S E T I S : an Intelligent System for Building Thermal Design

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ABSTRACT

SETIS is aiming at building a computer support for building thermal design. It deals both with the envelop of building and with its HVAC system. This project is managed by OCGR, a french civil engineering office, and a laboratory of Institut National des Sciences Appliquées de LYON. This collaboration is very important because SETIS is defined as a tool that integrates both algorithmic programs and knowledge based parts. Calculating tools and knowledge bases triggered by the inference engine of Nexpert Object, have been built. They both work on the same database where a thermal description of the building to design is stored. The algorithmic tools let the user reckon U-value of walls or simulate thermal behavior of the building. The knowledge bases make data input easier : SETIS is thus available since the initial state of design. They select HVAC principles too. Then, each airconditioning system can be evaluated on ten thermal, technical or economical criteria.

The following stages of this project are double: install SETIS in OCGR and INSA, and build a supervisor, that is a knowledge base which suggests modifications or actions to the designer.

INTRODUCTION

A short study of softwares the engineer in charge of thermal science can use, brings two main remarks.

First, softwares already available often split the building thermal design in the study of the building (walls, roof, insulation, glazing...) and the study of the HVAC systems.

Second, the main part of these softwares is devoted to a calculating and quantitative study. This way is very restrictive in the whole place of the design process.

So, the purpose of SETIS is to break these two points. The aim of this project is to develop a complete computer system in Building Thermal Design dealing both with building envelope and HVAC system. SETIS wants to model the design process in integrating standard techniques of computer science and recent tools of Artificial Intelligence (Expert Systems).

This project is managed both by Laboratoire Equipement de l'Habitat - I.N.S.A.(1) and by O.C.G.R. a civil engineering office (2). This coordination becomes meaningful when we take a close look at building design in general, and thermal design in particular. The first part of this paper is devoted to the study of thermal design process. It also draws up the aims SETIS must achieve. Then, we describe the structure of the system and its main algorithmic and knowledge-based parts. At last, a work session example is shown.

I. - ANALYSIS AND MODELLING

Our analysis is divided into two parts : the first one sets the problem in the broad field of building design, and specifies its main characteristic features ; then, a model of thermal building design is built using General System Theory (Bertalanffy 1968). This modelling stage enables us to define clearly our aims.

I.1. - Building design

Each building, because of its shape, its function, its settling and many others factors, is "one of a kind" : thus, it requires a particular design.
-> the object to design is "one of a kind".
-> each building design is specific.

Although the object designed results from a single creative process, design can be considered as an activity made of two interlinked levels of intricacy.

The first one is explained by the fact that a construction requires interventions of many corporate

bodies, knowledges about many technical areas. Looked at from that angle, to study a building is synonymous with giving a solution to interlinked problems : each one corresponds to the point of view of each specialist. The notion of point of view leads to a dialectical paradox : all specialists talk about the same object in looking at it and describing it with different eyes and words.
-> design is a multi-technical process.
-> design is a multi-actor process.

Within the context of multi-actor process, design looks like a continuous conflict solving activity, like a strenuous research of compromises. It follows from this that the design activity is relative. In this way, it is not a multi-criteria optimization process. We can not solve it with the ordinary tools of the Operational Research Methods.

Another problem strengthens this impossibility. The specifications of the object to design and the schedule conditions of the study, are often incomplete and ill-defined in the first stages of building design. So, it is very difficult to set the problem in terms of an use function to maximize.
-> design is not a multi-criteria optimization process.

To examine the particulars of design, answering the question "What does an expert do when he designs ?", leads us to notice that common computer technique, using procedures and algorithms, is not suitable to solve an ill-structured problem (Simon 1974).
-> design can not be modelled by common algorithm.

The second level of complexity is relative to the time dimension of design. It is underlying in the word elaboration included in the development of the object building during the cybernetical cycle "evaluate/compare/modify" (Le Gauffre 1988). The time dimension is also obvious because of the contractual association of studies and time limit. Therefore, design process is submerged in environment that interacts with it.
-> time influences design process.

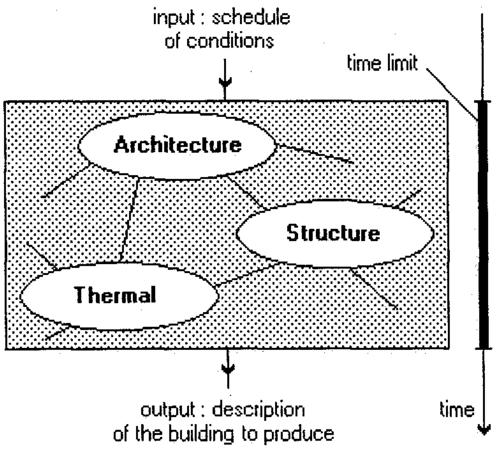

Figure 1 : Design Process in Building Science.

Figure 1 summarizes the main characteristic features of design, we have just set out.

I.2. - Building thermal design

Because it generally takes place at the end of the process, building thermal design is often constrained by choices about architecture or structure. Thus, the engineer in charge of thermal design has to "manage all right"; that means that he has to get the best couple comfort/cost as possible. Doing this way is quiet dangerous because it compromises the consistency of the project, the relevance of the whole building design.

After having restricted our study to its thermal aspect, we use "systemic" tools (Le Moigne 1983) stemming from General System Theory, to model the building thermal design. This model has the following graphical form :

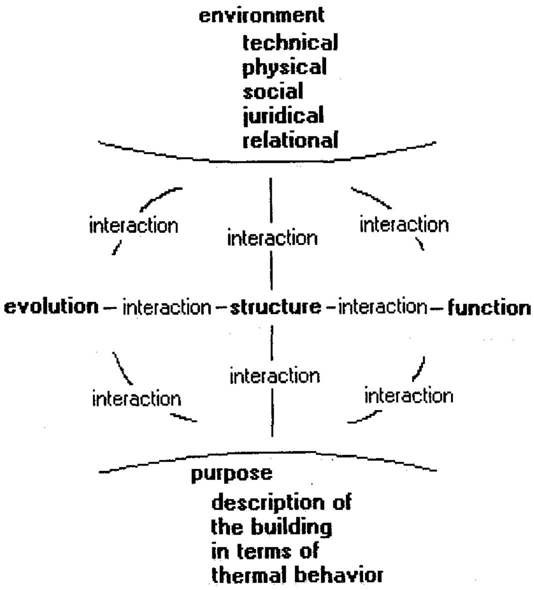

Figure 2 : Building Thermal Design Model.

The purpose, aim and intention of design, consists in describing what is applied to the behavior or the "thermal quality" of the future building. We have focused our study particularly on HVAC systems, without missing the problems linked to the walls of the building.

If an office is in charge of HVAC engineering, the economic factor can let us express the purpose in terms of a suitable solution (quality of design) given in the time limit.

The environment, where the object "building thermal design" takes place, is made of five centers :
- technical center : it groups together building material (concrete, glass wool...), plants of an HVAC system (chiller, fan-coil unit, humidifier...) and tools the designer can use to do his work (sheets of paper,

ruler, computer...).
- physical center : design parameters or "external" data (Miramond 1981), this centre groups together basic informations the designer cannot modify (examples : outside climate, purpose of the building).
- social center : it is made up of the wills of the customers (thermal comfort required).
- juridical center : it is composed of regulations relating to the thermal insulation of the building or to the HVAC system.
- relational center : it provides the consistency of our model with the last section ; thermal design is not studied as a sub-problem weakly interlinked with architecture or structure. Our processes is to focus on a particular technique, not to break up the entire problem, not to hide a part of complexity and fullness of the real problem. For this reason, this center is the linking agent which provides the homogeneity of the study.

The structure of the "building thermal design" system embodies people who work on design, the team of experts in thermal science and project managers.

The word development gives up an explanation for the changing number of people working on the projects.

In reference to a model of human designer, we have got two kinds of functions : modelling functions and negotiation functions. The first ones, purely intellectual, are the capacity of the decision-maker for analysis, his ability to use knowledge and information he perceives, to build a model of the real world. The second ones are the actions the designer can do according to the image of the real world he wants to achieve, to his situation in the relational network of design characters, and to the means available to him.

I.3. - Aims

As a designer must think up the whole building, it is necessary to guide and to evaluate as early as possible the effects of the choices about architecture and structure, on the thermal quality of the future building.

The complexity and imaginative side of design impose on us to focus our attention on the thermal point of view and to define the well-suited tool not as a designer system, but as a system for building thermal design assistance.

The assistance brought to the designer is consistent in the only case the computer system can run in the intial stages of the design process, that is to say, to begin to work with few data. This is the main feature of design : to generate information with few inputs. The main outcome of our computer system is a set of HVAC systems.

II. - SETIS, A SYSTEM FOR BUILDING THERMAL DESIGN SUPPORT

II.1. - Layout

To achieve the aims we have just set, we are going to try to solve each problems relating to our model.

Computer machine haven't got any capacity for imagination; nevertheless, thermal building design activities, like selecting building material (Bourdeau 1987) or choosing HVAC systems to ensure a given level for indoor comfort (Doheny 1986), need knowledge we can not express with algorithms. Our computer system must be able to deal with formalized symbolic knowledge which describe both qualitative and quantitative dimensions of the cognitive space. Added to the stage where the system must be consistent, we recognize the favoured area of expert systems, one of the most efficient development of Artificial Intelligence.

To implement an expert system is one part of the solution we have to bring : we also deal with the numerical side of design. Thus, our system has calcuting tools built on standard algorithms.

When an expert system is reasoning or a program is recknoning, we work on only one object, only one description of the object. The database (see II.2.1) becomes the main part of the system. So the layout of SETIS looks like a blackboard architecture (Hayes-Roth 1971) (Morel 1990).

Furthermore, the efficiency of a computer system is linked to a good user front-end. This part of a system is very important in matter of cognitive ergonomics (Hoc 1990) and C.A.D. (Begg 1984).

The four main parts of our system called SETIS are shown on Figure 3 which describes its structure.

The integration of calculating tools and expert system which collaborate and exchange data describing only one object, which work behind only one user interface, makes SETIS out to be a DSS (Decision Support System) (Levine 1989), aiming at to be integrated in the line of thought of the designer.

II.2. - Main components

II.2.1. - Database

The word database means the set of files describing the building. Open to the different kinds of tools, this set is made of dynamic files and static files.

II.2.1.1. - Dynamic files

These files hold the description of a building, that is to say, all the informations needed during the design of the building walls and its HVAC system. That information is dynamic because its number and its value change during the design process.

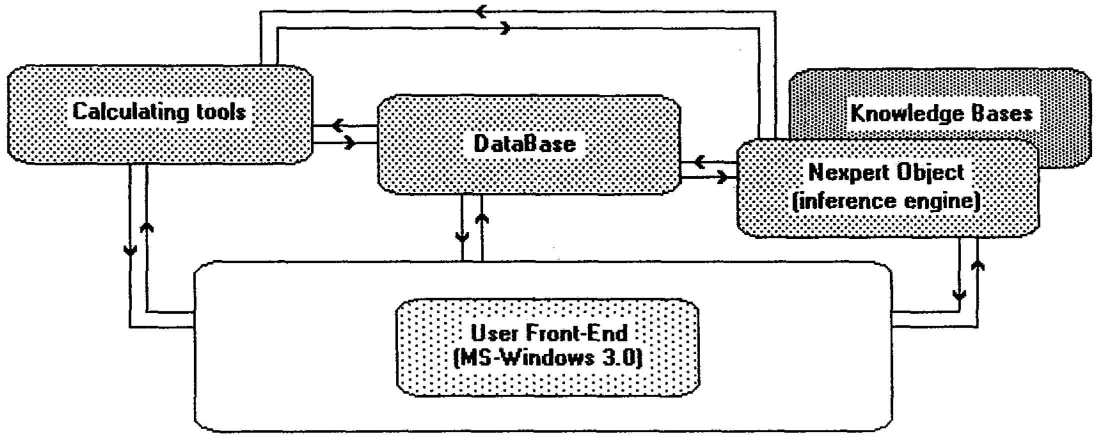

Figure 3 : SETIS Structure.

They are modified either by the designer or by the expert system or calculating tools. Open both to the user and to the system, dynamic files have got a fixed ASCII format.

The description of the building relates to the conceptual and calculating aspects (Björk 1990) of the thermal point of view (Dubois 1989). It also reduces the weight of the topological side (Carrara 1990) : SETIS looks at a building as a set of "blocks", of which the position in the entire volume of the building may be unknown. Consequently, a block is a concept, an artefact, intended to solve as easily as possible the problems of the designer : it takes the physical form of a room, or a group of rooms or the whole building. To do so, a block is defined by its faces in contact with the outside climate or other blocks. All the adjoining blocks are not necessary : for lack of datum, the adjoining blocks are neutral. So, the designer is not imposed to define all the blocks so as to deal with his problem.

As SETIS only selects the layout of HVAC system, the only information stored are the functions ensured by the future HVAC system, the list of the potential principles, and the one choosen among them by the designer after he knows its multi-criteria evaluation.

II.2.1.2. - Static files

This kind of file holds information we can consider time independent. We call DATA, normative knowledge laid down in the regulations, LIBRARIES, traditional description of a block regarding its purpose of use, and DIAGRAMS, set of graphical representation of the HVAC system.

II.2.2. - Knowledge bases

Before setting out the knowledges bases the user can trigger in SETIS, the characteristic features of the expert componant of the system are described.

II.2.2.1. - Expert system technique

Unable to imagine or to create or to reproduce human mecanisms accurately, expert systems allow us only to model some reasoning of an expert, that is to say, to get the same result as the expert.

Building a prototype of the expert component of SETIS, enabled us to choose an expert system generator. Nexpert Object of Neuron Data has been selected. The reasons of our choice are following :
- inference engine based on predicate logic.
- two formalisms for knowledge representation, rules and objects, that make the modelling of the cognitive space very efficient.
- integration with standard relational data bases and spreadsheets.
- SQL-like queries to all kind of database files
- external subroutines written in C-language can be called (you can call execute library that implements list manipulation or multi-values..., or your own functions).
- knowledge bases are supported on many computers, in our case on a MS-DOS micro-computer.

Knowledge acquisition required to build the bases, progresses in an iterative way using interview techniques. From the account given by experts, concepts are found by abstraction, then these concepts make up a model that experts check and test (Grundstein 1990) (Figure 4). At the same time, theorical knowledge has been collected by literature review. After the structuration step, knowledge bases are written.

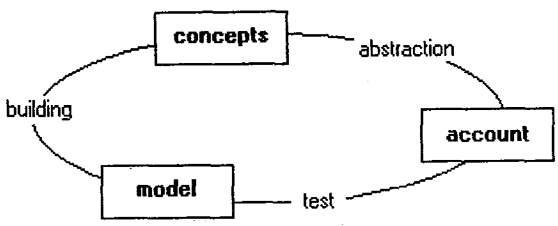

Figure 4 : Iterative Knowledge Acquisition.

II.2.2.2. - Description

Right now, SETIS integrates three knowledge bases.

The first two support the generation of objects fitting the constraints relating to the first stages of the design process. At this step, the designer knows only few data, but wants to trigger calculating tools enable to help him think over his problem. Therefore, each knowledge base helps him to create a building and a block. To do that, ask the user a very little number of data known from the early stage of design (examples : geographic situation, purpose of use of the blocks...), and generate in an expert way the lack of information. This way prevents the user from a boring data input, and ensures the right number of data to use the calculating tools of SETIS.

The third knowledge base selects the principles of HVAC system ; a principle is defined as a layout of functional units. At this step, HVAC system design is supposed to be divided into three weakly connected parts : the choice of principle, the choice of the plants ensuring the functions of the layout, and the choice of the controls of the plants (Camejo 1989). The first part, the only operational one at present, is linked to the functional models of a set of 68 principles. The change from principle to plants will be made in substituting plants for functional unit (it is not necessarily a bijective operation). This step is linked to a structural model, while the choice of controls is related to a behavioral point of view. Using multi-modelling knowledge bases with various aggregation levels is a key to solve the problem of technical system design (Chittaro 1989).

II.2.3. - Calculating tools

SETIS puts a "thermal toolbox" made up of ten tools with different level of complexity, at the disposal of the user. Among the simple ones are unit calculating U-value and capacities of the walls, evaluating the air flow due to infiltration, or generating the meteorological files. We are just going to describe the multicriterion rating unit. Among the complicated ones is the tool for the simulation the thermal and hygrometric behavior of a block.

II.2.3.1. - Thermal and hygrometric simulation

This simulation model is based on the enthalpy balance of a block, divided into its dry part and moisture part. This last one is quite simple, so we focus our attention on the thermal model only. This model is an adaptation from the Codyba code implemented by the Laboratoire Equipement de l'Habitat (Roux 1984) (Brau 1987). In SETIS, it is not aiming at doing exact recknons, but at valuing as fast as possible the effects of choice about architecture, structure of the building or functions of the HVAC system. Our model is built by analogy with electric phenomena and used a finite-difference method to solve a fixed set of 12 linear equations. Furthermore, it split the radiative and convective parts of heat transfer. Thus, this simple model is the right compromise solution for the length and the accurary of the calculating process, and suits both the inertia of the building and the assumptions made for our design problem.

II.2.3.2. - Multi-criteria rating system

This unit allows the user to compare the

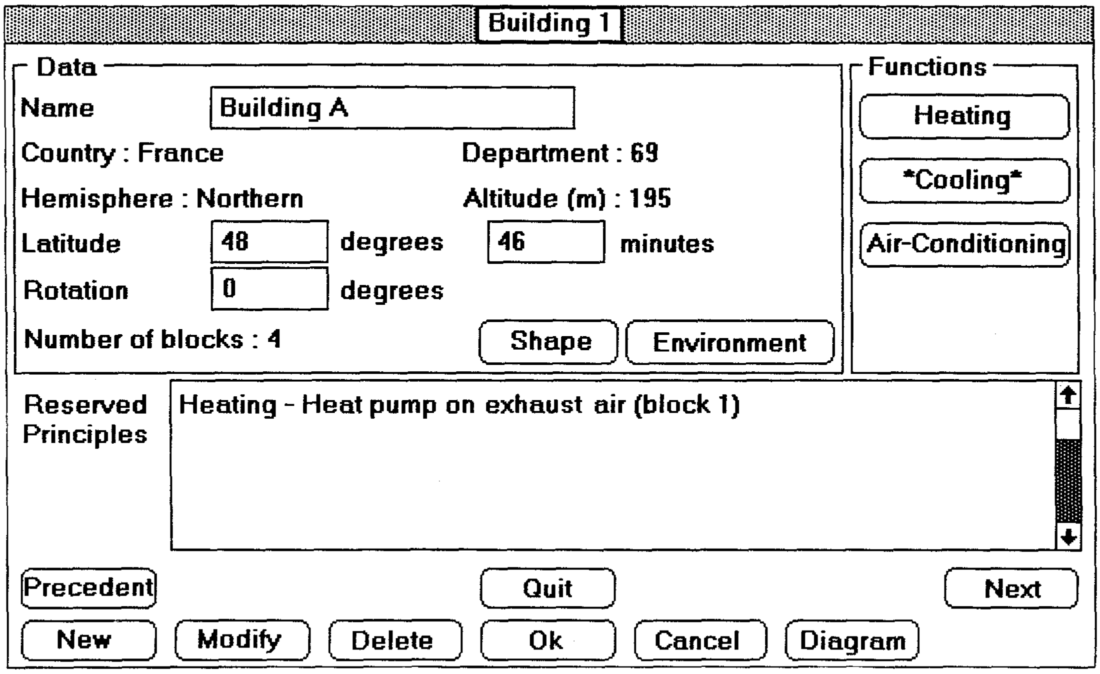

Figure 5 : Building Display.

HVAC principles contained within the set of solutions choosen by the third knowledge base described before (see II.2.2.2.).

This unit deals with the concept of the quality of a HVAC system. To do so, it gives a mark from 0 to 10 for criterion characteristic of the principles. These qualitative marks are given for ten criteria, making a right compromise for detailed information and the first stage of design : thermal comfort, hygrometric comfort, air quality, acoustics, congestion in the block and in the boiler room, technical nature, investment cost, maintenance cost and energy cost. These criteria are not only related to thermal science, but to other point of view like the economic one.

With these marks, the designer can calculate an average value weighed by a set of weights that expresses the main lines of his thought. To give a mark is interesting because of its simplicity to compare the different solutions proposed by SETIS.

II.2.4. - Front-end

Like the previous tools, the front-end is implemented with C-language and uses graphical means of MS-Windows 3.0. The user interface wants to be ergonomical and user-friendly as shown in the following section.

III. - WORK SESSION

This section is devoted to the presentation of an usual work session on SETIS.

Assume that a company wants to build an office in Lyon ; which building materials will make the walls ? which glazing will you use ? which kind of HVAC principles will you have to set ? how will it cost for investment and energy ? will the indoor space be comfortable ?....Now, we are going to answer these questions characteristic of a design problem handled by SETIS.

First of all, we must create the building to study. With three simple data, the country (France), the region or department in France (69 for Lyon) and the altitude of the site where the company wants to build its office (195 meters), SETIS triggers the knowledge base dedicated to this work : it creates all the data describing the building, and among others, the description of its meteorological environment and the usual category of HVAC principles usually required for the comfort conditions in the department. In our case, the category is cooling, that means the HVAC system ought to cool the air. All data generated by SETIS can be modified by the user using the window-screen called Building (Figure 5).

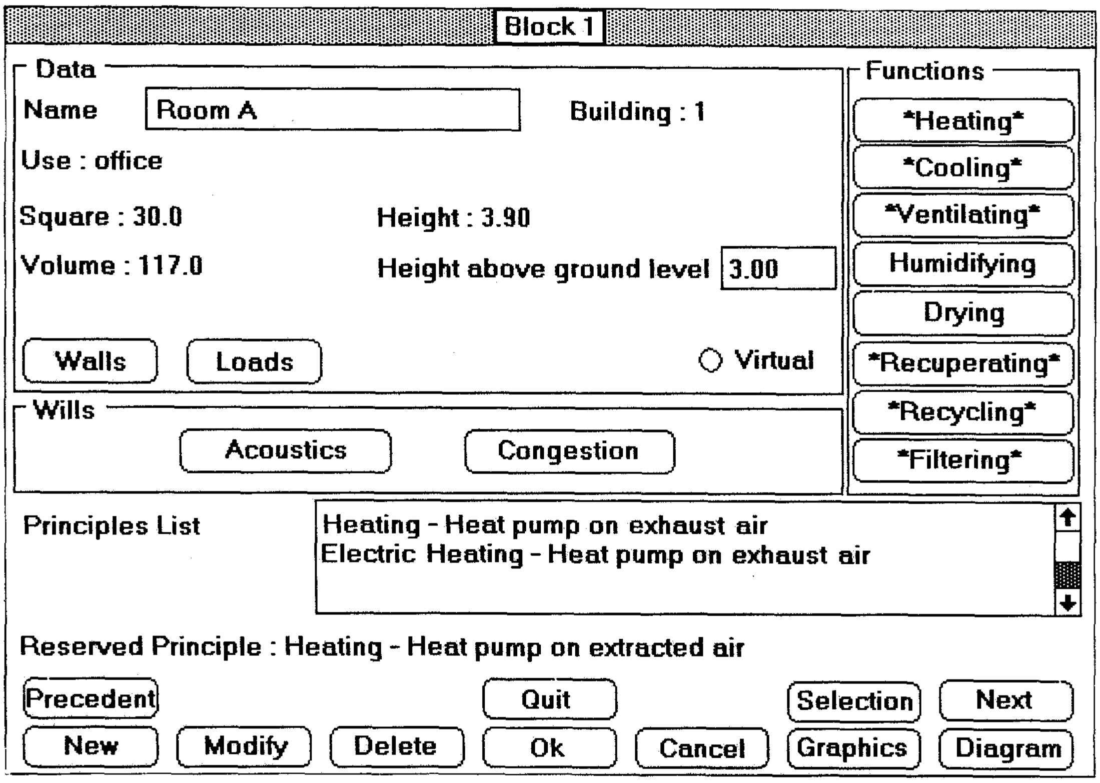

Figure 6 : Block Display.

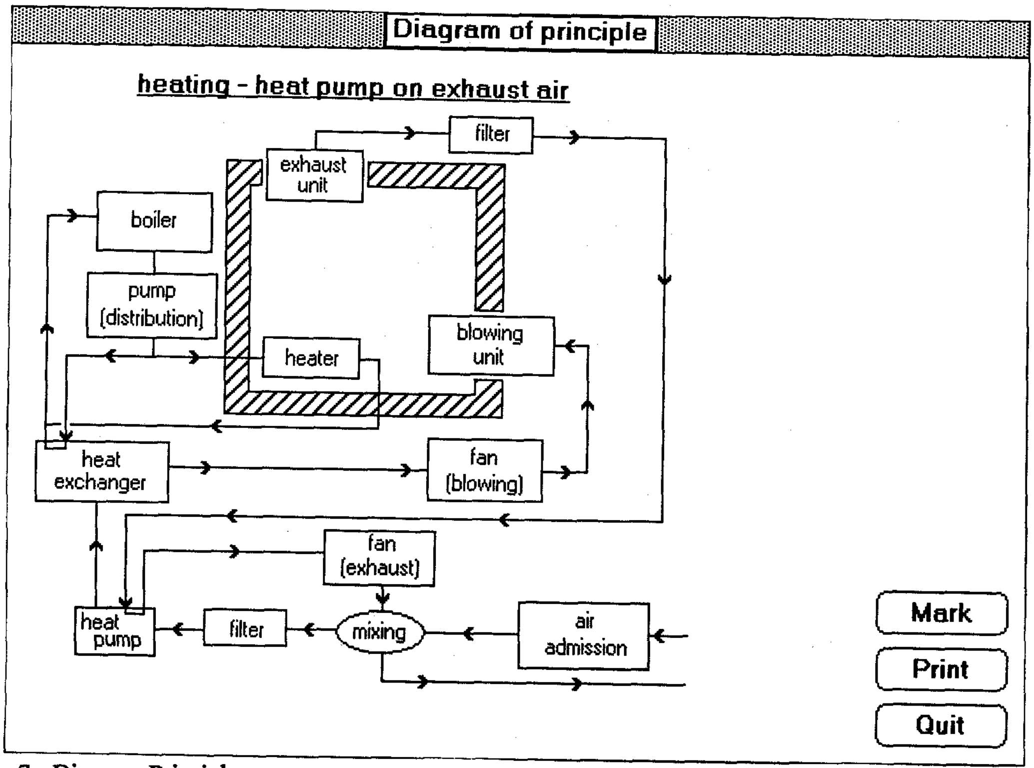

Figure 7 : Diagram Principle.

- Rating System -

Criteria	Weights absolute	Weights relative	Marks on 10 heating oil	Marks on 10 gas
thermal comfort	12	10	3	3
hygrometric comfort	12	10	0	0
air quality	12	10	4	4
acoustics	11	9	6	6
congestion in the block	7	6	9	9
congestion in boiler room	6	5	7	7
technical nature	8	7	7	7
investment cost	20	17	7	7
(in F/m2)			(545)	(545)
maintenance cost	9	8	7	7
(in F/m2/year)			(45)	(45)
energy cost	20	17	7	8
(in F/m2/year)			(16)	(11)
Average Value ->			5.53	5.70

Modify Ok Cancel Quit

Figure 8 : Multi-criteria Evaluation.

Second step, we must create a block in our building. The designer gives SETIS the use of his block (office) and its basic geometrical sizes (square, volume, height). The knowledge base devoted to the block generation creates a detailed structure, a distribution of internal loads and power related to the functions SETIS assumes for the HVAC system (Figure 6). At this stage, the designer can study the walls of his block, the power to put in, and the required temperature : he can use the simulation unit to value the effects of what he imagines. He can particularly check if the cooling function is efficient and evaluate its relevance.

Third step, the last one, the designer triggers the selection of the HVAC principles which fit the choosen functions. In the list of the possible solutions (Figure 6), he makes his final choice : he has graphical information, a diagram of the principle (Figure 7) and alphanumeric information, a spreadsheet for the multi-criteria rating system (Figure 8).

The linear way of this presentation is only formal, since the designer can perform his work using his imagination and the data he already knows. He can take into account a new datum, a new investment budget or performance level at any time.

CONCLUSIONS

This paper describes the building thermal design support system called SETIS available today. It is not only a prototype, but it cannot be called operational, because its knowledge bases are not completely validated yet.

This first version will be developed so as to discard its actual limits relating to the countries and the purposes of use of block for example. The implementation of the stages of equipment and controls selection will be delaied ; our work is now focused on the development of a "supervisor", a knowledge base helping the user to make his choice (modifications proposal), and keeping the building description consistent (actions proposal). The purpose of this research is to provide SETIS with meta-knowledges.

In our long-term plans, SETIS will be connected with standard C.A.D. softwares, in order to achieve its integration in the range of the usual tools of building thermal designers.

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