Computer Modeling & Cooling Strategies

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ABSTRACT. Comfort conditions in a warm/hot environment can be achieved by means of several cooling strategies ranging from the obvious sun shading to the less obvious radiant cooling. These strategies are identified and three selected computer models are evaluated in terms of their capability to cope with them. The result is that the most popular or sophisticated computer models available are not able to deal with passive cooling. Also the problem of is the interface between currently available computer models and their final users, the architects, is analyzed. Results are discouraging, in the sense that a bridging language between thermal analysis and design must be found (a computer model moving in this direction is briefly described: it is a model specialized in cooling issues). The following main needs are identified: i) development of new components for passive cooling; ii) development of new modeling approaches and capabilities; iii) efforts for overcoming the language misfit between analysts and architects.

1. INTRODUCTION

Heating, in the past years, has been the main concern of R & D in energy conservation in buildings and bioclimatic/passive architecture. The reason of this privileged focus may be explained as follows:

- the major emphasis of R & D has been on residential rather than commercial buildings;
- the majority of the countries leading R & D in this area are characterized by temperate/cold climates;

Things now are changing. Electric energy demand for cooling is fast growing both in cold and warm temperate climates, and booming in many developing countries. This trend is emphasized by the synergic effect of both the wide-spreading welfare, promoting a demand of higher standards of comfort, and the tertiarization process of industrialized countries.

Moreover, the architectural trend towards glazed envelopes, started in cold climates, is expanding also into warm temperate areas.

In the past 15 years or so, several tools have been developed for energy analysis in passive buildings but, because of the emphasis on heating, only in few cases they are suitable to passive cooling.

2. TECHNOLOGIES VS. STRATEGIES

Comfort control in a warm/hot environment requires a different approach, than in a cold environment, for the following reasons:

- in winter, outside temperature is always far from comfort conditions; air heating is thus necessary, and technological components able to produce heat, "let the sun in" and "keep the heat in" solve most of the energy problems;

- in summer, most of the times, part of the temperature daily range falls within the comfort conditions, therefore:

  a) it is possible to obtain comfort conditions by playing with many variables, namely air temperature, mean radiant temperature and air relative velocity;
  b) the required temperature difference between inside and outside is relatively small, if compared with winter conditions: most of the energy is thus needed for balancing solar and casual gains and for air humidity condensation.

Because of the above mentioned peculiarities, summer comfort can be achieved not only by air cooling, but also by means of many other techniques or strategies.

3. COOLING STRATEGIES AND DESIGN TOOLS

A taxonomy of cooling strategies is being produced [1] within the Annex XI, *Passive and Hybrid Solar Commercial Buildings*, of the IEA Implementing Agreement on Solar Heating and Cooling. Five different strategies for cooling have been identified, that can be used in combination:

1) <u>Solar radiation control</u>, involving window protection, special glazing, building protection and environmental protection;

2) <u>Heat avoidance</u>, involving reduction of transmission gains, reduction of infiltrations and zoning;

3) <u>Internal gains reduction</u>, involving reduction of lighting and casual gains;

4) <u>Heat extraction</u>, involving ventilation and mechanical cooling;

5) <u>Natural cooling</u>, involving physiological cooling and air, envelope and internal mass cooling.

Natural and hybrid cooling strategies can be handled by means of design options or technological devices or technical solutions or by a combination of all. Shading devices, for example, may be considered at the same time design options and technological devices. In other circumstances techniques and design options must go together, in order to be effective, as in the case of night flushing (high ventilation rate combined with heavy weight walls and partitions).

The large amount of strategies available and their combination makes especially difficult to evaluate which one, or which group of ones, may fit in specific situations that differ for climate, building type and use. Design tools for natural cooling strategies comparison and evaluation of their effectiveness are rare; some of them are simplified calculation methods dealing separately with a few strategies, like solar control by shading devices [2], or natural ventilation [3], or a combination of both introduced in well established methods for insulation and thermal mass effect evaluations [4]. Their reliability is rather limited, but they may be useful at the early stages of the design process, if a skilled thermal engineer is carefully using them, in the appropriate way. In general, no sophisticated (simulation) or simplified method exist dealing comprehensively with cooling strategies.

4. SIMULATION MODELS VS. STRATEGIES

Not only tools entirely capable of coping with cooling strategies do not exist; even models capable of dealing with some technical/technological option deriving from cooling strategies are very rare, unless the option is also useful for heating. On the other hand, it must be pointed out that a model capable of coping with all the technological/technical options coming from all the possible combinations of cooling strategies should be very complex and sophisticated: far more than the most sophisticated model presently available for energy analysis in winter.

This statement is confirmed by table 1, in which the capability of modeling cooling strategies is shown for three selected computer programs. The matrix shows three different levels: i) the model is fully capable to simulate a strategy; ii) it is capable only with some "trick"; iii) it is not able at all.

The computer models, all easily available in the market, have been chosen on the basis of the following parameters:

a) Ranking; ESP, developed in UK, is one of the most complete and reliable simulation programs; it can be considered as a sort of reference computer model within CEC activity in energy conservation in buildings; it runs on VAX, SUN-3 or White Chapel.

b) Popularity; SUNCODE, developed in USA, is well known also in Europe, where some upgrade has been made. SUNCODE has been especially designed for passive buildings energy analysis and it has been extensively used in simulation exercises within IEA research activities; it runs on PCs.

c) Specialization; OASIS, developed in France, is a simulation model especially conceived for coping with cooling issues, in both hot dry and hot humid climates; it runs on PCs.

Many other computer models have been developed, that could have been included in the list, from TRYNSYS to DEROBE, from DOE-2 to BLAST, etc., but an exhaustive analysis was not our aim. For our purposes, the three programs examined are sufficiently representative of the universe of the existing ones, as far as cooling issues are concerned.

The table shows that all the programs examined are designed to cope with permanent window protection, special glazing, external surface characteristics, thermal insulation, thermal inertia, zoning, internal gains and mechanical ventilation; in other words all of them are able to simulate a conventionally air conditioned building (SUNCODE gives only sensible heat loads: no cooling system can be simulated).

With ESP is possible to extend to summer conditions the use of the sophisticated routine able to simulate natural air movements in the building, that was mainly conceived for the analysis of cold air infiltrations in winter and of air transfer from warmer to colder zones. ESP is also the only one that explicitly gives the option of taking into account shadowing due to external obstructions (other buildings, trees, etc.).

OASIS, instead, is the only program, among the ones here examined, capable of simulating physiological cooling obtained by means of cold ceiling and walls, and evaporative cooling systems; in common with ESP it has the feature of simulating night radiative cooling and ventilated air gaps.

In SUNCODE a global surface coefficient is used, not split into convective and radiative as in ESP and OASIS. For this reason the program is not suitable for simulation of many cooling strategies. This is true for

Table 1. - Selected Models' Capability to Simulate Cooling Strategies

STRATEGY **SIMULATION MODEL**

LEGEND

■ Fully capable; ▒ Capable with some "trick"

NA: Not applicable; Blank: Not capable

STRATEGY	ESP	SUNCODE	OASIS
Solar Radiation Control			
Window protection			
Movable devices	■		
Permanent devices	■	■	■
Special glazing	■	■	■
Building protection			
Building orientation	■	■	■
Earth protection	▒	▒	▒
Outside vegetation protection			
Environment protection	NA	NA	NA
Heat avoidance			
Reduction of transmission gains			
External surfaces treatment	■	■	■
Insulation	■	■	■
Thermal inertia	■	■	■
Reduction of infiltrations	■	■	
Hierarchical layout of spaces	■	■	■
Internal Gains Reduction			
Reduction of lighting gains	■	■	■
Reduction of casual gains	■	■	■

Table 1. - Continued

STRATEGY **SIMULATION MODEL**

LEGEND

■ Fully capable; ▒ Capable with some "trick"

NA: Not applicable; Blank: Not capable

STRATEGY	ESP	SUNCODE	OASIS
Heat Extraction			
Natural ventilation (open windows)			
Temperature gradient effect	■		
Wind pressure effect	■		
Mechanical cooling			
HVAC systems	■		■
Night flushing	■	■	■
Natural cooling			
Physiological cooling			
Cross ventilation	■		
Radiant cooling			■
Air movement	▒		
Air cooling			
Evaporative cooling			■
Underground air ducts			
Envelope cooling			
Night-time radiative cooling	■		■
Convective cooling (ventil. air gap)	■	▒	■
Internal mass cooling			
Solar chimneys			

all those models in which, because of the surface coefficient calculation, accurate evaluation of surfaces temperature is not possible.

Routines for comfort evaluation are available both in ESP and in OASIS, not in SUNCODE.

Environment protection strategy is not applicable to present generation of computer models for buildings energy analysis: actually it cannot be considered part of a computer model for building design; it refers to outside climate control by means of specific technologies or techniques; on the other hand, outside environment natural cooling, of course, affects building's conditions.

5. LANGUAGE MISFIT BETWEEN PHYSICS AND ARCHITECTURE

Passive cooling implies a new order of boundary conditions on architectural design, by affecting both lay-out and building materials. These new boundary conditions must be embodied into the design process, in terms of new principles, their application (strategies) and new tools. New principles and new tools cannot be separated: if the new principles (the ones of bioclimatic architecture) are not included into the design process, tools are useless and — vice-versa — without appropriate tools, principles cannot be applied.

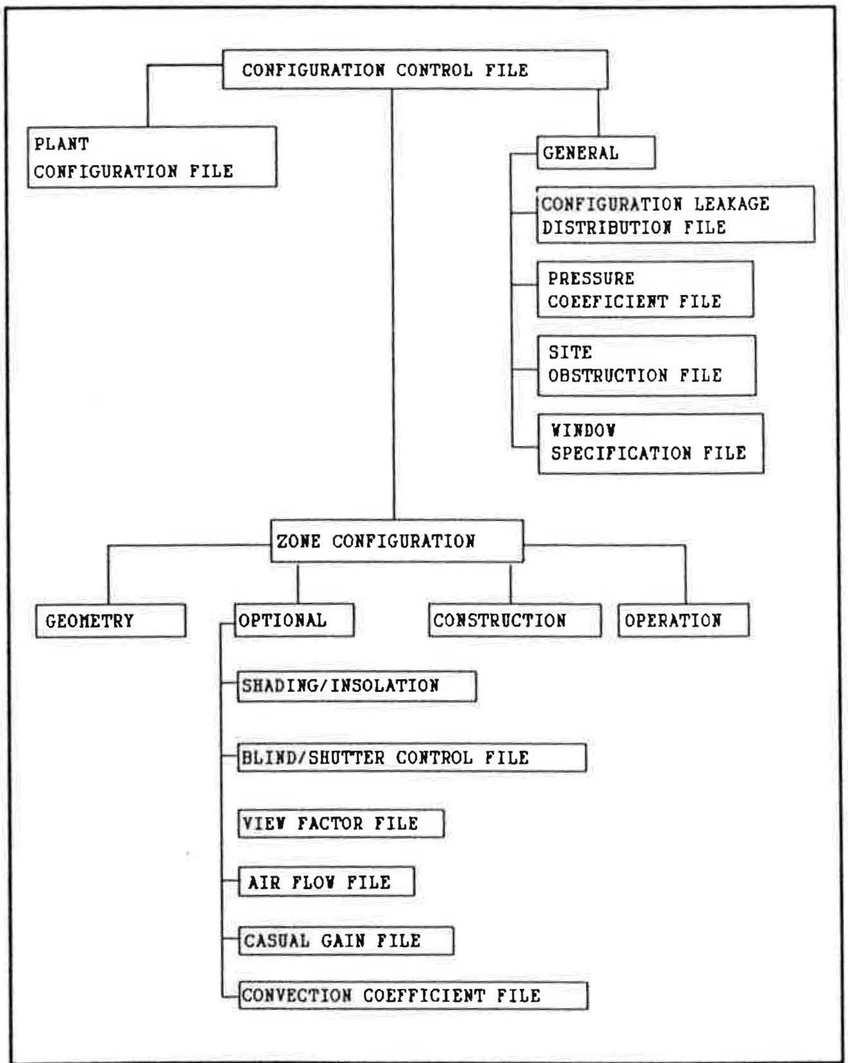

Fig. 1 - ESP Input Files

Actually, the interaction principles/tools is even more complex than that, otherwise it could not be explained the poor effectiveness of the efforts made in the last 10-15 years in the diffusion of either simple or sophisticated design tools for bioclimatic (heating) buildings design: in spite of the tools availability and of the apparent acceptation of the principles, only very few architects have used them. Why?

In order to give an answer to this question, let's have a look to the I/O structure of the programs examined.

Fig. 1 shows a simplified flow chart of the input structure of ESP. The amount of information required

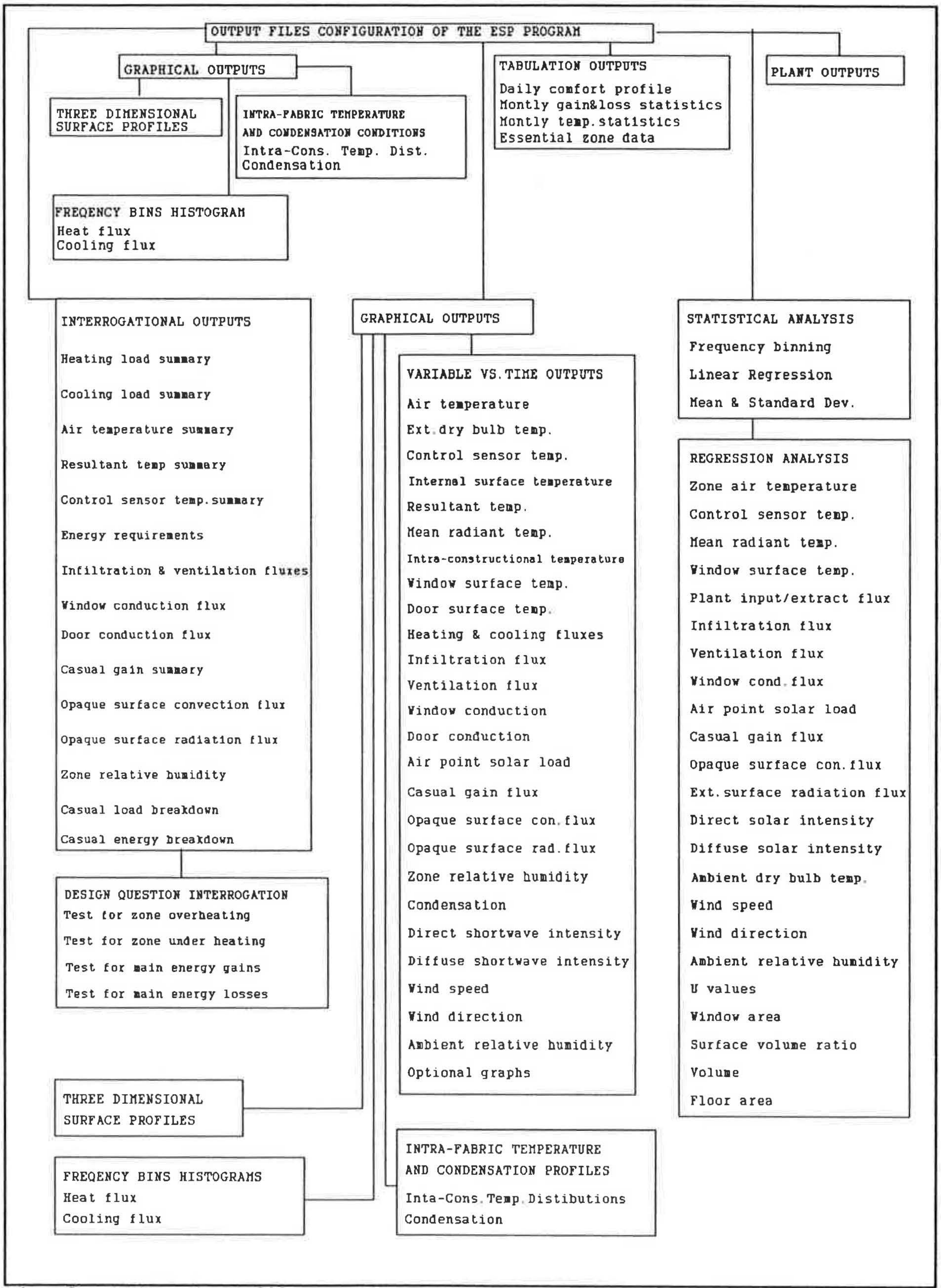

Fig. 2 - ESP output files

is huge, in order to manage all the options that the program offers and the level of detail of the analysis. ESP appears as a program written by experts in thermal engineering for experts in thermal engineering. The amount and the kind and the precision of the information required is never available at the early stages of the design process (when the most important decisions are taken) and hardly available during the design process. The program appears designed more for checking the behaviour of an already designed building than as an assistant in the design process.

In Fig. 2 the flow chart of the structure of the output of ESP is shown. The amount and detail of information available is terrific: any thermal engineering is made happy, but any architect is strongly discouraged.

SUNCODE's input and output structure is very similar to that of ESP, except that less information is required. This is paid with a lower amount and precision of the information obtainable as output and with a lower amount of options that the program is capable of dealing with. Conceptually no difference with the majestic ESP; only, the less you give, the less you get.

Different, and going towards a different direction, appears the I/O structure of OASIS. The leading idea of the input structure is that an architect with little training in thermal engineering should be able to dialogue interactively with the computer, and that simulation results should be easy to understand. Also, behind the program's structure there is a design methodological approach based on a step by step converging process: at each step more details are added; i.e. at the early stages only essential information is required, both on building's characteristics and on cooling system to be used. Later, when most of the decisions are taken, more detailed descriptions are required. In order to achieve this result, the program is structured as shown in Fig. 3. The user is asked to choose, in a library of pre-existing building types, the building that is more similar to the one he is going to design. Starting from this base case, and by browsing in other libraries of wall and glazing types, in libraries of occupancy schedules and cooling systems types and in the climate library, a new (or a set of new) building(s) is defined and run. Each new building type goes to enrich -if wanted- the buildings' library.

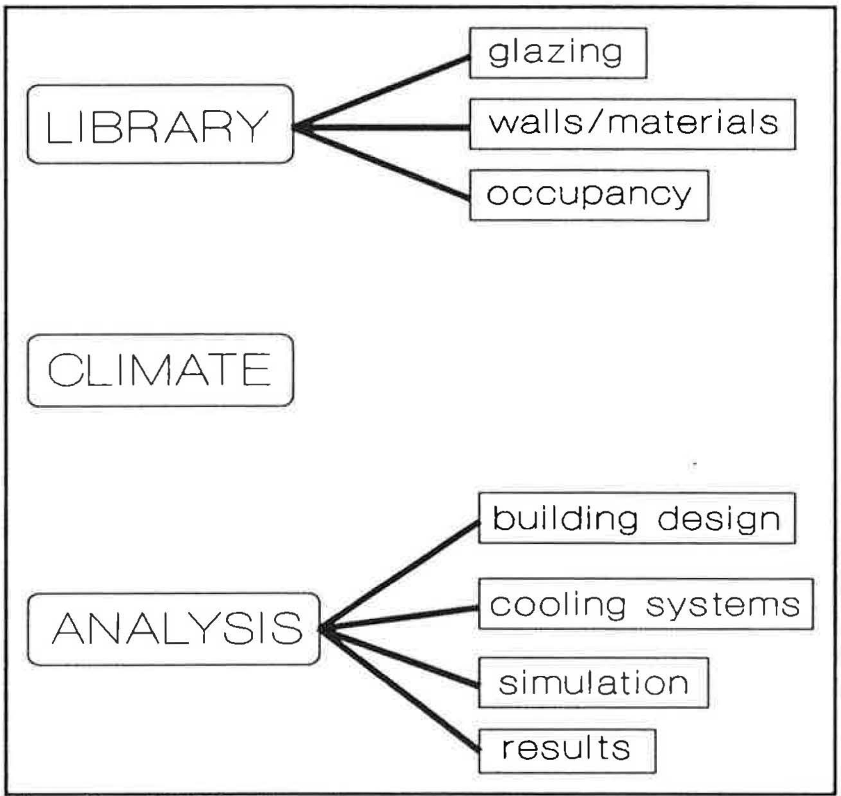

Fig. 3 - OASIS structure

Input data referring to climate, occupancy rate, glazing properties, are available also under graphical form, in order to let the user have a "feel" of them.

Output is a bunch of selected information also mainly given in graphical form, with the aim to describe the most significant performances of the building and how they are affected by the design options chosen.

Further efforts in this direction, i.e. in the direction of developing design tools tailored on designers, not on thermal engineers, are being made in several research centres all over the world. In Italy, National Research Council is currently funding a research (carried on at the Dipartimento di Energetica e Applicazioni di Fisica of the University of Palermo) whose aim is the development of an expert system as "Assistant for Environment Conscious Design" specialized in cooling issues.

The underlying ambition of this research is to be able to create a bridge, in terms both of language and conceptual framework, between architects and thermal engineers in the specific field in which they interact.

In summer 1989, a multisciplinary research group has been set up, made of thermal engineers, computer analysts, architects and an expert in computer aided learning.

The first stage of the research has been subdivided into two parallel actions:

1. develop an expert system able to navigate in the world of the thermal analysis and lighting, and to evaluate proposed design solutions, in terms of comfort and economic analysis; the aim is that this part of the final tool will be completely hidden to the user, unless explicitly requested to have it in foreground;
2. define the specifications of the interface between the above mentioned expert system and the architect.

The first stage, that may appear somehow "conventional", is very critical in itself and in its interactions with the second, being the "motor" of the technical/economical evaluation.

The second is actually more open to innovation and, therefore, to errors.

The main question we put to ourselves was: what we expect that the "assistant" should be able to do? We answered, on the basis of a previously developed conceptual framework [5], by defining the following specifications:

A) The "assistant" should be not only a powerful design tool, but — before and besides that — a powerful teaching/training tool. For this reason we choose a man-machine interface approach based on a strategies' classification referred to well known, famous (we call them "archetypal") architectural examples.
B) It should be able to avoid, or at least minimize, the "confirmation effect" that could derive from conceptually repetitive optimized design solutions proposed by the tool.
C) It should be able to be continuously adjourned as a rationalized and finalized file of new components, architectural examples, etc.

At present a preliminary, simplified, prototype of the expert system has been developed in PROLOG, able to make easier the initial choices of the design process, in terms of walls and glazing characteristics; the ES is designed for an user with a low skill in thermal analysis. A feature embodied in the prototype, that will be retained in the final product, is the possibility to interact with the tool even if the user gives very vague information (may be because at that stage of the design process the requested data are not available).

A data base and some simplified calculation methods for energy analysis and lighting are also being introduced.

6. CONCLUSIONS AND RECOMMENDATIONS

Very few and limited tools are available for dealing with cooling issues, and without appropriate means little can be done in order to face the present fast growing trend for electricity consumption for cooling.

It is necessary put resources in the development of tools able not only to simulate -with flexibility- all the possible strategies and their combinations, but also to eliminate the language gap between energy analysts and architects. Of course not only physicist have to learn architect's language; also architects should learn some of the physicists' language (this is a problem, to be faced and solved at european scale, of the university curriculum of architects).

Four main needs were identified arise from the analysis of the state of art in design tools for warm/hot environmental conditions:

a) need for new components (or new use of old components) development, testing and diffusion; an example is the combination of radiant ceilings and fans;
b) need for development and validation of routines able to simulate cooling strategies (for the short term);
c) need for a different structure of simulation models; models presently available are based on an old fashioned structure deriving from the programming languages used and the mentality of their users (one problem, one solution). Approaches like object programming, and A.I. languages combination should be used;
d) a deeper knowledge of the design process should be embodied in the computer tools, in order to face the "language misfit".

In synthesis, for appropriate passive cooling design, a new generation of design tools should be developed by multidisciplinary teams including, besides thermal engineers and computer analysts, also experts in AI, in communication sciences and architects: a new exciting scientific effort for a holistic approach to a holistic problem.

7. REFERENCES

[1] The group dealing with natural cooling in the Annex includes three countries: Belgium (A. De Herde), Italy (F. Butera) and Spain (J. Lopez de Asiain)

[2] *CEC Passive Solar Handbook*

[3] S. Alessandro, G. Silvestrini, 'Algorithms and Design Tools for Natural Ventilation Cooling of Buildings', proc. of International Congress on "Energy, Environment and Technological Innovation, Caracas, 22-26 oct. 1989

[4] F. M. Butera, 'Energy conscious building design', in: H. P. Garg et al. (eds.), *Physics and Technology of Solar Energy*, Vol. 1, 241-318. D. Reidel Publishing Company, 1987

[5] F. M. Butera, 'Conflicts between Physics and Architecture in Solar Systems Optimization', proc. Intl. Conf. Science and Technology at Service of Architecture, Paris, dec. 1989