Federal Relighting Expert System

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Significant energy savings compared to 1985 levels must be secured in the federal sector by the years 1995 and 2000 to comply with mandated energy efficiency improvements. Relighting projects are an essential ingredient in the mix of energy saving opportunities needed in the federal sector to meet these goals. The Federal Relighting Initiative, coordinated by the Federal Energy Management Program (USDOE/FEMP), is targeted toward federal facility managers to help them secure energy savings from their lighting systems. While there are many sources of information on lighting technologies, facility managers lack a single source to assist them with evaluation and implementation of relighting projects. The Federal Relighting Initiative provides a step-by-step approach to relighting projects and supports software tools suitable for facility managers. One of these tools is an expert system for project screening. It is combined with extensive product performance data base and life cycle cost analysis. This paper describes design goals, implementation experience, and progress on the development of the expert system portion of the Federal Lighting Energy eXpert (FLEX).

Introduction

Facility managers today face difficult decisions about energy efficiency upgrades to the lighting systems in their buildings and have numerous sources of information from manufacturers as well as general help and summary material (APPA 1990, CEC 1990, EPRI 1991, NYSERDA 91). They are faced with rapidly changing technologies from an industry racing to meet the demand for energy efficient lighting equipment. In the federal sector, the difficulty of upgrade decisions is compounded by the urgency of mandated energy intensity reductions. Energy savings in the Federal sector have been mandated under executive order PL-100-615 which sets a goal of reducing energy consumption in Federal Buildings 10% by 1995 (on a sq ft basis compared to 1985 levels). An additional executive order dated April 17, 1991 (12759) calls for an additional 10% savings by the year 2000.

Federal energy policies and options for improving energy efficiency have been considered (Office of Technology Assessment 1991) and have shown a clear need to accelerate the adoption of energy efficiency measures. The Federal Energy Management Program has a mission to support energy savings projects in all federal agencies and has supported the development of several computer programs toward this end (NBS Handbook 135 1987) (Firovid 1991). This paper describes the results of a FEMP sponsored expert system for federal facility managers considering relighting projects. The expert system provides managers with a simple tool they can use to screen their building and particular situations for a wide variety of recommended practices and changes. The expert system includes rules for making qualitative recommendations in the areas of maintenance practices, operations and controllers, efficient system hardware, room design, and outside help.

The Federal Lighting Energy eXpert system (or FLEX), is one tool provided to federal energy managers participating in the Federal Relighting Initiative (Harris and Purcell 1992). This paper describes the expert system portion of the software. Other features of FLEX not discussed here include simplified lighting survey methods, quick inputs, economic analysis, and technology selection. Other tools used in the Federal Relighting Initiative include a building screening tool for the identification of candidate buildings and a Lighting Technology Screening Matrix (LTSM Shankle 1992).

Background

There is nothing new about expert systems used to support design decision making. In fact, expert system building tools have been available for some time (Gevarter 1987); however, development of useful expert systems continues to be a demanding task compared to traditional programming (Raugh 1988).

There are a couple of examples of expert systems applied to lighting energy efficiency in buildings (LightX and XenLight) and there is continued interest in using expert systems for a wider range of building energy efficiency issues (AEDOT Brambly 1992). In 1989 the Solar Energy

Research Institute (now the National Renewable Energy Laboratory) developed a prototype expert system that included consideration of fluorescent delamp, delamp/relamp, and relamping practice. The present work is a continuation of that effort.

The Environmental Protection Agency has an interest in relighting to control pollution in the 'GreenLights' program. A Decision Support System (DSS) provides decision support for their program participants (Kwartin 1992). While the DSS is not an expert system, it provides a method for considering a wide variety of lighting 'packages' compatible with existing ceiling configurations in a building.

Design Goals

The design goals for the FLEX expert system software were written in 1991 with a three year software development plan. The goals for the software have not changed significantly since that time and are listed in Table 1 below.

Implementation

To meet the design goals, a public domain expert system library written in the 'C' language was selected. Several shell-based systems were not considered because they could not link with the selected graphical user interface or required run-time royalties. The C-Language Integrated Production System (CLIPS, a public domain software product available through NASA) met the first design goal of easy integration because of its availability in source code form. Availability of source code is critical if the programmer wants to use their own interface or understand the inner workings of the libraries they are linking to.

The second and fourth design goals were the most difficult to meet. Large expert systems involving many rules require UNIX or LISP based computers to operate with acceptable performance. There is always a balance between ease of development and computer platform requirements: the more capable the machine and libraries, the less difficult the development effort. A low-end PC platform was selected because it was a common denominator for the target audience. This platform requirement has been relaxed because of the speed with which available PC technology is advancing. The platform requirement may be relaxed further to require a 80386 processor and additional memory should present trends continue. The present platform requirement is 286 based PC with 2Mb expanded memory, and a VGA graphics monitor (a mouse is highly recommended but not required).

Normally, an expert system will ask the user an endless stream of questions about their situation because it starts with no information on the particular design problem being considered. The question and answer period quickly turns to drudgery if:

- The user has no knowledge of the goal or purpose of the questions
- The user must enter questions via the keyboard by typing a host of figures requiring the user to consult reference materials or perform conversions.
- The user has no control over stopping, starting, saving, or editing their responses.

To alleviate this problem, a menu system and response data base were developed in FLEX to allow user control over the question and answer sessions. The features of this menu system are described in the following section. In addition, the use of a graphical user interface allowed the use of prompts that are simple and appealing to use. The rule base is designed around the principle of simple response check-boxes (yes/no, small/medium/large kinds of responses) to eliminate keystrokes entirely!

The sixth design goal was met using a hierarchical system of rules and goals. This design allows the user to explore the system and spend appropriate levels of effort for the level of specificity they expect from the system. This approach also allows a structured knowledge engineering effort that focuses on different levels of detail in many areas of lighting technology.

To allow for an arbitrary level of rule expendability within the confines of personal computer equipment, the expert system rule base had to be divided into logical groupings called rule sets. These rule sets are associated with a particular branch in the hierarchy tree of goals. Branches representing new technologies require the addition of rule sets in the structure.

Results

An overview of the expert system hierarchy of forward chaining rules and goals is shown in Figure 1. This figure illustrates the scope of the expert system as well as its levels of specificity. Notice that all relighting options are categorized as a change to:

- Maintenance Practices
- Lighting Equipment

Table 1. Goals of the Design (1991)

#	Goal	Description
1	Audience	The application will be suitable for facility managers with little or no experience in lighting technology. It will also be very friendly to inexperienced PC users.
2	Integration	The expert system will operate in a seamless fashion with the selected user interface library. This means the user will only have to run a single executable to operate the entire system with a consistent look-and-feel.
3	Royalties	The developed application will reside in the public domain. No third party libraries requiring royalties per run-time copy will be considered.
4	Computer Platform	The software will run on easily available, low cost computer platforms that the target audience is likely to possess or easily acquire.
5	Ease of Use in the Expert System	The software will provide a context for the user and provide them with some control over the question and answer session.
6	Level of Detail Hierarchy	The expert system will make best use of the users time excluding question paths it can easily eliminate from consideration. It also will provide the user with results at various levels (and with different degrees of specificity) in the session. It will not wait until the very end of the decision tree to make a recommendation.
7	Qualitative Recommendations	The expert system will make qualitative recommendations and will link to other software to perform the necessary quantitative economic analysis of those recommendations.
8	Expansion	Given rapidly changing technology, the expert system rules must be in a form that can be easily expanded to accommodate new technologies.

- Operation Changes
- Room Redesign.

These categories were used to divide relighting projects into those affecting system efficacy, time-base of use, or base conditions. This division is not the only way to view relighting projects but it is a convenient way to categorize the larger scope of potential projects. Also, these divisions do not imply that the project types are exclusive; interactions in the rule sets cross these category boundaries.

The tree starts with 5 *trunks* and extends out to different *branches*. To extend the analogy, when you reach a *leaf* you cannot go any farther and the system has reached a recommendation. The *leaves* in the hierarchy are marked in Figure 1 with the ** characters. They can be at different levels in the hierarchy and are non-exclusive. Multiple endpoints can be reached in the expert system or no endpoints may be reached (no relighting project is suitable). In FLEX these recommendations are passed to algorithm modules that determine which combination is most economic.

The present FLEX development effort will take about three years from start to finish. This paper does not include any discussion of the analysis modules that are part of the completed software, rather it is focuses on the expert system portion of the tool.

Each of the branches in the structure shown in Figure 1 correspond to a goal. The object of the expert system is to determine if the goal at each successive branch is met. Goals must be met at one level before its related goals at

Level 0	Level 1	Level 2	Level 3

- Maintenance
  - Relamping Practice
    - Replace only burned lamps **
    - Replace all lamps in fixture during spot **
    - Spot to Group, with spot replacement of early failures **
    - Spot to Group, w/o spot **
  - Fixture Cleaning
    - With every Spot Relamping **
    - Synch with Group Relamping **
    - Other Cleaning Interval **
  - Fixture Cleaning Method **
  - Room Surface Maintenance **
- System
  - Different Source
    - Change to Quartz **
    - Change to Fluorescent **
    - Change to Compact MH **
    - Change to Compact White HPS **
    - Change to LPS **
    - Change to Other **
  - Upgrade Source
    - Incand. upgrade **
    - Quartz/Halogen upgrade **
    - Fluorescent Upgrade
      - Fluor. Delamp **
      - Fluor. Delamp/Relamp **
      - Fluor. Relamp/Reballast **
    - HID same source upgrade **
  - Replace Fixture **
  - Fixture Upgrade
    - Replace lens/louver **
    - Polarizing replacement **
    - Egg crate lens replacement **
    - Reflector upgrade **
  - General to Task-Ambient **
- Operations
  - New Controller
    - Static controller **
    - Dimmer **
    - Timer
      - Twist Timer **
      - Mechanical clock **
      - Solid State Clock **
      - Central Control **
      - Central Control w Local **
    - Occupancy Sensor
      - Infrared Sensors **
      - Ultrasonic Sensors **
    - Lumen Maintenance **
    - Local Tuning **
    - Daylight Following **
  - Controller Upgrade
    - Rheostat Replacement **
    - Dimmer to Solid State **
    - Time Clock Replacement
      - Twist Timer **
      - Mechanical clock **
      - Solid State Clock **
      - Central Control **
      - Cent al Control w Local **
  - User Training **
  - Saving Incentives **
- Design
  - Reorientation **
  - Window Treatments **
  - Architectural
    - Change Obstructions **
    - Change Partitions **
    - Redesign Ceiling **
    - Add/ Modify Light Shelves **
    - Change Room Colors **
- Outside Help **

Figure 1. Hierarchy of Expert System Goals

lower levels will be explored. Figure 2 illustrates a sample goal and its associated rule and clauses for one branch in the hierarchy.

Most of the questions in the expert system are associated with a *Lighting System* rather then a whole building. A *Lighting System* is comprised of a light source and a

Consider a change in Maintenance:

Rule IF *Relamping Practice* is NOT optimum OR *Fixture Cleaning Practice* is NOT optimum OR *Room Cleaning Approach* is No or *Room Refurbishment Approach* is NO.

Clause *Relamping Practice* is optimum IF (1) Managed by a Certified Lighting Management Professional (e.g. CLMP) OR (2) Based on life cycle cost analysis of best relamping method and interval.

Clause *Fixture Cleaning* is NOT optimum IF it is (1) never performed or (2) Performed at an unplanned interval OR (the Fixture Cleaning Method is NOT Electrostatic and fixture includes baffles or louvers) OR (the Fixture Cleaning Method is a dry cloth).

Clause *Surface Cleaning Approach* Do you consider the impacts on the lighting system when you select a room surface cleaning interval for the work spaces in your building? Y/N

Clause *Surface Refurbishment Approach* Do you consider the impacts on the lighting system when you select colors and repainting intervals for the work spaces in your building? Y/N

Figure 2. Sample Rules for the Level Zero Goal 'Maintenance'. Note the single goal associated rule and multiple clauses.

fixture. For instance, a recessed downlight with 150 Watt incandescent PAR lamp is one *Lighting System* while the same lamp in a wall-washer fixture is another system. Exit signs and task lighting also comprise separate *Lighting Systems*.

Features of the expert system include a *bookmark* that makes it easy to pick-up where you left off, an *edit* mode to review and edit your responses, and a *browse* mode to view the list of goals met by the expert system. These features are accessible from the graphical user interface.

During a question and answer session, the user can view their location in the hierarchy of rules being asked. Figure 3 is a picture of the screen showing the FLEX expert system in operation. The left side of the screen is a graphical representation of the decision tree used to locate yourself during input. It can also be use to move between branches during an *edit* session. The right portion of the screen is used to present simple questions to the user in different screen forms. All questions can be responded to with point-and-click operations of the mouse eliminating the need for keystrokes. A mouse emulator and hot-key equivalents are provided for users without a mouse.

Recommendations

The most difficult and time consuming task in expert system development is the knowledge engineering. This is the term given to the process of interviewing experts, discovering the rules in all of their comments, and stringing together all the rules into a unified whole. If expert systems are to be more widely adopted into software applications, this knowledge engineering must be

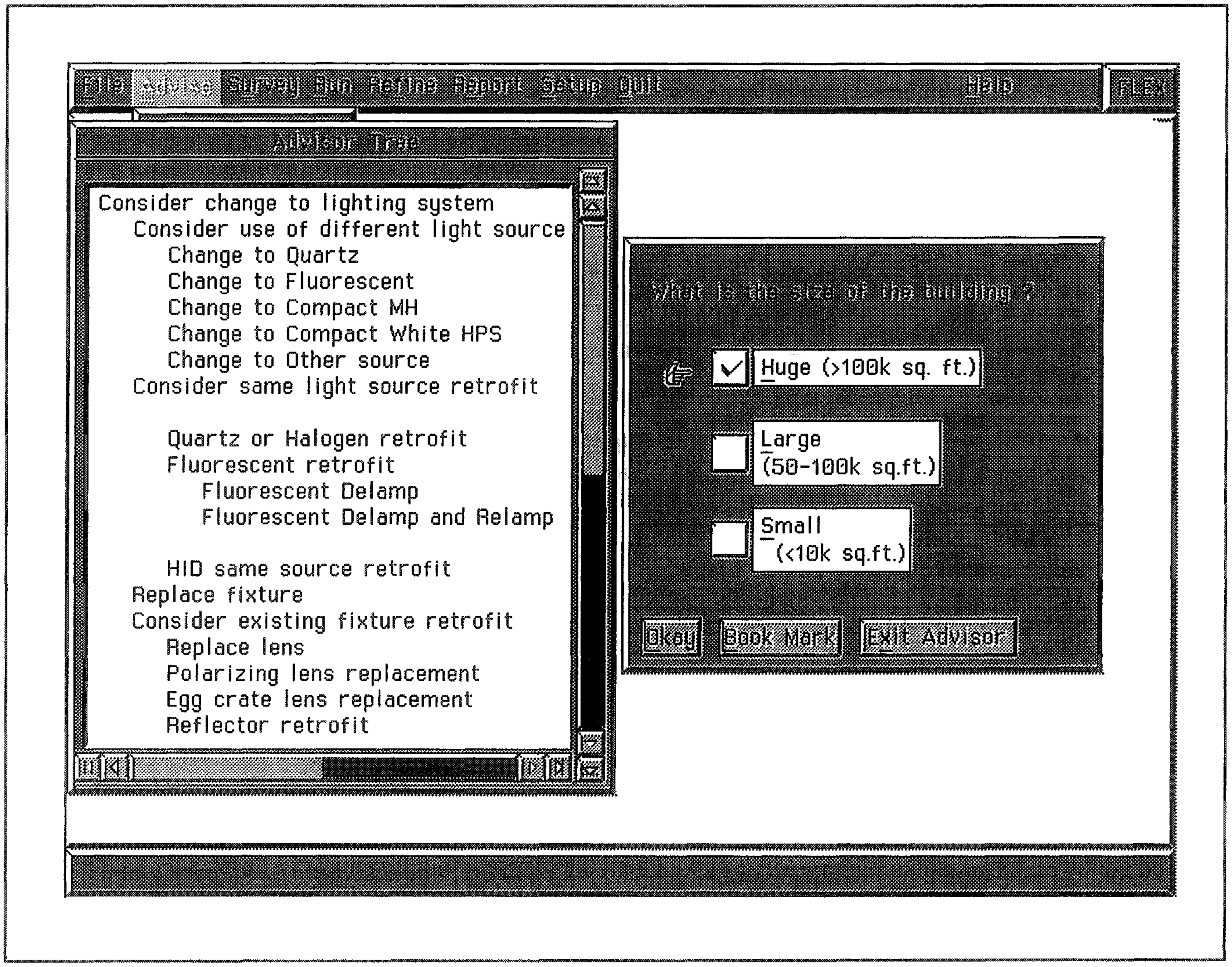

Figure 3. FLEX Expert System Screen

more automated. Some expert system development shells provide methods for inferring rules from examples entered by the knowledge engineer. While this method for knowledge gathering is attractive, it may have some limitations in a field as wide as relighting projects.

Rule set maintenance is also a difficult task. When the number of rules increases so does the number of relationships between rules. This makes maintenance and expansion difficult. What is needed is a tool for automating the knowledge engineering AND the rule set maintenance. Several commercially available expert system development shells advertise this capability but limit the user when it comes to embedding the system and choosing a user interface.

Several products are commercially available that offer elegant user shells allowing English-like rule input and maintenance. However, there are fewer tools available to automate the interview process with experts. The problem is that experts may know much about their field but typically know little or nothing about expert systems. Also, since an expert's energy is typically spent staying current in their field, they do not have much interest in becoming knowledge engineers. What is needed is an interview tool that can collect rules from these experts.

The ease of expansion of the lighting expert system is critical to its design. We can expect new products and relighting techniques to arrive on the market regularly. The task of updating the expert system must be well automated to accommodate this fast pace of change in the lighting industry.

Conclusions

The relighting expert system sponsored by FEMP is one part of a toolkit available to federal energy managers considering relighting projects. Expert systems offer a methodology for the solution of relighting design problems that are not easily represented with algorithmic solutions. The results of the present effort can be extended to other energy efficiency design problems in buildings.

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