A KB CAAD SYSTEM FOR THE PRE-CONCEPTUAL DESIGN OF BIO-CLIMATIC AND LOW ENERGY BUILDINGS

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This work discusses the structure of knowledge base CAAD systems for the design of solar and low energy buildings, along with the presentation of the different knowledge bases required for such systems. The general discussion is followed by presenting a KB-CAAD system PASYS, that was developed as a tool for determining thermal comfort design strategies in the pre-conceptual design stage. PASYS is based on a knowledge base which stores the existing information concerning thermal comfort rules of thumb and accurate procedural calculations, which facilitates defining thermal comfort design strategies that suite best the local climatic conditions and the specific constrains of the design problem at hand.

1. Introduction

Significant data and knowledge concerning bio-climatic and energy conscious design has been compiled during the last decade. However, the information has not been utilized widely by the designers due to its inaccessibility. When the initial design is based on correct climate- conscious principles, it may guarantee that later design stages will conform with the above principles and save expensive modification. The implication of changes at later design stages may sometimes be a redesign of the entire project. It is vital, therefore, to understand already at the pre-conceptual design stage what are the correct bio-climatic and passive solar design strategies which satisfy the requirements of the local conditions and which enable to achieve thermal comfort conditions, while conserving non renewable energy.

Shaviv and Kalay (1990) suggested that the process of designing energy-conscious buildings can be viewed as a sequence of decisions made at different levels of abstraction, each successive level more detailed and specific than the former one. These levels of abstraction correspond to discrete design stages, which include (Cross, 1977, Jones, 1970, Mitchell, 1977):

a. Briefing: statement of user needs.
b. Pre-conceptual design: feasibility study and determination of detailed program requirements.
c. Conceptual design: exploring different schematic design alternatives that agree with the programmatic requirements. This stage is concerned primarily with geometry and orientations, without considering material compositions.

d.	Preliminary design:	determining material compositions and building details.
e.	Detailed design:	exploring different detailed design alternatives. This stage deals with structure and material composition considerations.
f.	Design documentation:	preparing building documents.

Shaviv and Kalay (1990) proposed a methodology for supporting computationally all stages of an energy-conscious design and evaluation process, by partitioning the design process into discrete stages and identifying the energy-conscious characteristics of each stage. The methodology is based on merging procedural simulation and knowledge-based heuristic methods into one integrated system. The knowledge base contains heuristic rules for the design of passive solar buildings. Whenever possible, the knowledge-base guides the designer through the decision making process. However, if the rules of thumb are not valid for the particular design problem, the system guides the architect by means of the procedural simulation model (Shaviv and Peleg, 1990).

Nevertheless, the heuristics used by expert systems of this kind are formed by generalizations based on average cases. They may be totally inappropriate when applied to a particular, nonstandard case. Also, heuristic methods are suitable for evaluating the expected energy performance of typical design alternatives at the very early design stages but are not suitable for evaluating the actual expected performance of detailed particular design solutions.

Consequently, although procedural and heuristic methods are applicable and useful at particular stages of the design process, neither one can support the entire design stages on its own. Shaviv and Kalay suggested therefore to use through out the different design stages a combined heuristic and procedural methods as is shown in Figure 1. In this paper we further elaborate this approach by presenting the structure and the different elements of such KB-CAAD system.

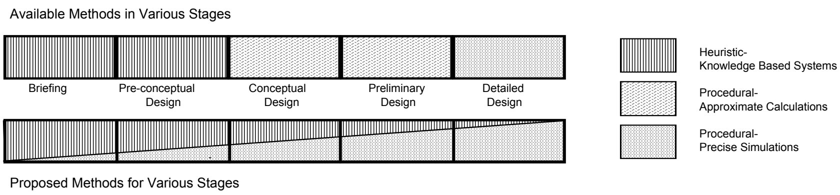


Figure 1: Schematic comparison of available vs. proposed energy evaluation tools in different design stages (from Shaviv and Kalay, 1980).

2. The Design Process

2.1 THE ITERATIVE DESIGN PROCESS

The design process is characterized by being an ill defined problem, which means that while searching for solutions, a better understanding of the goals and constraints might occur. Therefore, we present the design process as an iterative process (see Figure 2). An iterative process allows to advance securely from stage to stage, but at the same time enable the possibility of returning to previous stages. As the design advances, it should acquire a greater level of knowledge and details. However, the availability of the required knowledge at the right time, and specially during the early design stages, may reduce the necessity for too many iterations, or the need to go back to a very early design stages, after an advanced design stage has already been achieved.

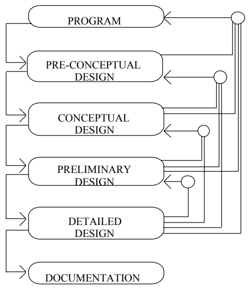


Figure 2: The Iterative Design Process

2.2 THE DESIGN ACTIVITIES

Each design stage, as was presented in figure 1, is composed from four activities (Maver, 1971); analysis, synthesis, appraisal and decision (see figure 3). We shall define these activities as follows:

a. Analysis:	Defining the goals, relations between the design parameters and possible conflicts as well as arranging the random by collected data in a reasonable way.
b. Synthesis:	developing partial and/or full design solutions.
c. Appraisal:	comparing the performance of the solution with predefined goals and constraints, and verify the consistency of the solution.
d. Decision:	choosing the best solution.

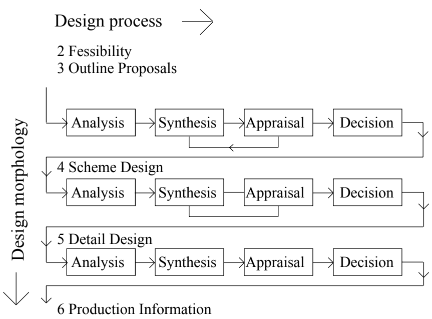


Figure 3: Basic scheme of a design process and its main activities (from Maver, 1971)

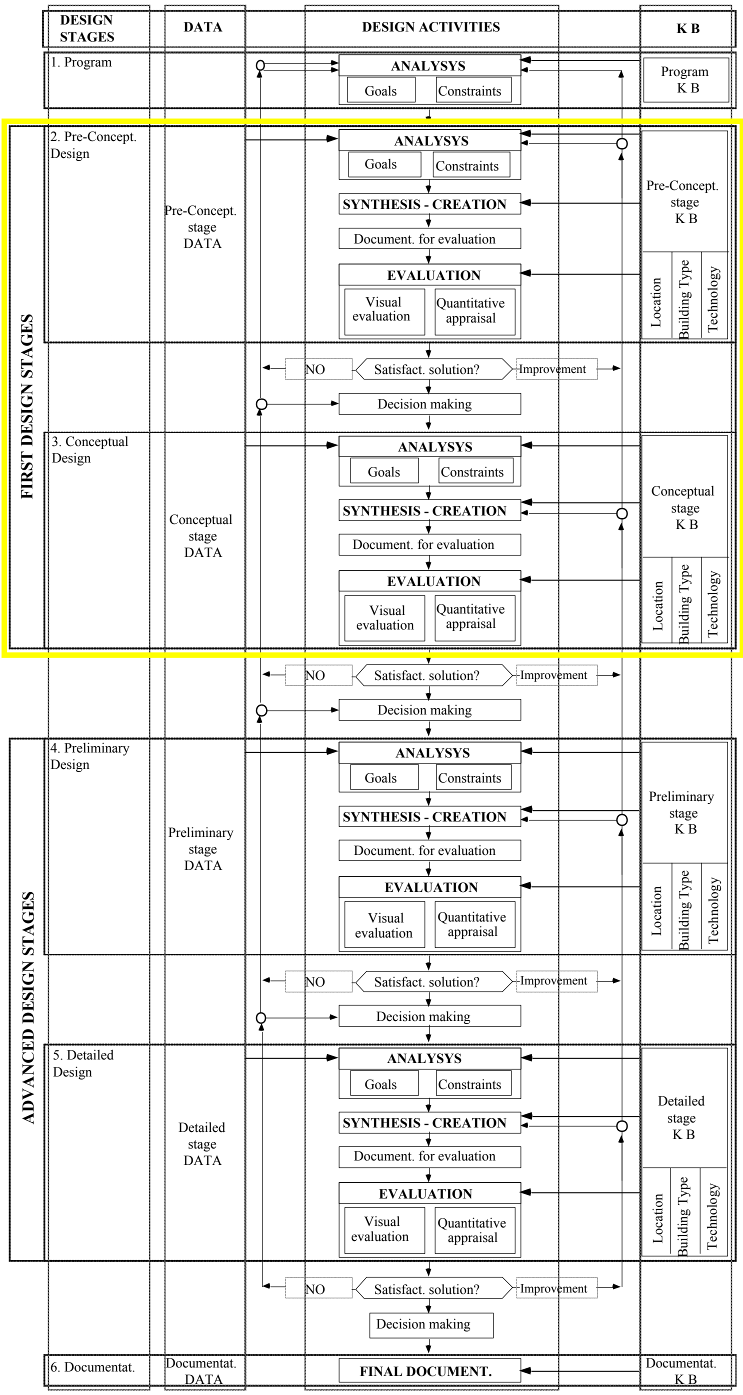


Figure 4: Basic scheme of a design process, main activities, knowledge bases and data

2.3 KB AND THE DESIGN PROCESS

To perform each activity at each design stage, one needs to accumulate the proper data and knowledge. The following question arises: should the data and/or knowledge base be related to the different design stages, or to the different design activities? Through the comprehensive development of a KB-CAAD system for the pre-conceptual and conceptual design stages (Yezioro, 1994), we found that the same data and knowledge bases are required for all activities in each design stage, but different data and knowledge bases are required for each design stage. We have summarized this conclusion in a chart that extend the design process suggested by Maver to include the knowledge bases as part of it (see figure 4).

Let us emphasis the fact that the knowledge, in KB-CAAD systems, should be available at the right time, but only the relevant knowledge should be presented, to avoid confusion due to excessive information. On top of it, the system should identify the level of accuracy required at each design stage. Redundancy in information can be as bad as not giving information at all, as the non energy expert designer might not be able to judge what to choose.

2.4 TYPES OF KB

Knowledge bases can be classified according to three main types (see figure 5):

a. Location:	according to general geographic location (climatic zone) or specific location, for example, Tel Aviv or Jerusalem.
b. Type of building:	according to recommendations for different types of buildings, for example, residential buildings, offices, schools, etc..
c. Technology:	according to the technological possibilities required to realize a solution.

The knowledge bases can also be divided into two types according to:

a. Fixed KB:	there is no need or possibility to change it
b. Dynamic KB:	should be changed according to the specific case.

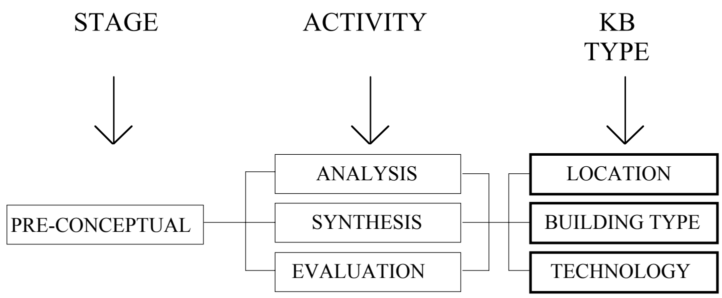


Figure 5: Types of knowledge base

3. PASYS - a Computer Aided Passive Solar Design System

The suggested outlines for the structure of knowledge base CAAD systems described above, is based on a thorough development of a computer-aided Passive Solar Design System (PASYS) that we have carried for the pre-conceptual and conceptual design stages. PASYS enables us to understand the relations between the different elements of the KB-CAAD system, and it serves as a case study.

PASYS behaves as an intelligent expert and is based both on a knowledge base which stores the existing information concerning solar-climatic construction in the form of rules of thumb, and on precise procedural models which enable finding solutions suited for the local climatic conditions. This knowledge can be retrieved and is available upon request. It also stores examples and explanations to allow the designer to better understand the different available design possibilities and in this way leads the designer to the best passive and low energy buildings in given climatic conditions.

The role of PASYS during the pre-conceptual design stage is to analyze the climatic conditions. On the basis of this analysis and the comfort chart, stored as a knowledge base, it suggests all possible combinations of passive design strategies that best fit the given location.

In the second stage, the conceptual design one, the role of PASYS changes and it presents existing passive systems for the summer and winter that comply with the suggested design strategies, as well as different examples of built solutions and principles, including explanations about each system and various heuristic rules to guild the designer. The passive solar systems can be determined on the basis of the required size of south glazing and the actual existing one. PASYS carries out a consistency check of the required passive systems for winter and summer, and recommends only those with components that suit both the cooling and heating requirements.

In each design stage PASYS deals with the various activities: analysis, synthesis, documentation, evaluation and decision making. The system is capable of proposing solutions corresponding with the particular design stage. These solutions take into account the constraints determined both by the designer and by the system itself, owing to the knowledge bases it contains. This work is limited to the presentation of the pre-conceptual design stage only (see figure 6).

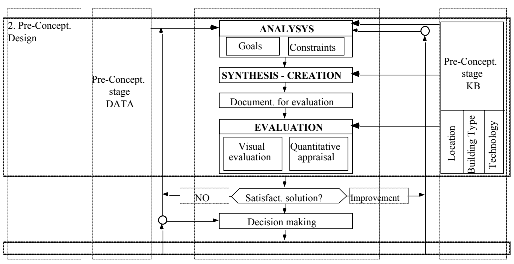


Figure 6: Basic scheme of the main activities in the pre-conceptual design stage

4. PASYS as a Design Tool for the Pre-conceptual Stage

Most Computer-Aided design systems are aimed to serve as evaluative tools at the advanced design stages, after a design solution has already been established by the architect. There are few CAD tools to help the designer in selecting the best suited design strategies at the very early pre-conceptual one. The decision about the preferred design strategies also determines the form of the solution and building and its performance.

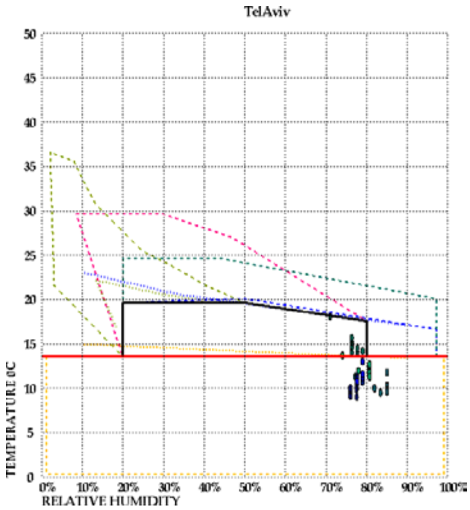
Bio-climatic comfort charts and psychrometric charts have been proposed by different researchers as a method to analyze the local climatic conditions at a given location (Olgyay 1963, Milne and Givoni 1979, Arens et al 1980, Szokolay 1986, ASHRAE 1989). These charts help the designers to find whether the local climatic conditions fall in the range of what is defined as the thermal comfort zone and to find out what passive and low energy design strategies best suite these conditions. We know however, that the thermal comfort depends heavily on the type of clothing (CLO) and level of activity (MET) and therefore, adaptation of the thermal comfort zone and the different passive design strategies zones on these charts should be corrected accordingly (see Fig. 7) . Such a correction is not an easy task, especially if the whole range should be corrected in order to see the complete picture. Additionally, the designer who is not an expert in bio-climatic design, does not always know the kind of constraints he should select for his current problem. Furthermore, such charts include an enormous number of possibilities, and there is no guarantee that the desired climatic design strategy will be selected.

We present here a new KB-CAAD system for determining thermal comfort design strategies that overcomes the difficulties presented above. This system was developed according to the lines describes above. It presents the user with a dynamic and sensitive chart adapted to the level of activity, the type of clothing and defines the suitable constraints for the specific type of building. These adaptations can be performed automatically according to the kind of problem at hand, or as requested by the designer. The system is based on a knowledge base, which stores the existing information concerning thermal comfort rules of thumb, and precise procedural calculations, which enable defining very easily the thermal comfort design strategies that best suite the local climatic conditions and the specific constrains of the design problem.

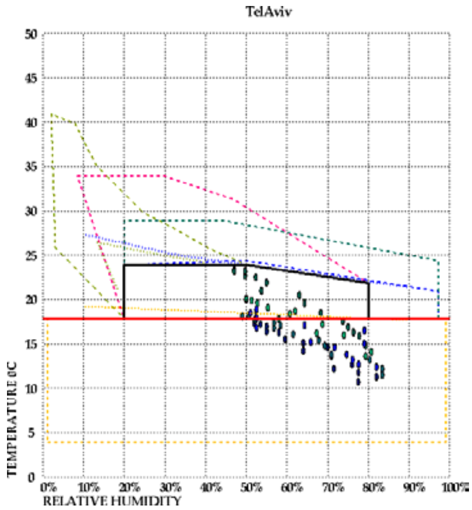
In the process of designing solar and low energy buildings, we can define the activities for the pre-conceptual design stage as follows:

4.1 ANALYSIS

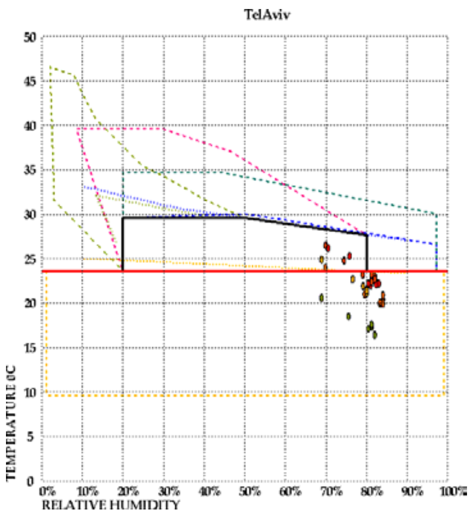
In the pre-conceptual design stage the analysis activity is the most dominant one. At this stage first adaptations between project demands, as is dictated by the program, specific constraints, specific conditions of the location and the available design strategies are taken place. In the analysis activity local climatic conditions are verified and checked against goals in order to establish the proper design principles.



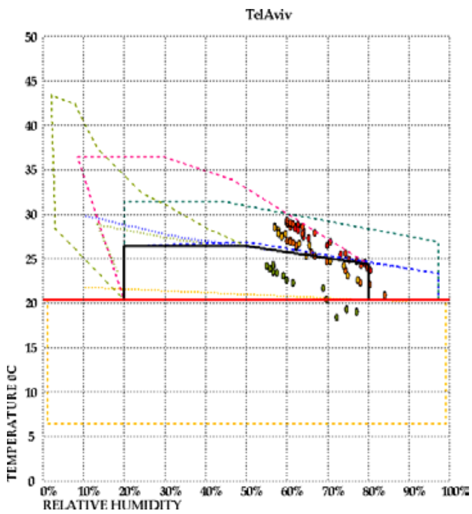
(a) Winter-Night: 3.0 clo 0.8 met



(b) Winter-Day: 1.0 clo 1.6 met



(c) Summer-Night: 0.5 clo 0.8 met



(d) Summer-Day: 0.5 clo 1.6 met

Figure 7. Dynamic bio-climatic chart for residential buildings.

4.1.1 Goals

From the climatic point of view the main goals for this stage are:

(I). To achieve a thermal comfort solution that will require minimal use of non-renewable energy. In other words, to look for energy conscious design solution on one hand, and to use, as far as possible, passive solar and low energy cooling strategies on the other hand.

(II). To reach goal (I) by using minimum thermal comfort design strategies, which means that a smaller diversity passive systems for heating and cooling will be required in the building. Goal (II) will ensure that less different building elements should be added to the building in order to achieve the required thermal comfort, thus obtaining a simpler and more economical solution.

4.1.2 Constraints

The constraints for this stage are: the level of activities, the level of clothing during winter and summer, day and night, as well as the maximum allowed wind, radiation and moisture in the building.

4.1.3 The knowledge base

The pre-conceptual design stage is based on a wide knowledge that presents the designer with the different comfort zones, the thermal comfort design strategies and the reasonable constraints. The knowledge bases can be classified according to three types, presented above, according to the location; like Jerusalem, Tel Aviv etc., building type; like residential buildings, commercial buildings, etc., and technology; like the different passive solar systems: direct heat gains, sunspace etc., or the different passive cooling systems, like thermal mass, night ventilation, natural ventilation radiative cooling, etc..

The knowledge base fixes the appropriate level of activity and type of clothing during day and night, for winter and summer and fixes the appropriate range of values for the different constraints. For instance, if the chosen activity is 'residential', than the system will allow higher wind speed in the room (see Fig. 8) than if the chosen activity would have been 'offices' (see Fig. 9, where the allowed wind speed in summer is only 1 m/s, in order to avoid papers being blown away). Also, it will assign proper values for clothing (CLO) and activities (MET), both for day/night and winter/summer. As for example in residential buildings this values for winter will be 1 CLO for day time and 3.0 CLO for the night, and 1.6 MET for the day and 0.8 MET for night time (see Fig. 8), while in the office building it will consider these values only for day time and these values are 1 CLO, and 1.4 MET (see Fig. 9). Moreover, the knowledge base recommends an appropriate comfort zone. For residential buildings a wider zone is applied (see Fig. 8) based on the chart suggested by Milne and Givoni [1979], while for an office building a narrower one is proposed (see Fig. 9) based on the chart suggested by Arens et al. [1980]. In this way an inexperienced designer has to deal with only few variables, while ensuring the consistency of the solution. All this is achieved just by clicking 'ADVICE ON' on the vertical menu (see Figures. 8 and 9). On the other hand the expert designer can choose 'ADVICE OFF' and examine any design variable by assigning different values to it. Thus he can "feel" the influence of the different design parameters on the space of possible solutions. For example, he can learn that just by dressing more heavily in winter or less in summer, thermal comfort may be achieved without adding mechanical means.

4.1.4 The data

The data required is according to the location, i.e. the local climatic conditions; temperature, relative humidity, wind velocity, etc. and the type of building; residents, office buildings etc..

4.2 SYNTHESIS - CREATING SOLUTIONS FOR PASSIVE COOLING AND HEATING DESIGN STRATEGIES

Since our design tool is a computerized one, it can carry out an hourly analysis of the climatic conditions in any specific location during the whole year. This is done after all the constraints are set up, either by the expert system of PASYS, or by the designer. The analysis is performed with respect to these constraints. The examination of the data consists of calculating the percentage of time during a month, a season, and the whole year, that the point, presenting the hourly climatic condition (temperature and humidity), falls inside the borders of the thermal comfort zone, or any thermal comfort design strategy. In such a case it is added to the total number of times such an event occurred.

4.2.1 Simple Solutions

First "simple" solutions are proposed instantly by the system (see right side of Fig. 8). These simple solutions are composed of only one cooling strategy and one heating strategy. The evaluation of each simple solution is performed and presented graphically and numerically for each month, season and for the whole year.

Each simple solution is represented by four parts as follows:

a. The first part indicates the comfort zone (CZ) i.e. it shows the percentage of time that the points presenting the climatic conditions (temperature and humidity) fall inside the boundaries of the comfort zone.

b. The second part is the passive solar heating strategy (PSH) i.e. the percentage of time that there is a need to provide heating in order to achieve comfort conditions. There is only one heating strategy defined in the thermal comfort charts and it represents in general the requirement for any passive solar system.

c. The third part represents one of the four possible cooling strategies i.e. the percentage of time that there is a need to provide a passive cooling strategy, in order to achieve comfort conditions. The possible cooling strategies are natural ventilation (NV), artificial ventilation (AV) using basically fans and ventilators, high thermal mass with night ventilation (HTM) and evaporative cooling (EC).

d. The fourth part is the amount of time that we need to provide the building with a non-renewable energy in order to achieve thermal comfort conditions. The need for non-renewable energy occurs when the sum of the above three parts is not 100%, otherwise its value is zero.

The overall evaluation for the simple solutions takes on the SGI Indy workstation less than one second. This means that the evaluation of any change that the designer makes on any constraint value or on any design parameter, are presented simultaneously on the screen and can be appreciated by the designer. If the designer is not satisfied with the results of the simple solutions he may ask the system to generate and present him "complex" solutions.

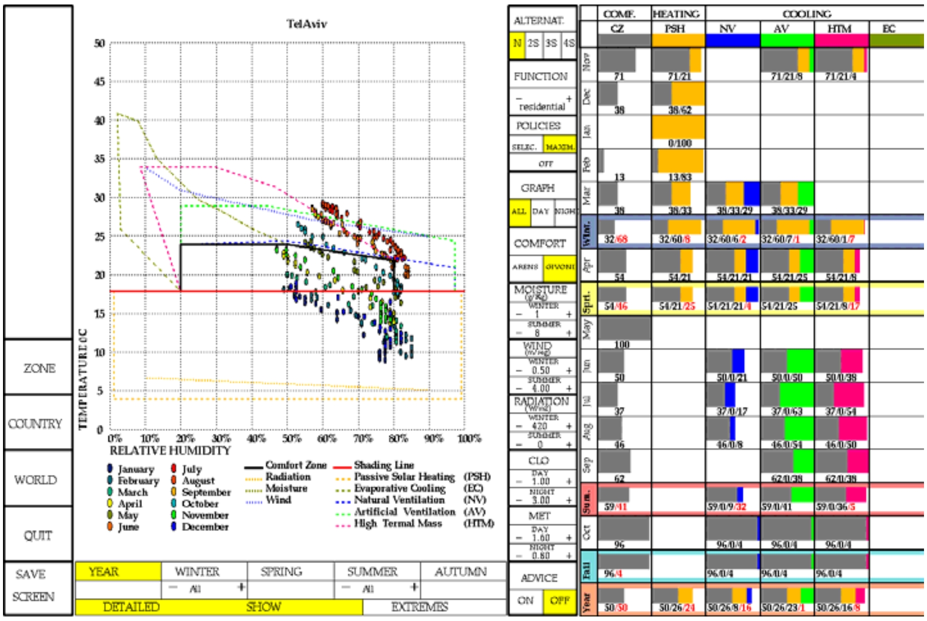


Figure 8. The bio-climatic chart for residential buildings and the space of simple solutions for the thermal comfort design strategies.

4.2.2 Complex Solutions

Contrary to the simple solutions that consist of only one passive cooling design strategy, complex solutions consist of more than one. (See the top part of Fig. 9). Let us mention that the bio-climatic chart includes only one zone that presents passive heating design strategy (without describing specific passive solar system). However, it shows more than one possibility for selecting a passive cooling design strategy. This means that the designer has the freedom to select more than one passive cooling strategy at the same time and that there exist different combinations to achieve a complex solution. When the designer selects 'ADVICE ON', the system takes care that any solution that includes more cooling design strategies than the former created solutions, should be better, in terms of thermal comfort and minimal use of non-renewable energy, than the previous created solutions. Such an evaluation, which is performed automatically while creating new solutions, guarantees that the two main goals presented before are satisfied (i..e. using as much as possible passive solar energy and achieving a low energy solution by using less different building elements). On the other hand the designer can choose the 'ADVICE OFF' option in order to create and examine any possible design solution he wishes to test.

The overall evaluation of two strategies takes less than a second on an SGI Indy workstation. Evaluation of three strategies takes less than five seconds and of four strategies about 10 seconds only. In any case the designer may choose the number of combinations he wants.

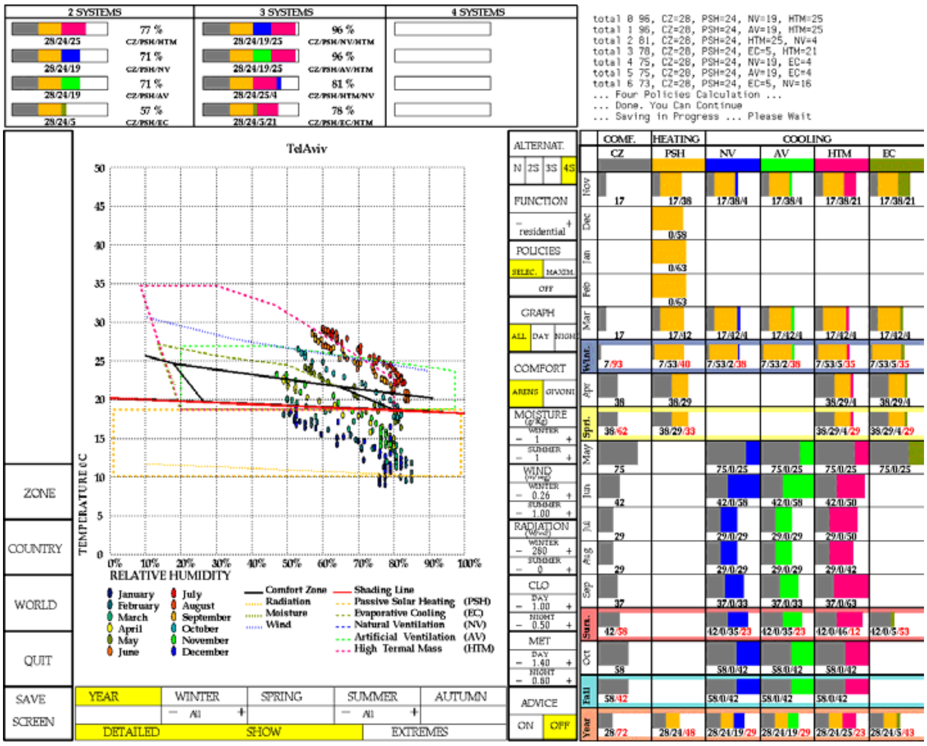


Figure 9. The bio-climatic chart for an office building and the space of simple and complex solutions for the thermal comfort design strategies.

4.3 DOCUMENTATION FOR EVALUATION

In the pre-conceptual design stage the documentation activity is very simple and is presented as schematic graphs (see fig. 9 up). It shows the types of required strategies, the energy saving by each strategy and the required backup system (the white spot). The documentation allows to evaluate quantitatively and visually the different possible solutions.

4.4 EVALUATION

In order to be able to distinguish between the performance of the different design alternatives so that one can make the right decision, it is important to include the evaluation activity in all the design stages including the pre-conceptual one. Such evaluation may prevent the necessity to perform too many iterations throughout the design process as well, although it does not guarantee it. The evaluation is of two types:

a. Visual evaluation. It receives values by means of the senses or feelings. In our case the color and size of the spots in the schematic graph shows visually the potential saving obtained from each strategy and the potential saving obtained from all the strategies acting together.

b. Quantitative evaluation. The solution is graded by means of calculations or measurements. In our case the amount of non-renewable energy consumption needed in order to achieve thermal comfort conditions is calculated as well and shown for each design alternative. This value can guide the designer in choosing his/her preferred solution.

4.5 DECISION MAKING

In this activity the designer examines the different available alternatives for selecting passive design strategies in order to choose the one that best fits the problem in hand. The complex solutions presented on the top part of the screen (see Fig. 9 up) turn to be an active menu where the designer may choose any of these solutions as the preferred one just by pointing at it. The preferred solution will be evaluated more thoroughly in the next step, which is the conceptual design stage and in which the exact passive solar systems and their preferred size are determined. The description of choosing the best passive heating system, which is not embedded directly in the bio-climatic chart, is out of the scope of this paper and will be presented elsewhere.

In order to maintain the flow of the process and allow the iteration design process, the active menu, which is composed from the complex solutions, created in the pre-conceptual stage, remains throughout the whole design process. This active menu, allows the designer, should it become necessary, return and choose different complex solution for farther development.

5. Summary and Conclusions

In this work general outlines for structuring KB-CAAD systems are presented along with an example of developing a KB-CAAD system (PASYS) for the design of solar and low energy buildings. The system is very heavily in use by the students in the faculty of architecture and town planing. It allows them to understand better how to design energy conscious buildings in the different locations in Israel and the entire world, without the need to really be in the location of the project (like the situations in international competitions). Even us, the expert in the field, found the system very helpful and we use it in all our consulting jobs. On top of it, we use this KB-CAAD system as researcher, by running it for the different locations in Israel, with the aim to establish design guidelines for selecting the best design strategies in different locations in Israel (Shaviv, Capeluto and Yezioro, 1996).

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