Conceptos
y fenómenos
fundamentales
de nuestro
tiempo

UNAM

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KNOWLEDGE-BASED SYSTEMS FOR ENERGY CONSERVATION PROGRAMS

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ABSTRACT

Giving the big number of small and medium sized enterprises, it is argued that it would be of great benefit to implement an energy conservation program in this kind of enterprise. This program should focus on design as well as simple maintenance and servicing measures, and should be based on the practical knowledge of energy experts, who would diagnose every case and prescribe the pertinent recommendations.

An economic way to implement this energy saving program would be to capture the corresponding expertise from the human experts into an Expert System. In this paper a selection of three expert systems for energy conservation programs, developed at the Intelligent Systems Laboratory of the National Autonomous University of Mexico is described and its results as means to save energy are discussed.

INTRODUCTION.

During the last decade the rationalization and conservation of energy has been a top issue in the energy planning seminars all over the world. Among the economic sectors, Industry and Services are the most energy intensive ones, bringing good possibilities to implement successfully energy conservation programs, according to the type of industry or service.

These programs should focus in its first stage on simple maintenance and servicing measures, easy to implement but effective to save energy.

These programs should be based on the practical knowledge of energy experts, who would diagnose every case and prescribe the pertinent recommendations, because decision making in this discipline is made taking into account a combination of:

A) Scientific theories and analytic techniques

B) Experimental methods

C) Individual experience and judgment as well as common sense.

This is due to several factors including:

a) Lack of specific information about the problematic systems

b) Uncertainty in the available information about those systems

c) The great diversity of phenomena and variables that affect the behavior of those systems

d) The occurrence of unexpected situations and conditions

e) The complexity of the problems

As a consequence, there is a need to ask the assistance of experts in the energy conservation domains in order to have the proper solution, when a difficult problem is encountered. This means that problems are not going to be solved unless the reservoir of technical knowledge and the expertise of the existent experts are made available in the sites where problems originated.

A way to implement an energy saving program of this kind would be to capture the corresponding expertise from the experts into a computerized knowledge base. This knowledge base would be then the nucleus of a microcomputer consulting program that would be widely distributed among small industries.

Taking this into account, the Intelligent Systems Laboratory of the National Autonomous University of Mexico developed a series of knowledge-based systems for energy conservation programs in small industrial and services enterprises. In this paper the characteristics of three of such developed Expert Systems are presented and their results as means to save energy are discussed. The first Expert System to be described is called EXILCO and was built for lighting systems analysis and design in commercial buildings and hotels, taking into account energy savings criteria. In the second part of this paper an Expert System called ESCAF built for the design and evaluation of energy efficient compressed air facilities in the industry is presented. Finally, in the third part of the paper a tutorial expert system for the training of specialized personnel in cogeneration technology is discussed.

EXILCO: AN EXPERT SYSTEM FOR LIGHTING SYSTEMS ANALYSIS AND DESIGN IN COMMERCIAL BUILDINGS AND HOTELS

The expert system EXILCO is aimed to optimize energy consumption by lighting in commercial buildings and hotels. EXILCO calculates the energy used by a given lighting system according to illumination levels in the different areas of the building and recommends energy saving policies and measures to improve the efficiency of the lighting system. The expert system was developed for the non-expert final user who wants to analyze a particular building illumination system to reduce costs.

Lighting is one of the most important issues in the marketing of any commercial product since it draws customers attention to the merchandise displayed, creating an appealing and inviting atmosphere. In fact, we can induce special desirable moods in the people through different types and arrangements of lights in commercial buildings or hotels. However, in addition to the decorative and psychological attributes of lighting, the energetic efficiency of lighting systems should also be considered. In this sense, experience and technical expertise from human experts are the key factors to obtain good results. However, in developing countries appropriate human experts are scarce, expensive or difficult to get. A way to get around this problem is by building an expert system to assist in the design, installation, operation and maintenance of lighting systems for commercial buildings and hotels all over the country. With this objective in mind, an expert system, named EXILCO was developed at our Intelligent Systems Laboratory, with the technical help of lighting equipment firms and available experts. It has been a valuable tool to provide assistance in efficient energy management of such facilities, including operation and maintenance tasks.

EXILCO can design an energy efficient new system as well as analyze and assess the efficiency of an existing one. In the first case, necessary conditions for an adequate functioning will be provided. In the second case, an energetic analysis will be done to determine if the present functioning conditions are adequate. If it is not the case, the system will provide the recommendations to improve the operation. EXILCO also prescribes measures for an adequate maintenance of the lighting equipment as well as helps on failure detection and its possible solutions.

Design of lighting systems for commercial buildings and hotels

Every time a lighting project is developed, several variables have to be considered and defined such as: the purpose of the installation; the kind of activities to be done under the lighting and finally, the energetic evaluations related with the nature of the building construction and how does it affect the costs of the illumination project.

The energetic evaluations are done by a team of specialists in lighting and electrical installations. They should have sophisticated measuring equipment. Moreover, the team should be permanently at the site, from a couple of days to several weeks depending on the size and complexity of the installation. Some of the activities to be done are following:

-**Information gathering**. The team must have access to blueprints of the installation and do a field recognition at the site. Then they must take luxometer lectures of the working and service areas and verify the reliability and completeness of the collected information

-**Lighting equipment specifications**. Technical specifications about the commercial equipment available should be collected, for instance, lamps ballast, luminaries, reflectors, louvers, etc

-**Actual costs analysis.** It must consider the general characteristics of energy consumption and use, energy cost, diverse costs and additional information like depreciation.

-**Efficiency evaluation.** It must compare actual efficiency against optimal use of energy, considering possible measures for energy savings

-**Definition of improving measures**. They may be for instance installation of new types of lamps, new types of luminaries, use of electronic ballast and addition of light controls.

Estimating illumination levels

Any lighting project must consider the characteristics of the site and the kind of work to be done in such area in order to estimate the recommended illumination levels. Some of the related variables are the spatial dimensions, the wall, ceiling and working surface reflections, the working atmosphere characteristics (humidity, dirt, etc.) and the setting of the minimum levels recommended by construction regulations and lighting handbooks.

The kind and accuracy of the work to be done in every area will provide the illumination level required for such activity. There are several methods to calculate the illumination levels for different site characteristics and equipment.

Energy saving measures

Efficient use of energy is also important in the design. There are several general measures for saving energy in buildings, for instance, to reduce lighting levels, to use daylight and to use more efficient lamps, ballast and equipments.

EXILCO objectives

For the development of EXILCO, we settled following objectives:

-To provide assesorship and support on designing new lighting systems with efficient energy use for commercial buildings and hotels.

-To identify possible measures for energy savings in lighting systems of existing commercial buildings and hotels.

-To evaluate and suggest the use of up-to-date technologies in lighting systems, taking into account their availability and economic feasibility.

EXILCO functions

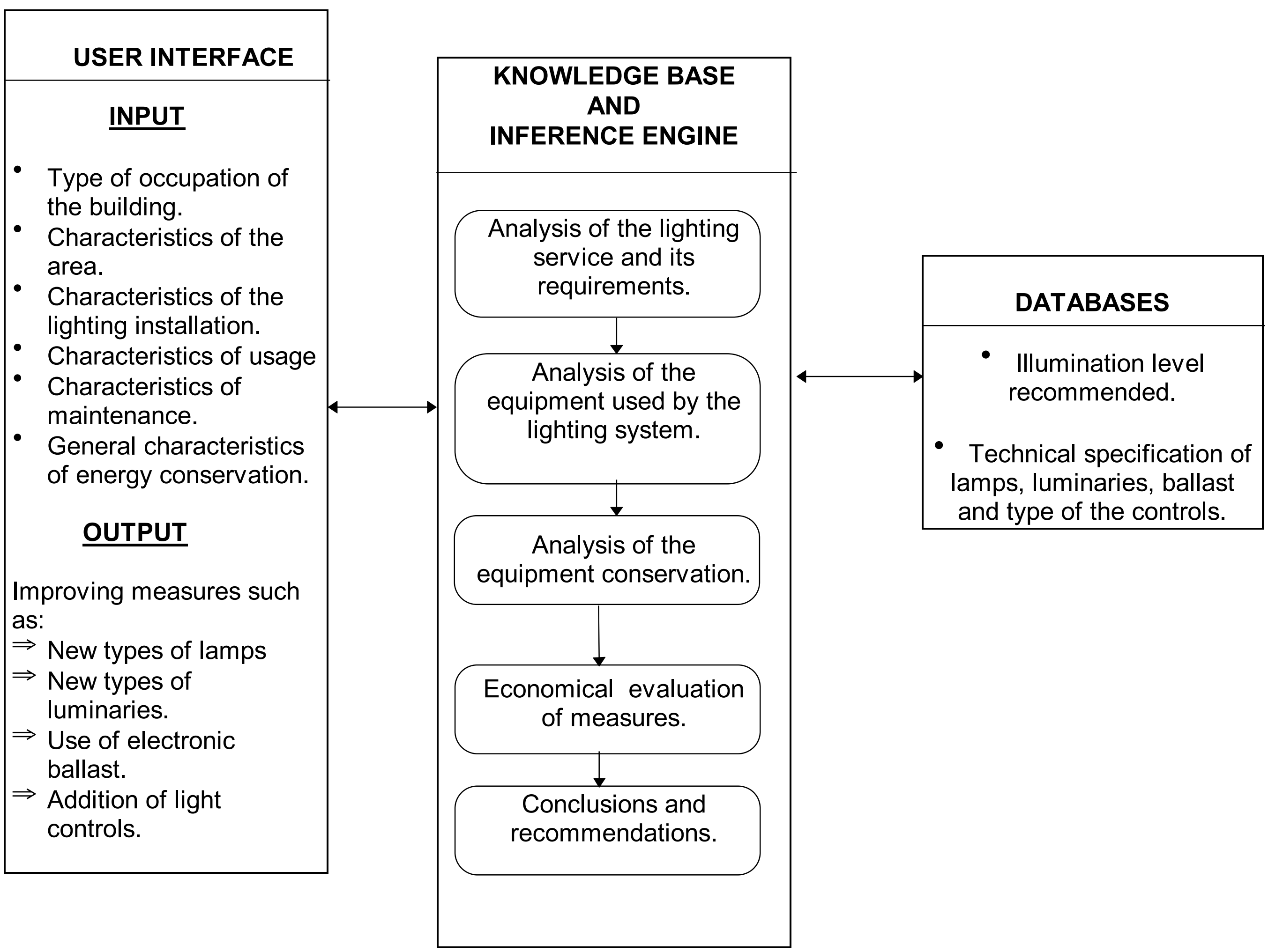
To fulfill the objectives proposed above, the structure of the expert system considers the following functions:

- Evaluation of actual lighting levels, according to the purpose of the installation and the kind of activities to be done under the lighting. In this sense, EXILCO uses the Lumen and the Point-by-point method. EXILCO assigns a minimum illumination level recommended for the specific area by construction regulations and lighting manuals based on the physical conditions and the activity performed.
- Evaluation of the equipment such as reflectors, lamps and ballast, to identify those affecting negatively the efficiency of the system.
- Evaluation of actual physical conditions at the selected site, including spatial dimensions, wall, ceiling and working surface reflections and working atmosphere characteristics (humidity, dirt, etc.)
- Evaluation of the conservation and maintenance policy of lighting equipment to define a maintenance and lamp replacing programs.
- Selection of measures to optimize the lighting levels according to the nature of the building construction and how it affects the costs of the illumination project.
- Selection of luminaries type and lamps to be used.
- Settling of depreciation factors for lamps and luminaries.
- Determination of the coefficient of usage (CU) for the specific area considering the wall and ceiling characteristics and luminaries placement.
- Calculation of the mean lighting level.
- Comparative evaluation of the proposed installation against the established levels and human expert recommendations.
- Presentation of a set of results both qualitative and quantitative and suggested measures to improve the quality and quantity of light as well as the energy efficiency and costs savings for the building.

System architecture

Throughout the evaluation process and analysis, the use of both technical and empirical knowledge in a sequential flow is required. Due to this aspect, EXILCO´s architecture is conformed by several sequential execution phases, each of them adding processed information (results) that can be partial or definitive.

The system architecture is represented in Fig. 1



User interface

The expert system, by means of interactive communication with the user, obtains from him some of the information required for the inference process, while some other (such as technical information about the equipment) is obtained from Exilco´s data bases. The kind of information needed by the production rules can be grouped as follows:

- Type of occupation of the building.
- Characteristics of the area.
- Characteristics of the lighting installation. Type of lamps and luminaries, lamp and ballast wattage, type of ballast, number of lamps per luminary, number of luminaries.
- Characteristics of usage. Hours of use, type of controls.
- Characteristics of maintenance. Inter-cleaning periods, in-between lamp replacing periods, cleanliness of the site atmosphere.
- General characteristics of energy consumption and use. Energy cost, diverse costs and additional information that might be needed by the expert system.

The information provided by EXILCO as output is following:

Improving measures such as:

⇒ New types of lamps

⇒ New types of luminaries.

⇒ Use of electronic ballast.

⇒ Addition of light controls.

Knowledge base and inference engine

Knowledge is represented within EXILCO by production rules linked to data bases and external programs that allow the expert system to process partial conclusions up to the final set of results and recommendations. The expert system offers also the possibility of "what if" analysis, re-assigning values to the variables involved, to compare the effect of different solutions. The inference engine permits to draw following results from the input data and the stored knowledge:

- Analysis of the lighting service and its requirements.

- Analysis of the equipment used by the lighting system.
- Analysis of the equipment conservation.
- Economical evaluation of measures.
- Conclusions and recommendations

Data bases

For its analysis, EXILCO needs complementary information like recommended illumination level and technical specification of lamps, luminaries, ballast and type of the controls, for instance, luminous efficiency, wattage and some other data the user may ignore. This information is obtained by the expert system from data bases in Lotus or Dbase III format.

Development of EXILCO

The knowledge needed by the production rules was obtained from following sources:

- Written sources such as lighting manuals and recommendations published by qualified organizations in Mexico.
- Human expert knowledge derived from the experience in the field of energy saving technology both by Mexican and foreign experts

Exsys Professional was selected as a tool for the development of the expert system due to no special hardware requirements (only a PC), possibility of rule execution control and possibility of external programs calling and data base handling.

Besides the programming language, the package includes a command language that enables the controlling of the rule execution. This language also provides programming mechanisms for data introduction, external program calling and output to the screen, file or printer. The package includes a program that is capable of compiling a text-form representation of the rules and turn it into a file usable by EXSYS.

EXSYS can also read directly from Dbase III files or Lotus 1-2-3 files without having to call them as external programs. These can be accessed from the production rules, the report file or the command file. The package provides the final user of the expert system with help based on keywords within the rules, qualifiers, variables, etc. This allows text, graphics or any other external program to be used to assist the user.

Validation and results

The expert system was validated by different lighting specialists. They compared the results obtained by the system against the reports of several studies performed by the government energy agency FIDE in different commercial centers in Mexico City along 1993 and 1994. The effectiveness shown by the expert system was of 85% in average with a cost reduction of up to 60% compared to the cost of traditional studies.

ESCAF: AN EXPERT SYSTEM FOR THE DESIGN AND EVALUATION OF ENERGY EFFICIENT COMPRESSED AIR FACILITIES IN THE INDUSTRY

Among the projects better issued for energy conservation, there are those related with facilities for generation and distribution of compressed air in industry. ESCAF is an expert system to design compressed air facilities for small and middle size plants in the cement, chemical, pharmaceutical, painting, glass, mining and textile industry and review existing ones in order to optimize the energy used in such facilities.

The design and management of energy efficient compressed air systems in industry, should be made according to the characteristics of the industry, as well as to the nature of commercial compressed air equipment. In this sense, experience and technical expertise from human experts are the key factors to obtain good results. Therefore, as human experts are scarce, it would be convenient to have an Expert System to assist in the design, installation, operation and maintenance of compressed air systems all over the country. With this objective in mind, an Expert System, named ESCAF (Expert System for Compressed Air Facilities) was developed at the Intelligent Systems Laboratory of the National Autonomous University of Mexico, with the technical help of compressed air equipment firms and available experts. It has been a valuable tool to provide assistance in efficient energy management of such facilities, including operation and maintenance tasks.

ESCAF can design an energy efficient new system as well as analyze and assess the efficiency of an existing one. In the first case, necessary conditions for an adequate functioning will be provided, such as the type and capacity of the compressor and drying system, dimension of pipes, recommended line accessories and possible cooling systems. All this information is given considering criteria of efficient usage of energy. For an existing installation, an energetic analysis will be done to determine if the present functioning conditions are adequate. If it is not the case, the system will provide the recommendations to improve the operation. ESCAF also prescribes measures for an adequate maintenance of the compressor, the distribution network and accessories as well as helps on failure detection and its possible solutions.

In following paragraphs we will describe the principal characteristics of ESCAF.

Structure of ESCAF

The structure of ESCAF consists of three basic modules and two auxiliary modules.
The three basic modules are following:
Module 1. Design and installation of a new compressed air system.
Module 2: Analysis of an existing compressed air system.
Module 3. Maintenance of the compressor, distribution system and accessories.

The functions performed by each module are described below:

Module 1. Design and installation of a new compressed air system.

The purpose of this module is to help in the design of a new compressed air system. Its first screen permits to select one of six submodules, covering following tasks:

a) Selection of compressors, drying equipment and store tanks. This submodule collects information through capture screens about the type of industry and type of industrial processes requiring compressed air, as well as quantity of the air required at the consumption points, detailing if the compressed air should be oil free or not. Another factor to be considered is the quality of compressed air within each industry, according to humidity contents, oil contents, solid particles contents and microorganism contents. In fact, different applications have different requirements in air quality, for example:

- Air for atomization painting must be dry, oil free and clean.
- Air for control instruments must be very clean.

The submodule also asks for information about the environmental characteristics of the site, such as altitude, maximal and minimal atmospheric pressure, maximal and minimal air temperature, size of suspended particles, relative humidity, etc. that are important to evaluate the available air quality.

An analysis is then done by ESCAF to get the total quantity of the compressed air to be consumed in the industrial plant. The required air volume is simply the sum of the consumptions of air at each point. For each one of the industrial processes requiring compressed air a capture screen appears asking for following data: drying temperature of the compressed air, demanded volume, working pressure in the process, expansion factor, use factor and maximal size of tolerated particles in the air. All this information is kept in a data base. Then ESCAF calculates the total demanded volumes corresponding to oil free compressed air, compressed air with oil traces and compressed air for pneumatic tools. ESCAF also gives the total number of processes demanding different conditions of the compressed air. The average pressure required by most of the industrial systems is 6 bar, however, generally the output pressure of compressor is 7 bar, to compensate for the loss of pressure in the lines. With these data ESCAF prescribes the type and number of required compressors, their capacity and pressure, the size of the store tanks and also the number of different distribution networks with their special accessories, like oil free devices, dryers, filters, antibacterial treatments, etc. according to the volume and quality of the air required at the consumption points and other points of the system.

b) Assistance by installing the equipment. In this submodule, ESCAF aids to define if there should be only one compressed air station or several stations; the number of compressors, the best place to locate the compressor room, its size and facilities. ESCAF also prescribes the nature of the foundations for the compressors, the quality of air and the type of electrical and control equipment to be used.

c) Selection of type of cooling method and equipment. ESCAF gives also recommendations about the type of cooling systems for the compressor and/or dryer that should be used according to environmental characteristics, such as altitude, temperature, relative humidity, barometric pressure, etc. These factors determine the type and quality of the external air available in the area. This part of the system also helps to select the cooling method: air cooling or water cooling. In the case of water cooling ESCAF gives the characteristics of water quality to be employed.

d) Selection of type of compressed air distribution network. This submodule helps on the selection of an internal or external distribution network. It also assists to tackle the problems of oil and condensed water in the distribution pipelines.

e) Design of compressed air distribution network. In this submodule ESCAF gives the internal dimensions of the pipelines according to the output airflow, length and working pressure.

In the design of ESCAF we considered that a network has four components:

Main line that conducts the compressed air from the compressor room to the consumption areas.

The distribution line, that distributes the compressed air inside of the consumption area.

Service line, that carries compressed air from the distribution line to the working site.

Line accessories, like valves, connectors, air preparing units, hoses, etc. that are required to conduct the compressed air from the service line to the consumer, which can be a machine, equipment or specific process.

ESCAF also helps to define the lengths of lines and the type and quantity of accessories required in the distribution network.

f) Energy saving measures. Once the requirements of air pressure, quality and volume have been determined, ESCAF suggests two kind of energy saving measures: heat recuperation and leaks detection and provides information about the necessary conditions for the compressor system and distribution network to be efficient.

Module 2: Analysis of an existing compressed air system.

This module does an analysis of an existing system, reviewing the characteristics of the compressors, the distribution system and the accessories. It also gives recommendations on possible improvements for energy saving purposes. This module contains following submodules:

a) Calculation of total compressed air volume. This submodule checks if the supply capacity of the system satisfies the demand. For this analysis information should be entered about compressor and store tank characteristics (type, capacity, application, etc.), line accessories and dimensions and type of the distribution lines.

b) Calculation of actual compressed air consumption. This submodule reviews if the actual compressor is sufficient to supply the volume required. As a first step it calculates the actual air consumption in terms of total air volume, maximal frequency in the cycle, atmospheric pressure, temperature of input air, temperature in reception tank and capacity of the compressor. Then ESCAF assess if actual compressor is adequate or not.

c) Selection of an adequate compressor. If the actual compressor is not adequate for the requirements, ESCAF helps the user to select an appropriate one.

d) Selection of an adequate dryer. In this chapter ESCAF calculates the required capacity of the dryer, in terms of the input air temperature to the dryer, the cooling temperature, the wet point at the required pressure, the working pressure, the capacity of the compressor and the correction factor. With all this data, ESCAF prescribes the type of dryer (adsorption, absorption of refrigerating) and its output.

e) Required ventilation in compressor room. This part analyzes following points: heat balance, ventilation air flow, size and power of ventilator motor and size of input and output grids.

f) Pressure fall in pipelines. This submodule analyzes the pressure fall in the pipelines due to their internal diameter and due to air leaks and gives recommendations to minimize such pressure loss.

Module 3. Maintenance of the compressed air equipment.

This module provides support to apply adequate preventive maintenance both in the compressor and the distribution systems. It contains following submodules:

a) Compressor maintenance. This submodule considers two kind or compressors: oil free compressors and lubricated compressors. The oil free compressors are classified into piston compressors, rotating compressors and screw compressors. ESCAF gives for all these types of oil free and lubricated compressors adequate programs of periodic preventive maintenance.

b) Dryer maintenance. ESCAF gives for adsorption dryers and refrigerating dryers adequate programs of periodic preventive maintenance.

c) Network maintenance. ESCAF indicates the most frequent leak points in the network, how to detect leaks, the causes of leaks and a weekly preventive maintenance program.

d) Accessory maintenance. This submodule indicates the replacement periods of filters and other consumable parts.

e) Fault diagnosis. ESCAF permits the user to diagnose different kind of malfunctions of the compressed air system, including failures related with the compressor, distribution system and accessories (containers, dryers, condensators, etc.).

Auxiliary Modules

ESCAF has also two auxiliary modules:

- A small tutorial about compressors, distribution system and accessories.
- System's help**.**

In the first auxiliary module a brief introduction to compressors is given for the inexperienced user. Information about the distribution system and accessories is also displayed.

The Help Module is integrated to the system. Each screen has a helping key in line which gives information about the system's functioning.

External communication possibilities.

In each one of the modules described above, ESCAF has access to external data bases designed in DBase III+, in order to retrieve technical characteristics of single parts of the equipment. This makes the system independent of changes of equipment characteristics. All the user must do is to maintain the data bases actualized.

ESCAF asks the user for information through capture screens, that can be key groups, display screens o graphic screens. To introduce this information both keyboard and mouse can be used. To provide information, the system uses display screens and graphic screens.

Development of ESCAF

The main programming tool used to develop ESCAF was Level 5 Object, a shell to develop object oriented expert systems under Windows 3.1 environment. Level 5 Object turned out to be adequate for ESCAF development due to the following reasons:

- Level 5 Object is an object oriented environment, running on Windows.
- Level 5 Object can handle several forms of knowledge representation like objects (frames), rules, demons and functions. In this way, knowledge can be represented in the most appropriate form.
- Level 5 Object has a Graphic User Interface (GUI) highly developed for programming. An expert system can be programmed mostly only with the mouse.
- Level 5 Object has the ability to handle information in a non-sequential form and according to the user's knowledge and requirements through hypertexts and hyperregions.
- Level 5 Object has the capability to interact with external programs (data bases, spreadsheets and executable programs).
- The hardware requirements to run programs developed on Level 5 Object are easily met: PC 386 or higher, hard disk 40 Mbytes, 4 Mbytes in RAM, Windows 3.1, Mouse.

The knowledge acquisition phase of the project required over six months of work of the three co-author students. The knowledge for ESCAF was captured from private sources (compressor experts, manufacturers, academicians, researchers and qualified technicians) and from public sources (technical handbooks, magazines, etc.). The information about commercial equipment was taken from equipment manuals.

Validation and Results

ESCAF was validated by experts engineers from a very prestigious international corporation dedicated to designing and manufacturing compressed air equipment. The experts made very positive evaluations of the performance of ESCAF and recommended it for internal use at their corporation. A license for unlimited use of ESCAF was given to that company.

Part of these evaluations are following:

1. - For a new compressed air facility ESCAF provides in an adequate way the type and capacity of the compressors and drying system if necessary, as well as dimensions of pipelines and recommended accessories including cooling systems. All this information is given considering criteria of efficient usage of energy.

2. - For an existing installation, ESCAF provides an analysis of actual equipment and the necessary recommendations for an adequate supply of compressed air, according to energy efficiency.

3. - For both cases ESCAF recommends appropriate preventive maintenance programs and allows detection and correction of operative failures.

TUTORES: A TUTORIAL EXPERT SYSTEM FOR THE DESIGN OF ENERGY COGENERATION PLANTS

TUTORES is a tutorial expert system, developed for training of technicians and engineers in the field of design and evaluation of cogeneration plants.

Within the field of efficient use of energy, industrial cogeneration of energy is a very important way to reduce waste and to increase the supply of this important resource. However the bottleneck for the full implementation of this solution at the level of the industrial sector in Mexico lies on the lack of trained human resources for the design and operation of cogeneration plants. In fact, there are very few human experts in such field compared with the number required by industry.

In this sense, it was decided to develop a tutorial expert system to provide technical training in the design, selection and evaluation of cogeneration plants, considering the new technologies available in the market. The users of this system would be engineering students, technicians and professionals interested in this theme as well as training departments of industrial corporations interested on this kind of energy saving measures.

Intelligent Tutoring Systems emerged as a result of the application of AI methodology and techniques to the problems of instruction at all levels. These kind of systems can implement several instructional strategies according to the knowledge level and other characteristics of the users (O'Neil, Slawson & Baker 1991). A tutorial expert system (TES) is then an interactive computer program to provide personalized training about a specific matter, considering the current state of knowledge of the student and his/her achievement. This system emulates the behavior of a human instructor. Some of the tutorial expert systems reported in the literature are Steamer (Stevens, Roberts & Stead, 1983), PROUST (Johnson & Soloway 1987), GUIDON (Clancey, 1987), a TES on chess (Gadwal, Greer & McCalla 1993), a TES on design of complex systems (Gisolfi & Loia 1994) and a TES for computer engineering ICAI-C (Kong 1994).

The advantages of a tutorial expert are:

Autonomy: After a tutorial expert system has been designed and implemented, it becomes autonomous. This means that the system is physically independent of the system's developer and the domain expert.

Reproducibility: A tutorial expert system and the knowledge it contains can be reproduced easily, if necessary, to thousands of copies in a few minutes. On the other hand, a human expert takes years to become fully skilled.

Low Purchase and Operation Cost: Having instructors available at all times is very expensive. On the other hand, The cost of a tutorial expert system lies only on its design and development. These costs can be later distributed among all users of the system, making each single copy very cheap.

Disposability: The system can be easily distributed to different locations and it can also be used in difficult working conditions.

Flexibility to expansion and modifications: The information contained in the knowledge base can be easily updated to incorporate new technological advances, simply by accessing text files because these files are not part of the knowledge bases.

Structure of TUTORES

TUTORES has following characteristics related to the teaching-learning process.

- a) A qualification test to diagnose the user knowledge level.
- b) Activation limited to the topics corresponding to the user knowledge level.
- c) Periodic partial evaluations to detect topics where knowledge needs to be reinforced.
- d) Final evaluations for each module. If the user approves the final module test, he/she is able to go on to the next module; otherwise he/she is brought back to those failing topics.

The tutorial is constituted by six topics that appear in the initial screen (Figure 2):

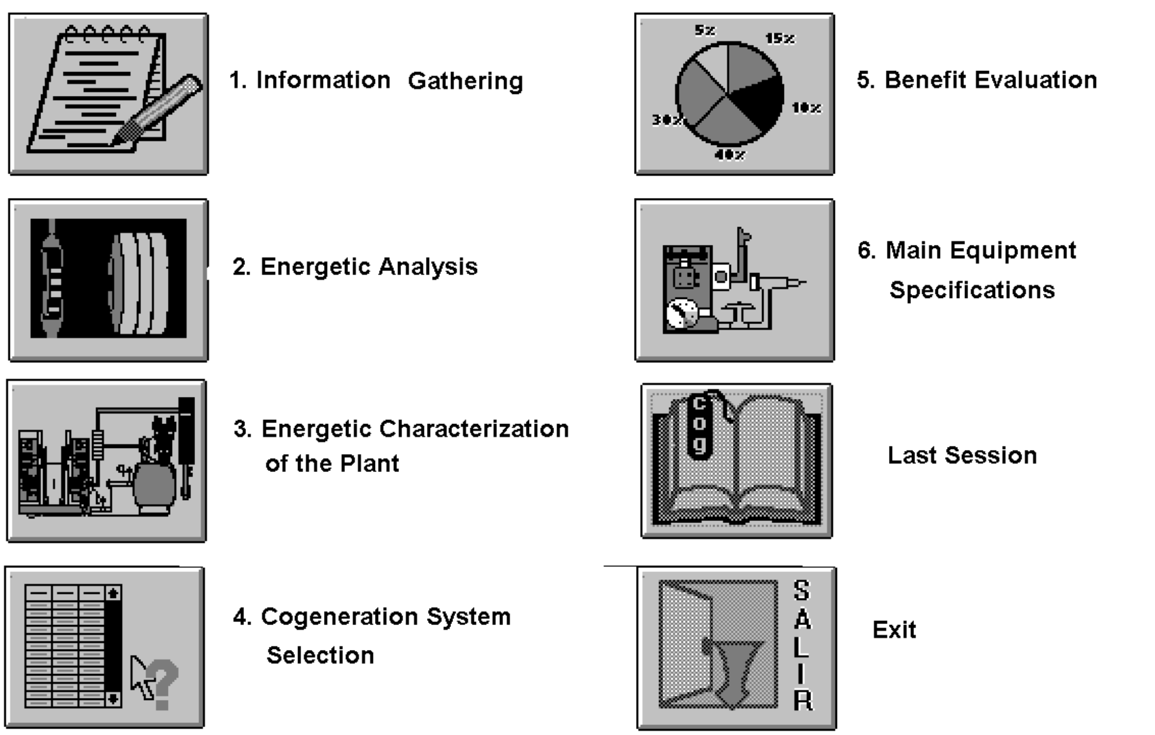


Figure 2. Introductory screen with the different modules of the Tutorial.

- I: *Information Gathering*. The purpose is to provide the user with procedures to collect the required data to design a Cogeneracion System.

- II: *Energetic Analysis.* It trains the user to analyze the distribution of energetic resources in the enterprise, based on statistical information or data collected during a monitoring period.

- III: *Energetic Characterization of the Plant.* It presents the user the appropriate methodology to assess the cogeneration potential of the plant, based on thermal and electrical parameters.

- IV: *Cogeneration System Selection.* This topic contains the methodology to select a Cogeneration system, including its capacity to fulfill the plant needs.

- V: *Benefit evaluation.* It talks about the procedure to evaluate the net power produced by each cogeneration scheme proposed, as well as the fuel demand under different load conditions.

- VI: *Main Equipment Specifications.* It offers information about different criteria and factors needed to specify the main equipment of the cogeneration scheme selected.

The sequence of topics was suggested by the experts as the best for learning the topics. All the topics are interrelated in a sequential way, according to the design process of cogeneration plants. Access to a certain topic requires to have approved the previous ones.

This scheme guarantees system's flexibility and repeatability of the training process. A functional independence was obtained by developing modules for each topic.

To improve comprehension in some topics, we use hypertext to access additional explanation screens, without interfering with the sequence of the system.

Evaluation of the student

For administrative purposes the system has a module for data acquisition and consulting related to the students. This module gives access codes to the system for each student. Without the authorized access code it is not possible to use the system.

The evaluation process consists on questionnaires and problems the student should solve after completing some group of topics. The system suggests, through an intelligent feedback process, the topics the student needs to review.

The exams have a level of difficulty based on the user's profile. During the whole tutorial the student presents at least three exams and each one of them is chosen randomly among three possible types. Each exam is composed by ten questions with multiple options.

For monitoring the progress of the students, the system has a database storing the values of some control variables like: topic, sub-topic, topics total, sub-topics total, last topic, grades of each student in each exam, type of exam, student's full name and access code. This database was developed in Dbase III.

Architecture of TUTORES

The system is composed by 12 modules: Master, Main Menu, Topic One, Topic Two, Topic Three, Topic Four, Topic Five, Topic Six, Exam One, Exam Two, Exam Three, and Data. Each module is composed by fifteen objects. These objects control the system process. Each topic has rules and demons (events) that are the core of the inference engine of the expert system. Each module can be execute alone. Only the MASTER and MAIN MENU modules are forced to be linked with other module. The data acquisition module was elaborated as support for the training coordinator for monitoring the advance of the students.

Development of TUTORES

Since we are dealing with an educational application, the shell selection was highly influenced by the possibility to create friendly user interfaces and the possibility to communicate with other applications. The system was developed in Level 5 Object because:

- It allows the use of graphics, leading to a better understanding of the topic being explained.
- It allows the use of hypertext and hyper-regions. These are reserved regions of the screen that relate with other explanatory screens that become active when the mouse pointer is over them and the user clicks them.
- It allows the use of Dbase III Plus databases.

The technical requirements of the system are: A 386 PC or better, VGA card, 4 Mb of RAM and 12 MB of hard disk space. Also requires DOS 5.0 or above, Windows 3.1 and Level 5 Object 2.5 runtime only.

Validation and results

TUTORES was carefully validated by cogeneration specialists and instructors as well. Its evaluation took place at the National Commission for Energy Conservation in Mexico, in special courses designed to train people from industry and the public sector. The results have been excellent.

ACKNOWLEDGMENTS

The authors wish to acknowledge the work of following former students from the Intelligent Systems Laboratory whose enthusiasm and intensive work made possible the development of the described knowledge-based systems:

Octavio Hernández **(EXILCO),** Roberto Mojica Mercado**,** Carlos Jesús Olivas Olguín and Oscar Ortíz Díaz **(ESCAF),** Carolina De La Paz Alva and Julia Alcántara Zavala **(TUTORES).**

CONCLUSIONS

Throughout the research and testing of the expert systems we could notice the following facts:

- There is an increasing interest by business people not only for saving money through energy saving measures but for creating a energy saving culture among their employees.

- There is still a lot of people that consider the results of their particular studies as something secret notwithstanding the fact that they are needed in order to develop new strategies within the field of energy saving.

- Some commercial building owners are a bit afraid to change their lighting installation because they think they could lose marketing impact on their customers as they reduce lighting levels.

EXILCO provides a very efficient alternative to perform energetic analysis because it diminishes significantly the cost and time required by such studies. In fact, the expert system was validated by different lighting specialists. They compared the results obtained by the system against the reports of several studies performed by the government energy agency FIDE in different commercial centers in Mexico City along 1993 and 1994. The effectiveness shown by the expert system was of 85% in average with a cost reduction of up to 60% compared to the same studies. The methodology used by the expert system allows to identify the critical points in the installation to suggest possible energy saving measures.

ESCAF (Expert System for Compressed Air Facilities), helps to get an optimal functioning of a compressed air system from the point of view of energy efficiency. The program can design an energy efficient new system as well as analyze and assess the efficiency of an existing one. In the first case, necessary conditions for an adequate functioning will be provided. In the second case, an energetic analysis will be done to determine if the present functioning conditions are adequate. If it is not the case, the system will provide the recommendations to improve the operation. ESCAF also prescribes measures for an adequate maintenance of the compressed air equipment and helps on failure detection and its possible solutions. The knowledge base of ESCAF has been specifically developed for the following industrial branches: cement industry, chemical, pharmaceutical and painting industry, glass industry, textile industry and mining. ESCAF has been validated and tested in real situations with great success by experts engineers from a prestigious international manufacturing corporation dedicated to designing and manufacturing compressed air equipment.

TUTORES was developed for training of technicians and engineers in the field of design and evaluation of cogeneration plants. The system is composed by 12 modules. Each module is composed by objects that control the system process. This system has a shell structure useful to build another tutorial expert systems by changing the information contained in the modules. TUTORES was carefully validated by cogeneration specialists and instructors as well. Its evaluation took place at the National Commission for Energy Conservation in Mexico, in special courses designed to train people from industry and the public sector. The results have been excellent.

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