluation process. The KB-CAAD tool, presented in this paper, combines geometric design with solar considerations. It is based on integrating a knowledge base with a procedural simulation model and any available graphic system for building representation. The knowledge base contains the heuristic rules for the design of passive solar buildings and is stored in the computer. Whenever it is possible to apply rules of thumb, it guides the designer through the decision-making process. However, when rules of thumb are not adequate for the particular design, the KB-CAAD system guides the designer by using the procedural simulation model.

The new design tool uses heuristic rules to assign automatically values to particular design parameters, such as walls thickness and composition, that are required input to the simulation model and to the graphic system for building representation. As a result, fewer data must be specified by the designer. By not having to insert detailed data describing the building, we benefit both in the schematic phase of design of energy-conscious buildings and in developing the two-dimensional and three-dimensional representations. Moreover, as some detailed data is assigned automatically by the system, usage of accurate simulations in the early design phases is enabled. This method overcomes the possibility that the rules of thumb, which were developed for standard cases, may not apply to our innovative design.

The Complexity in Predicting the Thermal Performance of Buildings.

The number of various energy-related design parameters needed for simulating the thermal performance of buildings is very large. The building data include the floor area and its volume, the area and heat capacity of the isothermal mass, the initial wall temperature conditions, and the internal heat gain according to a given schedule. This data include also the information about the mode of operation, size of mechanical equipment (thermostat settings and hours during which the heater or cooler operate) and the number of air changes during day and night (due to infiltration and natural or forced ventilation). Information about the number of walls, including all opaque elements in the external envelope (such as roofs and floors) should be given. For each external element, the heat capacity, heat conductivity and thickness of each layer must be specified, as well as the albedo and emissivity of the element and its shading factors. The external elements data also comprise of geometrical design parameters such as the azimuth, inclination and area of the element. The data incorporate the type, azimuth, inclination, shading coefficients, and area of each window located on this element as well.

Figure 1 shows part of the many energy-related design parameters that must be specified before a simulation can be run. The simulation used in the present case is the ENERGY code. This program solves simultaneously the heat transfer equation through all exterior walls, taking into account the thermal mass of each external wall and internal partitions. The simulation model calculates the energy consumption of the building during winter and summer (see Figure 2). In addition, it computes the maximum in-house summer temperature without air conditioning (Tmax-NV or Tmax-V) or with a fan only (Tmax-F). Most of these results, while of considerable importance to the user of the building, are not available in the approximate models. Special effort has been invested in the computer code ENERGY, to produce an algorithm that solves the implicit scheme of the time-dependent equation for the heat flow in an efficient way. Thus, to run an hour by hour simulation of a full-scale comprehensive building requires only 10 seconds on a Personal IRIS workstation.

An energy-conscious design process comprises the choice and assignment of appropriate values to the many design parameters presented in Figure 1. The process is complicated because many interdependent design parameters must be specified simultaneously.

To demonstrate this point, we have performed many simulation runs (Shaviv and Capeluto 1990), showing that the relationship between various design parameters is not universal and varies with the particular conditions existing in the building. This means that the same change in a given parameter may have different effects, all depending on the particular state the building is (see Figure 2).

BUILDING'S GEOMETRY					
180.0					TOTAL FLOOR AREA
504.0					VOLUME OF BUILDING
6					NO. OF EXTERNAL WALLS
0.0					AZIMUTH OF REFERENCE WALL
INTERNAL PARTITIONS					
300.0					AREA OF INTERNAL MASS
8400.0					HEAT CAPACITY OF INTERNAL MASS
18.3					INITIAL TEMP. DISTRIBUTION
MECHANICAL SYSTEMS AND BUILDING USE POLICIES					
250.					HEAT GAINS: CONSTANT
1000.	18.0	22.0			HEAT GAINS: SCHEDULE
10000	07.0	22.0	18.0	19.0	HEATER: SCHEDULE; TEMP.SET
6000	07.0	22.0	24.0	28.0	COOLER: SCHEDULE; TEMP.SET
2	18.0	07.0	0.75	4.0	VENT: TYPE, SCHEDULE, ACH: DAY; NIGHT
ENVELOPE					
	1				WALL NO 1
	3				NUMBER OF LAYERS
500.0	1.40	0.02			(c,l,d) 'OUTSIDE PLASTER'
75.0	0.23	0.20			(c,l,d) 'YTUNG BLOCK 800'
450.0	0.87	0.01			(c,l,d) 'INSIDE PLASTER'
180. 90.					WALL: AZIMUTH, INCLINATION
.65 .95					WALL: ALBEDO, EMISSIVITY
37.56					AREA OF WALL
90. 90. 90. 90.					SC-SUMMER: DIR,DIF; SC-WINTER: DIR DIF
1					NO OF WINDOWS AND SOLAR ELEMENTS
WINDOWS AND SOLAR ELEMENTS (ON WALL NO 1)					
1 18.00					WINDOW:TYPE;AREA
10. 50. 90. 90.					SC-SUMMER:DIR,DIF;SC-WINTER:DIR DIF
18. 07. 5. 3.5					U WINDOW:SCHEDULE;DAY;NIGHT

Figure 1. Part of the energy-related design parameters that should enter the simulation model ENERGY.

Figure 2 shows the thermal performance of a middle floor apartment with a large southern window in Jerusalem (a region of cold winters and mild summers) and in Tel Aviv (a region of mild winters and hot-humid summers). As for example, one can see that improving the walls' insulation, in the climate of Jerusalem, reduces significantly the energy consumption of the building (compare JE-SL with JE-IL). However, the same improvement in the climate of Tel Aviv will increase the total energy consumption of the building (compare T-SL with T-IL). Moreover, the improvement in the walls' insulation in a poorly ventilated building will deteriorate the summer thermal performance of the same apartment (see Tmax-NV and compared JE-SL to JE-IL). This is because the heat stored in the thermal mass is released to the unvented rooms, and the improved insulation prevents its loss through the building's envelope. Such conclusions could not be reached using approximate, steady-state calculations.

We see also that in Jerusalem the energy consumption for heating the building can be reduced by painting the walls dark (JE-SL compared with JE-SD). This factor is not significant in the well-insulated building (JE-IL, JE-IM, and JE-ID). On the other hand, light color is always preferable under summer conditions. Again, this factor is not significant if the building is ventilated well. These examples show that maximization or minimization of some design parameters will often lead to suboptimal solutions. Rather, trade-offs must be made to achieve a good balance. For instance, in Tel Aviv a light-colored, standard-insulated building behaves thermally as well as a dark-colored, better insulated building (T-SL compare with T-ID). It would be obviously cheaper to paint the building white than improve its insulation.

To overcome the difficulties of predicting the thermal performance of buildings, Shaviv and Kalay (1990) presented a process of designing energy-conscious buildings as a sequence of decisions made at different levels of abstraction. In each successive level more detailed and specific design parameters are explored. Accordingly, various energy-related design parameters are likely to be considered at different design stage (see Figure 3).

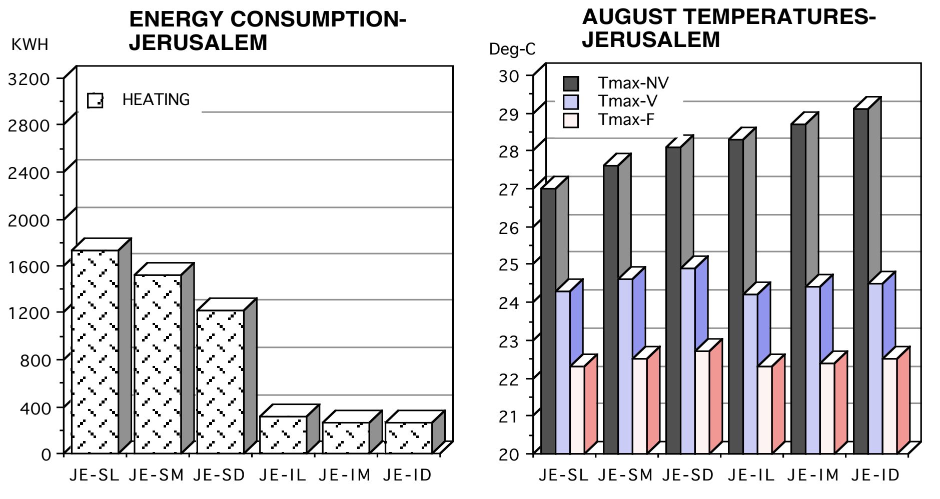
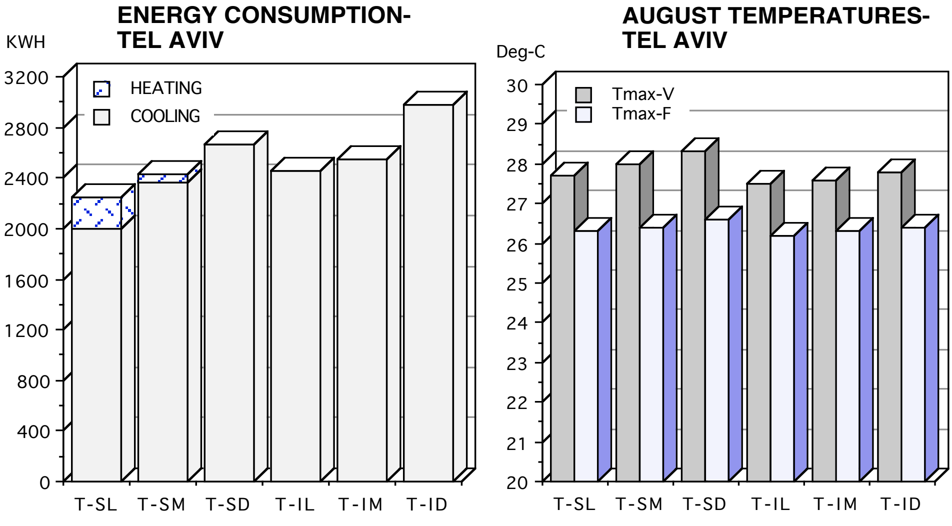


Figure 2. The energy consumption and thermal performance of a middle floor apartment with a large southern window in Jerusalem (up) and in Tel Aviv (down). (JE:Jerusalem; T:Tel Aviv; S:standard insulation; I:Improved insulation; L:Light color; M:Medium color; D:Dark color; Tmax-NV:maximum in-house summer temperature with poor ventilation; Tmax-V: the same with good ventilation; Tmax-F:ventilation with fan.)



Most parameters are not assigned specific values early in the design process. Therefore, the designer is free to choose almost any value for the parameter of his current concern. As the design progresses, the previously assigned values may restrict the designer's freedom in choosing the values that are assignable to parameters considered later. For example, if the designer wishes to run an energy simulation at the schematic design phase in order to find the best proportion of the building in the Jerusalem climate, the designer must determine the materials from which the building will be constructed. If the walls were assigned a material composition of standard insulation, they must be painted with a dark color in order to reduce the energy consumption for winter heating. Once a dark color to the walls has been assigned, the designer must be careful to design the building with good ventilation for summer conditions, so as to avoid overheating. On the other hand, if the building is well insulated, colors have a negligible influence on its energy consumption, hence the designer is free to choose any color for the walls. To assist the designer at the early design process, the system could provide him or her with reasonable defaults for walls' insulation and color, based on the recommended R value for the climatic zone in which the building is located.

We presented the examples above to show that the complexity of evaluating the thermal performance of buildings warrants the use of accurate simulation models rather than approximated ones. But on the other hand, due to the strong interdependencies between different design variables, much expertise is required to reach good conclusions without actually running many simulations. We believe, therefore, that integration of heuristics methods, in which such experience can be stored, and procedural simulations methods through which the former can be tested, will support all phases of energy conscious design and evaluation processes and will benefit from the advantages of both methods.

DESIGN PHASE	a.	b.	c.	d.	e.
TOTAL FLOOR AREA	*		+	+	
VOLUME OF BUILDING		*	+	+	
NO.OF EXTERNAL WALLS			*	+	
AZIMUTH OF REFERENCE WALL			*	+	
AREA OF INTERNAL MASS				*	+
HEAT CAPACITY OF INTERNAL MASS					*
INITIAL TEMP. DISTRIBUTION		*			
HEAT GAINS: CONSTANT	*				
HEAT GAINS: SCHEDULE	*				
HEATER: SCHEDULE; TEMP.SET		*			+
COOLER: SCHEDULE; TEMP.SET		*			+
VENT: TYPE, SCHEDULE, ACH: DAY; NIGHT		*			+
WALL NO 1					
NUMBER OF LAYERS				*	+
MATERIALS((c,l,d)				*	+
" " "					
" " "					
WALL: AZIMUTH, INCLINATION			*	+	
AREA OF WALL			*	+	
WALL:ALBEDO,EMISSIVITY					*
WALL:SC-SUMMER,WINTER				*	+
NO OF WINDOWS AND SOLAR ELEMENTS		*	+		
WINDOW: AREA	*	+			
WINDOW: TYPE		*	+		
WINDOW: SC-SUMMER, WINTER	*				+
U WINDOW: DAY; NIGHT				*	+
U WINDOW: SCHEDULE	*				+

Figure 3. The design phase at which the various energy-related design parameters are first considered * and reconsidered +. The design phases are: a-Briefing, b-Pre-conceptual c-Conceptual, d-Preliminary, and e-Detailed design.

The Sensitivity Analysis of Various Design Parameters

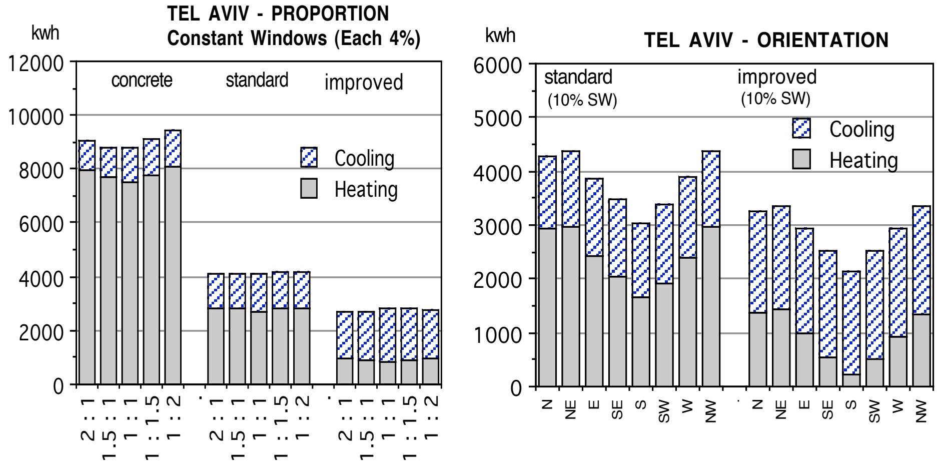
The key questions that arise are:

- Is it necessary to design the building with all its details first, and only then run an energy simulation to obtain an accurate thermal evaluation?
- What inputs are important for running energy simulations during the early design stages?
- How rigorous must the data describing the building be at the early design stage?
- At the initial phases what values should be assigned to parameters, that are likely to be considered only at later design stages?
- How can values be assigned simultaneously to several parameters at the same design phase?

A large number of simulations were run and the results analyzed with the purpose to obtain answers to the above questions (Shaviv and Peleg 1989, Shaviv and Capeluto 1990, 1991). This study was carried for typical residential apartment buildings and for different climatic regions in Israel. The results were summarized in an easy to comprehend and presented in a graphical format (see for example Figure 4).

In Figure 4 we present some results that were obtained from the study that was carried out for residential buildings in Tel Aviv climate (Shaviv and Capeluto 1990, 1991). The design parameters in both cases are the geometrical ones (the building's proportions and its orientation). In the first case (Figure 4a) one can see that changing the building's proportion (the ratio of the length of southern and northern walls to the length of eastern and western walls, in a rectangle floor plan, is changed from 2:1 to 1:2) has a small effect on the energy consumption of the building. On the other hand, a change in the orientation of the building, so that the large window is not directed to the south, has a major effect on the energy consumption (Figure 4b). Other design parameters were examined in the same way.

The results obtained from the simulation model provide the knowledge base. This knowledge base contains case-specific rules that guide the system how to assign defaults to various design parameters. The knowledge base defines also the acceptable range of values for the design parameters that are considered at the different design phases. In addition, it includes the rules that guide the designer and the system as far as when to run a simulation, in order to provide rigor to the heuristics used by the early design phases. At last, the most important point to mention is the fact that the sensitivity analysis of the various design parameters shows that three different categories of parameters exist. They will be presented in next chapter.



a. b.

Figure 4. a. The influence of building's proportion on its energy consumption **b.** The influence of building's orientation on its energy consumption. Both cases are for a standard and improved insulated building (Tel-Aviv climate).

Different Categories of Design Parameters

The three categories of design parameters that were found may be defined as follows:

a. A design parameter with a strong influence on the energy performance and is insensitive to other design parameters. This kind of parameter should get its recommended value from the KB-CAAD systems as a default to ensure good energy performance. As it is not sensitive to other design parameters, its refinement can be carried out in the more advanced design phases.

b. A design parameter with a strong influence on the energy performance and sensitive to other design parameters. The KB-CAAD system has knowledge about type b parameters. Therefore, whenever needed, the system performs a series of simulation runs to guide the architect through the design of the particular building. This module of the KB-CAAD system provides deep knowledge and can overcome the problem that heuristic rules are valid for the average cases only.

c. A design parameter with a weak effect on the energy performance and therefore is always insensitive to other design parameters. The value of this kind of parameter may be arbitrarily specified by the user or by the system as a default. A check in later design stages can be made to fix the exact value.

To summarize, the three categories of design parameters are: First, those for which default values can be specified by the knowledge base according to the specific climatic conditions and type of building. Only heuristic rules are used in this step (case-specific defaults). Second, those that have a significant influence on the energy consumption and are very sensitive to the other design parameters. These design parameters require a continuous guidance for their proper values. In this case heuristic rules are used with simulation analysis (*combined case-specific defaults tested by simulation evaluation)*. And third, those that are free design parameters that can be arbitrarily specified, either by the system as defaults or by the designer (arbitrary design parameters).

The Building's Input

The knowledge-based system was first developed on a microcomputer as an open system that can be connected to a simulation design tool and to a commercial CAAD system. The connection between the different modules is carried out by files, which serves as an output for one module and as an input for the other one and vice-versa. This is not an ideal state, and we intend to run all modules in the future on the same workstation.

For the conceptual design phase, a 3D representation is important to allow visualization of the proposed design. The 3D representation can be obtained by using any available 3D software. In our case the input can be introduced by the commercial CAAD system ARC+ (ACA ltd. 1989). Yet, we found that this is not convenient, since each time one passes from the simulation run to the 3D commercial CAAD system, one must quit the CAAD software and reenter it again. This will change when the KB-CAAD and the 3D commercial CAAD systems run on the same workstation under UNIX operating system that allows multi-processing. As simple 3D representation is sufficient at this stage, we developed a schematic 3D representation as a module of the KB-CAAD system. The use of the commercial 3D software is restricted to the documentation stage.

The building's input is given by defining the shape of each room as a polygon and by introducing the heights of the room at each corner (see Figure 5). The input file for the simulation evaluation (see Figure 6) is automatically created by the KB-CAAD system. It is implemented by interpreting the graphical input that was introduced by the designer and by assigning values, that are based on the heuristic rules, for the different design parameters. The values assigned by the KB-CAAD system guarantee to achieve good thermal performance of the building. The treatment of the different design parameters was carried out according to the three categories that were defined.

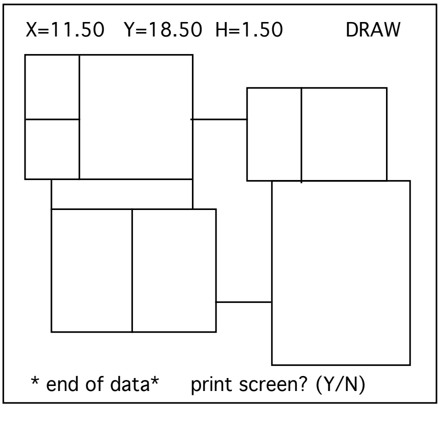


Figure 5. The introduction of the building geometry by a schematic plan (using the mouse) and heights at each corner (using the keyboard).

The different Treatment of Design Parameters

A. Case-Specific Defaults. The first category includes design parameters that according to some special conditions should be assigned default values from the knowledge base using heuristic rules. This category is classified into two subcategories: design parameters that do not depend on the local climatic conditions but on the type of building (presented in Figure 6 by plain text) and those that depend on the local climatic conditions (presented in Figure 6 by bold text).

For example, in the first subcategory, one can find the internal heat gains and the schedule and temperature setting for operating the heater and cooler, while in the second subcategory one can find the recommended size of heater and cooler and the suggested walls' insulation. Based on the specific local climate and the designer's specification of the type of walls, the system suggests details for the walls, such as thickness, materials, etc. Detailed geometrical data for the design and representation of the building are introduced by the system automatically. This procedure saves labor and time, and the result is a better design building.

ALT1-5					
BUILDING'S GEOMETRY					
146.3					TOTAL FLOOR AREA
351.2					VOLUME OF BUILDING
13					NO.OF EXTERNAL WALLS
<u>**5.0**</u>					AZIMUTH OF REFERENCE WALL
INTERNAL PARTITIONS					
203.2					AREA OF INTERNAL MASS
5690.					HEAT CAPACITY OF INTERNAL MASS
18.3					INITIAL TEMP. DISTRIBUTION
MECHANICAL SYSTEMS AND BUILDING USE POLICIES					
250.					HEAT GAINS:CONST.
1000	18.0	23.0			HEAT GAINS:SCHEDULE
5000	07.0	23.0	18.0	19.0	HEATER:SCHEDULE;TEMP.SET
5000	07.0	22.0	24.0	28.0	COOLER:SCHEDULE;TEMP.SET
	18.0	07.0	0.75	4.0	VENT:SCHEDULE,ACH:DAY;NIGHT
	18.0	07.0	**5.0**	**3.5**	U WINDOW:SCHEDULE;DAY;NIGHT
ENVELOPE					
	1	WALL NO 1			
	3	NUMBER OF LAYERS			
500.0	**1.40**	**0.02**			(c,l,d) 'OUTSIDE PLASTER'
175.0	**0.23**	**0.20**			(c,l,d) 'YTUNG BLOCK 800'
450.0	**0.87**	**0.01**			(c,l,d) 'INSIDE PLASTER'
0. 90. *.65 .95*					WALL:AZ,INC,ALBEDO,EMISSIVITY
1	**45.60**				NO OF WINDOWS OR SOLAR ELEMENTS;AREA OF WALL
90. 90. 90. 90.					SC-SUMMER:DIR,DIF;SC-WINTER:DIR DIF
1	**5.28**				WINDOWS OR SOLAR ELEMENT:INDEX;AREA
10. 50. 90. 90.					SC-SUMMER:DIR,DIF;SC-WINTER:DIR DIF

....

	1	WALL NO 3	
	3	NUMBER OF LAYERS	
500.0	**1.40**	**0.02**	(c,l,d) 'OUTSIDE PLASTER'
175.0	**0.23**	**0.20**	(c,l,d) 'YTUNG BLOCK 800'
450.0	**0.87**	**0.01**	(c,l,d) 'INSIDE PLASTER'
180. **90.** *.65 .95*			WALL:AZ,INC,ALBEDO,EMISSIVITY
1	**43.60**		NO OF WINDOWS OR SOLAR ELEMENTS;AREA OF WALL
90. 90. 90. 90.			SC-SUMMER:DIR,DIF;SC-WINTER:DIR DIF
1	**24.82**		WINDOWS OR SOLAR ELEMENT:INDEX;AREA
10. 50. 90. 90.			SC-SUMMER:DIR,DIF;SC-WINTER:DIR DIF

Figure 6. Part of the building data file. Plain text is for building type defaults, Bold for local climatic conditions defaults, Italic for arbitrary non geometrical parameters, Outline for arbitrary geometrical parameters that are introduced graphically, and Underline-outline is for the sensitive design parameters.

B. Combined Case-Specific Defaults Tested by Simulation Evaluation. The second category includes design parameters that have a great influence on the energy performance and are very sensitive to other design parameters. Therefore, continuous guidance for specific values should be provided by the KB-CAAD system, using the simulation model. In this category, one can find the recommended size of the southern glazing and the orientation of the building (presented in Figure 6 by underline and outline text).

The system treats the sensitive design parameters in two ways: First, the system presents a default solution that is based on the statistical cases. Second, it suggests a series of simulation runs for the specific case. Also, if for some reason, the user is unwilling to accept the recommended solution and suggests a different one, the system offers to perform simulation runs. Thus, continuous guidance is provided by the system.

For example, the suggested area of windows for specific climatic conditions and wall orientation is decided based on recommendations stored in the knowledge base as heuristic design rules. The recommended windows are introduced by the system automatically and presented in axonometric view (See Figure 7). The system locates each window in the middle of the specific wall. The designer is allowed, at this stage, to shift the windows anywhere on the given elevation, so that the best design is achieved according to his taste (see Figure 8). While shifting a window around a specific elevation, the designer can keep the area and size of the window fixed or can divide the proposed window into several smaller windows, while keeping the total window area equal to the area suggested by the system. Also the designer can change the recommended area or add more windows on other elevations (see Figure 9). At this point, the system offers to evaluate the thermal performance of the building for the new proposed design alternative. The thermal performance of the building, as seen in Figure 10, will be presented graphically on another window of the powerful workstation. Since the system runs on a microcomputer, the evaluation starts only by clicking an item on a menu. This clicking initiates the creation of the building data file and the reevaluation of the design by the simulation model. This continuous evaluation can be carried out because the knowledge base includes the information that windows belong to the category of sensitive design parameters for which continuous guidance by the system is critical.

The recommended orientation of the building for specific climatic conditions is also a sensitive design parameter and depends on the size of the windows located on each wall. The recommended orientation of the building in alternative 1 was 5^{o} west of south. When the designer adds a window on the western and eastern walls (alternative 3), the system reevaluates the best orientation for the specific case and suggests that the best orientation for that particular case is due south (see Figure 11). This module of the KB-CAAD system overcome the difficulty that the heuristic rules, known to the system, are appropriate for average cases only by coupling the rules to a simulation model.

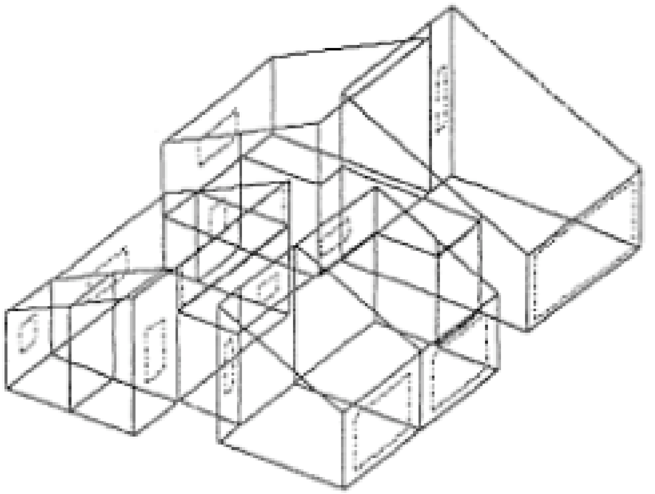


Figure 7. An axonometric view of the proposed building with the recommended area for each window (alternative # 1). The system locates the windows in the middle of each wall.

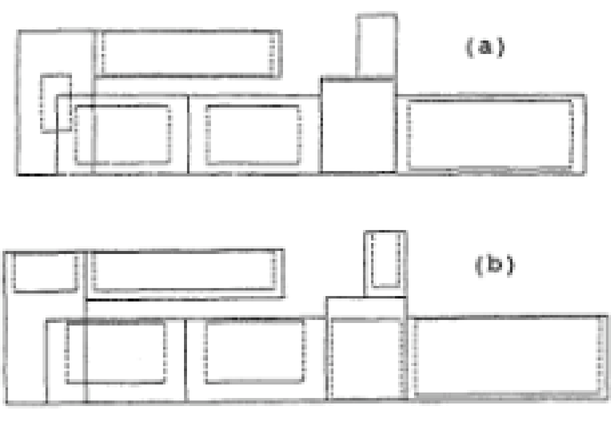


Figure 8. a. The windows on Southern elevation as proposed by the system. The designer can now change the locations of windows very easily. **b.** The windows on Southern elevation as were changed by the designer.

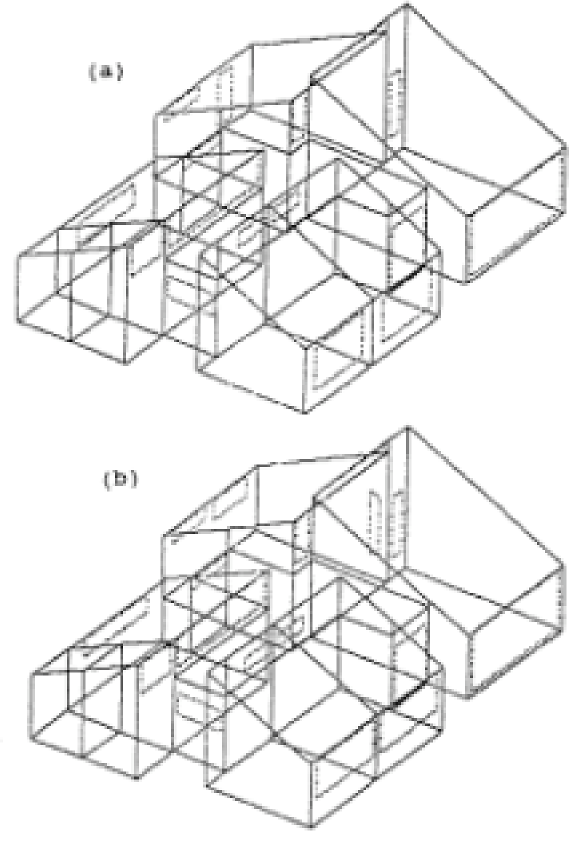


Figure 9. a. An axonometric view of alternative # 2. A new window is added to the Western elevation. **b.** An axonometric view of alternative # 3. A new window is added to the Eastern elevation.

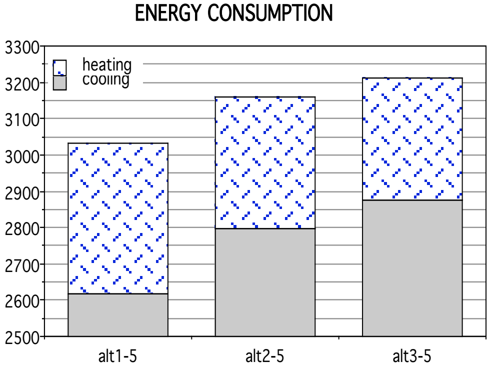


Figure 10. A comparison between the thermal performance of the three proposed building alternatives.

C. Arbitrary Design Parameters. The third category comprises design parameters that do not have a great influence on the energy performance of the building. They, therefore, can be treated as free parameters and may be determined arbitrarily, either by the system as defaults or by the designer. We classify this category of design parameters into two subcategories: design parameters that do not determine the form of the building and those that dictate the shape of it. In the first case, initial values will be given by the system as defaults, while in the second, we prefer to leave the decision to the designer. In both cases, these design parameters can be specified more explicitly in the advanced design stages.

The color of the building's envelope belongs to the first subcategory. It was found in the preliminary study that the color of the wall has a negligible effect on the thermal performance of a well insulated wall and vice versa. So a medium color is assigned first to the well-insulated walls by default (presented in Figure 6 by italic text). Once the design reaches advanced stages, we may decide to change the recommendation for the insulation of walls (which was given as a default). Therefore, at the advance stages, the best color should be reexamined.

The building's proportions belong to the other subcategory. Here again, it was found that this design parameter has little influence on the thermal performance of the well-insulated, medium color building as long as the area of windows on each orientation is kept fixed and the suggested area of windows on the southern elevation can be achieved. In such a case, the authors suggest leaving these design parameters as free parameters. The designer can specify the form of the building according to personal taste and other functional considerations provided the recommended area of windows on the southern elevation is satisfied. The introduction of the free geometrical design parameters is carried out by the three-dimensional module of the KB-CAAD system. The KB-CAAD system interprets this graphical input and creates the numerical data file in the required format for the simulation run. (These free geometrical design parameters are presented in Figure 6 by outlined text). If the orientation of the building changes, the recommended window area is recalculated, and the proportions of the building are rechecked. The system gives a warning if the southern walls do not comply with the suggested southern windows area.

CLIMATIC REPORT - ALT3-5 TEL AVIV

ANNUAL CONSUMPTION (KWH):

Total=3211 Cooling=2875 Heating=336

Inside Temperatures - January (with heater):

ave=19.5 max=22.2 min=17.4

Inside Temperatures - August (with cooler):

ave=25.2 max=27.0 min=24.0

PREDICTING INSIDE TEMPERATURES-AUGUST (Deg-C)

without cooler: **BUILDING IS TOO HOT**

ave=26.9 max=28.0 min=25.5

with fan: **BUILDING IS TOO HOT**

ave=25.9 max=27.4 min=24.1

BEST ORIENTATION IS DUE SOUTH (+-10 Deg)

Figure 11. A short report of the energy performance of the design alternative ALT3-5 (5^{o} west of south)

Summary and Conclusions

We present in this work a new KB-CAAD tool for the schematic design and evaluation of passive solar buildings. The KB-CAAD system is based on an integration of knowledge-based and procedural simulation methods and any available commercial CAAD system for building documentations. The KB-CAAD tool combines the geometric design with solar considerations. This is done by applying a knowledge base that contains the heuristic rules for the design of passive solar buildings. The knowledge base is stored in the computer and provides the basis for guiding the designer through the decision-making process, whenever it is possible to use rules of thumb. Thus, the knowledge base controls some design parameters that should enter the simulation model. Yet, rules of thumb are not adequate to deal with particular projects, which involve deviations from standard designs. Should that be the case, the KB-CAAD system guides the architect by using the procedural simulation model.

The knowledge base was developed from recommendations obtained in a preliminary study performed by running many simulations. This knowledge base has two merits:

a. It saves the results of many simulation runs as rules for standard design cases and complete automatically the missing design information required to evaluate the thermal performance of the building.

b. It saves labor and time during building design and documentation by introducing automatically, based on the heuristic rules and the recommendations from the simulation study, the geometrical and technical data required to present the building in two or three dimensions.

The case study presented here demonstrates the advantages of a knowledge-based design system. It shows that by using the knowledge-based CAAD system, not only can a better solar building be designed, but it takes (based on the case study shown in Figure 12) only about one-tenth of the time to introduce the geometrical data that would be required if only three-dimensional representation and documentation were desired. We believe that future CAAD systems should follow this suggested approach and should include a knowledge base to guide the designer during the different design stages.

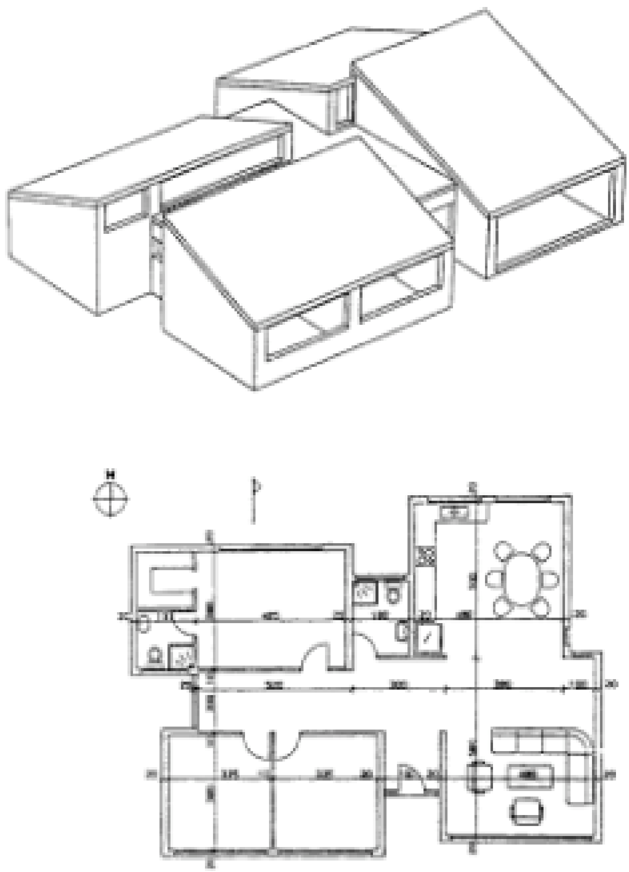


Figure 12. A perspective view and documentation of the passive solar building. The geometrical data base, needed for the 3D model and the 2D drafting system, was automatically built by the knowledge based system.

Acknowledgment

The research was partially supported by Miami Energy Research Fund Grant number 022-470.

References

Antony S. 1987. "ARCADE: Architectural Computer Aided Design Amender." M. Arch. Thesis, School of Architecture and Planning, State University of New York at Buffalo.

ACA ltd. 1989. "ARC+ 3-D Architectural software - User's guide", Israel.

ASHRAE Handbook of Fundamentals.1972, Atlanta, GA..

Arumi F.N. 1979. "DEROB: Dynamic Energy of Building." Numerical Simulation Lab., School of Architecture, University of Texas, Austin, Texas.

Balcomb J.D., R.W.Jones, R.D. McFarland, and W.O.Wray. 1984. "Passive Solar Heating Analysis - A Design Manual," LANL, ASHRAE ISBN 0-910110-38-7, Atlanta, GA.

Beckman W.A., S.A. Klein and J.A. Duffie. 1977. “Solar Heating Design by the F-Chart Method”, Wiley-Interscience. NY.

Bharati J. 1990. "Evaluation of Designs for Energy Performance Using an Expert System", in "Evaluating and Predicting Design Performance" (Y.E. Kalay, ed). John Wiley & Sones, Inc. N.Y.

Brown G.Z. 1990. "Desirable Interface Characteristics of Knowledge-Based Energy Software Used by Architects." ASHRAE Transactions, V. ST-96-2. Atlanta, GA.

Clark J.A. 1982. "ESP: System Documentation Set", ABACUS Publication, University of Strathclyde, UK.

Gero J.S. and R. Coyne. 1984. "The Place of Expert Systems in Architecture," CAD84, Butterworth, Guilford (pp. 529-546). UK.

Kalay Y.E. Swerdloff L.M. and A.C. Harfmann. 1987. "A Knowledge-Based Computable Model of Design," Expert Systems in Computer-Aided Design (Gero, ed.), North Holland Publishing Co..

Klein S.A., W.A. Beckman, and J.A. Duffie. 1976. “TRNSYS, A Transient Simulation Program”, ASHRAE Transactions, Vol. 82, Part 1. Atlanta, GA.

LBL and LASL DOE-2 reference manual. 1982. Version 2.1. Lawrence Berkeley Lab. and Los Alamos Scientific Lab.

McFarland R.D. 1978. PASOLE: A General Simulation Program for Passive Solar Energy. Informal Report LA-7433-MS. USA.

Maher M.L. and S.J. Fenves. 1985. "HI-RISE: A Knowledge-Based Expert System for the Preliminary Structural Design of High Rise Buildings," Report No. R-85-146, Department of Civil Engineering, Carnegie Mellon University, Pittsburgh, PA 15213.

Palmiter L., T. Wheeling, and R. Judkoff. 1982. "SERIRES: Solar Energy Research Institute- Residential Energy Simulator" ,SERI Report.

Papamichael K.M., S.E. Selkowitz. 1990. "Modeling the Building Design Process and Expertise." ASHRAE Transactions, V. ST-96-2. Atlanta, GA.

Pikes A. (ed.),1978. Proceeding of the 3rd Int. Conf. and Exhibition on Computers in Engineering and Building Design, Brighton. IPC Science & Techn Press, , England

Pohl J., L. Myers and A. Chapman. 1990. "A knowledge Based System for the Design of Passive Solar Buildings." ASHRAE Transactions, V. ST-96-2. Atlanta, GA.

Schmitt G, 1987. "Expert Systems in Design Abstraction and Evaluation," Computability of Design (Kalay ed.), John Wiley & Sons, New York.

SERI report, 1980. “Analysis Methods for Solar Heating and Cooling Applications - Passive and Active Systems”, SERI/SP-35-232R.

Shaviv E. 1977. "A Model for Predicting Thermal Performance of Buildings and its Use in the Design for Minimal Energy Consumption," The Building Center of Israel Quarterly (in Hebrew) No. 4, (pp. 26-33).

Shaviv E. 1979. "Building Design for Passive Energy Conservation," PARC 79, Berlin, Germany. (pp. 135-144).

Shaviv E. 1989. “The use of simulation models in the schematic design stage for the design of energy conscious buildings.” Proc. of the 2nd European Conf. on Architecture, "Science & Technology at the Service of Architecture," Paris, 1989. Edited by: T.C. Steemers and W.Palz, Kluwer Academic Publishers.

Shaviv E. and I.G. Capeluto. 1990. "The Influence of Geometrical Design Parameters on the Energy Consumption and Thermal Performance of Apartments Buildings-Part 1." Research report no. 0220474. Technion Research & Development Foundation Ltd. Haifa (In Hebrew).

Shaviv E. and I.G. Capeluto. 1991. "The Influence of the Geometrical Design Parameters on the Passive Cooling and Heating of Buildings" Proc. of ISES 1991 SOLAR WORLD CONGRESS, Denver, CO.

Shaviv E. and Y.E. Kalay. 1990. "Combined Procedural & Heuristic Method to Energy Conscious Building Design & Evaluation", in "Evaluating and Predicting Design Performance" (Y.E. Kalay, ed). John Wiley & Sones, Inc. N.Y.

Shaviv, E. and U.J. Peleg. 1989. "The Influence of Geometrical Design Parameters on the Energy Consumption and Thermal Performance of Buildings." Research report no. 0220474. Technion Research & Development Foundation Ltd. Haifa (In Hebrew).

Shaviv E. and U.J. Peleg. 1990. "A knowledge Based System for the Design of Passive Solar Buildings." ASHRAE Transactions, V. ST-96-2. Atlanta, GA.

Shaviv E. and G. Shaviv. 1977. "A Model for Predicting Thermal Performance of Buildings," WP ASDM-8 report, Faculty of Architecture & Town Planning, Technion. Haifa.

Shaviv E. and G. Shaviv. 1978a. "Modelling the Thermal Performance of Buildings," Building & Environment, Vol. 13, Pergamon Press Ltd., England, (pp. 95-108).

Shaviv E. and G. Shaviv. 1978b. "Designing of Buildings for Minimal Energy Consumption," CAD, July, Vol. 10, No. 4, IPC Business Press, England, (pp. 239-247).

Tham K.W., H.S. Lee and J.S. Gero. 1990. "ICAD: An Intelligent Computer-Aided Design Environment" ASHRAE Transactions, V. ST-96-2. Atlanta, GA.

U.S. Army Construction Engineering Research Lab. 1977. "BLAST: Building Loads Analysis and System Thermodynamic Program." AD-A048982/3ST, AD-A048734/8ST. USA