Development of an Expert System for Evaluating The Environmental Quality of Office Buildings

by

Rabee Mohammed Reffat Ahmed

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

ARCHITECTURAL ENGINEERING

June, 1994

Order Number 1360401

Development of an expert system for evaluating the environmental quality of office buildings

Ahmed, Rabee Mohamed Reffat, M.S.

King Fahd University of Petroleum and Minerals (Saudi Arabia), 1994

U·M·I
300 N. Zeeb Rd.
Ann Arbor, MI 48106

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DEVELOPMENT OF AN EXPERT SYSTEM FOR EVALUATING THE ENVIRONMENTAL QUALITY OF OFFICE BUILDINGS

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بسم الله الرحمن الرحيم

"واتقوا يوماً ترجعون فيه إلى الله ثم توفى كل نفسٍ ما كسبت وهم لا يظلمون" * صدق الله العظيم (البقرة ، ٢٨١)

"And fear the day When ye shall be brought back to GOD. Then shall every soul be paid what earned, and none shall be dealt with unjustly"

(The Holy Quran, S II, 281)

"praise be to god, the merciful, the compassionate, the lord of the two words, and blessing and peace upon the prince of prophets, our master muhamed, whom god bless and preserve with abiding and continuing peace and blessing until the day of the faith !"

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS
DHAHRAN 31261, SAUDI ARABIA

COLLEGE OF GRADUATE STUDIES

This thesis, written by **RABEE MOHAMED REFFAT AHMED** under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in ARCHITECTURAL ENGINEERING .

Thesis Committee

Dr. ALI ALI SHASH (Advisor)

Dr. E. L. Harkness (Member)

Dr. Fahd Al-Said (Member)

Dr. Mostafa M. Aref (Member)

Department Chairman

Dean , College of Graduate Studies

29.10.94

Date

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This thesis is dedicated to

My beloved parents, brothers and sisters.
Your effort can not be duly appreciated;
Your tender care can not be ignored .

ACKNOWLEDGMENT

All praise be to *ALLAH,* the lord of the two worlds, the Almighty with whose gracious help it was possible to accomplish this work.

I wish to express my sincere appreciation and gratitude to my Thesis Advisor Dr. Ali A. Shash for his continuos guidance and valuable suggestions. I am deeply indebted to Dr. E. L. Harkness, Thesis Committee Member for his continuous help and great care.

Thanks and gratitude to Dr. Fahd AL Said, Thesis Committee Member, for his encouragement. I would like to thank Dr. Mostafa Aref, Thesis Committee Member, Computer Science Department, who helped me to improve the performance of the expert system.

I would like to thank King Fahd University of Petroleum and Minerals and College of Environmental Design for supporting me during my study. My gratitude to all the interviewed domain experts and to all my friends every where.

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THESIS ABSTRACT

Name	:	**Rabee Mohamed Reffat Ahmed**
Title		**Development of an Expert System for Evaluating the Environmental Quality of Office Buildings**
Major Filed	:	**Architectural Engineering**
Date of Degree	:	**June 18, 1994**

An office building is designed and built to host a group of people performing distinct office work. The performance of the users of such a building is substantially influenced by its environmental quality. Environmental Quality Factors (EQF) are lighting, acoustic, thermal and indoor air quality. The evaluation of environmental quality of such a building is an indication of how well this building achieves the environmental comfort for its users.

This study addressed the evaluation of environmental quality of office buildings as an integrated approach (lighting, acoustic, thermal and indoor air quality). In this research, the performance criteria (variables) of EQF and the scales used for evaluating these performance criteria (attributes) were extracted from two main sources: The first by carrying out an extensive literature review through published papers, reports, books, etc. related to EQF. The second by conducting the interviews with 21 academicians and 29 practitioners who are considered experts in these areas in the Eastern Province of the Kingdom of Saudi Arabia.

Sixty five performance criteria (variables) and their attributes were extracted to investigate and comprehend the EQF and used to build the knowledge base of environmental quality evaluation of office buildings. Also, the evaluation methods that the domain experts are using for assessing the environment of office buildings were analyzed.

A computerized unified program using Expert System for Environmental Quality Evaluation (ESEQE) of office buildings was developed simulating the methods that the domain experts used in office environment assessment. This computerized program correlated 100% with a hand worked solution.

Master of Science Degree
King Fahd University of Petroleum and Minerals
Dhahran, Saudi Arabia

June 1994

خلاصة الرسالة

إسم الباحث	:	ربيع محمد رفعت احمد
عنوان الدراسة	:	تطوير نظام خبرة لتقييم الكفاءة البيئية للمباني الإدارية
التخصص	:	هندسة معمارية
تاريخ الشهادة	:	يونيه ١٩٩٤م

يُصَمَّم ويُبْنَّي المبني الإداري ليوفر لمستعملية تأدية أعمال مكتبية مميزة. ويتأثر أداء هؤلاء المستعملين لهذا المبني بصورة واضحة بمدي كفاءته البيئية. ولقد صُنفت العوامل التي تعبر عن الكفاءة البيئية للمبني بأربعة عوامل رئيسية هي: الإضاءة ، الصوت ، الحرارة ، جودة الهواء الداخلي. وإن تقييم الكفاءة البيئية لمبني ما إنما هو دلالة علي مدي ما يحققه هذا المبني لمستعمليه من راحة بيئية.

وتتعرض هذه الدراسة لتقييم الكفاءة البيئية للمباني الإدارية بصورة متكاملة تتضمن كفاءة الإضاءة ، الصوت ، الحرارة ، جودة الهواء الداخلي. ولقد تم في هذا البحث إستخلاص المتغيرات لمعايير الأداء لعوامل الكفاءةا البيئية و كذلك المقاييس (الرموز) لهذه المعايير من مصدرين أساسيين أولهما دراسة مستفيضة و فاحصة لمعظم ماكُتب عن عوامل الكفاءة البيئية من كتب و أبحاث ، والثاني من خلال مقابلات شخصية تم إنجازها مع (٢١) من الأكاديميين و (٢٩) من العمليين والذين تم إختيارهم بعناية ويعدُون من الخبراء في عوامل الكفاءة البيئية بالمنطقة الشرقية بالمملكة العربية السعودية.

ولقد تم إستخلاص عدد (٦٥) معيار أدائي وكذلك المقاييس الخاصة لكل معيار أدائي ليتم علي أسا سها فحص و تقييم عوامل الكفاءة البيئية بصورة متكاملة. ولقد إستُخدمت هذه المعايير و مقاييسها في بناء قاعدة المعلومات لتقييم الكفاءة البيئية للمباني الإدارية في المناطق الحارة.

وفي هذه الدراسة تم إستخدام أنظمة الخبرة لتطوير برنامج فريد يُنفذ بواسطة الحاسب الآلي ويستخدم لتقييم الكفاءة البيئية للمباني الإدارية و يحاكي الطرق التي يستخدمها الخبراء في هذا المجال. ولقد أعطي هذا البرنامج نتائج متوافقة ١٠٠٪ مع نتائج التقييم التي يجريها الخبراء في مجال الكفاءة البيئية للمباني الإدارية.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول و المعادن
الظهران ، المملكة العربية السعودية

يونيه ١٩٩٤م

CHAPTER 1

INTRODUCTION

In matters of accommodation it is the user who is more and more in the center. The word user does not refer only to the owner or the lessee of a building but in particular to the person at the workplace. An office building is designed and built to host a group of people performing distinct office work. The performance of the users of such a building is substantially influenced by its environmental quality.

Environment, in its broadest scene, is that man's environment which can be described as a stimulus field to which he responds in some way. The physical limits of man's environment cannot be defined in precise terms, as stimulation arrives from a great range of distances. Touch requires direct contact. Strong odors can be smelt at a distance of several hundred meters. A loud noise can be heard several kilometers away. The eye can perceive light from distant stars. Thus, if we take the environment as limited by the range of human sense organs, the tactile, olfactory, sonic and luminous; environments will all be of different magnitudes [Szokolay, 1980].

We can speak of the momentary environment of one person in a defined position or state. We can distinguish the working environment of a group of persons throughout the working hours. We can consider the general environment of a large number of people throughout everyday life, a whole town, for example use the term of "environment" is equally justified in all these cases, but it is important to specify at what level we speak of it. The term "environment" implies a subjective view point [Szokolay, 1980].

Environmental quality is the combination of environmental elements that interact with users of an office building to enable that office environment to be the best possible one for the activities that go on in it. Environmental quality in one office building is not necessarily resemble the environmental quality in another similar building in every detail, but there are number of constants across both building environments that determine the quality environment level in almost all office buildings.

Environmental quality is a question of degree. Most offices can be a degree or more better than they are now. The question is not why improve office quality. People simply work better in a better quality environment. the question is really, why not improve office environmental quality. For doing that the evaluation of office environmental quality is essential [Vischer, 1989].

There is, since the energy crises, great pressure on the architect to design office buildings that use less energy and therefore cost less to run and this may strongly influence the basic design of the building. In this new situation, close liaison with some source of environmental analysis is vital, the current method of sending the design to and fro between the engineer and the architect for analysis and refinement is clumsy and inefficient, and may will lead to poor compromise, or to the engineer having undue influence over the design [Reynolds, 1980].

It is common knowledge that architects have become increasingly concerned with building evaluation in recent years. The growth of this concern probably stems from the architect's new interest in the user, instead of measuring his building against aesthetic standards. He now wants to measure it against utilization standards. At first glance the idea of office building evaluation seems fairly clear cut. What one wants to determine is how well the building fulfills the functions it was intended to serve [Gutman, and Wester Gard, 1989].

In any case, user expectation of comfort have been steadily rising and most people in offices expect their work place to be adequately heated and ventilated winter and summer; they also expect reasonable standards of acoustic isolation and privacy. If the building is not to be very expensive to build and run, therefore, careful analysis of its environmental quality is essential [Reynolds, 1980].

1.1 STATEMENT OF THE PROBLEM

The twentieth century has seen tremendous change in almost all aspects of human arts and sciences. Architecture, bridging both realms, has grown and changed at an accelerated pace since the century began. By around 1950, some architects had broken rank with their historical roots, pursuing creative excursions with scant attention paid to any precedent from the past. Under this new system, many office buildings were built. Unfortunately, this practice too often resulted in buildings that are photographed well in the slick publications of the trade press but that many have lost touch with their purpose of providing an appropriate setting for working, planning, healing or learning [Preiser, 1988].

In recent years analysis of the environment in office buildings has been turned over almost entirely to the mechanical and electrical services engineer. The Architect has normally relied on experience and rules of thumb to produce an adequate basic design and the engineer has worked out the details of the lighting and the heating, cooling and ventilation plant needed to serve the design. Occasionally he would advise the architect to change some details if it would give significant advantages in simplicity or cost saving [Reynolds. 1980].

A major function of an office building is providing a comfortable environment. This environment conventionally is defined in terms of specific factors which building services specialists and architects have to design into building with specified values laid down by regulatory bodies: thermal comfort, acoustics and so on.

Griffiths, Huber, and Baillie (1987) indicated that the environmental factors are evaluated traditionally independently of each other by the designer although the designer typically tries to solve the individual problems by an integrated approach. Decision about day light may have severe consequences for thermal comfort and decisions about how to deal with noise problems may lead to sealed building with consequences for air conditioning. This process may produce office buildings with poor quality working environments even if the individual environmental experts are competent in their field. **So, the integration of environmental quality factors is important.** A solution of the EQE problem may well be provided by the use of computer [Reynolds, 1980].

This study attempts to develop a system to aid architects in evaluating the environmental quality of the working environment of office buildings. This could be done by creating an expert system for environmental quality factors.

Environmental Quality factors in office buildings. Environmental science is the body of knowledge concerning the environmental quality and its relationship to humans. For the designers this must be extended to include a study of changes from user actions and the effects resulting therefrom. They must be able to predict the consequences of their decisions.

1.2 OBJECTIVES OF THE STUDY

This study is initiated to achieve the following objectives:

1. Analyzing the evaluation methods that the experts in the eastern province of the kingdom of Saudi Arabia are using it for evaluating the office building environment in the tropical areas.

2. Developing a computerized expert system model for evaluating the environmental quality (lighting, acoustic, thermal, and indoor air quality) of office buildings during its design stage and simulating the expert thoughts in an integrated approach.

1.3 SIGNIFICANCE OF THE STUDY

The significance of this study is supported not only by the lack of existing methods used for evaluating the environmental quality of offices but also by the substantial and unfulfilled need for an integrated EQE in offices during the design stage [Griffiths, Humber, and Baillie, 1987] and [Milbank, 1978].

Also, this study endeavors to fulfill the architect's desire to evaluate their buildings during design stages, and to know if their buildings and space will support the work activities and the environment inhibit or restrict successful completion of those activities.

In order to implement the EQE more easily, accurate and efficient, the study proposes to develop a computerized program using an expert system to help the architects conducting the EQE. Also, the architects will benefit from the previous experience of experts' knowledge which will be used to build the computerized program.

EQE of a new building provides a valuable feedback loop. A detailed, careful examination can be balanced to fine tune the new building, or it can help others learn from the experience [Lushington, 1990].

And also, it can help not only for trouble shooting during the shake down period, that is after the move in, thereby correcting unforeseen problems in building use but also for documentation of successes and failures in building performance, thus justifying new construction or remodeling for existing building.

On the other hand, most people like to quantify things. We ask questions, such as what is the score? A symbol such as "Score" is good way to immediately perceive a situation [Pena, 1977]. For that reason we want to quantify environmental quality to have score.

Finally we can summarize the significance of the study for the following:

1. Need in the industry.
2. The EQE will enable the architects and engineers to improve the design to achieve the satisfaction of clients and users.
3. Changes at the design stage are very cheap as compared with the cost after the project completion.
4. Architects will regain the control over design.
5. The computerized expert system model will provide the architects and engineers with accurate, easy, and more efficient results for EQE of office buildings.

1.4 SCOPE AND LIMITATIONS

The scope of this study will be limited to the followings:

1. In respect to the environmental quality of office buildings the main factors: acoustics, lighting, thermal and indoor air quality are necessary to achieve comfortable environment inside office buildings.

2. Office buildings are chosen for the EQE because of environmental quality has great effect on office worker morale, and productivity.

3. The study will be limited to air conditioned office buildings because it is essential in the arid region environment of Saudi Arabia.

CHAPTER 2

LITERATURE REVIEW

The review or relevant literature will be handled in three parts: Office Building Organization, Environmental Quality in Office Buildings, and Evaluation of Environmental Quality in Office Buildings.

2.1 OFFICE BUILDING ORGANIZATIONS

2.1.1 OFFICE FUNCTION

Most employees in advanced economics work in offices. Office work primarily involves handling information and making decisions based upon information. This definition hides enormous variations in size of office organization, office technology and styles of management.

Much office work is sedentary but offices also include spaces for machinery, canteens, meetings, filing, libraries and other ancillary activities which can take up 1/3 of spaces needed by organization [Neufurt, 1990].

Office organizations change rapidly in many respects. Extreme care should be taken to avoid building obsolescence into a new building.

2.1.2 OFFICE BUILDING LAYOUT BY FUNCTION

Office operation is like a large machine which needs to have all of its parts synchronized and moving smoothly. Each office function must mesh smoothly with the others with a minimum of friction.

The office machine's source of power is information, and it is the purpose of good office layout design to permit this information to flow smoothly, avoiding unnecessary turns and traps. There is certainly no one office layout that will fit all companies, any more than there is an all-purpose machine, but there are some reasonably good principles of layout by function that could be applied to any office situation. [Joesph, 1990].

If we were to make a list of the typical office functions, we would find it quite a long one. Every office needs management, communication, filing, billing, payroll, purchasing, and accounting. Other functions are added, according to the purpose of the business such as production, production engineering, quality control, shipping and receiving, cost accounting, industrial engineering etc.

However, all office function can be categorized into one of these six groups: [Joesph, 1990].

1. Management
2. Finance
3. Sales
4. General Services
5. Production

2.1.3 OFFICE BUILDING TYPES

There are two types of office buildings, conventional planning and open space planning.

2.1.3.1 CONVENTIONAL PLANNING

Before landscape planning came along, conventional planning had become so well established that it hardly needed description. Now that it is being changed, it is necessary to review what the more traditional approach really is. It derives from the method of architects in dealing with may different kinds of building design and can be summarized as involving these steps [Pile, 1976].

1. The functional needs of the client that have called the project into being are listed.

2. These needs are related to space requirements in a specific way. This leads to a listing of so-called spaces, rooms that are required with the approximate square foot areas that each will require.

3. The interrelationship of these areas is studied to determine which things to be near each other and which can be far apart. In office planning this usually means using the typical business organization chart to identify departments and their interrelations.

4. Other requirements for the expression of hierarchical status, special desires for superior esthetic values, etc., are noted and allowed for. Top

people go to corner windows. Board rooms get carpet and oil paintings.

5. Circulation patterns are studied to attempt simple, direct, and linear routes of movement.

6. Planning is continued according to current architectural esthetic preferences for orderly, orthogonal, geometric relationship with, possibly, occasional variations in limited introduction of curved forms or diagonal patterns.

The goal is a plan that will look clear and organized, under the assumptions that this will lead to qualities of clarity and organizations in the built space. An example of typical conventional planning is shown in figure (2.1).

2.1.3.2 OPEN PLAN SPACE

The idea of open plan space involves the following basics:

1. Planning based on a serious study of actual patterns of communication and work flow rather than on the formal patterns illustrated in conventional hierarchical organization charts.

2. The abandonment of fixed or semi fixed partitioning of office space into rooms. This makes possible a new degree of flexibility so that layouts can be changed quickly and inexpensively to accommodate to organizational change.

3. Abandonment of any reliance on regular orthogonal geometry as a basis of planning. Free grouping of clusters of workplaces is substituted, leading to the sense of the irregularity characteristic of landscape plans.

4. Several other less important features will be mentioned here. Although in recent years not every office landscape has incorporated all these features, they were regarded as essential by the quick borne team [Pile, 1976].

A. Instance that open planning be applied to all of an organization, including its top executive levels.

B. Minimization, of storage at workplaces and elimination of filing distributed through the office in favor of a highly developed, central filing system.

C Provision of employee lounge spaces freely available to staff for rest and coffee breaks.

D. Growing plants used extensively as secondary visual barriers and soften the otherwise possibly forbidding character of the office space.

In what might be called "orthodox quick borne " planning, these principles are still respected. However, in many variants one or several of these lesser points are ignored. An example of open plan office is shown in figure (2.2).

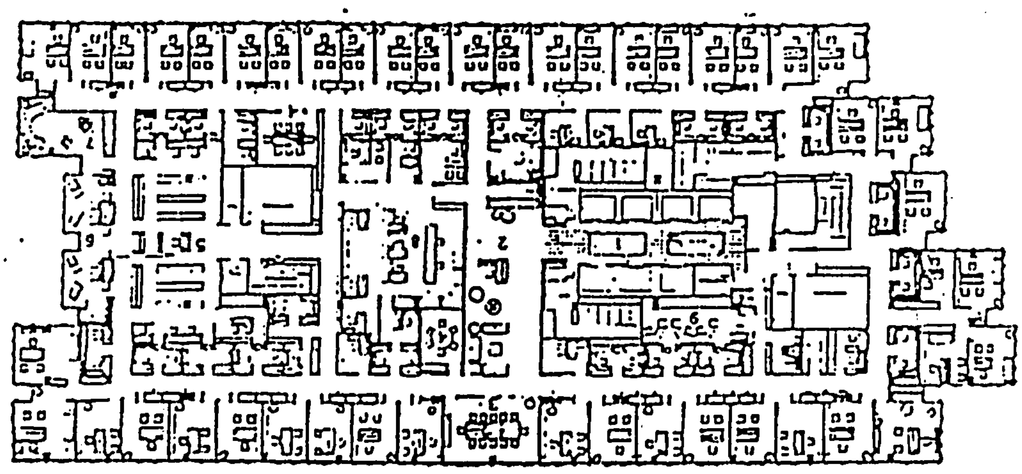

Figure (2.1) Typical Conventional planning [Pile, 1976].

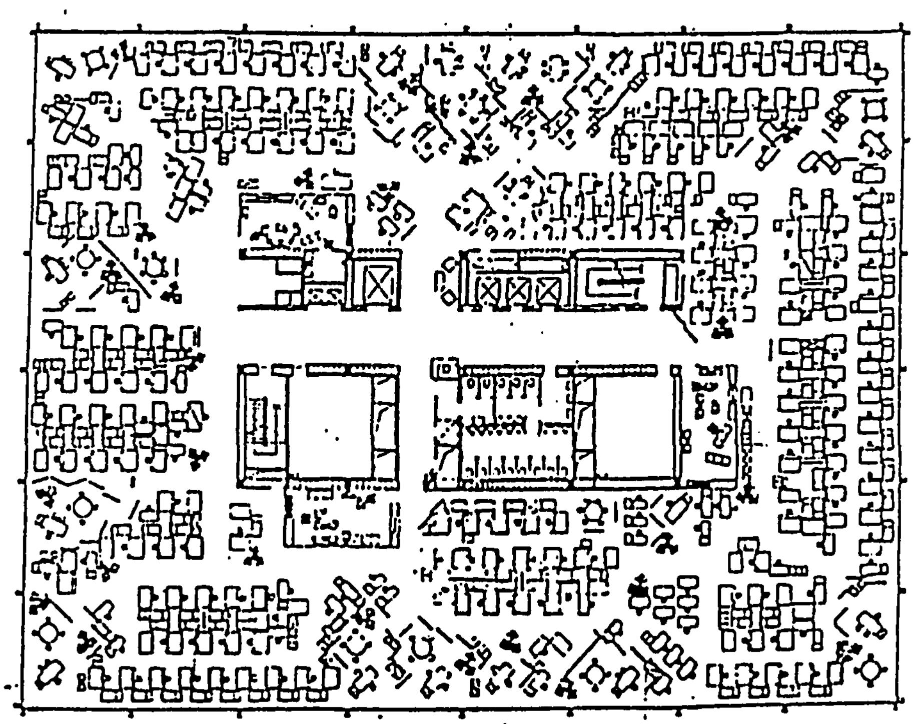

Figure (2-2) Open plan office [pile, 1978].

2.1.4 OFFICE PLANNING CONCEPT

The office planning concept has a strong effect on design. The concept is properly dealt with in programming, since it influences building size and form. Two main concepts may be considered: the conventional plan in which most of the building perimeter is taken up by fully enclosed private offices and the open plan, which assigns all or most occupants to spaces enclosed by low screens or modular furniture.

There are several pros and cons for each of the two main concepts. As implied by its name, the conventional plan for many years has been the customary way of arranging office space, and it may be ingrained in the attitudes of at least the older generation of management. In a corporate headquarters, where the ratio of managers to clerical and technical people may be quite high, application of the conventional plan may result in the use of almost the entire perimeter for enclosed office.

The advantages of the conventional plan are: [Joseph, 1990]

1. Visual and aural privacy can be provided for the offices of executives and managers.
2. The plan is well suited for a company the wishes sharp lines drawn between ranks of its staff and that considers a private office a measure of promotion.
3. The need for conference space is minimized.

The disadvantages include:

1. Partitions must the documented or demolished when space changes are necessary.

2. Natural light and view of the exterior is denied to those working in the interior.
3. The energy savings made possible by directing natural light to the interior are minimal.

The open plan has its ultimate application in the office landscape concept, whereby even senior executives are situated in open areas screened by low partitions or plantings. Office landscaping originated in Europe and was introduced in the USA in the 1960s, where the concept was employed in such major corporate headquarters as Uniroyal and Weyerhaeuser.

In recent years, open planning has gained acceptance, but few headquarters today are designed with enclosed offices for senior executives and high level managers. In the resulting compromise plan, managers below a certain level may be assigned to comfortably sized work stations. Inherent in the open planning concept is the need for an acoustical environment that offers aural privacy.

The advantages of the open plan are : [Joseph, 1990].

1. Most employees enjoy natural light and a view of the exterior.
2. The plan is highly flexible. Space can be arranged or offices moved with relative ease.
3. By using modular work stations, variations in the user's needs can easily be accomplished.
4. The plan is compatible with energy conserving design.

The disadvantage of the open plan includes:

1. There is , inevitably, some loss of aural and visual privacy.
2. The plan is not feasible in buildings with narrow wings or many obstructions.
3. Orientation of visitors may be more difficult than in the conventional plan.
4. More conference space may be necessary than for the conventional plan.

As noted above, recent office plans represent a compromise between the two basic concepts. This usually requires that part of management staff be assigned to open locations. However, such offices can be placed on the perimeter to preserve the intent of the conventional plan. Another compromise involves the executive core concept which places fully enclosed offices (with glazed wall sections) at the interior, thus keeping the perimeter open to the interior.

2.1.5 THE MAIN ELEMENTS OF OFFICE BUILDING

The office Building elements will show the most important items which make up the office buildings design.

2.1.5.1 RECEPTION AREAS AND VISITOR CONTROL

Visitors receive their first impression of an organization from the decor and layout of the reception area. It should be attractive, neat, businesslike, and above all, adequate to accommodate normal visitor traffic [Joseph, 1990].

The reception area may have to fulfill a number of functions; in determining the appropriate size, layout and form, consider the following: [Bailey, 1990].

- Traffic flow of staff and visitors
- Relationship between entrance and main circulation, Horizontal and vertical access to office areas; meeting rooms, lavatories etc.
- Number of people likely to be waiting at any one time and type of seating.
- Security requirements.
- Image.
- Visibility from outside

2.1.5.2 OFFICE WORK PLACE

There are two types of office workplace: conventional plan workplace, and open plan workplace. These two types were discussed in items 2.1.3 and 2.1.4

2.1.5.3 CORE

The office building core could be defined as the heart of the office building and consists of the following [Neufurt, 1980].

A. Elevators

Number and size depend upon population of building, number of floors, and required waiting time. Elevators should be grouped so that availability of any elevator in a bank or in any floor can be easily observed. In tall buildings elevators are usually grouped to serve 10 or more floors.

B. Ducts

Vertical ducts required for heating, telephone, electric's, drainage, and water supply; also in Air-conditioned building for air movement. Provide on generous scale, particularly for increasingly important electric and telecommunications.

C. Lavatories

The numbers of lavatories depend on the population on the floor.

D. Stairs

Width of stairs is determined by regulation on means of escape and in particular by numbers of staff to be provided for.

E. Cleaner's cupboards

On each floor of multi-story office building provide cleaners' cupboard containing store and slop-hopper.

2.1.5.4 MEETING AREAS

The term "Meeting" can cover a very broad spectrum of activities, including: [Bailey, 1990]

- Informal discussion around a desk
- Group discussions around a table
- Formal meetings or presentations
- Gathering of the entire staff
- Interviews
- Conferences, training sessions, lectures, Seminars etc.
- Trades union or other staff meetings

Many of these functions overlap in their requirements. Types of meeting space are categorized at those occurring at the workstation, meeting areas within normal working space (i.e. those defined by furniture and other flexible elements). Table (2.1) shows the characteristics of meeting types.

The conference and meeting room should be centrally located to the users. Interior space, which is not the most desirable for office purposes, is well suited for conference use. This location eliminates outside distraction and the need for window covering during visual presentations. Access to conference rooms should be through corridors or through reception areas [Joseph, 1990].

2.1.5.5 REST AREA

In contrast to largely physical activity, which puts a load on body frame and muscles, sustained office work, because of the small amount of movement involved, tends to tire the central nervous system which can have repercussions on the heart and circulation. Consequently, office workers need relaxation, refreshment and other interests at regular intervals.

Such breaks of relaxation are particularly helpful when each person is able to take them just when his own biological "clock" tells him he should, and when he does not have to spend these breaks at this desk. Special rest areas are important; they should be close to the place of work but visually and acoustically separated from the work environment; they should be placed conveniently for washrooms and WCs, and if possible near windows, so that people can see outside and even get out into the open if possible. There should be enough seats for at least 10 percent of the employees at any one time [Kraemer, 1977].

TABLE (2.1) CHARACTERISTICS OF MEETINGS TYPES [BAILEY, 1990].

Type of Space	Usage	Provision, furniture & equipment	Location
Provision at the workplace 1. Meeting at Desk	Short discussions, briefing subordinates, personal interviews	1 or 2 visitors chairs at workstation	Screened if in open-plan space.
2. Meeting area Working discussions amongst staff or with visitor	Table, chairs, pinboard, white board		
Provisional for a group of workplaces 3. Meeting area	Working sessions within group or personnel from outside. May last several hours	Table, chairs, screening, flip charts pinboard, white board Possible location for group notices	Within group area adjacent to primary circulation to limit disturbance
Provision for all members of staff 4. Interview room	Interview personnel or sales represent-tatives. Discussing with members of public. Short periods of use up to 3/4 hours.	Aural and visual privacy required	Good access from main reception and departments with major usage. May require adjacent waiting area if used frequently.
5. Meeting Room	Meetings with outside visitors or internal policy making and planning meetings. Duration 2-3 hours.	Slides, overhead projector, flip charts, dimmer lights, good ventilation. Storage for drinks and audio visual equipment	Ease of access to all departments. Easily services with refreshment. Access for outside visitors without going through work areas. Coats storage adjacent.
6. Rest area	Primarily for refreshment breaks, but also an area where general notices can be displaced. Used throughout the day for short periods.	Vending machines, stand-up counters low tables and easy chairs. Display board. Screening form work area.	Adjacent to WCs and rest room. Easily accessible to all personnel.
7. Boardroom	Formal board meeting, signing of contracts. Management meetings. Business lunches and entertaining. 2-3 hours	Formal layout. Audio-visual equipment. Good ventilation. Space and facilities for stenographer.	Anteroom for coats and refreshments attached
8 Conference room	Presentations Working discussions with outside visitors	Audio-visual equipment. Dimmer lights and black-out. Storage for equipment and furniture. Allow space for alternative layouts.	Easy access for visitors.
9 Lecture room	Large conferences, presentations, lectures and training sessions	Video display. Control room for audio-visual equipment	Adjacent area for audience to assemble before/ after meetings

2.1.5.6 CIRCULATION AREAS

This is the area required to conveniently permit ingress and egress to workstations. The size of an aisle should be governed by the amount of traffic it bears.

The following categories with regard to internal circulation will be:[Joseph, 1990].

A. Aisles leading to main exits from areas which carry substantial traffic (Main Aisles).
B. Aisles which carry a moderate amount of traffic (Intermediate Aisles).
C. Aisles between rows of desks (secondary Aisles).

2.1.5.7 SPECIAL SERVICES

Offices may contain special areas like library, computer rooms, exhibit space, etc.

2.1.5.8 GENERAL SERVICES

General services are mainly the heating, ventilation, and air conditioning (HVAC) systems which have many components, some of which take up a large area [Bovill, 1991]. Also, electrical services.

2.1.5.9 STORAGE

Office workplace should not be used for bulk storage. Only working inventories of office supplies and other materials should be maintained in offices, preferably in standard supply cabinets. Secondly space, such as basement areas, should be used to locate supply operations [Joseph, 1990].

Filing cabinets are still predominant method of storing office paper: but other possibilities, including suspended and lateral filing, which can be considerably more efficient in space use. Micro film can be used to reduce bulk of paper because of complexity of information stores, frequency of retrieval cost, and legal requirements to keep original copy [Neufurt, 1980].

2.1.5.10 PARKING AREAS

In respect to the car parking locations there are two alternatives that could be used for that purpose, open areas around the building and floor areas inside the building. In the second one, which is infocus of the study, the most important aspect on it is the ramp systems.

> A ramp system includes any portion of storage floors used by vehicles moving between levels. Nearly every successful ramp system requires vehicles to follow an approximately circular path when traveling between parking levels. The number of 360 degree rotations required to circulate through the garage and parking structure height are major concerns. [Joseph, 1990].

2.2 ENVIRONMENTAL QUALITY IN OFFICE BUILDING

2.2.1 ENVIRONMENTAL QUALITY AND COMFORT

Quality in office buildings is that attribute of actions and things that, if present in office buildings, reassures not just those who work inside them but also the owners, developers and managers of such buildings and the people in the street who watch them being built and sit in their plazas and atria. Quality is something more than increased productivity of the individual or increased profit of the organization. To define quality is not an easy task, but speculation on the managing of quality is necessary before advancing a definition of "Environmental Quality".

Quality is the continuing stimulus which our environment puts upon us to create the world in which we live. Now, to take that which has caused us to create the world, and to include it within the world we have created, is clearly impossible. That is why quality cannot be defined. If we define it, we are defining something less than quality itself [Vischer, 1989].

We are quick, however, to recognize the lack of quality in something. Poor quality or lack of quality inspires criticism and rejection. The difficulty is not in knowing quality or in recognizing it where it exists, the difficulty is in assessing quality, in measuring it and objectifying it so that it can be described to others. Although the experience of quality is subjective, it is also consensus. This does not mean it is capricious or transient, this means it is real.

At the moment of pure quality perception, there is no subject and there is no object. There is only a sense of quality that produces a later awareness of subjects and objects. At the moment of pure quality, subject and object are identical [Visher, 1989].

From the point of view of those experiencing the quality, the fact there is a "later awareness" of quality means that the presence of quality can be defined- and communicated - to those who have not had direct experience of it. In fact, the experience of environmental quality - or working in a good quality environment - can be communicated to those who make decisions about buildings. Designers, building managers, and office workers', union, for example, may make an assessment of the quality of a particular environment to aid them in the next design, to help them set priorities on building improvements, or the intervene on behalf of their members.

Comfort may be defined as occurring when the range of stimuli are adequate for performance of a task, during which that stimulus or others do not detract attention from that task. Thus the stimuli must be above a minimal threshold of stimulation and below a maximum threshold of stimulation. The minimum threshold is that which just permits perception by stimulation of the sensory organs. The maximum threshold is that level at which the stimulation causes distraction, discomfort, pain, temporary or permanent damage to the sensory organ or which causes discomfort to other organs not directly associated with perception of the object of regard. For example, the visual perception of movement may include travel sickness and nausea. Acoustic energy can be so great as to cause bodily organs to vibrate and cause nausea [Harkness, 1993].

2.3 ENVIRONMENTAL QUALITY FACTORS IN OFFICE BUILDINGS

Environmental Quality in office building means the ability to provide lighting comfort, acoustic comfort, thermal comfort, and air quality for its occupancy, as well as to provide building integrity versus debilitation [Davis, 1986].

To begin with, the evaluation of the environmental quality in offices must breakdown into the relevant performance requirements: lighting comfort, acoustic comfort, thermal comfort and indoor air quality.

2.3.1 LIGHTING COMFORT

The term light refers to the sensation caused by a relative wave length of electromagnetic energy radiation, from about 380 to 780 nm (nanometer = 10^{-9}m). Loosely the term is also applied to the energy radiation itself. In a homogenous medium light travels along a straight path. Its velocity is approximately C = $3x10^{8}$ m/s (=300 000 km/s). Materials exposed to light behave in various ways. Some transmit light to a certain extent; these are referred to as transparent. Some block its passage; these are termed opaque. Behind an opaque object there will be no light (no direct light), i.e., it castes a shadow. A great thickness of glass or water will be opaque and a thin film of metal may be transparent or at least translucent. This term describes an object which transmits light, but breaks its straight passage and scatters it in all directions, creating diffuse light [Szokoly, 1980].

Traditionally, lighting has played an important part in building design implicitly if not explicitly, while architects have always recognized the visual environment as a top priority, in the context of space, form and color, with natural light. Until the post war period, prediction of day light in the interior was mostly associated with law rather than with comfort and convenience [Addleson, 1972].

Many factors may be relevant to the design of a particular lighting system. The following are the main factors that need to be considered, the priorities will depend upon the type of situation [McMullan, 1983].

2.3.1.1 LIGHT QUANTITY

The first requirement is the adequacy of lighting. This is a quantitative requirement, which depends on the nature of the visual task: the contrasts and fineness of detail present in the object to be viewed and the speed with which the object viewed changes. The possible consequences of errors must be considered at this point: errors in perception to be tolerated, permissible, or not? [Szokly, 1980].

The quantity of light reaching certain surfaces is usually the main consideration in designing a lighting system. This quantity of light on a surface is specified by illuminance measured in lux and, as this level varies across the working plane, an average figure is used. Service illuminance is the mean illuminance averaged over the area being considered and throughout the maintenance cycle of the lighting system.

The illumiance need for a particular task depends upon the visual difficulty of the task, the average standard of eyesight involved and the type of performance expected [McMullan, 1983].

2.3.1.2 DIRECTIONAL QUALITY

Depends upon the three dimensional effect required and the nature of the lamp and luminarie. It can be specified by vector and scalar illumninace [McMullan, 1983].

Scalar illuminance (Es) is the average illuminance received by a small sphere from all directions. It is thus the measure of the total quantity of light, regardless of its direction and measured in lux. Illuminance vector (ΔEmax.) is a composite quantity, having both a magnitude and a direction. Its magnitude is the maximum difference in illuminance between diametrically opposed points on the surface of the small sphere. The vector/scalar (ΔEmax. / Es) ratio is a measure of the directionality of light and is a good indicator of its modeling qualities. When the ratio equals 4, it means that we have a completely mono directional light. In practice this value is always less than 4. A value 0 indicates a perfectly diffuse, omni directional lighting [Szokly, 1980].

2.3.1.3 NATURAL LIGHT (DAY LIGHTING)

Daylighting may be used as a complete source of light or to supplement artificial light sources. The quantity of natural light inside a room is governed by the following factors. By analyzing these factors it is possible to describe daylight numerically and to predict its effect in a room [McMulan, 1983].

1. The nature and brightness of the sky.
2. The size, shape and position of the windows.
3. Reflections from surfaces inside the room.
4. Reflections and obstruction from objects outside the room.

Daylight factor is the ratio between the actual illuminance at a point inside a room and the illuminance possible from an unobstructed hemisphere of the same sky.

$$DF = \frac{Ei \times 100}{Eo} \quad \text{[McMullan, 1983]}$$

Where DF = Daylight factor at a chosen reference point in the room (per cent)

Ei = Illuminance at the reference point (LUX)

Eo = Illuminance at that point if the sky was unobstructed (LUX)

2.3.1.4 COLOR QUALITY

Color is a subjective effect that occurs in the brain when the eye is stimulated by various wavelengths of light. It is difficult to specify color by any method and especially difficult by means of this black and white printing. But the description and measurement of color is important in the design of lighting schemes [McMullan, 1983].

The property of light which facilitates the perception of surface colors is termed "Color Rendering". This depends on the spectral composition of the light and not in its color appearance [Szokaly, 1980].

2.3.1.5 GLARE COMFORT

Depends upon the brightness and contrast of light sources and surfaces, and the viewing angles. It is usually specified by a glare index [McMullan, 1983]. Glare is a condition in which there is discomfort or reduction in the ability to see significant objects, or both, due to unsuitable distribution or range of luminance or to extreme constraints in space or time.

Also glare is the discomfort or impairment of vision caused by excessive range of brightness in the visual field. Glare can be caused by lamps, windows , and painted surfaces appearing too bright in comparison with the general background. Glare can be further described as disability and discomfort glare (McMullan, 1983].

Disability glare is the glare that lessens the ability to see detail. It does not necessarily cause visual discomfort and discomfort glare that causes visual discomfit without necessarily lessening the ability to see detail. the amount of discomfort depends on the angle of view and type of location. If the direction of view is fixed on a particular visual task, then glare caused by lighting conditions will be more noticeable.

2.3.2 ACOUSTIC COMFORT

Acoustics is the science of sound in general, whereas Architectural Acoustics is the control and manipulation of sound in buildings [Ibrahim, 1989]. Sounds consist of variety of different frequencies all occurring at the same time. Sound usually is initiated by mechanical energy (vibrations) coupled with the air which is converted to acoustic energy. This is then converted back into mechanical energy by the eardrum, ossicles, and basilar membrane. The signals from the basilar membrane are electronic to the brain [Harkness, 1993].

The objectives of good acoustic design are to enhance wanted sounds and control unwanted sounds (noise). People prefer to work in an environment that is quiet but not totally free from sound. People use sound for orientation and awareness and also for masking individual voices and conservations. People in offices need to communicate easily, both with each other and on the telephone, without the strain of shouting to be heard or the stress of feeling that all conversation is overhead. Different office tasks and activities vary widely in their acoustical requirements. Most offices are designed to standard acoustic specifications that do not respond to this wide variation in requirements [Vischer, 1989].

The acoustical environment in an occupied space is the resultant of the sound arriving at the space from the engineering services, the adjacent areas, the external environment, and from sound generation within the space. The main sources of noise in environmental noise control can be classified in two main groups:

a. Indoor Noise:

People are responsible for the most common noise sources, which are produced by loud conversation, sound of people moving, etc., and others from equipment like printers, typewriters, etc. and also from mechanical and electrical systems.

b. Outdoor Noise:

Most noises of this category are produced by vehicles, rail traffic, aircraft exposed mechanical or construction equipment, etc. Characteristics of some common sound sources are given in figure (2.3) [Ahmad, 1988].

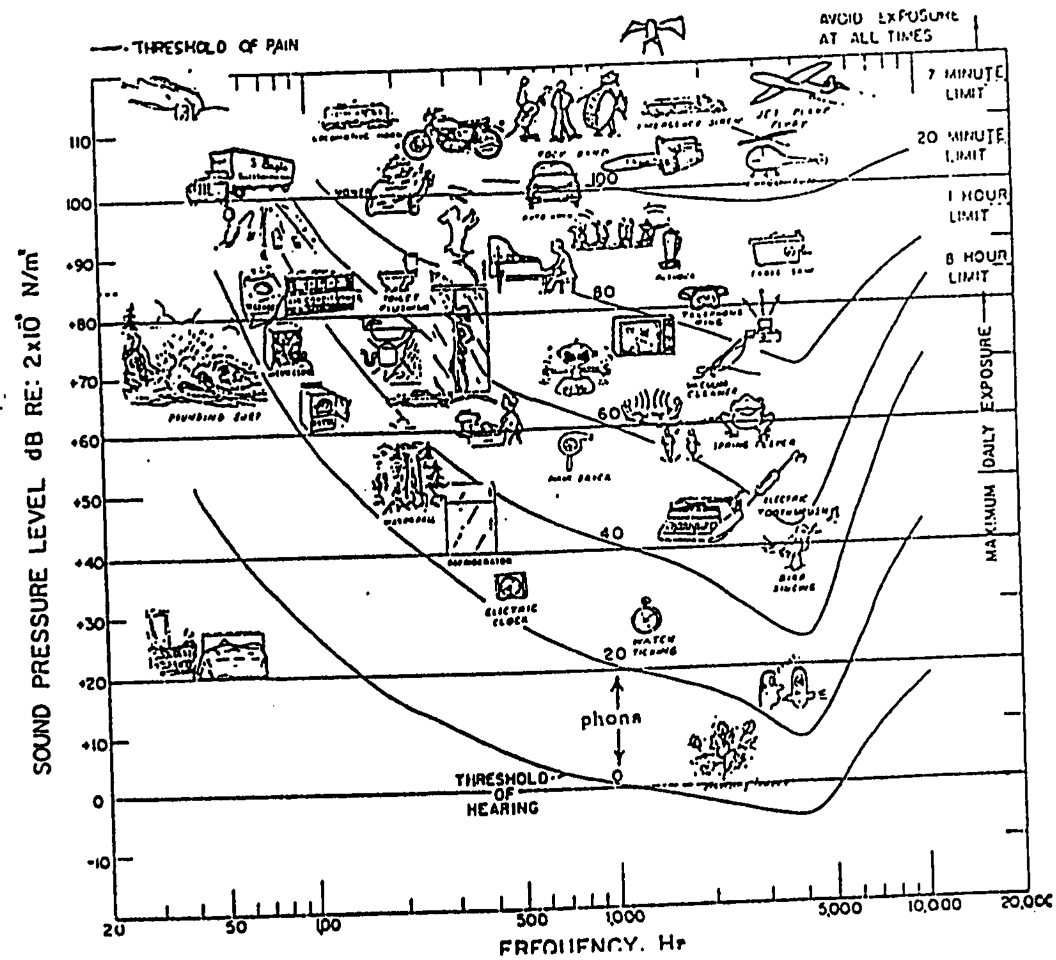

Figure (2.3) Characteristics of some common sound sources [Ahmad,1989].

In order to have a comfortable office space from the acoustics point of view, some acoustical principles should be considered: general noise level, noise criteria, speech privacy, noise from equipment, noise from air handling, noise from outside.

2.3.2.1 BACKGROUND NOISE LEVEL

There is always some ambient or background noise which is usually complex i.e., consisting of a variety of frequencies of different duration [Harkness, 1993]. An adequately quiet background is provided by the building enclosure and its exclusion of outdoor sound, and controls on the noise from building systems (such as lighting and ventilation). Adequate loudness of desired sounds and proper distribution of sound in a space depend on the shape of the room and the type of materials used as finishes. Adequate protection of office workers from unwanted sound (Noise) in their offices depends on spacing and furniture layout, on the finishing materials, and on the design and the sound transmission rating of various types of partitions [Vischer, 1989].

2.3.2.2 NOISE CRITERIA

Criteria have to be set according to the type of activity housed or the nature of the occupancy of the building considered. The first criteria is to avoid auditory damage. Instantaneous loss of hearing would occur at 150 dB, a level unlikely to be encountered in buildings. Much lesser levels can cause loss of hearing to persons exposed to them for prolonged periods.

In broad terms noise effects can be listed according to weighted sound levels:[Szoklay, 1980]

65 dB (A)	Up to about this level noise or unwanted sound may create annoyance, but the result is only psychological (nervous effects). Above this level physiological effects, such as mental and bodily fatigue, may occur.
90 dB(A)	Many years of exposure to such noise levels would normally cause permanent hearing loss.
100 dB(A)	With short periods of exposure to this noise levels the aural acuity may be temporally impaired (TTS = Temporary Threshold Shift) and prolonged exposure is likely to cause irreparable damage to the auditory organs.
120 dB(A)	Is painful.
150 dB(A)	Causes instantaneous loss of hearing.

2.3.2.3 SPEECH PRIVACY

The ideal office's acoustical environment will permit occupants to talk easily with a visitor or on a telephone without distracting or being distracted by those nearby. Speech privacy criteria should be established early in the planning process. For example executive and sensitive areas may require confidential privacy. The effect of confidential privacy is that the sense of a conversation can not be understood by persons in adjoining office or work station. Minimum privacy or the ability to avoid distractions from an adjoining offices or workstation is usually necessary for most office workers [Harris, 1981].

In partitioned offices speech privacy may be achieved by ensuring adequate sound transmission loss in the walls and windows between the occupants and persons outside that particular room, or may be achieved by ensuring an air seal around the door to an office using patent seals to the sides and top of the door and the use of a threshold that effects an air seal. In open planned offices, the need for speech privacy may require the introduction of particular levels and frequency of background noise and to provide some acoustic privacy. The introduction of background noise might include "White Noise" similar to that noise produced by noisy air supply distributors [Harkness, 1993].

2.3.2.4 NOISE FROM EQUIPMENT

A common acoustic problem in the open plan office is the equipment that generates noise. This noise does not have to be loud for workers to find it disturbing; persistent noise is also tiring and stressful because it contributes to an overall high level of sound in an enclosed space. Even the clatter of VDT keyboards can create a noise problem when there are many together in one room. Typewriters, copiers, and printers are well known noise generators. If such equipment does not come with sound covers (which should be used), order sound covers or have them made.

Enclose larger machines, such as mainframe computers, in their own rooms. Locate noisy equipment outside office areas or where the noise is least intrusive to workers [Vischer, 1989].

2.3.2.5 NOISE FROM AIR HANDLING

In a sealed building, occupants like to hear some sound from the air handling system, as this assures them that it is on. However, if it is a variable air volume system, some people become alarmed when the system cycles off. As a result, engineers often prefer air handling systems to be silent all the time. Unfortunately, this sometimes convinces users (especially those seated in poorly ventilated areas) that they are not receiving any air at all.

In a large number of offices , the background "whoosh" of air handling system is the only sound masking available and the desirability of knowing that air is being delivered out weighs the intrusiveness of background noise. Although, acousticans counsel against using air handling systems for sound masking, consider this as a solution to low background sound situations. People dislike of the sound masking "Whoosh" coupled with their desire to know that there is ongoing ventilation may make this a more effective sound masking option [Visher, 1989].

2.3.2.6 NOISE FROM OUTSIDE

When a given noise source exists outside the site, the first measure the designer can employ is to place the building as far away from the source as particular, but definitely outside the 68 dB contour. With a restricted site this may not be possible as it would waste much valuable land. The second measure would be to use some form of barrier at the boundary, but in some cases even this would be insufficient. If it is, the building itself can be designed in such a way that it turns its back, as it were, towards the noise source. This requires a plan arrangement which places the least noise - sensitive rooms on the exposed side and all major rooms and their windows on the side away from the noise source. The difference in noise exposure between two sides of a building can be as much as 30 dB [Szokolay, 1980].

2.3.3 THERMAL COMFORT FACTORS

Thermal comfort is the state of mind that express satisfaction with thermal environment [ASHRAE, 1981]. It is achieved through the gain and loss of heat to and from the human body to and from the environment. This heat exchange is called thermal balancing. Also, thermal comfort could be defined as the net effect on the occupant on the conductive, radiative, and evaporative balance that is established between the occupants and the environment [Contur and Kamerud, 1985]. A human being is said to be thermally comfortable when he can not say whether he would prefer cooler or warmer surroundings.

In general, the perception of comfort, temperature and thermal acceptability is related to one's rate of metabolic heat production, which is heat transportation by condition to the body services where it is dissipated through convection, radiation and evaporation; its rate of transfer to the environment and the resulting physiological adjustments and body temperatures. The metabolic heat produced must be dissipated in order to keep the body internal temperature at about 37 °C, and the whole body temperature at its correct level. So, if human beings are to be thermally comfortable, not only must the appropriate quantity of heat be produced, but proper balance must be maintained between various modes of loss [Alisani, 1988].

Sometimes it is thought that an adequate coverage of the design requirements for thermal comfort would consist simply of a schedule of required air temperature, air movement and possibly humidity. But, unfortunately, this is not true, because the human occupant is seldom limited to relying on the designer's thermal comfort alone to attain his desired environmental conditions [Fisk, 1981].

The following are the major six factors influencing thermal comfort and they are devided into main categories:

1. Environmental Factors

A. Air Temperature
B. Mean Radiant Temperature
C. Relative Humidity
D. Air Movement

2. Personal factors
   A. Activity Level
   B. Clothing

In addition of these factors, secondary factors such as the rate of change of any of the above mentioned factors could result in the change of comfort. If any of the above mentioned determinants (environmental and personal) changed, the other must be adjusted to maintain the thermal equilibrium between heat gain and heat loss in the body [Broadshaw, 1985]. Figure (2.4) shows human heat loss and thermal comfort factors. The factors are discussed as follows.

2.3.3.1 AIR TEMPERATURE

Air temperature is a temperature measurement which is independent of radiant heat from the surroundings [Broadshaw, 1985]. It is perhaps the most important determinant of thermal comfort, but not the only one, since a narrow range of comfortable temperature can be established almost independently of the other variables [Szokolay, 1980].

There is actually a fairly wide range of temperature that can provide comfort when combined with the proper combination of relative humidity, mean radiant temperature, and air movement. But, as any of these conditions varies, the dry bulb temperature must be adjusted in order to maintain comfort conditions [Broadshaw, 1985].

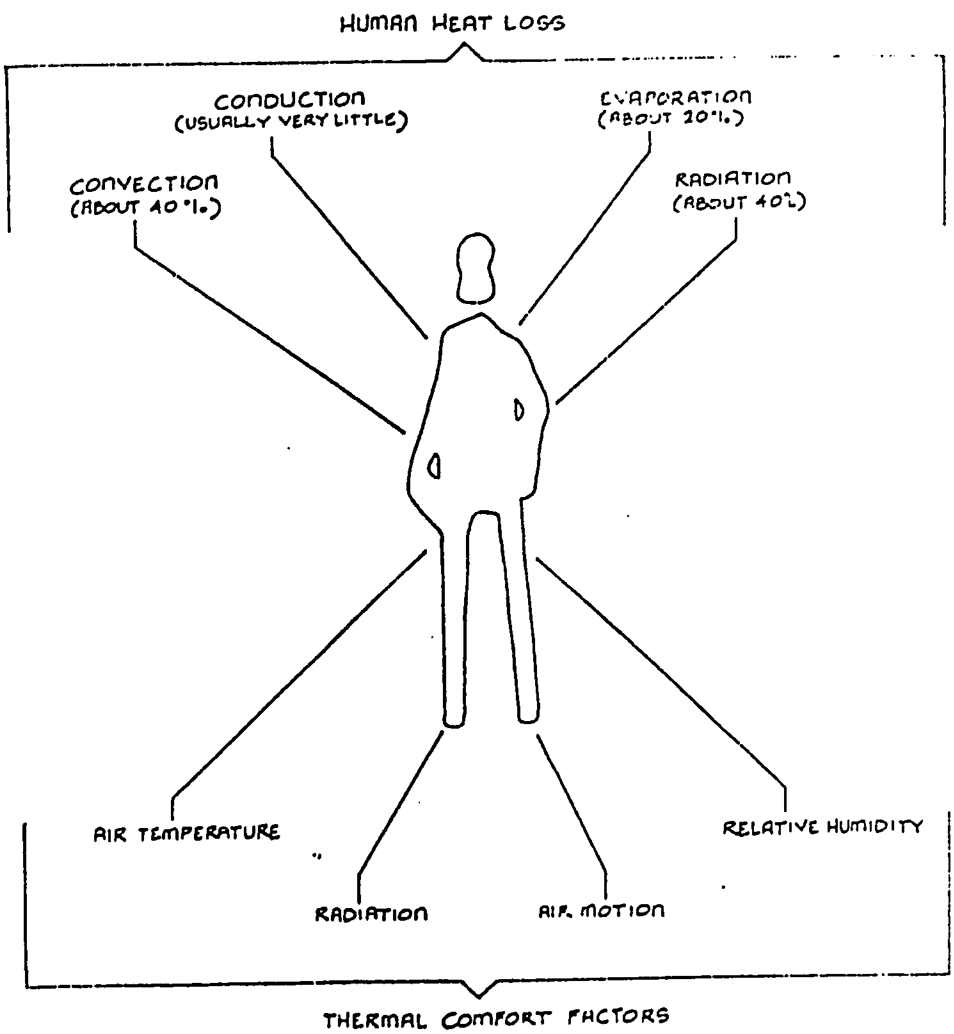

Figure (2.4) Human Heat Loss and Thermal Comfort Factors [Egan, 1975].

The human body also responds to these changes by some kinds of adjustments. For example, when the environmental temperature drops below the comfort zone, the skin temperature reduces (particularly of the hand and feet) and the tone of the muscles increases which elevates the metabolic heat production [Givoni, 1976].

2.3.3.2 MEAN RADIANT TEMPERATURE (MRT)

Human comfort within an enclosed structure depends upon the radiation exchange between the human body and the surrounding surfaces. The mean radiant temperature is the temperature of a uniform black enclosure in which a solid body or occupant would exchange the same quantity of radiant heat as in the real non uniform environment. MRT also could be defined as a distance weighted average of the surface temperatures in a space, and is closely related to the mean surface temperature [Smith, and Philips, 1982]. It can be as important as air temperature in affecting the rate of heat loss and comfort [ASHRAE, 1981]. In fact, some recent work suggests that the MRT of the environment is twice as significant as the dry bulb air temperature (DBT) [Szokolay, 1980].

2.3.3.3. RELATIVE HUMIDITY (RH)

RH, expressed as a fraction or percentage, is the amount of water vapor in the air compared to the maximum amount that can exists in a space at a given temperature, without condensation. Although it is the most immediately relevant as it determines the possible evaporation rate, it is not a useful environmental index unless the accompanying dry bulb temperature is known [ASHRAE, 1985]

The humidity of the air has little effect on thermal comfort sensation at or near the comfortable temperature, that is , comfort is maintained over a wide range of humidity conditions [Broadshaw, 1985]. Therefore human tolerance to humidity is much greater than tolerance to temperature [Egan, 1975].

Both extremely low and extremely high humilities have adverse effects. In cold discomfort, very dry air increases the feeling of cold, as there is always moisture reaching the skin surface through an osmotic process, which will evaporate and give an unwanted cooling effect [Szokolay, 1980]. On the other hand, high humilities cause condensation problems on cold surfaces, and retard human heat loss by evaporative cooling [Broadshaw, 1985].

2.3.3.4 AIR MOVEMENT (AIR VELOCITY)

Air movement results form natural and forced convection as well as from occupant's bodily movements [Broadshaw, 1985]. Since it is difficult to measure the air speed accurately, due to rapid fluctuation and variations, mean values of air speed are often used. Air movements significantly affect body heat transfer in two different ways, via convection and evaporation. The faster the air motion the greater the rate of heat flow by both convection and evaporation. Hence, it is one of the factors which must be considered when assessing human comfort conditions [Broadshaw, 1985], [Smith and Phillips, 1982].

The effects of air velocity and air temperature on the convective heat exchange in an occupied zone are interrelated, as the convection is a function of the product of some power of the velocity and the temperature difference between the skin and the air (Givoni, 1976].

When ambient temperatures are within acceptable limits, there is no minimum air movement that must be provided for thermal comfort, because the natural convection of air over the surface of the body allows for the continuous dissipation of body heat [ASHRAE, 1981]. But, when the temperature or the moving air is less than the skin temperature, the convective heat loss increases due to increments in air velocity, and thus, it produces cooling effects on the body [Szokolay. 1980]. As air temperature rises above skin temperature, natural air velocity is no longer sufficient and must be artificially increased such as by the use of fans [Broadshaw, 1985].

2.3.4 INDOOR AIR QUALITY

Indoor air quality is defined as an air in which there are no contaminants at harmful concentrations and with which a substantial majority of the people exposed do not express dissatisfaction (unhealthy) [Uthman, 1989]. Indoor air quality, which depends on many factors, will be discussed as follows:

2.3.4.1 VENTILATION COMFORT

The entry of external air is usually controlled mechanically in large modern buildings. It is obvious to limit the cold and hot air entering buildings in order to lower energy cost and energy consumption. The outcome of tight buildings with sealed windows and heavy insulation is increasing the chance of holding in pollutants [Gainen, 1985]. So, the ventilating system is more important, and is determined by the amount of air needed to provide risk-free and comfortable conditions to building occupants. Projections of the amount of fresh air provided are based on building design, heating, cooling, and occupancy loads. The total amounts of outdoor and recirculated air are specified to meet the projected requirements of the building based on the estimated number of individuals expected to occupy the building [Sterling, 1985].

2.3.4.2 AIR EXCHANGE RATE

Air exchange rate is the rate at which indoor air is exchanged with outdoor air. Air exchange rate should be viewed from three perspectives. Infiltration, natural ventilation, and mechanical ventilation. The rate is expressed as the volume of air exchange per unit time (hour is used as the time unit). Volume of air expressed in terms of the volume of the structure. A pressure difference between the indoor and outdoors is responsible for infiltration of air into a structure with closed windows and doors. Natural ventilation refers to air flowing into and out of a structure through open windows and doors, mechanical ventilation refers to air exchange that is driven by a motorized system or fan. Local or spot ventilation refers to the ventilation of only a part of a building, as is the case of a bathroom exhaust fan [Nagada, 1987].

2.3.4.3 INDOOR AIR POLLUTANTS

Indoor air pollutants are the prime concern of any indoor quality. Indoor pollutants are controlled by many factors affecting their indoor concentrations. These factors are the following Al-Qahtani, 1993].

1.	Carbon Monoxide (CO)	2.	Carbon Dioxide (CO_2)
3.	Nitrogen Dioxide (NO)	4.	Sulfur Dioxide ($SO2$)
5.	Formaldehyde	6.	Dust
7.	Fibrous Particles	8.	Ozone
9	Odors	10	Microbes
11	Tobacco Smoke	12	Hydro carbons

2.4 ENVIRONMENTAL QUALITY EVALUATION OF OFFICES [PAST, PRESENT, AND FUTURE]

2.4.1 STANDARDS OF ENVIRONMENTAL QUALITY EVALUATION FOR OFFICE BUILDINGS.

People making environmental quality decisions as managers of a buildings or members of a design team, or supervisors of a work group, are not only prejudging what quality is but are also assuming how much it is or will be worth to building users. Although each user has a sense of how much effort to exert to achieve a personally acceptable level of environmental quality, decision makers do not know how much environmental quality to provide for the people for whom they are responsible.

Bearing in mind that degree of quality, is largely but not exclusively a matter of affordability and cost, what kind of guidelines do we have, first, to formulate the right kinds of trade - offs between dollar cost and human benefits, and second, to make the right decisions an how to spend the limited money at your disposal?. There are some established ways for making decisions such as whether to improve lighting or analyze air quality, whether to landscape the outdoors or to provide sound covers for the computer printers. These are analytic problems solving models of decision making, which separate the problem into its component parts: namely, the building (its physical features), and the users (their behavior, needs, and satisfaction). For the purpose of this discussion, these ways of solving building problems are organized into four categories of problems analysis [Vischer, 1989]

- The application of standard and codes
- The satisfaction of user's needs

- The reductionist approach, and
- The environmental determinism

2.4.1.1 THE APPLICATION OF STANDARD AND CODES

Building designers and managers rely heavily on standards of comfort, health, and safety to ensure environmental quality. Standards indicate how much fresh air should be introduced into an office building's ventilation system; they prevent polluted air form cafeteria exhaust or underground garages from being recycled through buildings; they indicate how much light people need to see to do their work, they help protect workers from excessive noise; they monitor important structural items that prevent walls from cracking and roofs from leaking. The implementation of health and safety standards and building codes requirements is often seen as insurance to the decision maker (Building designer, owner, manager) and as assurance to the user (worker, occupant, consumer) that environmental quality is monitored in that building.

2.4.1.2 SATISFACTION OF THE USERS' NEEDS

Studies of the people / building relationship have tried to analyze and understand how to design optimum environments for people through evaluating existing buildings. Much of environmental evaluation relies on people's rating of their own satisfaction as the criterion of a successful environment.

The user satisfaction approach reflects the beliefs that the best buildings are those with the most satisfied users, and that to be good, environmental design should meet specific human needs. This assumes both that needs in buildings are constant and can be identified and that design is capable of meeting them. By creating a direct relationship between the number of needs and the number of need- meeting or user- derived design features in a building, a sort of hierarchy of user requirements is implied, as illustrated in figures (2.5).

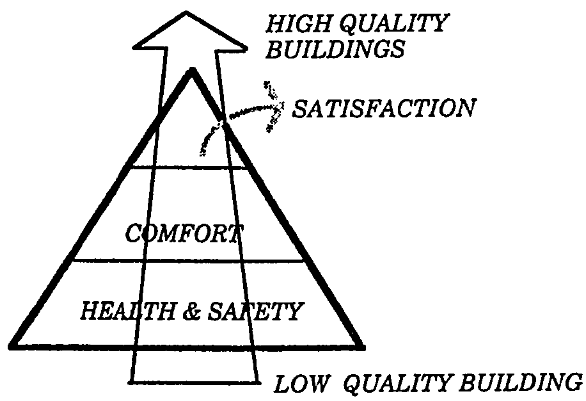

Figure (2.5) Habitability Pyramid [Visher, 1989]

The diagram shows that a building may meet the broad based human requirements for safety (At the base of the pyramid) and be habitable. If it also meets standards of comfort and satisfaction (at the apex of the pyramid), because they are the most personalized and therefore the most difficult to satisfy, it is more than just habitable - it is a high quality building [Vischer, 1989].

2.4.1.3 THE REDUCTIONIST APPROACH

The reductionism approach attempts to isolate units of environmental experience that, decomposed, can be observed and possibility measured, and composed constitute environmental quality. This approach applies the conventional scientific paradigm of analysis (decomposition) of the users' experience of the building. This is usually done through measuring user's perceptions of their environment. Students of the approach assert that such perceptions, in order to be reliable, must distinguish personal preferences, which are subjective and not reliable, and comparative appraisals, which are more reliable because the individual is judging the item in comparison to an implicit standard of comparison [Craik and Zubs, 1976].

2.4.1.4 ENVIRONMENTAL DETERMINISM

Environmental determinism assumes that people's behavior in buildings is directly caused by the physical elements of those buildings. Therefore, if people's behavior is unsatisfactory - they are complaining, they do not get along, or their work is not getting done, the solution of the problem lies in changing the design of the building. In this approach, the building and the environmental elements that it comprises are considered the stimulus, and what people do in buildings is seen as the response [Vischer, 1989].

2.4.2 AN OVERVIEW OF OFFICE ENVIRONMENTAL QUALITY EVALUATION (PREVIOUS WORK)

An ever - increasing number of persons are involved in office tasks which range from intellectual and creative to the routine and mechanical. As the number of office workers grows, increased attention is being directed to working conditions in offices and to the impacts of the work environment on professional effectiveness and productivity [Wineman, 1982].

Through the literature, the following are some of the studies have been done toward office environment evaluation.

2.4.2.1 THE AMBIENT ENVIRONMENT

Three aspects of the quality of the ambient environment (heating, ventilation, and air conditioning) are of major concern to office workers: Air temperature, the supply of exterior air, and air contaminants. Hardy (1974) found that good air circulation and right work place temperature are among the most important factors to office workers' comfort, yet these are factors with which many workers are dissatisfied (Louis H. and Associates, 1980). High-and low ambient temperatures have been associated with discomfort, physiological arousal, impaired task performance, irritability, and asocial behavior (Bell, F.) [Wineman, 1982]"

According to a report by the national research council's committee on indoor pollutants (1981), these efforts to achieve tightly sealed buildings, coupled with energy conserving reductions in ventilation rates, could aggravate problems of indoor air quality. Twenty possible air borne irritants have been identified as potential contributions to office workers' health complaints (Stellman 1977, 19871) [Wineman, 1982].

A recent study about the indoor air quality in the eastern province (Al-Qahtani, 1993) concluded that 30% of the surveyed building are proven sick building, 67% of the sick building have glass envelopes, and 44% of the sick buildings use corridors as a return duct. The study found that the indoor air quality factors have the highest effect on the reported symptoms with the following correlation factors: Odor strength 0.3872, dust accumulation 0.2966, and air clarity 0.2563.

2.4.2.2 LIGHTING AND VIEW

Users rank lighting as among the most important aspects of the office environment; it is also one of the factors with which office workers are generally satisfied (Louis H. and Associates, 1980; Kraemer et. al 1977).

Artificial lighting optimum illumination levels depend upon task difficulty and required accuracy. Both of the quantity of light and the perceived quality of light are important to office work. (Kraemer and his association, 1977) found that worker's evaluations of office lighting and office conditions in general, were influenced by the level of illumination at workstations and such qualitative factors as lighting level, contrast and glare. Another qualitative is color rendition [Wineman, 1982].

Natural lighting and view outside are important factors contributing to environmental satisfaction in offices (Louis H. and Associates, 1978; Wineman 19794) found that although office workers were satisfied with the quality and quantity of light on their work surface, they expressed a desire for a better view outside and more natural lighting [Wineman, 1982].

2.4.2.3 ACOUSTICAL PRIVACY AND COMFORT

A place to work without interruption has been identified as a principal factor in office workers' comfort (Louis Harris and Associates, 1980) Unwanted stimuli, such as noise, which interrupt activities or task completion can cause dissatisfaction. When auditory stimuli are unpredictable, controllable, or very intense, excessive arousal interferes with task performance. In addition, research suggests that the effects of noise on performance may continue after exposure to noise has terminated (Cohen, 1980) [Wineman, 1982].

Disturbance due to noise has been found to be a function of the sound source, the sound level, and the level of background sound. A certain level of background sound is necessary to mask conversations and other office sounds. Although sounds might be perceived by workers as quite loud, they are not necessarily distracting unless they stand out from or are not masked by background noise [Wineman, 1982].

2.4.2.4 BUILDING SYSTEM INTEGRATION

Al-Garny conducted a study about investigating and evaluating the system integration of office buildings and computed the performance index of such type of building. The study classified the systems to mechanical, envelope, interior and structure. The performance mandates for building systems are spatial, thermal, indoor air quality, acoustic, visual, and building integrity [Al-Garny, 1992]. The study developed a mathematical model that computes the performance index of the building from which an optimum combination and integration of systems could be determined.

2.5 CRITIQUE

The existing methods for environmental quality evaluations for office buildings are mainly focusing on evaluating each component of environmental quality (light, acoustic, thermal and air quality) separately. These methods cannot really determine the impact of importance for each environmental quality among others nor the impact of importance of each office building element among the whole elements.

A major function of office buildings is to provide a comfortable environment, which conventionally is defined in terms of specific factors which building services specialists and architects have to design into office buildings, with specified values laid down by regulatory bodies: thermal comfort, acoustic comfort and so on.

Traditionally, these have been treated as independent of each another, although the designer typically tries to solve the individual problems by an integrated approach. Indeed, this approach is necessary since, decisions about daylight may have severe consequences for thermal comfort and decisions about how to deal with noise problems may lead to sealed buildings with consequences for air conditions [Griffths, Huber, and Baillie, 1987].

The previous study does not provide architects and designers with the procedures to be followed in the assessment and evaluation of environmental quality of office buildings at the design stage.

Because of the substantial shortcomings of the previous methods, the development of an integrated environmental quality evaluation system of office buildings is a must.

Therefore, the proposed study will deal with environmental quality as an integrated component. First, we have to determine the assigned weigh for each environmental quality factor and for each office building design element. The scales of EQE have to be determined.

Using a computerized model (Expert System) to handle EQE will make the evaluation of environmental quality of office buildings more easily, accurate, faster and more efficient.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter presents all the necessary steps which were taken in the development of an expert system for environmental quality evaluation of office buildings at the design stage. These steps are shown in figure (3.1) and described in the following paragraphs.

3.1 SOURCES OF KNOWLEDGE

The first step in the development process was to decide on the sources of knowledge for the EQE of office buildings. Personal experience, text books, reports, papers, case studies, and empirical data were considered as the best sources for obtaining the necessary knowledge.

In view of personal experience, two kinds of professionals were considered to have the necessary knowledge for the EQE model. The professionals are practitioners and academicians.

The practitioner is defined as an expert if he satisfies the following requirements:

- His specialized work has to be one or more of the following activities:

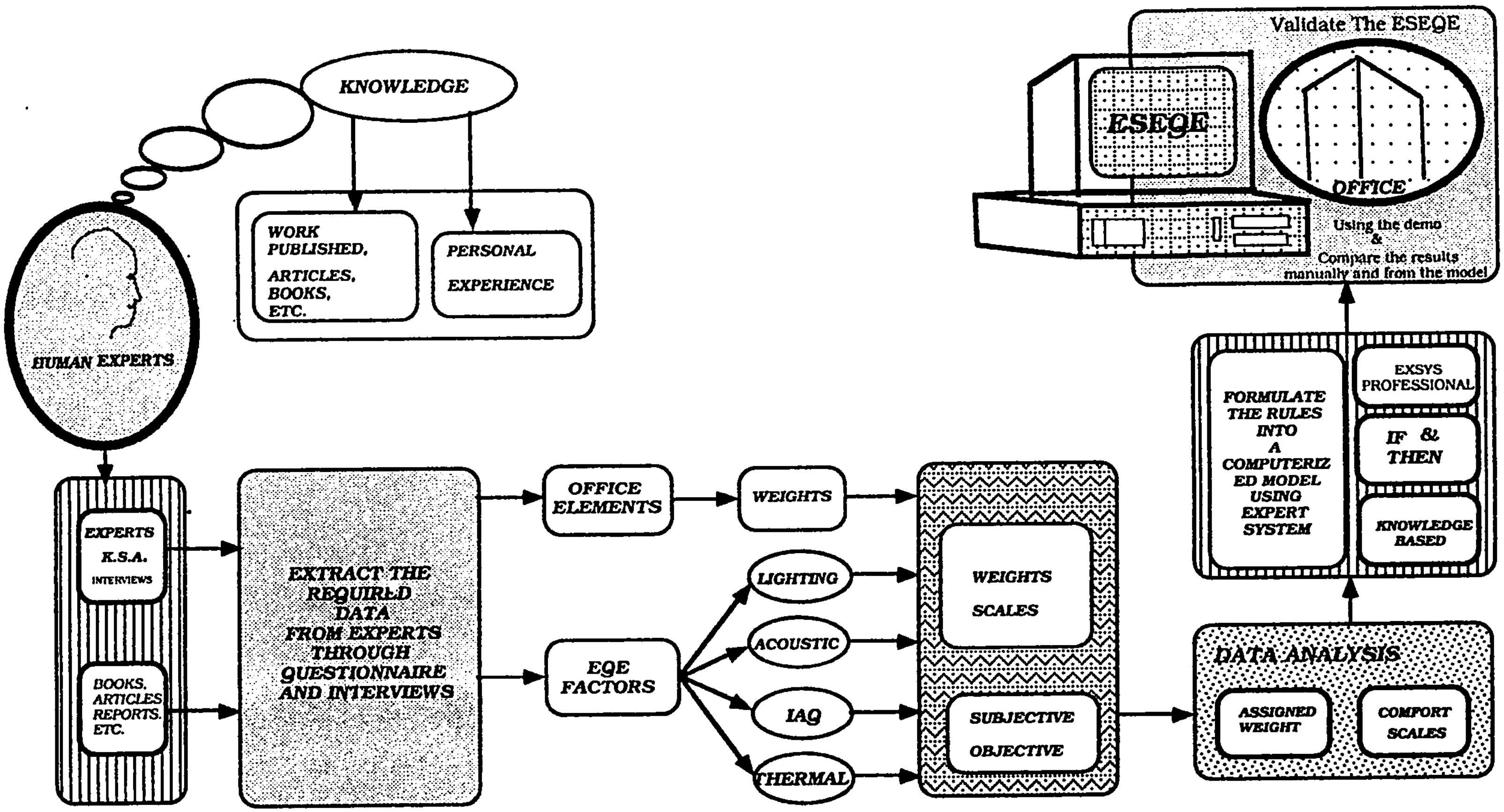

Figure (3.1) *Stages of an Expert System Development Cycle*

- Lighting design
- Acoustic design
- thermal design
- Indoor Air quality
- Facility planning

- Has experience with evaluation using comfort scales (subjective and objective) of office buildings.

The academic professional is defined as an expert if he satisfies the following requirements:

- His specialized work has to be one or more of the following activities:

  - Lighting design
  - Acoustic design
  - thermal design
  - Indoor Air quality
  - Facility planning

- Contributed or published work in his specialization.
- Has experience with evaluation using comfort scales (subjective and objective) of office buildings.

3.2 EXTRACTION OF REQUIRED DATA

The second step in the development of the EQE was to extract the knowledge from the experts. At this stage the following will be determined: concepts, relations, and control mechanisms are needed to describe problem solving in the EQE of office buildings. And also, Sub tasks, strategies, and constraints related to the problem solving will be explored. The level of knowledge base represented will have to be determined. The knowledge and data required at this stage are:

1. Comfort condition ranges of environmental quality factors of office buildings in the tropical areas
2. The importance of each office building element among other office elements.
3. The importance of each Environmental Quality (EQ) factor among other EQ factors for each office building element.
4. The performance criteria that should be considered in EQE (Lighting, Acoustic, Thermal, and Indoor Air Quality) for an office building at the design stage.
5. The scales that will be used (subjective and objective) to assess each performance criterion.

3.3 DATA ANALYSIS

The third step in the development of the EQE was to analyze the extracted knowledge and data from both sources: experts and literature.

An intensive literature review was performed and comfort condition ranges of the performance criteria of the environmental quality factors and their scales such as comfortable, reasonable and uncomfortable were extracted.

Other knowledge and data were obtained from experts in the Eastern Province of the Kingdom of Saudi Arabia. A structured questionnaire was developed to collect the necessary knowledge and data. This questionnaire consists of seven parts covering most of the related points to the environmental quality evaluation of office buildings. These parts of questions were enhanced and developed many times through a pilot study at the beginning of conducting the interviews. After the pilot study was finished, structured questions were ready to be used in the interviews.

The first part of the questionnaire contains questions seeking information from the experts answering the questionnaire such as years of experience, the number of office buildings they applied their expertise in, the methods that they used for EQE, etc.

The second part consists of questions on facility planning. This part seeks experts opinion on the level of importance of office building elements to each other in view of environmental quality factors such as lighting, acoustic, thermal and indoor air quality.

The third part consists of questions seeking knowledge from experts on the importance of environmental quality factors to each other in each office building element

The other fourth parts (from the fourth to the seventh part) consist of questions seeking knowledge from experts on the influential effect of the performance criteria of lighting, acoustic, thermal and indoor air quality respectively. Also to determine the comfort condition ranges of the performance criteria of lighting, acoustic, thermal and indoor quality in office buildings and their scales (comfortable, reasonable, uncomfortable).

A survey was done in the Eastern Province of the Kingdom of Saudi Arabia select the experts in the related fields of environmental quality evaluation of office buildings . From academicians 21 were contacted and interviewed. Academicians are from King Fahd University of Petroleum & Minerals and

Kind Faisal University. From practitioners 29 were contacted and interviewed and selected from the largest and best design offices in the Easter Province. Side discussions were conducted to cover the reasons and justifications of their inputs.

The following requirements were determined:

1. The importance of office building elements to each other. A Paired comparison method was used to transform the inputs of each expert into a scoring matrix (figure 3-1) to determine the assigned weight of each office building element. The following procedures were executed:

   - The row score for each office element was calculated by summing the assigned letters in the scoring matrix .
   - The assigned weight for each office element was calculated by converting the row scores to a scale of 1-10 with 10 being assigned to the criteria with the high row score, and the other was adjusted accordingly.
   - The average of the assigned weight for each element statistically was determined.

2. The same procedures in step 1 were followed to find the assigned weight for each Environmental Quality (EQ) factor among other EQ factors for each office building element. Ten matrices were established covering all of the office building elements. Table (3.2) illustrates the scoring matrix to determine the importance of each of the environmental quality factors among other EQ factors (for example, reception areas).

3. The assigned weight for each performance criterion in each environmental quality factor depends upon its influential effect. The consideration or negligence for each one of the performance criteria was assessed by experts during the interviews. The influence of each performance criterion under each requirement will be assessed as follows:

Random Variable	Outcome		
4	Extremely Influential	=	E.I
3	Major Influential	=	M.I
2	Influential	=	I
1	Somewhat Influential	=	S.I
0	Not Influential	=	N.I

TABLE (3.1)

Scoring Matrix to determine the importance of each office building element among other office elements

A	**Reception areas**	**B**	**Office work place**
C	**Core**	**D**	**Meeting areas**
E	**Rest areas**	**F**	**Circulation areas**
G	**Special facilities**	**H**	**General services**
I	**Storage**	**J**	**Parking areas**

	B	C	D	E	F	G	H	I	J
A									
B									
C									
D									
E									
F									
G									
H									
I									

Please fill boxes of the above Scoring Matrix by one of the following.

Example:

A/B Means A is important as B
A2 Means A is medium importance to B
A3 Means A is Major importance to B

Also **B2**, **B3** could be used instead of A depending on your preference

Name : ------------------------ profession:-----------------------

Company:----------------------- Date:-----------------------------

TABLE (3.2)

Scoring Matrix to determine the importance of each Environmental Quality (EQ) factor among other EQ factors for Reception areas in the office building

A **Lighting comfort**
B **Acoustic comfort**
C **Thermal comfort**
D **Indoor Air Quality**

	B	C	D
A			
	B		
		C	

Please fill boxes of the above Scoring Matrix by one of the following.

Example:

A/B Means A is important as B
A2 Means A is medium importance to B
A3 Means A is Major importance to B

Also **B2**, **B3** could be used instead of A depending on your preference

Name : ------------------------ profession:----------------------

Company:---------------------- Date:----------------------------

The assigned weight for each performance criterion was analyzed as follows:

- The expected value of each performance criteria was calculated as follows:

Expected value (E(x)) =
[The summation of the random variables from x=0 to x=4 multiplied] X $\frac{\text{(No. of experts respond)}}{\text{(Total No. of experts participated)}}$

- The severity index for each performance criteria will be calculated as follows:

$$\text{Severity index} = \frac{\text{Expected value}}{4} \times 100\%$$

- The assigned weight for each performance criteria was calculated by ranking the severity index. By assigning the highest percentage rank 1, and by adjusting others accordingly.

- The average of the assigned weight statistically was determined.

4. The scales used (subjective and objective) to assess the performance criteria of environmental quality factors were achieved by analyzing the recommended scales from experts, also the comfort standards were involved in the analysis.

The (SPSS WIN) Statistical Package for Social Science under windows was used to conduct the relevant statistical analysis. The results from these analyses were used to put the conditions of the rules in the computerized expert system model.

3.4 FORMALIZATION

The fourth step in the development of the EQE was expressing the key concepts and relations in some formal way, usually within a frame work suggested by an expert system language. This process was achieved through the use of graphical representation approach with dependency diagrams or decision trees. A decision tree is a visual representation of the factors. The dependency diagram is an essential tool for representing information and facilitating the rule creation process.

3.5 IMPLEMENTATION

The fifth step in the development process was formalizing the knowledge into a working computer program, and building up a program. The process off associating rules with the relationships and converting all formalized knowledge into production rule format is referred to as implementation. In this phase , a decision tree was converted to a set of rules. To each a certain leaf, an object must satisfy all the conditions specified in a particular path from the root of leaf. Each decision tree path corresponds to a rule in the form:

If $A = A_i$ & $B = B_j$ & $C = C_k$
Then $Dec = Dec_n$

Where A, B, and C indicate variables: A_i, B_j, C_k indicate their assigned value, respectively. Dec indicates decision whether it is a subgoal or a goal; and Dec_n indicates the value of Dec.

3.6 EXPERT SYSTEM SHELL

The most common implementation medium used in expert systems is the expert system shell, a tool to assist in the development of expert systems. These tools are often simply referred to as "expert systems" in much the same way the database management systems are sometimes simply called databases. A shell is not a system, it is an implementation tool or environment [Mahmoud, 1993].

All expert system tools have strengths and weakness, and no single tool is dominant for a wide spectrum of application or over a wide range of functionality.

To provide an application with the best chance of success, Expert System tools should be matched to the applications requirements rather than forcing an application to fit a given tool [Mettrey, William, 1991].

Four considerations are important when the expert system shell was selected to handle EQE of office buildings:

1. The user-friendliness of the system.
2. The flexibility of the system or the ability to modify and expand the system.
3. The adaptability of the system to run on an IBM personal computer (or compatibles).
4. The capacity and ability to handle a large knowledge base.

EXSYS professional therefore was chosen as a robust shell that is capable of handling up to 3,000 rules [Hanna, 1992].

EXSYS Professional is a general purpose expert system building tool. This means that is not a skeletal expert system shell, but a general purpose knowledge engineering programming language, which makes it more flexible to deal with [Mahmoud, 1993].

EXSYS Professional was selected to be used as the building tool for having an abundance of features and advantages that will suit the problem at hand.

3.7 EXPERT SYSTEM APPROACH

An expert system is a system that employs human knowledge captured in computer to solve problems that ordinarily require human expertise. Well designed systems imitate the reasoning processes experts use to solve specific problems. Such system can be used by non experts to improve their problem solving capabilities. Expert systems can also be used by experts as knowledgeable assistants. Expert systems are used to propagate scarce knowledge resources for improved, consistent results. Ultimately, such systems could function better than any single human expert in making judgment in a specific, usually narrow, area of expertise (Turban, 1992).

Expert systems are best known as self contained entities which exist quite separately from other computer aided design systems. Equally, if not more important is the notion of imbedding explicit knowledge of the kind that is encoded in an expert system within more general computer design tools (Boutdeau, 1987).

The key to every expert system is knowledge. Because knowledge forms the core of expert systems, expert systems are often referred to as knowledge systems or knowledge based systems. The field of expert system is concerned with ways to acquire knowledge from human experts and represent it in a form compatible with computers. The computers perform a kind of knowledge processing when the user taps the knowledge (Frenzel, 1987).

Knowledge Engineer (KE) applies the tools of artificial intelligence to build expert systems, i.e., the sophisticated computer system capable of solving complex problems within a particular domain expertise, that traditionally require both specialized knowledge and human reasoning (Gari, 1992). Also, KE helps the expert(s) structure the problem area by interpreting human answers to questions, drawing analogies, posing counter examples, and bringing to light conceptual difficulties (Turban, 1992).

3.8 STRUCTURE OF AN EXPERT SYSTEM

Expert systems are composed of two major parts: the development environment and the consultation (run time) environment as illustrated in figure (3.2) (Turban, 1992). The development environment is used by the expert system builder to build the components and to introduce knowledge into the knowledge base. The consultation environment is used by a non expert to obtain expert knowledge and advice. The following components may exist in an expert system:

- Knowledge Acquisition System

- Knowledge Base
- Inference Engine
- Blackboard
- User Interface
- Explanation Sub-System

Expert system development tools contain two components that facilitate the creation of expert systems. A way to store the expert's qualitative knowledge used to address a given problem, and an inference control mechanism that decides how the stored knowledge will be implemented (Waterman, 1986).

3.9 WHY USE A RULE BASED SYSTEM?

Several factors favored the use of a rule based system for representing knowledge gathered for this study rather than another representation method. Besides personal familiarity and the popularity of this method in the evaluation process, other factors will be as the follows [Hamid, 1993].

1. Production rules are simple and very readable. Debugging and validation of the system would be easily performed and achieved for any domain expert who may wish merely to brows through the rules in order to check the system.

2. Any expert systems being built with its expandability is a must that should kept in mind while being built. So, using a rule based method of representation facilitates any needed updates, addition or correction to the system.

3. Availability and flexibility of expert system development with knowledge representation in the form of production rule.

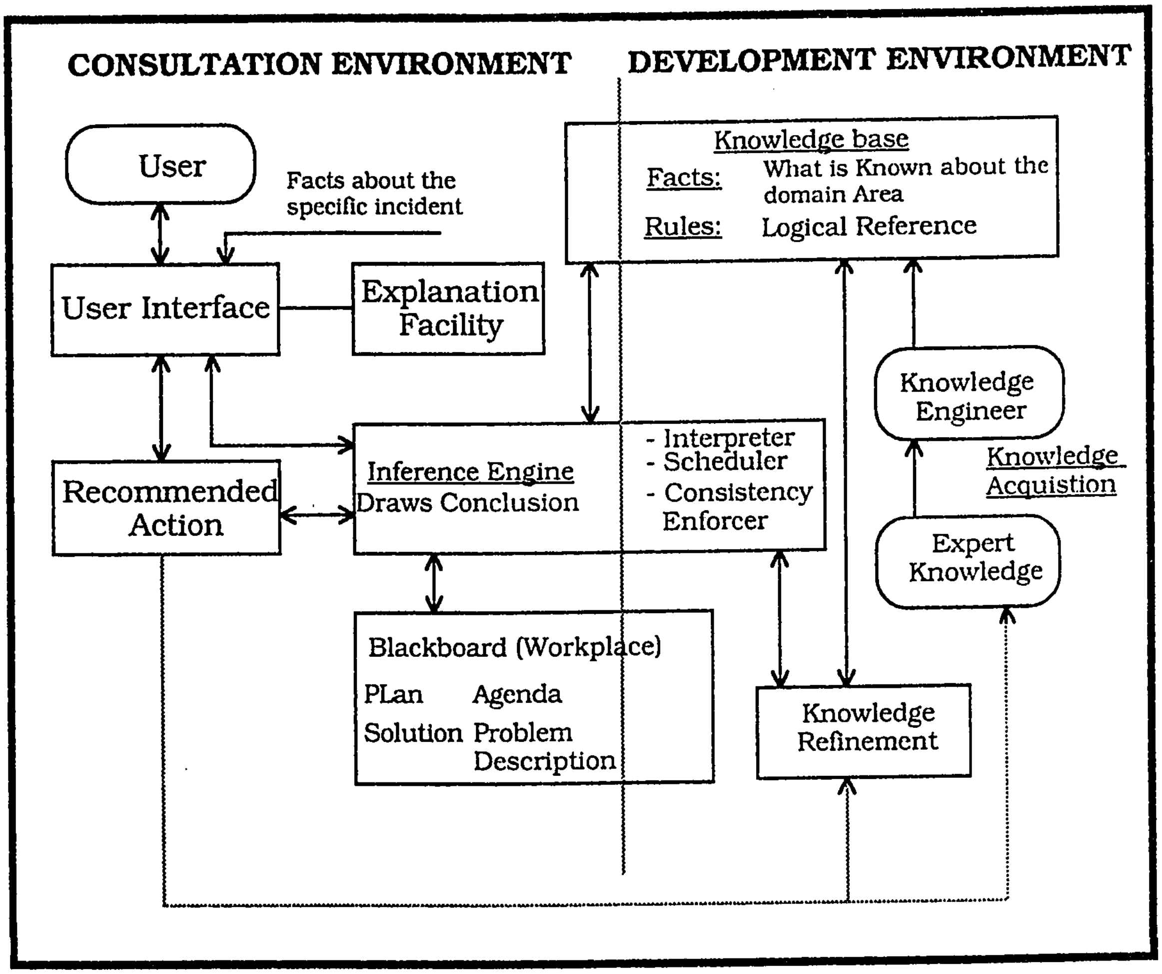

Figure (3.2) Structure of an Expert System

CHAPTER 4

ANALYSIS AND DEVELOPMENT OF ESEQE MODEL

This chapter presents two major items, the first is the analysis of the interviewed experts in the eastern province in Saudi Arabia and their evaluation methods of office building environment. The second are procedures which were followed in the development of the expert system ESEQE model for evaluating the environmental quality of office buildings in the tropical areas.

4.1 EVALUATION OF OFFICE BUILDING ENVIRONMENT BY EXPERTS

This section presents the characteristics of the interviewed experts such as education degrees and years of experience. The methods that they used to evaluate the office building environment are presented. Also, their opinion on developing a unified system for evaluating the environmental quality of office buildings in an integrated approach is discussed.

4.1.1 THE CHARACTERISTICS OF THE DOMAIN EXPERTS

4.1.1.1 THE NUMBER OF THE DOMAIN EXPERTS IN EACH FIELD

As mentioned before in chapter 3, two kind of professionals were selected under certain criteria to be interviewed. The professionals totally are 50: 21 academicians and 29 practitioners. Their distribution in each field is illustrated in figure 4.1.

4.1.1.2 YEARS OF EXPERIENCE FOR THE INTERVIEWED EXPERTS

The average years of experience that the experts have been practicing their expertise in design and evaluation of office buildings is illustrated in figure (4.2).

4.1.1.3 EDUCATION DEGREES FOR THE INTERVIEWED EXPERTS

The education degrees for the domain experts in each field are illustrated in figures (4.3a, b, c, d and e).

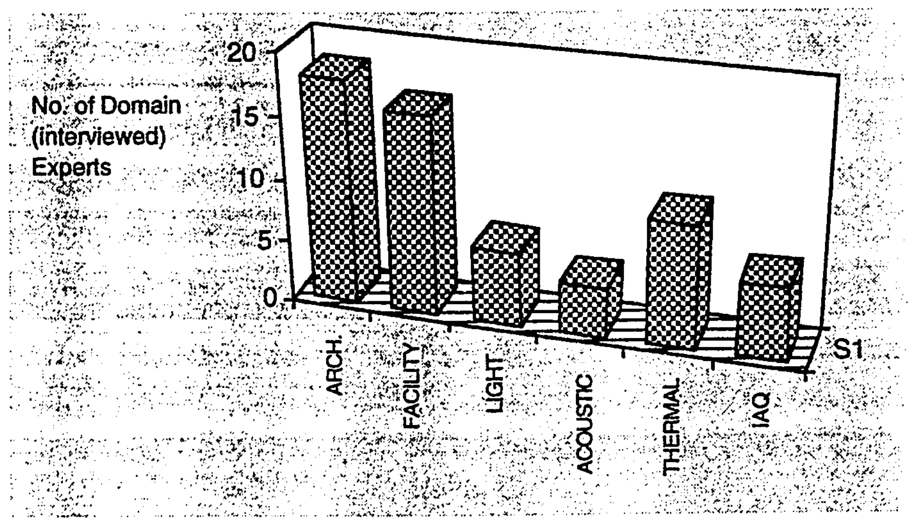

Figure (4.1) The domain experts who participated in the interviews in each field.

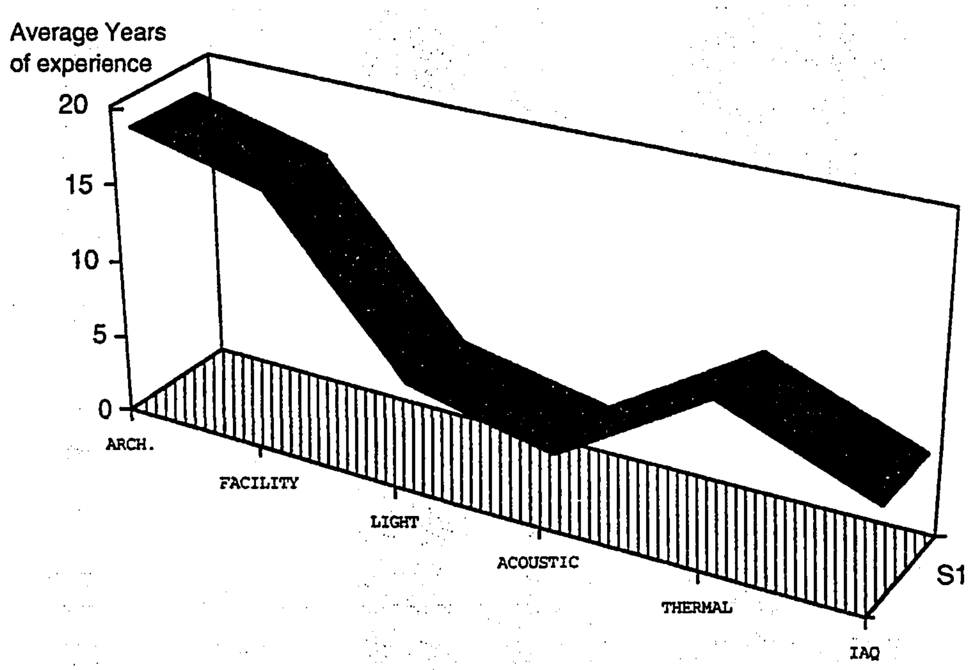

Figure (4.2) The average years of experience for the domain experts

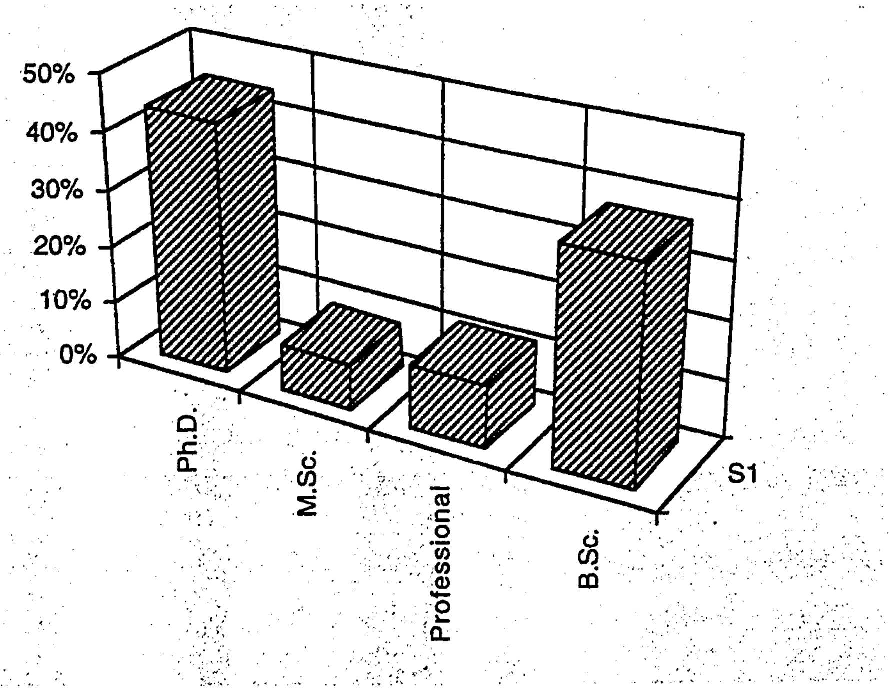

Figure (4.3a) The education degrees for the domain experts in Architecture.

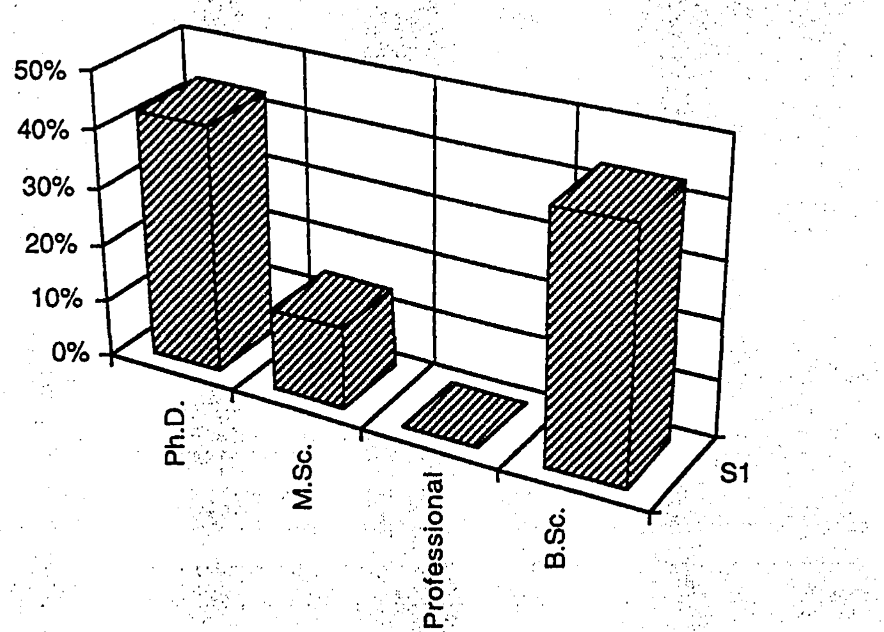

Figure (4.3b) The education degrees for the domain experts in Lighting

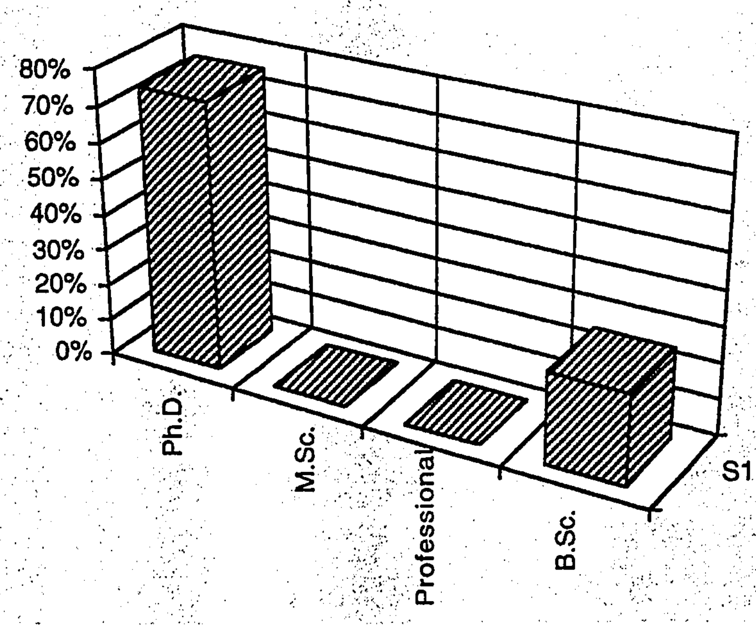

Figure (4.3c) The education degrees for the domain experts in Acoustics.

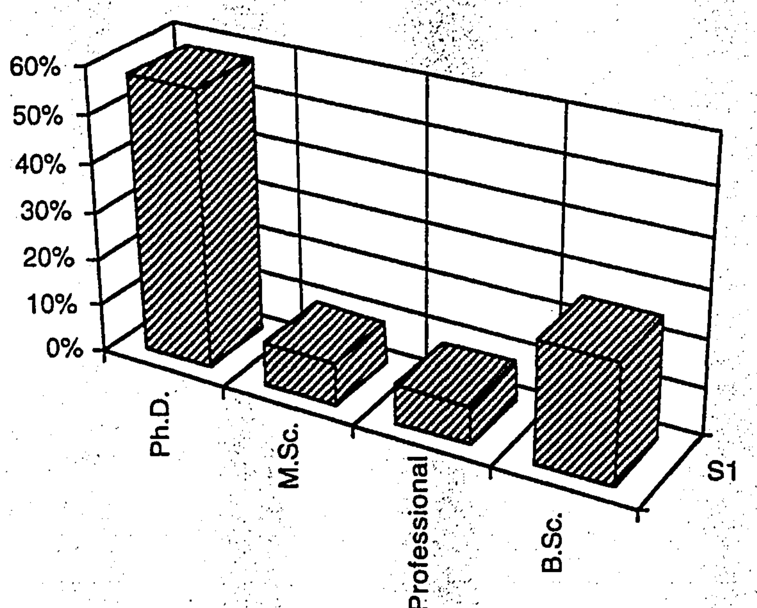

Figure (4.3d) The education degrees for the domain experts in Thermal

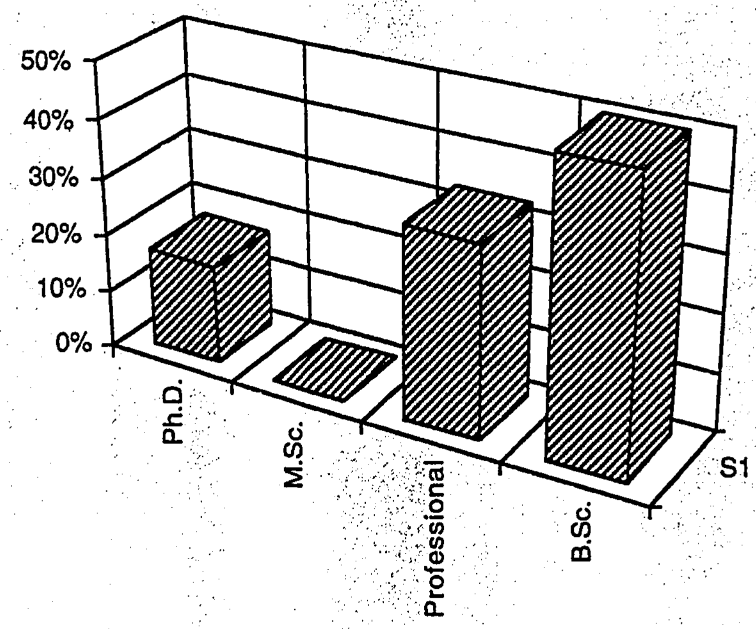

Figure (4.3e) The education degrees for the domain experts in Indoor Air Quality

3-15

4.1.2 THE MODE AND DURATION OF COMPLETING A QUESTIONNAIRE

The survey was conducted in the eastern province of Saudi Arabia by selecting the domain experts in the related fields of environmental quality evaluation of office buildings. A brief introduction which is the first two pages from the questionnaire, see appendix 1, was sent to them by fax or by hand. The purpose of this introduction is to give them in brief the objective of the study, the scope of evaluation as well as the contents of the questionnaire and inviting them to participate in their fields to carry out this study.

After that, the appointments were made to interview the domain experts. Most of the interviews were conducted in two or three sessions, each session was carried out within two to three hours.

Through the interview two copies from the questionnaire were on the table, one for the interviewee (domain expert) and the other one on the hand of the interviewer who performed the knowledge engineering job in the expert system process. The interview session was started by the interviewer who raised the question and discussed it with the interviewee who answered the questions and filled it out in his copy and interviewer noted the comments and other related knowledge in his copy and so on. until the whole questionnaire were answered.

A notice should be mentioned here that during the interview sessions some of domain experts went back to their references, reports and their projects to point out the right answers for the questions.

4.1.3 EVALUATION METHODS OF OFFICE BUILDING ENVIRONMENT BY EXPERTS

The methods that the domain experts in each field used to evaluate the environmental quality evaluation of office buildings is illustrated in figure (4.4a,b,c,d and e). These results indicated that the majority of domain experts through the evaluation process were highly dependent on their own experience and some of them depend on a checklist, but unfortunately it is not a well established checklist, few of them used computer languages to build their own programs to solve specific points. Most of them used FORTRAN, and BASIC languages to solve algorithm problems.

Since the experts are heavily dependent on their experience to evaluate the office building environment then it is worth developing the model to describe and analyze their way of thinking and how they apply their expertise to figure out the evaluation results.

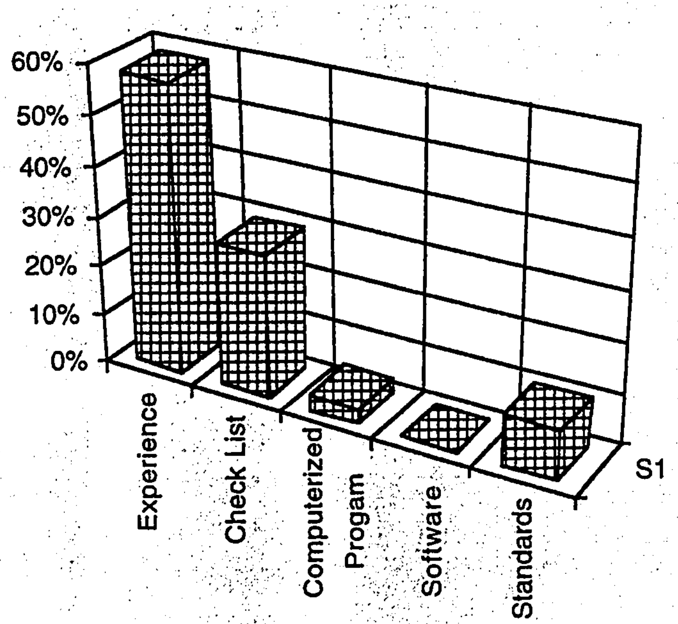

Figure (4.4a) The methods that domain experts in Architecture used to evaluate the environmental quality of office buildings

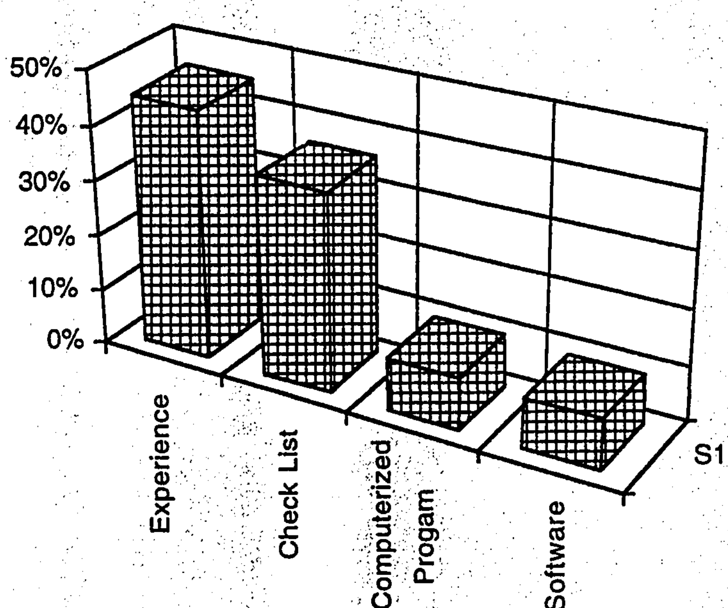

Figure (4.4b) The methods that domain experts in Lighting used to evaluate the environmental quality of office buildings

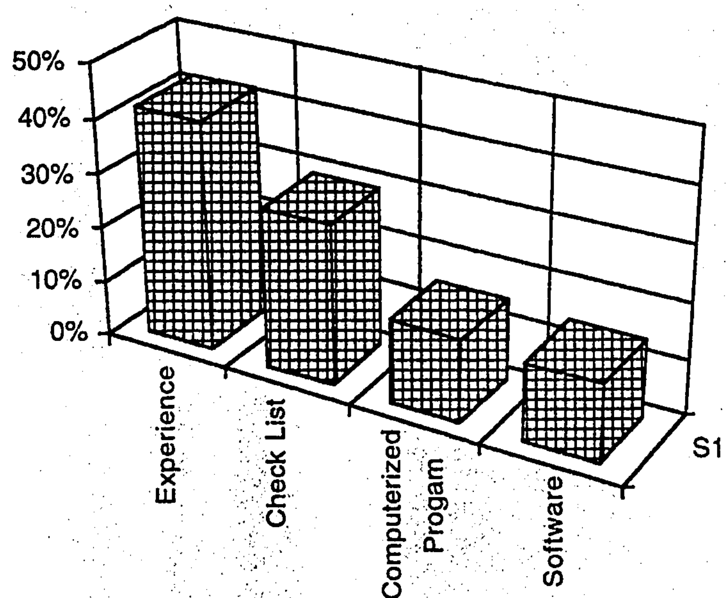

Figure (4.4c) The methods that domain experts in Acoustics used to evaluate the environmental quality of office buildings

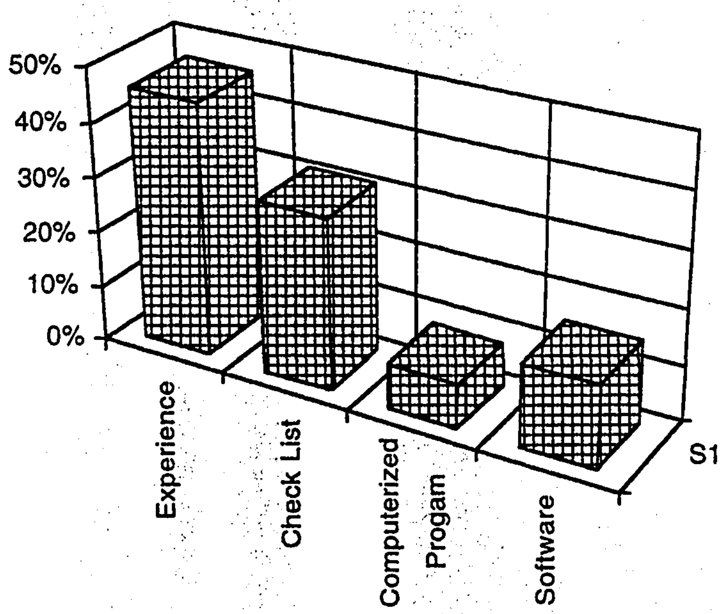

Figure (4.4d) The methods that domain experts in Thermal used to evaluate the environmental quality of office buildings

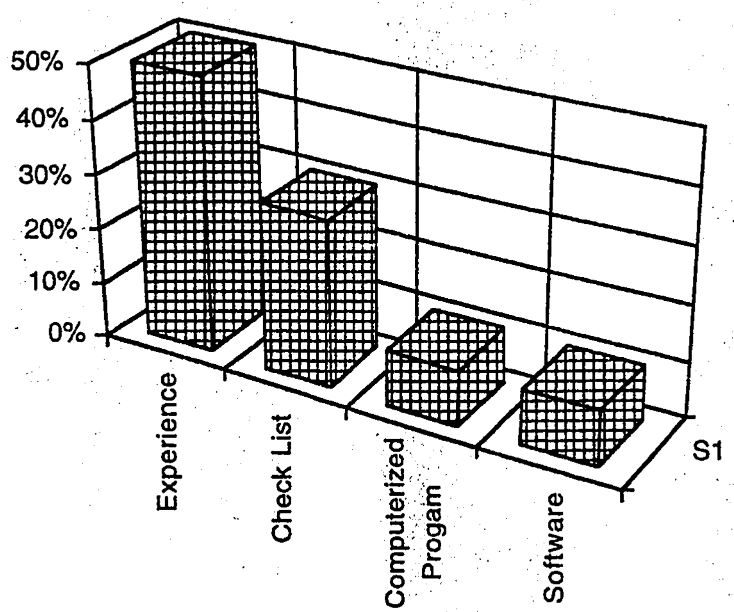

Figure (4.4e) The methods that domain experts in IAQ used to evaluate the environmental quality of office buildings.

4.1.3.1 FACILITY PLANNING AND ENVIRONMENTAL QUALITY FACTORS

The professionals who were interviewed in this part were 22 experts and mostly architects, 12 of them participated in both facility planning and environmental quality factors and the other 10 participated only in one part, so the total number of the questionnaires filled out were 34. Domain experts in this field evaluated the office building environment as follows:

- Classifying the office building into major components
- Assigning weights for each component within the whole components.
- For each component they elaborated the scope of the evaluation of each office component such as lighting, acoustic, thermal and indoor air quality by assigning other weights for each environmental category in that office component.

Actually, This is the accurate way recommended by experts to be used but, unfortunately they have not been documented. There is no established list containing this knowledge, although it is well known in their minds but each time they have to warm up their thoughts and concentration.

4.1.3.2 LIGHTING QUALITY EVALUATION

The domain experts interviewed in this section were 7 experts, 4 of them are lighting designers and the other 3 were building engineers. Domain experts in lighting evaluate the light quality of office buildings as follows:

- Each one of the interviewed experts has a set of criteria or variables using them to evaluate the light quality of offices.
- Each criterion has a specific range of comfort conditions and specific weight.
- The domain experts tested the office building under these criteria and figured out the final result.

The integration of criteria from the domain experts included the following:

- Illuminance (E) for Electrical Light
- Daylight Factor
- Direction and Position of Electrical light
- The Ratio of the minimum illuminance to the Average Illuminance in the General Office area
- The Ratio of the Illuminances at the Workstation
- The Average Luminance of any Wall to the Average Illuminance in the Horizontal Workplace
- The ratio of the illuminance on the task Area to the Illuminance around the task Area
- The Directional Strength of light (Vector/Scalar Ratio)
- The Correlated Color Temperature of Light
- The Color Rendering of Light
- The Glare Index of Light
- The Direct Ratio of the Total Downward Flux from the Luminaries falls directly on the Workstation
- The Reflectance of the :
    - Ceiling Surface
    - Wall Surface
    - Window Gloss Finishing
    - Floor Finishing
    - Equipment and furnishing Surfaces
    - Immediate Background

4.1.3.3 ACOUSTIC QUALITY EVALUATION

The Professionals interviewed in acoustics were 4, all of which were acousticans. Those acousticans evaluated the acoustic quality of an office building as follows:

- There are certain variables which control the acoustic quality of office building.
- Each variable or criterion has a range of comfort conditions and scales of comfort.
- Each variable has been assigned its own weight within the whole criteria

Acousticans assessing the office building according to these variables or criteria pointed out what the acoustic quality of an office building is. The following are variables that control the acoustic quality of an office building:

- Background Noise Level
- Reverberation Time
- Impact Generated Sound from adjoining Floors
- Noise Generated From HVAC
- Speech Interference Level
- Sound Transmission Class for walls , partitions, floors and ceiling
- Impact Sound Insulation of walls, partitions and ceilings
- Noise Isolation Class
- The Difference between Speech Sound Level and the level of background noise.
- The Time Taken between the Initial Sound and its reflection as received by the ear
- The Total Area of Window glazing
    - Sound Absorption of

- Wall Materials
- Ceiling Materials
- Floor Materials

4.1.3.4 THERMAL QUALITY EVALUATION

The professionals interviewed in respect of the thermal quality evaluation of office buildings were 10 experts, 8 of them were mechanical engineers and the other two were building engineers. The domain experts evaluated the thermal quality of an office building as follows:

- Thermal quality is governed by some sort of criteria which adapt the office environment to be comfortable.
- Each criterion has a comfort zone and specific scales.
- The experts assigning a weight for each criteria

The domain experts evaluated the thermal quality of an office building by testing the office under these criteria and figuring out the final results. The following are the whole criteria that control the thermal quality of an office building:

- Air Temperature
- Mean Radiant Temperature
- Relative Humidity
- Air Movement
- The Average Temperature of the Internal Surfaces
- Maximum Increase in the Radiant Temperature on the Head over the Main Radiant Temperature
- Air Temperature Between Head and Feet
- Heat Recovered from Light
- Frequency of Temperature Shifts

4.1.3.5 INDOOR AIR QUALITY (IAQ) EVALUATION

The professionals interviewed in indoor air quality evaluation of office buildings were 7 experts, 5 of them were mechanical engineers and the other two were building engineers. The domain experts in the indoor air quality evaluated the office buildings as follows:

- Indoor air quality is controlled by some sort of criteria to reach high levels of comfort.
- Each criterion has a specific ranges to achieve certain quality.
- Each criterion has its own weight within the whole criteria of IAQ.

The domain experts examined the indoor air quality of office buildings under these criteria, then they summed up all criteria and their weights to figure out the final evaluation. The following are the criteria that control the indoor air quality of an office building:

- Air Exchange Rate
- Air Change Per Hour
- Air Filtration Efficiency
- Air Mixing Efficiency
- The Efficiency of entrainment of Room Air by the primary stream outside the zone of occupancy
- Odors from:
    - Smoking Areas
    - Bathrooms
    - Kitchenette
- Air pollution in the general office area:
    - Carbon Dioxide
    - Carbon Monoxide

- Nitrogen Dioxide
- Sulfur Dioxide
- Formaldehyde
- Ozone

If the domain experts finished their evaluation and the final results are not satisfying their expectation and needs, they go back to their criteria and try to enhance their conditions by redesigning the related elements in the building till they reach the desired results. Also, through the interviews with the experts they notified that their evaluation most of the time independently with other categories such as lighting, acoustic and thermal because it is not easy to find experts in lighting, acoustic, thermal and indoor air quality in one design office but they are doing their level best to enhance the environmental quality of their designs.

4.1.4 EXPERTS OPINION ON DEVELOPING A UNIFIED SYSTEM FOR EQE OF OFFICE BUILDING

During the interviews, data was collected regarding the experts' opinions on developing a unified system for the environmental quality evaluation of office building simulating the thoughts and the expertise of the interviewed professionals. The results indicated that 57% of experts recorded that it is extremely important, 27% is a major important and 13% is important, see figure 4.5.

These results ensure that really there is a need for unified systems integrating the main four categories of environmental quality and their variables, weights and scale. This system simulates the expertise of the professionals for evaluating the environmental quality of office buildings.

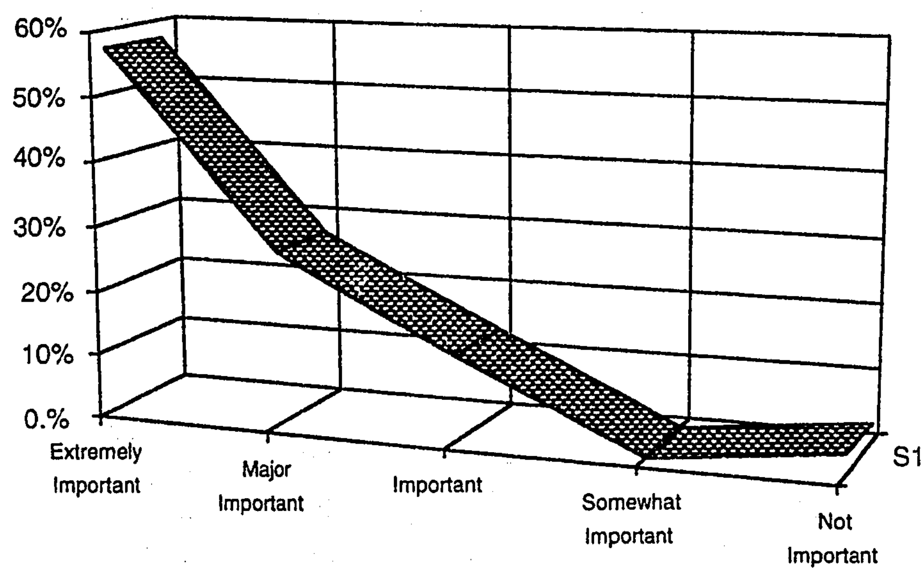

Figure (4.5) The degree of importance of using an integrated approach for EQE.

4.2 DEVELOPMENT OF AN EXPERT SYSTEM FOR ENVIRONMENTAL QUALITY EVALUATION OF OFFICE BUILDINGS

This section presents all the procedures which were followed in the development of an expert system for environmental quality evaluation (ESEQE) of office buildings. These procedures include the knowledge base development, weights determination, decision trees, production rules, computer program development, validation of the ESEQE model, and the instructions to run the model.

4.2.1 KNOWLEDGE BASE DEVELOPMENT

The EQE knowledge base was developed with great care since it comprises the heart of the expert system controlling all the deciding expertise upon which a decision can be made. The EQE knowledge base was built as it was recommended by experts who were interviewed and experts who expressed their expertise from the analysis, in published papers, reports, and books. This knowledge base is classified into lighting, acoustic, thermal and indoor air quality categories. The main components of the ESEQE model is illustrated in figure (4.6).

The performance variables for each category were carefully determined from interviewed experts and literature. The most suitable variables of lighting, acoustic, thermal and indoor air quality were determined and shown in tables 4.1, 4.2, 4.3 and 4.4 respectively.

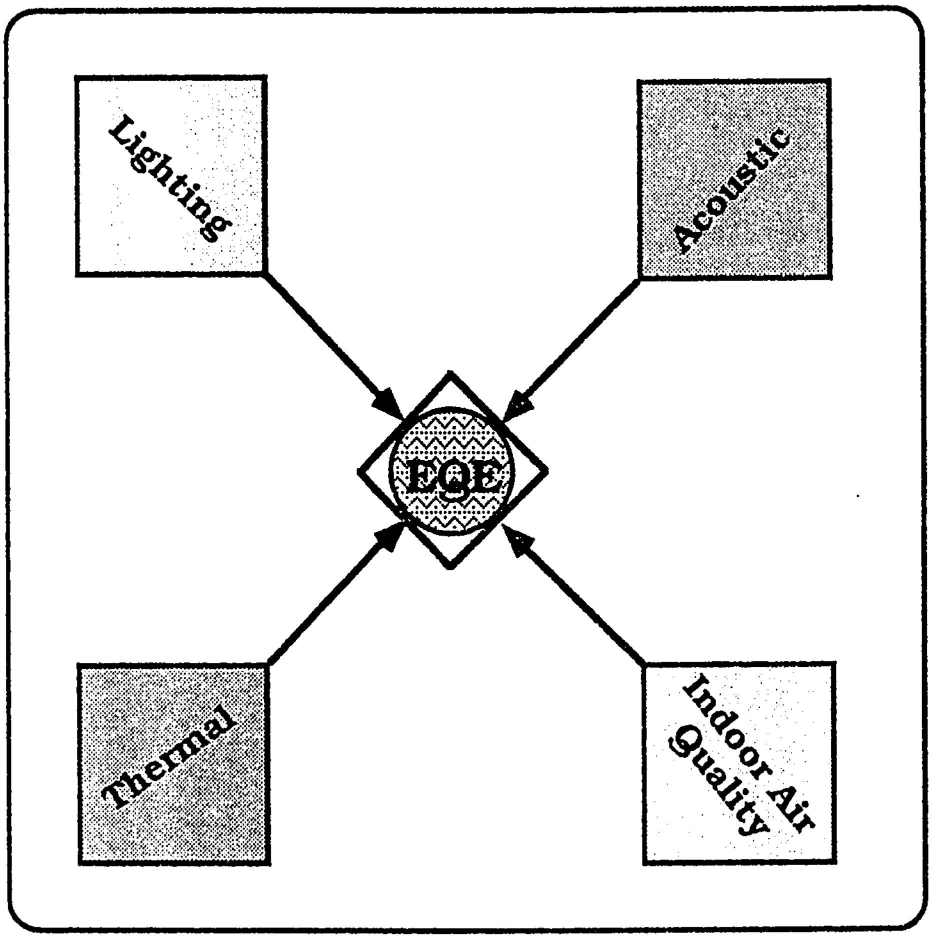

Figure (4.6) Environmental Quality Components

Table (4.1) Acoustic Comfort Variables

No.	Variables	Description
1	BNL	Background Noise Level
2	RT	Reverberation Time
3	IGSF	Impact Generated Sound from adjoining Floors
4	GNHVAC	Generated Noise From HVAC
5	SIL	Speech Interference Level of Workplace Area
6	SILT	Speech Interference Level of Typing area
7	STC	Sound Transmission Class for walls , partitions, floors and ceiling
8	ISI	Impact Sound Insulation of walls, partitions and ceilings
9	NIC	Noise Isolation Class
10	DSSLBNL	The Difference between Speech Sound Level and the level of background noise level
11	TIMEIR	The Time Taken between the Initial Sound and its reflection is received by the air
12	TAWG	The Total Area of Window glazing
13	SAWM	Sound Absorption of Wall Materials
14	SASM	Sound Absorption of Ceiling Materials
15	SAFM	Sound Absorption of Floor Materials

Table (4.2) Lighting Comfort Variables

No.	Variables	Description
1	EELGC	Illuminance (E) for Electrical Light in General Areas
2	EELT	Illuminance (E) for Electrical Light in Types Areas (using computers)
3	EELF	Illuminance (E) for Electrical Light in Filing of documents Areas
4	DFWS	Daylight Factor on the Workstation (assume external reference illuminance = 10,000 Lux)
5	DFWA	Daylight Factor over the whole Areas (assume external reference illuminance = 10,000 Lux)
6	DDEL	Direction and Position of Electric Light (in case of daylight supplement electrical light)
7	RMEAE	The Ratio of the minimum illuminance to the Average Illuminance in the General Office area
8	REWS	The Ratio of the Illuminances at the Workstation
9	ALWAEWP	The Average Luminance of any Wall to the Average Illuminance in the Horizontal Workplace
10	REOTEUT	The ratio of the illuminance on the task Area to the Illuminance around task Area
11	DSLVSR	The Directional Strength of light (Vector/Scalar Ratio)
12	CCTL	The Correlated Color Temperature of Light
13	CRL	The Color Rendering of Light
14	GIL	The Glare Index of Light
15	DRTDFLWS	The Direct Ratio of the Total Downward Flux from the Luminaries falls directly on the Workstation
16	FPCS	The Reflectance of the Paint of Ceiling Surface
17	FPWSF	The Reflectance of the Wall Surface
18	FWGL	The Reflectance of the Window Glass Finishing
19	FSFF	The Reflectance of the Floor Finishing surface
20	FESFS	The Reflectance of Equipment and furnishing Surfaces
21	FIB	The Reflectance of the Immediate Background

Table (4.3) Thermal Comfort Variables

No.	Variables	Description
1	ATW	The Air Temperature in Winter
2	ATS	The Air Temperature in Summer
3	MRTW	Mean Radiant Temperature In Winter
4	MRTS	Mean Radiant Temperature In summer
5	RHW	Relative Humidity in Winter
6	RHS	Relative Humidity in Summer
7	AMW	Air Movement in Winter
8	AMS	Air Movement in Summer
9	ATIS	The Average Temperature of the Internal Surfaces
10	TS	Temperature Shifts
11	MIRTHMRT	Maximum Increase in the Radiant Temperature on the Head over the Main Radiant Temperature
12	FT	Floor Temperature
13	ATHF	Air Temperature Between Head and Feet
14	HRFL	Heat Recover from Light
15	FS	Frequency of Temperature Shifts

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Table (4.4) Indoor Air Quality Variables

No.	Variables	Description
1	AER	Air Exchange Rate (Fresh Air Make up)
2	ACPH	Air Change Per Hour
3	DOT	Air Filtration Efficiency
4	AME	Air Mixing Efficiency
5	EERA	The Efficiency of entrainment of Room Air by the primary stream outside the zone of occupancy
6	SA	Odors from smoking Areas
7	OCBR	Odors from Bathrooms
8	OCKN	Odors from Kitchenette
9	QCOIA	Carbon Dioxide in indoor Air in the general office area
10	QCO2IA	Carbon Monoxide in indoor Air in the general office area
11	PNO2IA	Nitrogen Dioxide in indoor Air in the general office area
12	QSO2IA	Sulfur Dioxide in indoor Air in the general office area
13	QFIA	Formaldehyde in indoor Air in the general office area
14	QOIA	Ozone in indoor Air in the general office area

4.2.2 WEIGHTS DETERMINATION

4.2.2.1 THE WEIGHT OF OFFICE BUILDING ELEMENTS

Data was collected through interviews to determine the weights of each office building element among various elements of the office building from an environmental quality (acoustic, lighting, thermal and indoor air quality) point of view. A paired comparison method was used to find out the weights by determining the importance of each of the office building elements compared to other elements. Part 1 from the structured question (Appendix (1)) is converted to an evaluation matrix to find out the row score and the assigned weight for each office building element. An example of the analysis of the inputs from the domain experts is illustrated in Table (4.5).

After getting all the assigned weights from each domain expert the statistical analysis was carried out using SPSS and the SPSS out put is illustrated in appendix (2). The means of the assigned weights of office elements indicated that the office workplace has got the highest weight (9.58 from 10 point scales) in office buildings from environmental quality point of view. Meeting areas, reception areas and special facilities have the weights 7.39, 7.55 and 7.85 respectively. The comparison among the weights of office building elements is illustrated in figure (4.7). Then the study is mainly concentrated on the environmental quality evaluation of the office workplace.

Table (4.5)

Scoring Matrix to determine the importance of each office building element among other office elements

	B	C	D	E	F	G	H	I	J
A	B3	A4	D2	A/E	A2	G3	A4	A4	A4
B		B4	B2	B3	B4	B/G	B4	B4	B4
C			D3	E2	F2	G4	C/H	C4	C3
D				D3	D4	G2	D3	D4	D4
E					E2	G3	E3	E4	E4
F						G4	F2	F3	F4
G							G4	G4	G4
H								H2	H2
I									I2

	Office Building Elements	**Row SCORE**	**Assigned Weight**	**Rank**
A	Reception areas	16	5.7	4
B	Office work place	26	9.3	2
C	Core	8	2.9	6
D	Meeting areas	23	8.2	3
E	Rest areas	16	5.7	4
F	Circulation areas	11	3.9	5
G	Special facilities	28	10	1
H	General services	5	1.8	7
I	Storage	2	0.7	8
J	Parking areas	0.0	0.0	9

Please fill boxes of the above Scoring Matrix by one of the following.

Example:

A/B Means A is important as B
A2 Means A is medium importance to B
A3 Means A is Major importance to B
Also **B2**, **B3** could be used instead of A depending on your preference

Name : Dr. Medhat Hassan
Company: KFUPM - Dhahran
Profession: Architect
Date: 27-3-1994

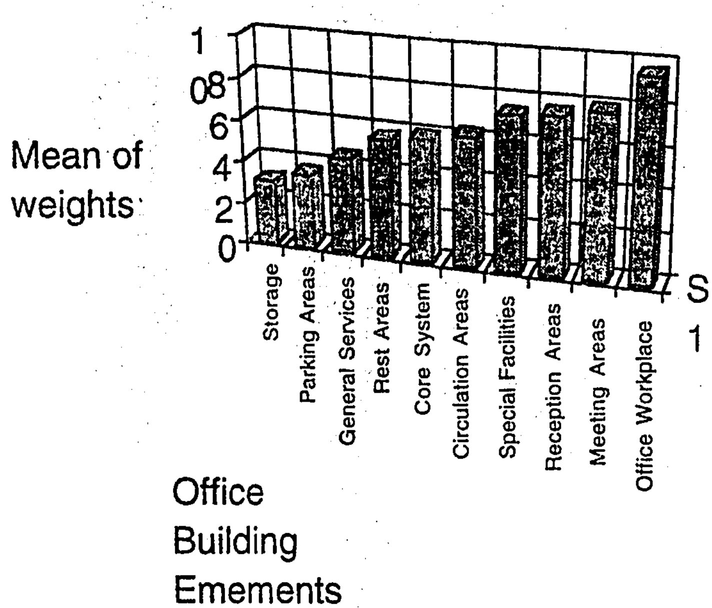

Figure (4.7) The mean of the weights of office building elements from the EQE point of view

4.2.2.2 THE WEIGHTS OF ENVIRONMENTAL QUALITY FACTORS

Data was collected through the interviews to determine the weight of each environmental quality (EQ) factor (lighting, acoustic, thermal and indoor air quality) compared to other EQ factors for each office building element. A paired comparison method was used to find out the weights by determining the importance of each environmental quality factor compared to other factors for each space (office element) in the office building. The part 2 from the structured questions (Appendix (1)) is converted to an evaluation matrix to find out the row score, assigned weight, and the rank of each environmental quality factor in each space (office element). An example of the analysis of inputs of one expert from domain experts is illustrated in table (4.6).

After getting all the assigned weights for inputs from each domain expert, the statistical analysis was carried out using SPSS and the SPSS output is illustrated in appendix (2). For example, the means of the assigned weights of environmental quality factors in the office workplace indicated that the lighting has got the highest weight (9.56 from 10 point scale). Thermal, indoor air quality, acoustic comfort have the weights 6.35, 6.61 and 5.56 respectively. The comparison among the mean of the weights of environmental quality factors of office buildings is illustrated in figure (4.8).

From the previous results, the final function which integrates the weights of lighting, acoustic, thermal and indoor air quality is derived to give the final percentage of achievement of environmental quality of the evaluated office building. The weighted average for each environmental quality factor from the total 10 point scale is illustrated in table (4.7).

Table (4.6)

Scoring Matrix to determine the importance of each Environmental Quality (EQ) factor among other EQ factors for Reception areas in the office building

A Reception Areas

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	4	10	1
B	Acoustic comfort	3	7.5	2
C	Thermal comfort	4	10	1
D	Indoor Air Quality	0.0	0.0	3

	B	C	D
A	A/B	A/C	A2
	B	B/C	B/2
		C	C2

B Office Workplace

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	5	10	1
B	Acoustic comfort	2	4	2
C	Thermal comfort	5	10	1
D	Indoor Air Quality	0.0	0.0	3

	B	C	D
A	A2	A/C	A2
	B	C2	B2
		C	C2

C Core

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	10	10	1
B	Acoustic comfort	3	3	2
C	Thermal comfort	1	1	4
D	Indoor Air Quality	2	2	3

	B	C	D
A	A4	A3	A3
	B	B2	B/D
		C	C/D

Table (4-6) continued -1

D Meeting Areas

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	3	10	1
B	Acoustic comfort	3	10	1
C	Thermal comfort	3	10	1
D	Indoor Air Quality	3	10	1

	B	C	D
A	A/B	A/C	A/D
	B	B/C	B/D
		C	C/D

E Rest Areas

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	2	2.86	3
B	Acoustic comfort	7	10	1
C	Thermal comfort	2	2.8	3
D	Indoor Air Quality	3	4.29	2

	B	C	D
A	B3	A/C	A/D
	B	B3	B/D
		C	C/D

F Circulation Areas

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	8	10	1
B	Acoustic comfort	1	1.25	3
C	Thermal comfort	5	6.25	2
D	Indoor Air Quality	0.0	0.0	4

	B	C	D
A	A3	A2	A3
	B	C2	B/C
		C	C2

Table (4-6) continued -2

G Special Facilities

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	3	10	1
B	Acoustic comfort	3	10	1
C	Thermal comfort	3	10	1
D	Indoor Air Quality	3	10	1

	B	C	D
A	A/B	A/C	A/D
	B	B/C	B/D
		C	C/D

H General Services

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	9	10	1
B	Acoustic comfort	2	2.22	2
C	Thermal comfort	2	2.22	2
D	Indoor Air Quality	2	2.22	2

	B	C	D
A	A3	A3	A3
	B	B/C	B/D
		C	C/D

I Storage

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	Lighting comfort	6	10	1
B	Acoustic comfort	0.0	0.0	3
C	Thermal comfort	2	3.33	2
D	Indoor Air Quality	6	10	1

	B	C	D
A	A3	A2	A/D
	B	C2	D3
		C	D2

Table (4-6) continued-2

J **Parking Areas**

	Environmental Quality Factors	Row Score	Assigned weight	Rank
A	**Lighting comfort**	9	10	1
B	**Acoustic comfort**	1	1.11	4
C	**Thermal comfort**	1	1.11	3
D	**Indoor Air Quality**	7	7.78	2

	B	C	D
A	A4	A4	A/D
	B	B/C	D/3
		C	D/3

Please fill boxes of the above Scoring Matrix by one of the following.

Example: **A/B** Means A is as important as B
A2 Means A is medium importance to B
A3 Means A is of Major importance compared to B

Also **B2**, **B3** could be used instead of A depending on your preference

Name :	Dr. Rafiq Ul Hussain	Profession:	Architect
Company:	KFU - Dammam	Date:	26-3-1994

For Example:

- Weighted x average of Acoustic = $5.26 \times \frac{10}{27.78} = 1.89$
- **(Total Environmental Quality Evaluation) =**
  (1.89 * [Acoustic] + 2.29 * [Thermal] + 2.39 [Indoor Air Quality] + 3.44 * [Lighting])

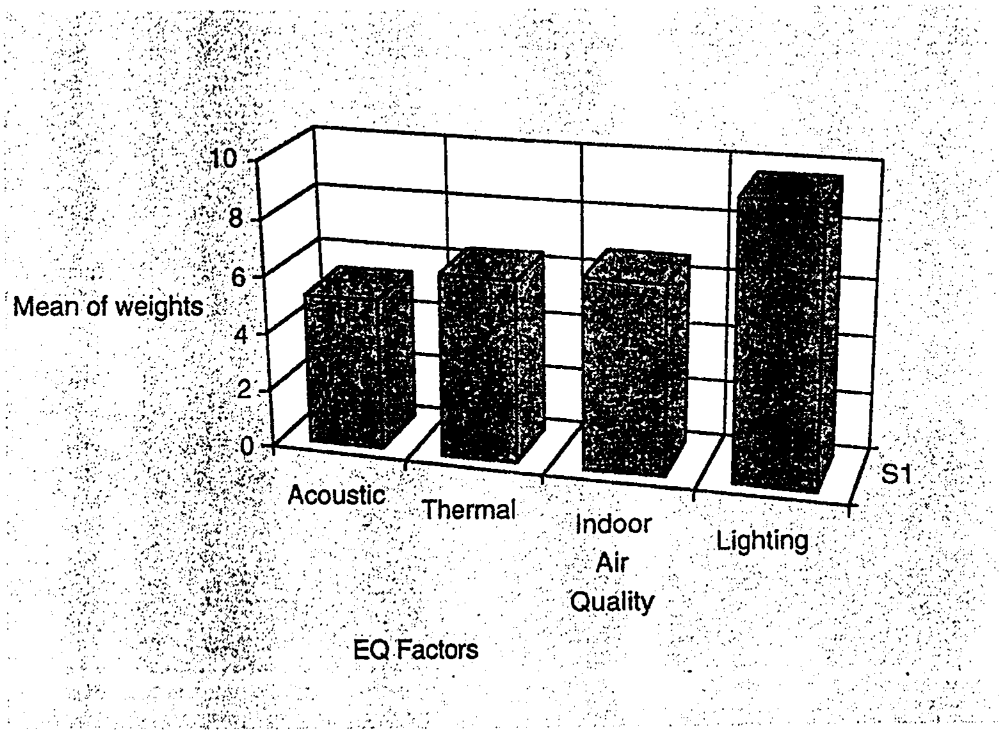

Figure (4.8) The means of the weights of the environmental quality factors for office buildings.

Environmental Quality	Mean	Sum	Weighted Average
Acoustic	5.26		1.89
Thermal	6.35		2.29
Indoor Air Quality	6.61	27.78	2.38
Lighting	9.56		3.44
			10

Table (4.7) The Weighted Average of Each Environmental Quality Factor

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4.2.2.3

Collected data through the interviews to determine how the influential effect of each performance criteria (variable) used for evaluating lighting, acoustic, thermal and indoor air quality of office workplace in the open plan office buildings (managerial work). The parts 3,4,5 and 6 from the structured questions (Appendix (1)) was analyzed as follows:

For example, to find out the weighted average for one of the performance criteria in thermal comfort (Air Temperature in winter) from a total 100 point scale the calculation was conducted as follows: Table (4.8) illustrates the data collected for air temperature from 10 experts in thermal comfort.

Outcome	Random Variable	No. of Responses	P (X)
E.I	4	3	3/10
M.I	3	4	4/10
I	2	3	3/10
S.I	1	0.0	0.0/10
N.I	0.0	0.0	0.0/10

Table (4.8) Data Collected for Air Temperature

- Expected value (E(X)) = 4(3/10) + 3(4/10) + 2(2/10) + 0(0/10) + 0(0/10) = 3
- The expected value of (3) implies that the mean of responses of experts is major influential.
- The severity index = (3/4) * (100) = 75%
- Sum of the expected values of performance criteria for thermal comfort = 46.
- The weighted average from 100 point scale is = $\frac{(3) * (100)}{46} = 6.56$

The rest of the final analysis of the performance criteria of lighting, acoustic, thermal and indoor air quality is illustrated in Tables 4.9, 4.10, 4.11 and 4.12 respectively.

TABLE (4.9) The assigned weight of each performance criteria (variable) of Acoustic Comfort

No.	Criterion	Influential Effect					Severity Index	Rank	Assigned Weight
		E.I	M. I	I	S.I	N.I			
1	Background Noise Level		●				75%	2	6.8
2	Reverberation Time			●			50%	3	4.5
3	Impact Generated Sound from adjoining Floors		●				75%	2	6.8
4	Generated Noise from HVAC		●				75%	2	6.8
5	Speech Interference Level of Workplace Area		●				75%	2	6.8
6	Speech Interference Level of Typing area	●					100 %	1	9.10
7	Sound Transmission Class for walls , partitions, floors and ceiling		●				75%	2	6.8
8	Impact Sound Insulation of walls, partitions and ceilings		●				75%	2	6.8
9	Noise Isolation Class		●				75%	2	6.8
10	The Difference between S.S.L.and the B.N.L		●				75%	2	6.8
11	The Time Taken between the Initial Sound and its reflection	●					100 %	1	9.10
12	The Total Area of Window glazing			●			50%	3	4.55
13	Sound Absorption of Wall Materials			●			50%	3	4.55
14	Sound Absorption of Ceiling Materials	●					100 %	3	9.10
15	Sound Absorption of Floor Materials			●			50%	3	4.55
									≈ 100.0

TABLE (4.10) The assigned weight of each performance criteria (variable) of Lighting Comfort

No.	Criterion	Influential Effect					Severity Index	Rank	Assigned Weight
		E.I	M. I	I	S.I	N.I			
1	Illuminance (E) for Electrical Light in General Areas		◍				75%	2	6.0
2	Illuminance (E) for Electrical Light in Types Areas (using computers)				◍		25%	4	2.0
3	Illuminance (E) for Electrical Light in Filing of documents Areas				◍		25%	4	2.0
4	Daylight Factor on the Workstation (assume external reference illuminance = 10,000 Lux)			◍			50%	3	4.0
5	Daylight Factor over the whole Areas (assume external reference illuminance = 10,000 Lux)			◍			50%	3	4.0
6	Direction and Position of Electrical (in case of daylight supplement electrical light)			◍			50%	3	4.0
7	The Ratio of the minimum illuminance to the Average Illuminance in the General Office area		◍				75%	2	6.0
8	The Ratio of the Illuminances at the Workstation	◍					100 %	1	8.0
9	The Average Luminance of any Wall to the Average Illuminance in the Horizontal Workplace		◍				75%	2	6.0
10	The ratio of the illuminance on the task Area to the Illuminance around task Area		◍				75%	2	6.0

TABLE (4-10 continued)
The assigned weight of each performance criteria (variable) of Lighting Comfort (Continued)

No.	Criterion	Influential Effect					Severity Index	Rank	Assigned Weight
		E.I	M. I	I	S.I	N.I			
11	The Directional Strength of light (Vector/Scalar Ratio)			◍			50%	3	4.0
12	The Correlated Color Temperature of Light			◍			50%	3	4.0
13	The Color Rendering of Light			◍			50%	3	4.0
14	The Glare Index of Light	◍					100 %	1	8.0
15	The Direct Ratio of the Total Downward Flux from the Luminaries falls directly on the Workstation		◍				75%	2	6.0
16	The Reflectance of the Paint of Ceiling Surface		◍				75%	2	6.0
17	The Reflectance of the Paint of the Wall Surface			◍			50%	3	4.0
18	The Reflectance of the Window Glass Finishing			◍			50%	3	4.0
19	The Reflectance of the Paint of the Floor Finishing			◍			50%	3	4.0
20	The Reflectance of Equipment and furnishing Surfaces			◍			50%	3	4.0
21	The Reflectance of the Immediate Background			◍			50%	3	4.0
									≈ 100.0

TABLE (4-11) The assigned weight of each performance criteria (variable) of Thermal Comfort

No.	Criterion	Influential Effect					Severity Index	Rank	Assigned Weight
		E.I	M. I	I	S.I	N.I			
1	The Air Temperature in Winter		◍				75%	2	6.52
2	The Air Temperature in Summer		◍				75%	2	6.52
3	Mean Radiant Temperature In Winter		◍				75%	2	6.52
4	Mean Radiant Temperature In summer		◍				75%	2	6.52
5	Relative Humidity in Winter		◍				75%	2	6.52
6	Relative Humidity in Summer		◍				75%	2	6.52
7	Air Movement in Winter		◍				75%	2	6.52
8	Air Movement in Summer		◍				75%	2	6.52
9	The Average Temperature of the Internal Surfaces		◍				75%	2	6.52
10	Temperature Shifts	◍					100 %	1	8.7
11	Maximum Increase in the Radiant Temperature on the Head over the Main Radiant Temperature	◍					100 %	1	8.7
12	Floor Temperature		◍				75%	2	6.52
13	Air Temperature Between Head and Feet		◍				75%	2	6.52
14	Heat Recover from Light			◍			50%	3	4.35
15	Frequency Shifts		◍				75%	2	6.52
									≈ 100.0

TABLE (4-12) The assigned weight of each performance criteria (variable) of Indoor Air Quality Comfort

No.	Criterion	Influential Effect					Severity Index	Rank	Assigned Weight
		E.I	M.I	I	S.I	N.I			
1	Air Exchange Rate (Fresh Air Make up)		◍				75%	2	7.89
2	Air Change Per Hour		◍				75%	2	7.89
3	Air Filtration Efficiency		◍				75%	2	7.89
4	Air Mixing Efficiency		◍				75%	2	7.89
5	The Efficiency of entrainment of Room Air by the primary stream outside the zone off occupancy		◍				75%	2	7.89
6	Odors from smoking Areas	◍					100 %	1	10.53
7	Odors from Bathrooms		◍				75%	2	7.89
8	Odors from Kitchenette		◍				75%	2	7.89
9	Carbon Dioxide in indoor Air in the general office area		◍				75%	2	7.89
10	Carbon Monoxide in indoor Air in the general office area			◍			50%	3	5.26
11	Nitrogen Dioxide in indoor Air in the general office area			◍			50%	3	5.26
12	Sulfur Dioxide in indoor Air in the general office area			◍			50%	3	5.26
13	Formaldehyde in indoor Air in the general office area			◍			50%	3	5.26
14	Ozone in indoor Air in the general office area			◍			50%	3	5.26
									≈ 100.0

DECISION TREES

At this stage a sufficient familiarity with the domain is achieved and the next step is to simulate the evaluation process and draw the relations between the collected information (variables and weights). Decision trees are the means of representing the relations between various attributes of problems.

The aim is to draw how an expert arrives at a decision through looking at different aspects of a task. In a decision tree, each variable represents a node, while the values of each variable may indicate different paths. In other words, each node can be a question with one or more answers radiating from it. The concept is helpful to visualize and explain how an expert analyzes a problem and how an inference engine searches through the knowledge base. When decision trees are drawn, the variation according to different decision values are assumed based on these trees. Then we can imagine the search space growing an increment at a time, as the inference space engine moves from a node to the next looking for a solution.

Decision trees for the attributes and weights of variables and attributes of EQE, lighting, acoustic, thermal and indoor air quality are illustrated in figures 4.9, 4.10, 4.11, 4.12 and 4.13 respectively.

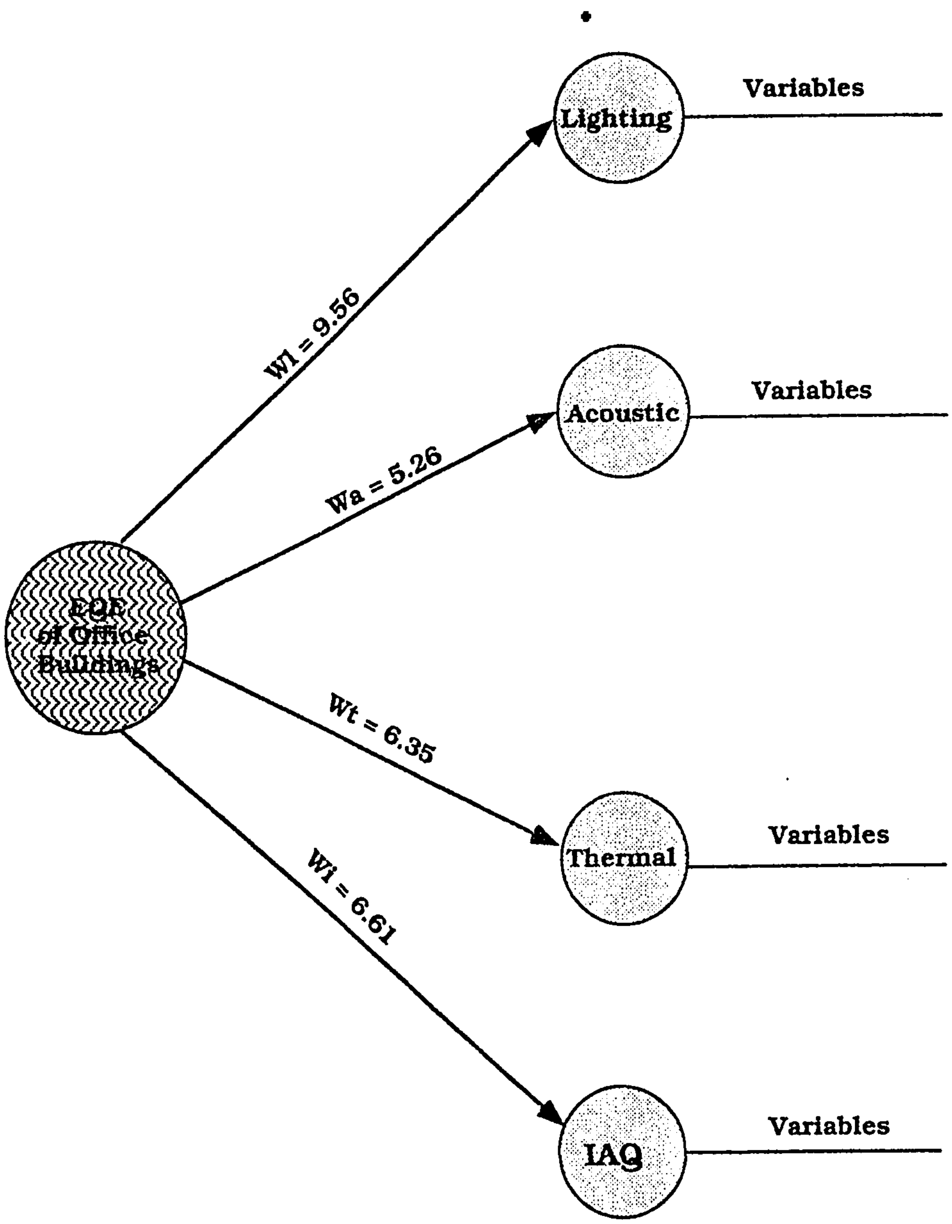

Figure (4.9) General Decision Tree for search root through EQE

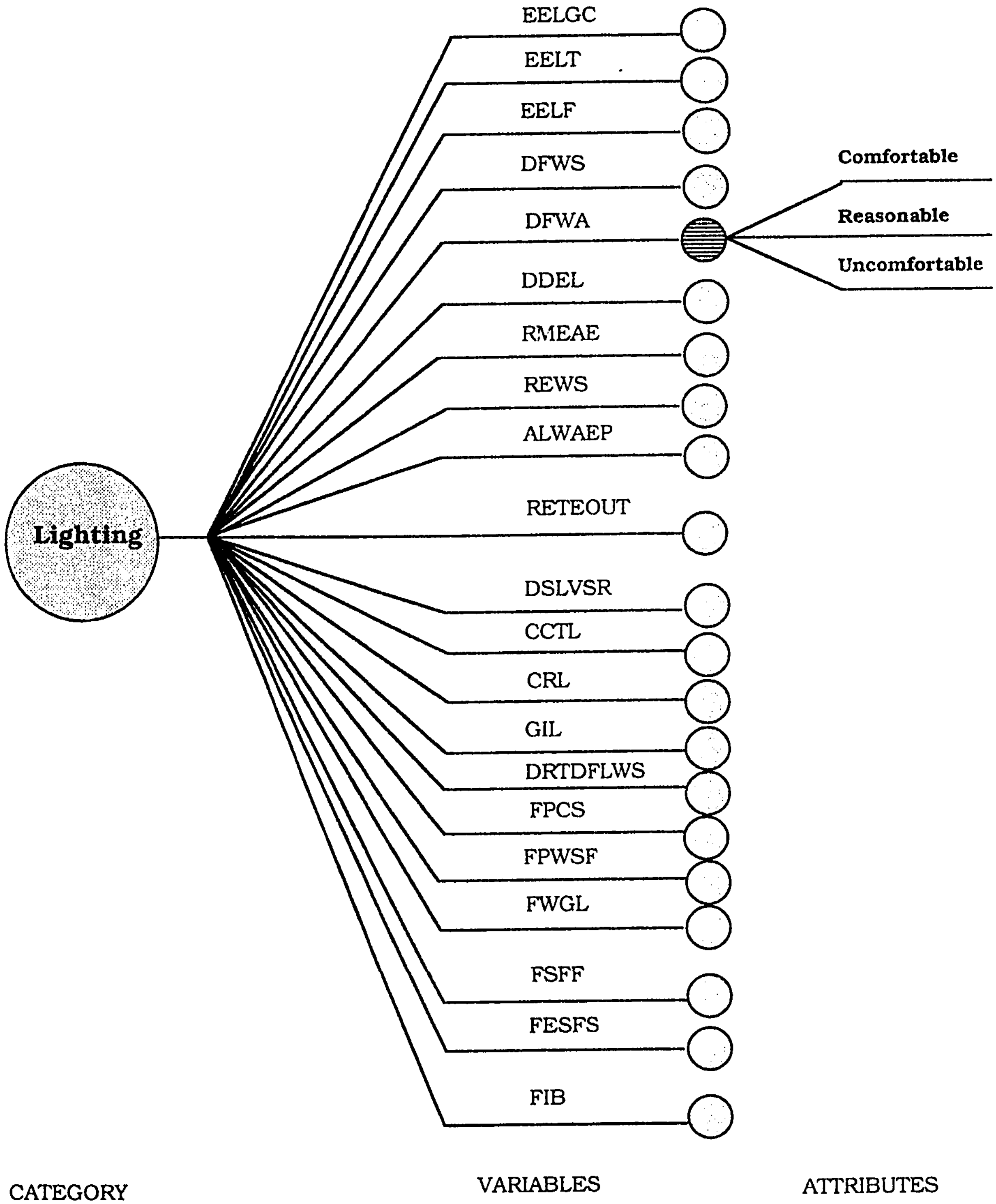

Figure (4.10) Decision Tree for search root through Lighting Evaluation

3-15

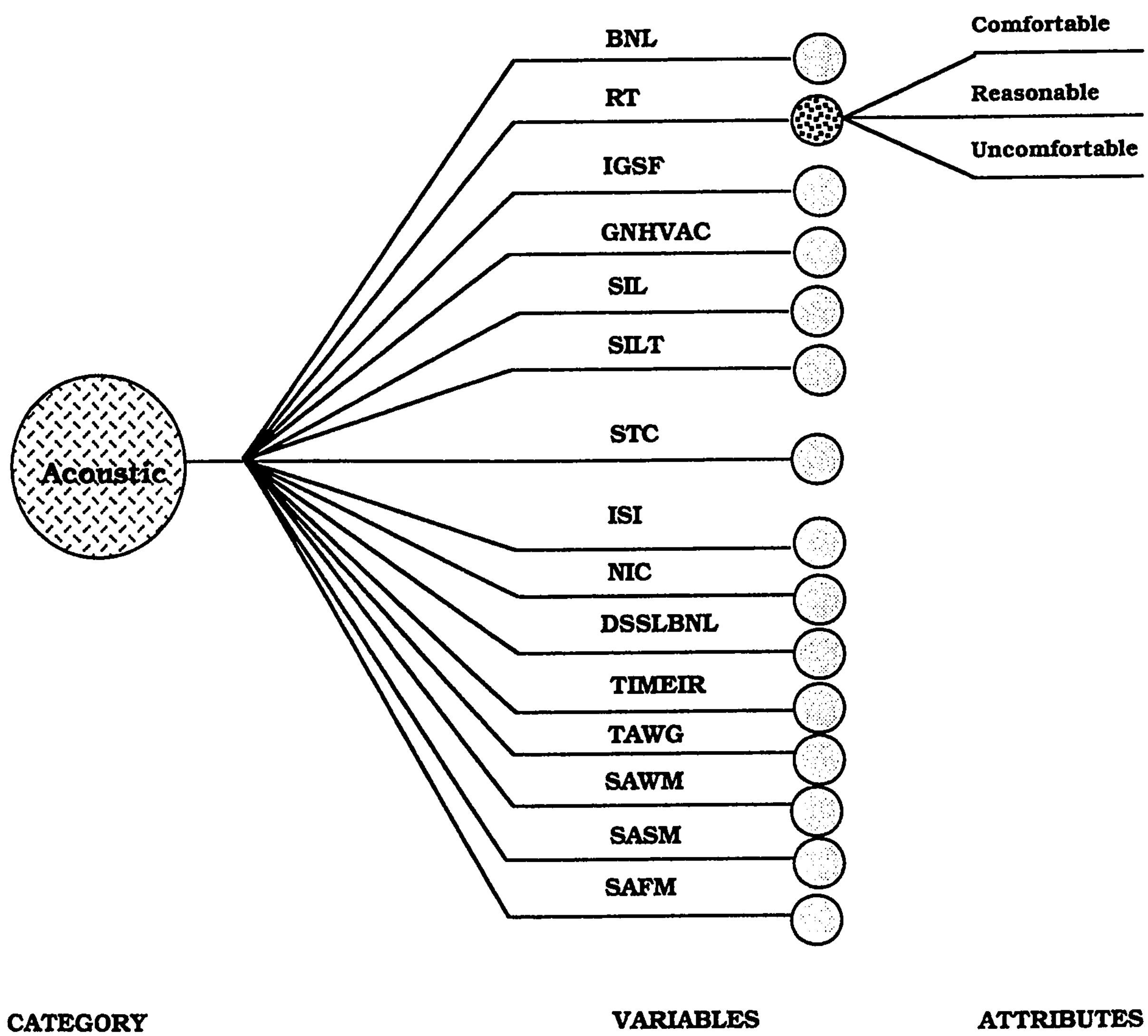

Figure (4.11) Decision Tree for search root through Acoustic Evaluation

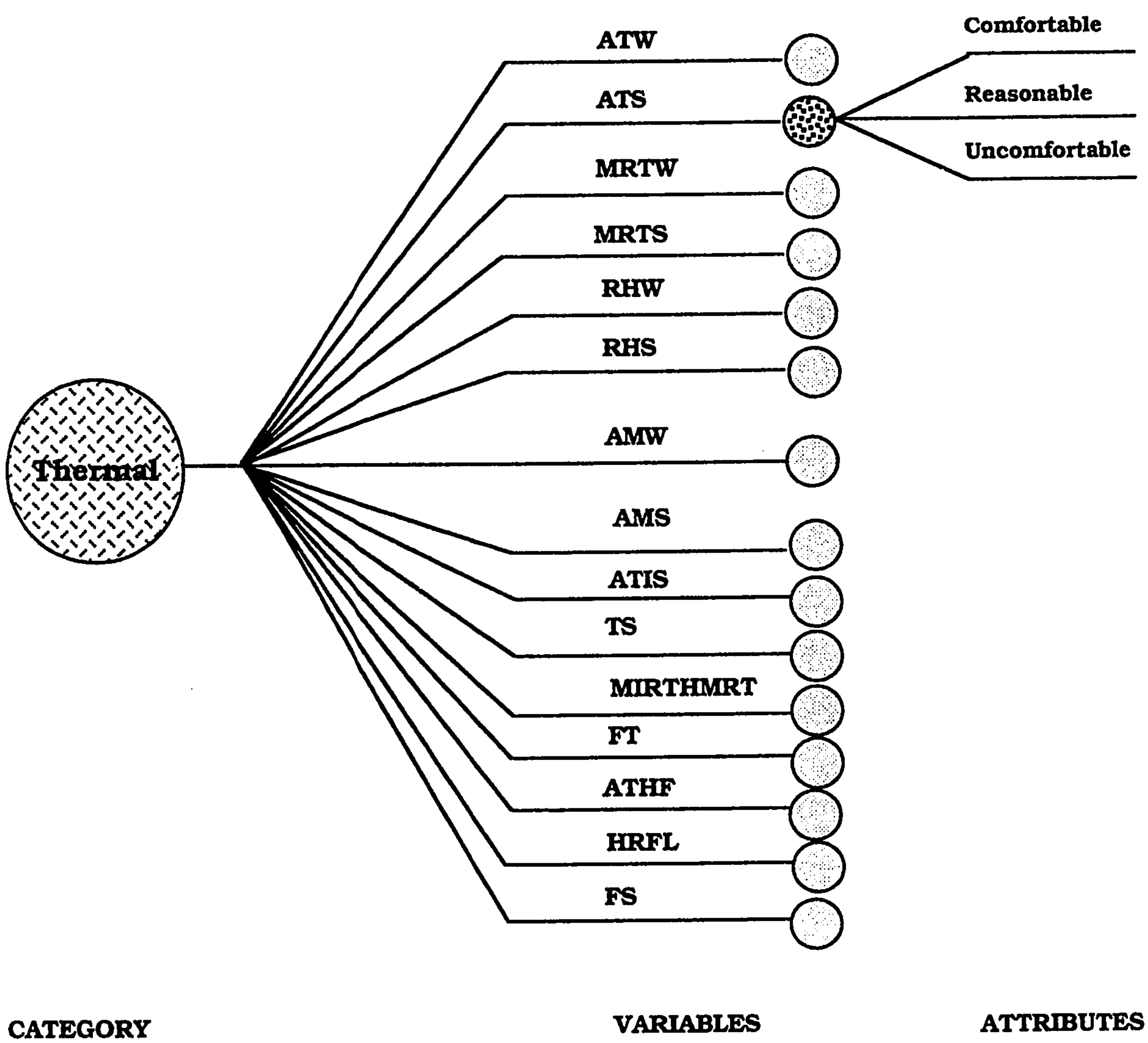

Figure (4.12) Decision Tree for search root through Thermal Evaluation

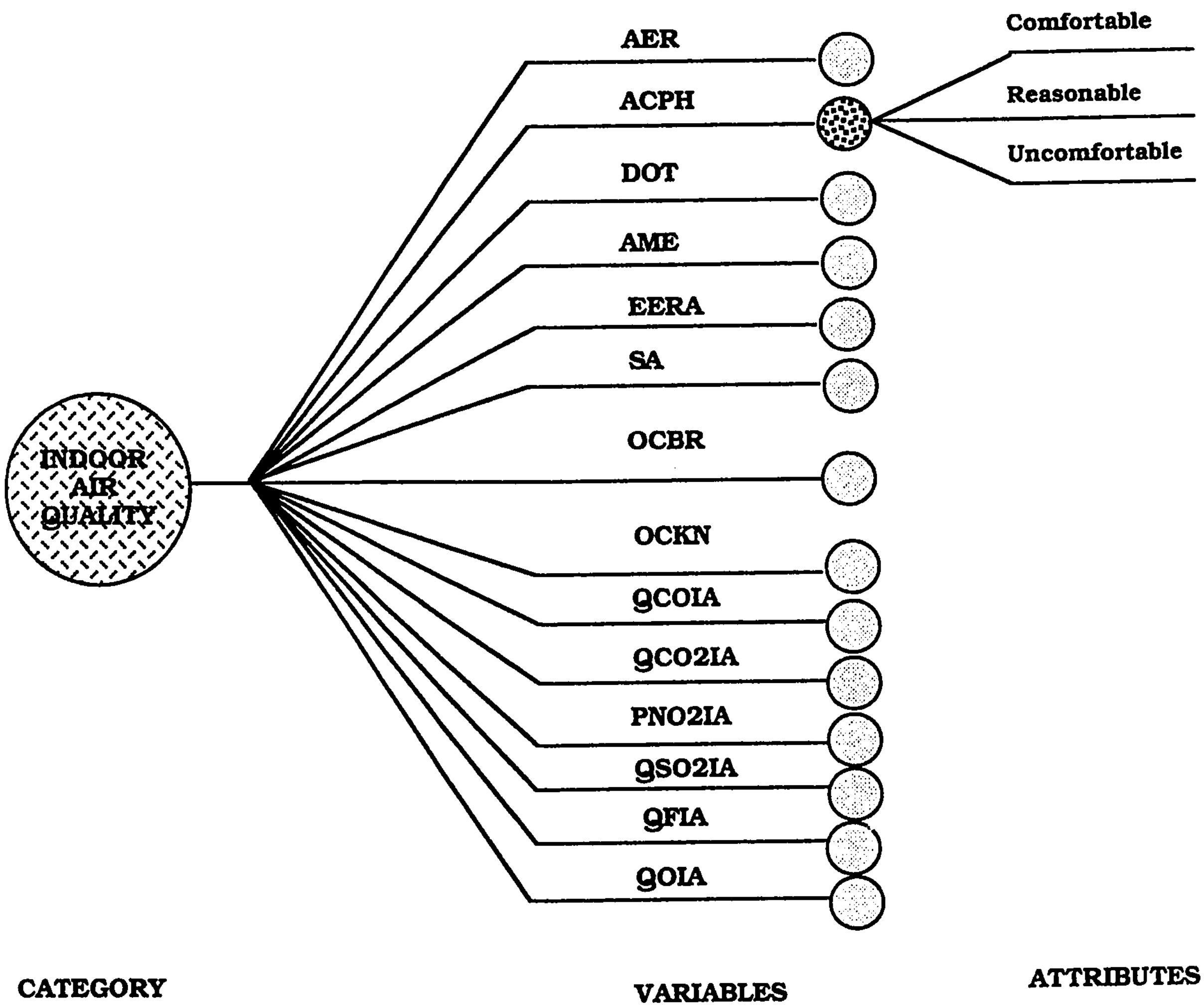

Figure (4-13) Decision Tree for search root through Indoor Air Quality Evaluation

4.2.4 PRODUCTION RULES

The relationship established through previous stages are implemented or associated together in the form of production rules. From the analysis of the comfort ranges and the weights of lighting, acoustic, thermal and indoor air quality categories and their variables, the results of these ranges, weights and scales were used to build the qualifiers of the ESEQE model of an expert system (see the qualifiers in appendix (3)).

Since search forms the core of any intelligent process, it is useful to structure an expert system program in a way that facilitates describing the search process. Production systems provide such structures. A definition of production system is given below.

A Production System Consists of:

- A set of rules, each consisting of a left side (a pattern) that determines the applicability of the rule, and a right side that describes the action to be performed if the rule is applied.

- One or more databases that contain whatever information is appropriate for the particular task. Some parts of the database may be permanent, while other parts of it may pertain only to the solution of the current problem. The information in these databases any be structured in any appropriate way.

- A control strategy that specifies the order in which the rules will be compared to the database and a way of resolving the conflicts that arise when several rules match at once (Rich, 1983).

After the analysis of the ranges of the scales of Environmental quality variables, the production rules were built from this tabulated knowledge. The tabular knowledge representing format proved to be very effective in facilitating the task of rule production. Rule as an example of building production rules.

RULE NUMBER 1

IF:

Background Noise Level ((using Noise Criteria - NC curve) is (Less than 20 dB)

or: Background Noise Level (using Noise Criteria - NC curve) is (Greater than or equal 45 dB to Less than 60 dB)

THEN:

Background Noise Level - Confidence = 7/10

and: [BNL] IS GIVEN THE VALUE ((0.068) * 7)

NOTE:

For practical measurements of sound strength it is convenient to use a decibel (dB) scale based on constant ratio.

REFERENCE:

R. Macmillan, "Environmental Science in Building," The Macmillan Press Ltd., London (19083).

Knowledge was loaded directly into the shell (EXSYS Professional) into the form of IF - THEN rules. The rules are developed by creating a series of qualifiers. A qualifier has two parts (Hamna, 1992).

1. An incomplete sentence ending with a verb
2. Associate values representing all the possible relevant situations to the qualifier.

The IF part of the rule consists of one or more of the qualifier's values and conditions that can occur. The THEN part consists of another qualifier value or variable or choices (possible solution to the rule), and represents action that must be taken. Note represents any text to explain specific point and the reference shows from where the text was quoted.

4.2.4.1 DEVELOPING AND VALIDATING A DEMO

A demo was first developed for testing purposes. The demo is a structurally complete expert systems, but on a smaller scale. In other words, with a smaller number of rules. The purpose of developing a demo is to ensure that the system is complete and capable of producing valid results. The demo was used to assess the acoustic quality of an office building. It contains 47 rules covering all the acoustic variables.

The validation of the model was done by taking a hypothetical case of office building and their variables and handle the acoustic quality manually using experts' methods of acoustic quality evaluation and finding out the percentage of acoustic achievement. The conditions of the variables are shown in Table 4.13.

The percentage of acoustic comfort achieved was calculated as follows:

= (10 * ((10 * 0.068) + (7 * 0.068) + (10 * 0.045) + (7 * 0.091) + (10 * 0.068) + (7 * 0.068) + (10 * 0.068) + (4 * 0.068) + (7 * 0.068) + (7 * 0.068) + (10 *

0.091) + (10 * 0.045) + (7 * 0.045) + (7 * 0.091) + (7 * 0.045)) = 79.3

Table (4.13) The conditions of the variables of Acoustic Quality

No.	Variables	Conditions
1	BNL	Greater than or equal 35 dB to less than 45 dB
2	RT	Greater than or equal 0.8 sec. to less than 0.6 sec.
3	IGSF	Less than 20 dB
4	GNHVAC	Greater than or equal 35 dB to less than 45 dB
5	SIL	Greater than or equal 30 dB to less than 40 dB
6	SILT	Greater than or equal 30 dB to less than 40 dB
7	STC	Greater than or equal 45 dB
8	ISI	Less than 35 dB
9	NIC	Greater than or equal 40 dB to less than 50 dB
10	DSSLBNL	Greater than or equal 20 dB to less than 35 dB
11	TIMEIR	Less than 20 milli/sec.
12	TAWG	Less than 40%
13	SAWM	Greater than 50% to less than or equal 75%
14	SASM	Greater than 30% to less than or equal 50%
15	SAFM	Greater than 35% to less than or equal 55%

The ESEQE demo and was tested and run under the previous variables at the same conditions of acoustic and the percentage of acoustic comfort achievement is = 79.3 (refer to screen print out in item 4.2.6). By comparing the results in both ways they are totally the same.

4.2.5 DEVELOPMENT OF A COMPLETE ESEQE MODEL

After the successful run of the demo, the ESEQE model was completed through the following steps:

1. The number of the rules covering the full scope of ESEQE model was increased.
2. The conditions, values and rules for each variable were added.
3. The execution rules were added to complete the program.

The complete ESEQE model consists of 200 rules covering all aspects of environmental quality evaluation of office buildings in the tropical areas.

The structure of ESEQE model is summarized and illustrated in figure (4.14). The structure depends on the interaction between the system and the user during an evaluation process. The result of EQE decision making process through the expert system depend on the selection attributes. A poor EQE results form a poor set of attributes. Selection of the attributes is not a haphazard procedure and demands professional experience.

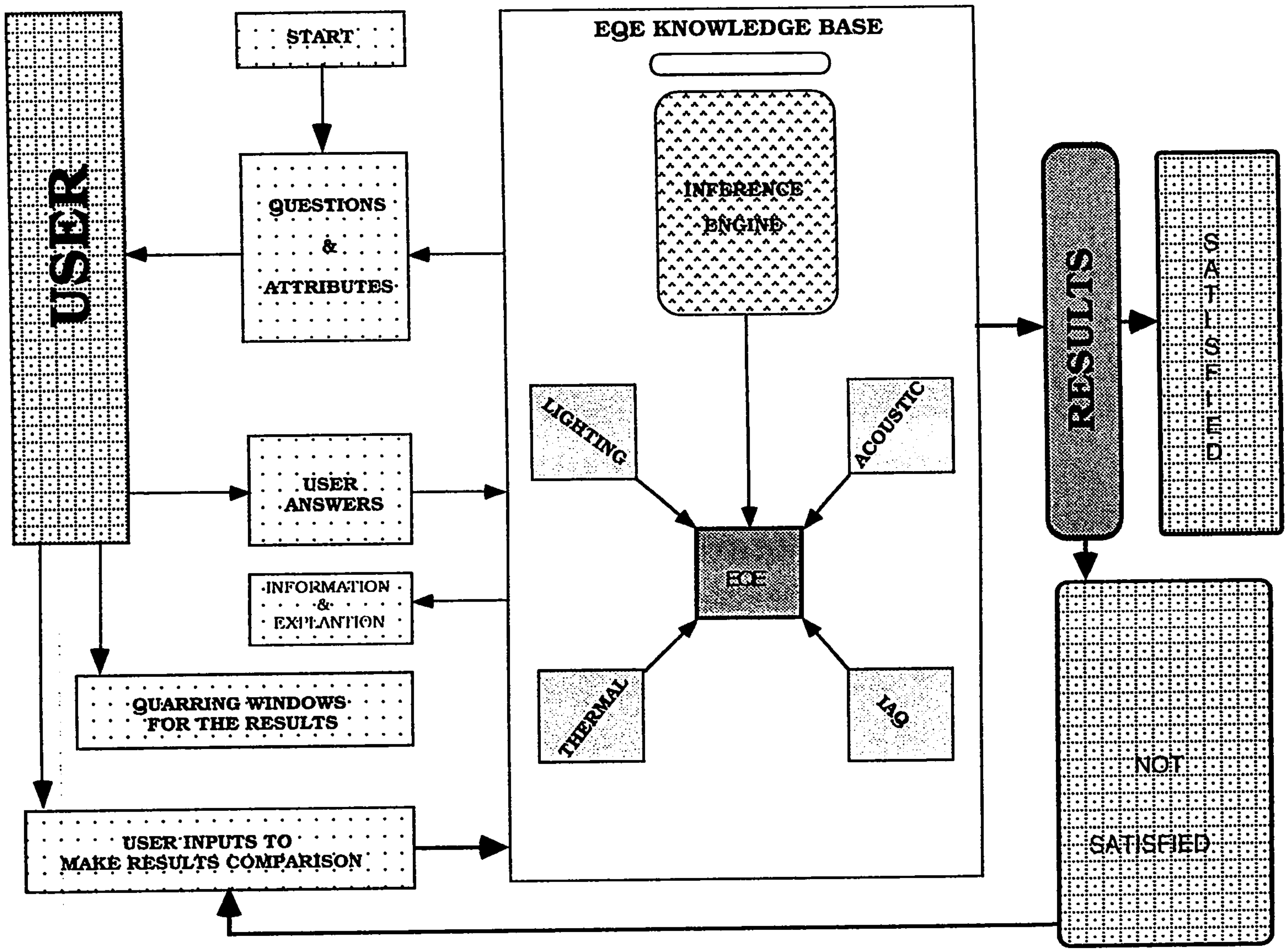

Figure (5.8) ESEQE Structure (Performance Procedures).

4.2.6 VALIDATION OF THE COMPLETE ESEQE MODEL

The procedures were used to validate the demo elaborated here to cover the complete variables, 65 variables, of the ESEQE model. The test of the model was carried out using the previous variables of the demo and the following variables of lighting as shown in Table 4.14.

The percentage of lighting comfort achievement was calculated as follows:

= (10 * ((10 * 0.06) + (7 * 0.02) + (10 * 0.02) + (10 * 0.04) + (10 * 0.04) + (10 * 0.04) + (10 * 0.06) + (7 * 0.08) + (10 * 0.06) + (7 * 0.06) + (10 * 0.04) + (10 * 0.04) + (7 * 0.04) + (10 * 0.08) + (7 * 0.06) + (4 * 0.06) + (7 * 0.04) + (7 * 0.04) + (4 * 0.04) + (7 * 0.04) + (7 * 0.04)) = 81.4%

The same procedures were done on the evaluation of thermal and indoor air quality under the conditions and the variables as shown in the screen print out in item 4.2..6. and the results were as follows:

- The percentage of thermal comfort achievement = 85.641%
- The percentage of indoor air quality achievement = 80.222%
- The total environmental quality evaluation = 81.572%

After the manual evaluation was finished for the complete model, the complete model was tested and run under the same conditions and variables and the results for the all items are totally the same as shown in item 4.2.6

Table (4.14) The conditions of the variables of lighting Quality

No.	Variables	Conditions
1	EELGC	Greater than or equal 200 Lux to less than 400 Lux
2	EELT	Less than 200 Lux
3	EELF	Greater than or equal 400 Lux to less than 600 Lux
4	DFWS	Greater than or equal 4% to less than 6%
5	DFWA	Greater than or equal 2% to less than 3%
6	DDEL	Directed from other direction and a way from the window
7	RMEAE	Greater than or equal 1:1 to less than or equal 1:2
8	REWS	Greater than or equal 1:2 to less than or equal 1:3
9	ALWAEWP	Greater than or equal 1:1 to less than or equal 1:2
10	REOTEUT	Greater than or equal 1:3 to less than 1:10
11	DSLVSR	Greater than or equal 2.5
12	CCTL	Greater than 5300 k (cool)
13	CRL	Greater than or equal 40 to less than 70
14	GIL	Greater than or equal 17 to less than 21
15	DRTDFLWS	Greater than or equal 0.6 to less than 0.8
16	FPCS	Less than 0.6
17	FPWSF	Greater than or equal 0.3 to less than or equal 0.5
18	FWGL	Greater than or equal 0.5 to less than 0.7
19	FSFF	Less than 0.2
20	FESFS	Greater than or equal 0.1 to less than 0.3
21	FIB	Less than or equal 0.2

. Now, we have the complete ESEQE model simulating the evaluation process of the interviewed experts and their thoughts supported by extensive findings from the literature was used to build the knowledge base. the results came from the ESEQE model corresponds successfully with the manual results using experts evaluation methods.

4.2.7 INSTRUCTIONS FOR RUNNING ESEQE

In order to turn the ESEQE model the computer should be equipped with the following minimum hardware requirements:

- IBM PC, AT or Compatible
- 2M of Ram or more
- Hard disk
- VGA Monitor and Display Card

Once you booted up the computer change the directory to drive b (C:\ cd A:) and press enter, you will find the prompt A: just write (A: Almostafa) then you will find the screen of EXSYS Professional and the screen of EXSYS editor. Then press "R" for run.

Then the name of the expert system and author will be displayed followed by an introductory screen developing a brief description of the ESEQE. Press any key to start, then you will be answering questions that would lead to the possible solution the system will infer through your inputs and system knowledge base. The system starts up by asking you a series of questions in a friendly manner.

You can always ask "WHY" and you will be answered by the system showing you the set of rules that requires your particular answer or the system can tell you how it arrived at that conclusion and from where it acquired its information. You can also tell the system that you need more information to make up your mind about the answer you are asked to give and the system will display an information screen to guide you about.

When the system receives all the information to make it start the inferring chain. The system will display the ending text and if you press any key the results will appear on the screen.

A complete run for ESEQE model is illustrated in the following pages.

Complete run of an Expert System for Environmental Quality Evaluation (ESEQE) of Office Buildings .

To run the ESEQE mode the procedures are as follows:

1. Reboot the computer, change to drive A: or B:
2. Write "*ALMOSTAFA*" at the prompt, then you will find the Plate 4.1 appears on the screen.
3. Write "*R*" on the prompt of this plate, then the Plate 4.2 will appear.

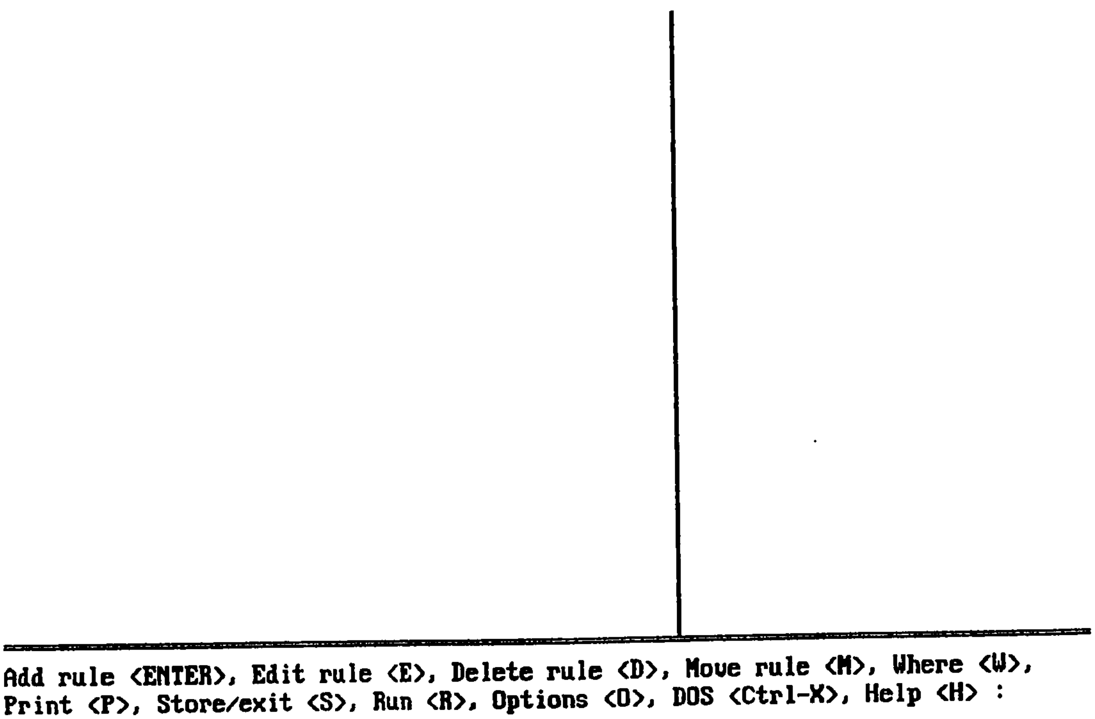

Plate 4.1 EXSYS starting screen

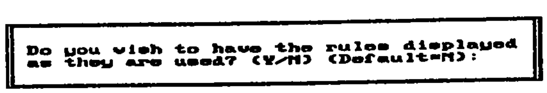

Plate 4.2 Rules Display Option

4. If you want to save your input then write the file name and press enter. If you do not just press enter then you will get Plate 4.3

Recover previously saved input Y/ N (default = N) :

Plate 4.3 Input saving option

5. Press enter, the ESEQE starting screen will appear as shown in Plate 4.4

EXSYS Pro

AN EXPERT SYSTEM FOR
ENVIRONMENTAL QUALITY EVALUATION OF
OFFICE BUILDINGS IN TROPICAL AREAS.

BY: RABEE MOHAMED REFFAT

© *COPYWRITE 1994*

Press any key to start:

Plate 4.4 Starting screen of ESEQE model

6. Press any key to start with the ESEQE model. The start will be an introduction to ESEQE model as shown in Plate 4.5.

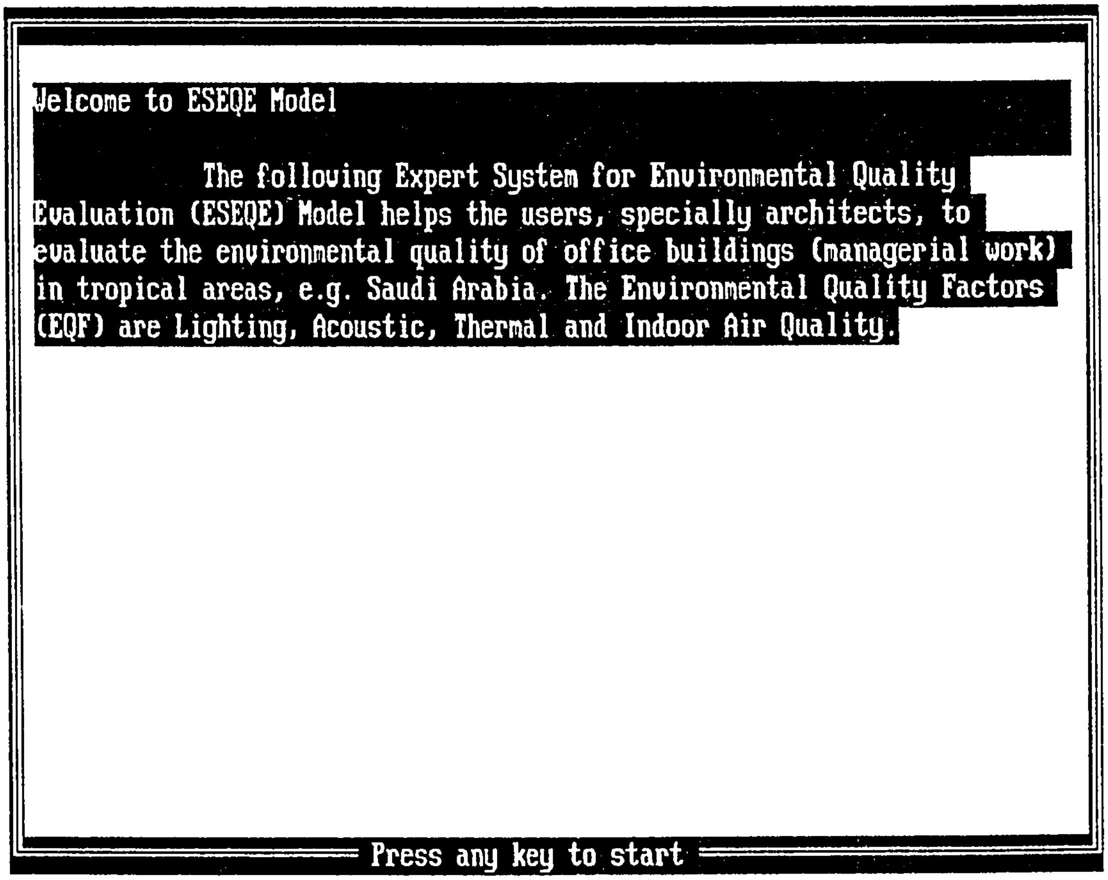

Plate 4.5 Introduction to ESEQE model

7. After pressing any key to start with the model, a series of the plates will be appeared on the screen respectively. You will be asked to choose one of the variables in each plate and press enter to proceed with the others. A series of plates are shown below.

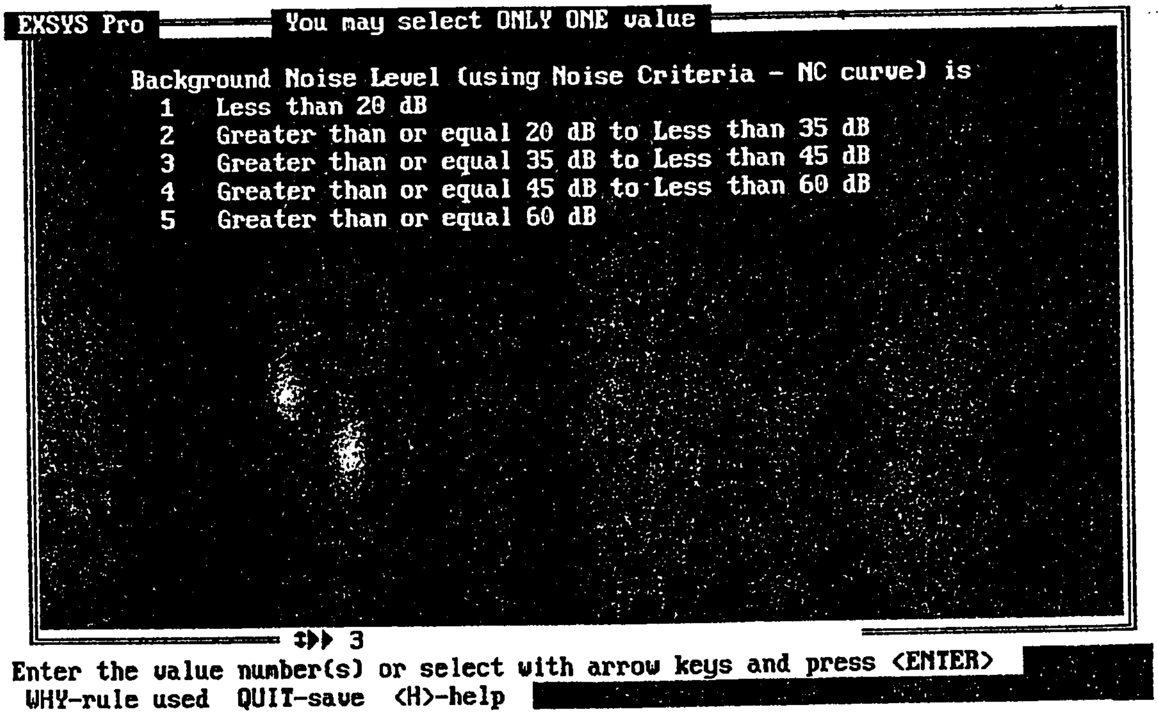

Plate 4.6 Background Noise Level

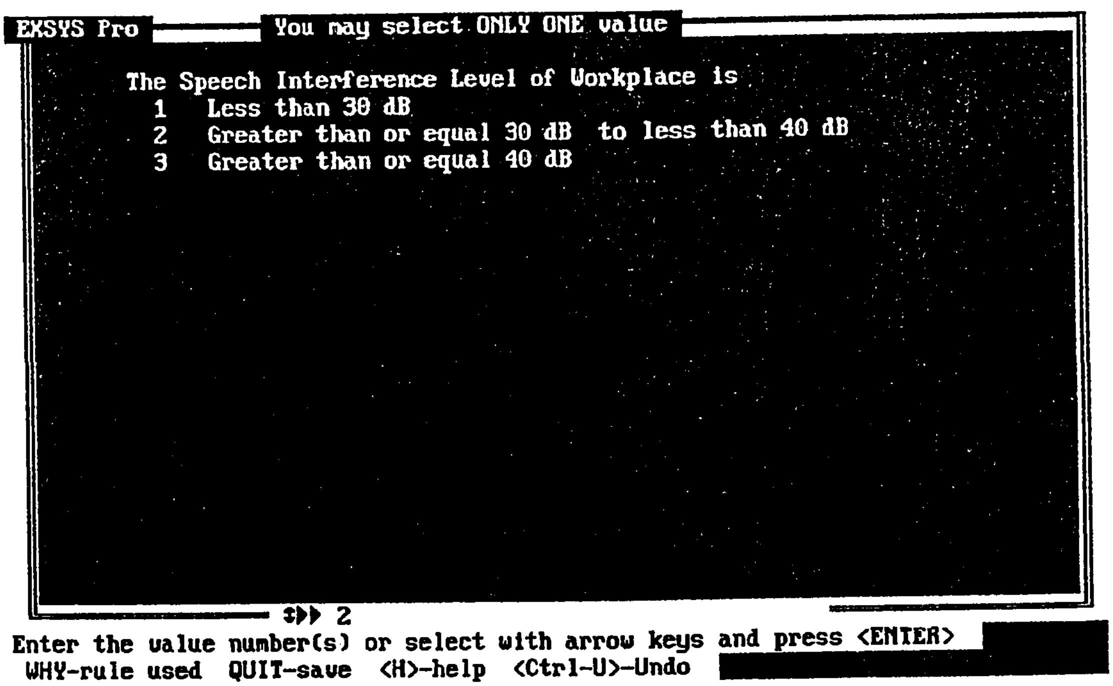

Plate 4.7 Speech Interference Level of workplace

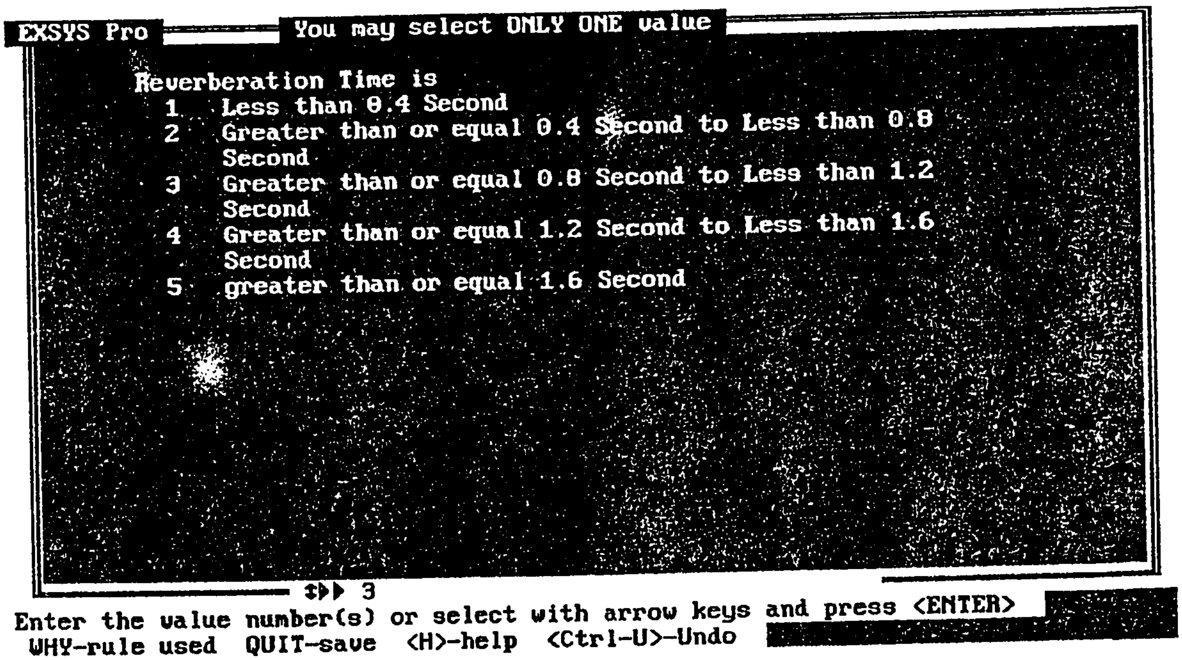

Plate 4.8 Reverberation Time (RT)

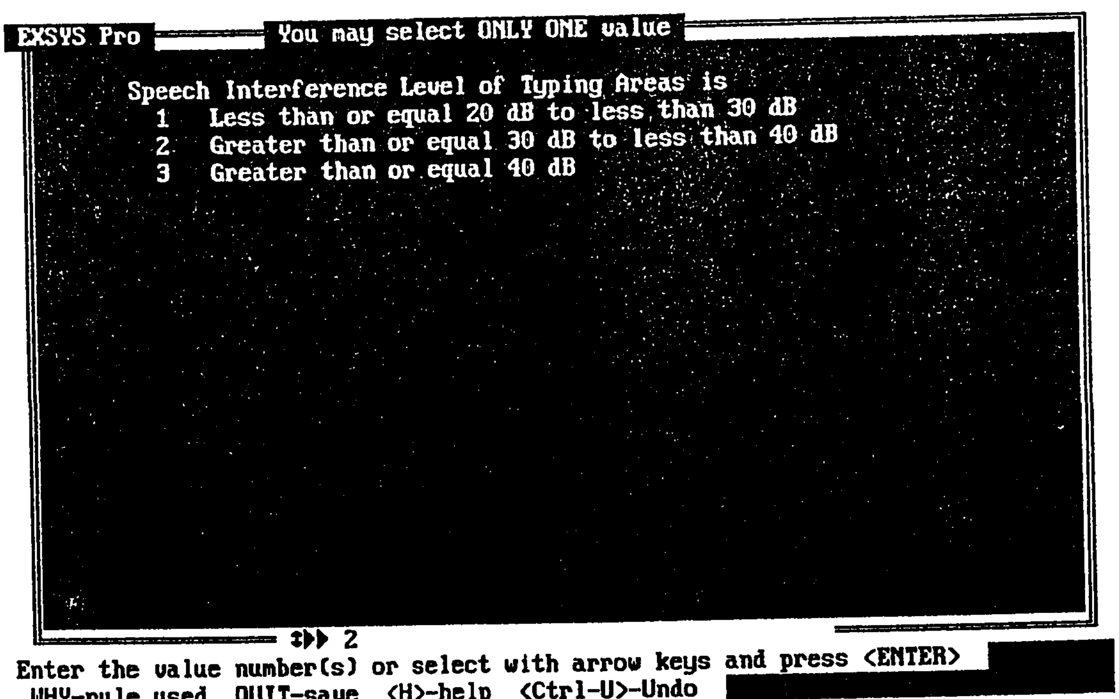

Plate 4.9 Speech Interference Level of typing areas

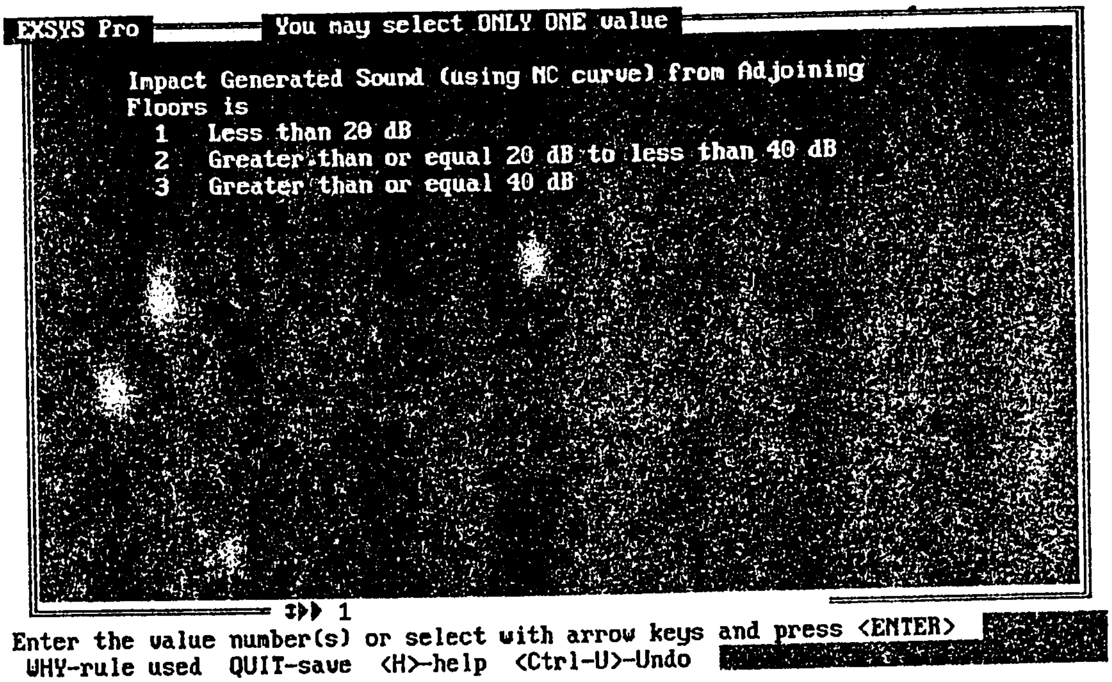

Plate 4.10 Impact Generated Sound from adjoining floors

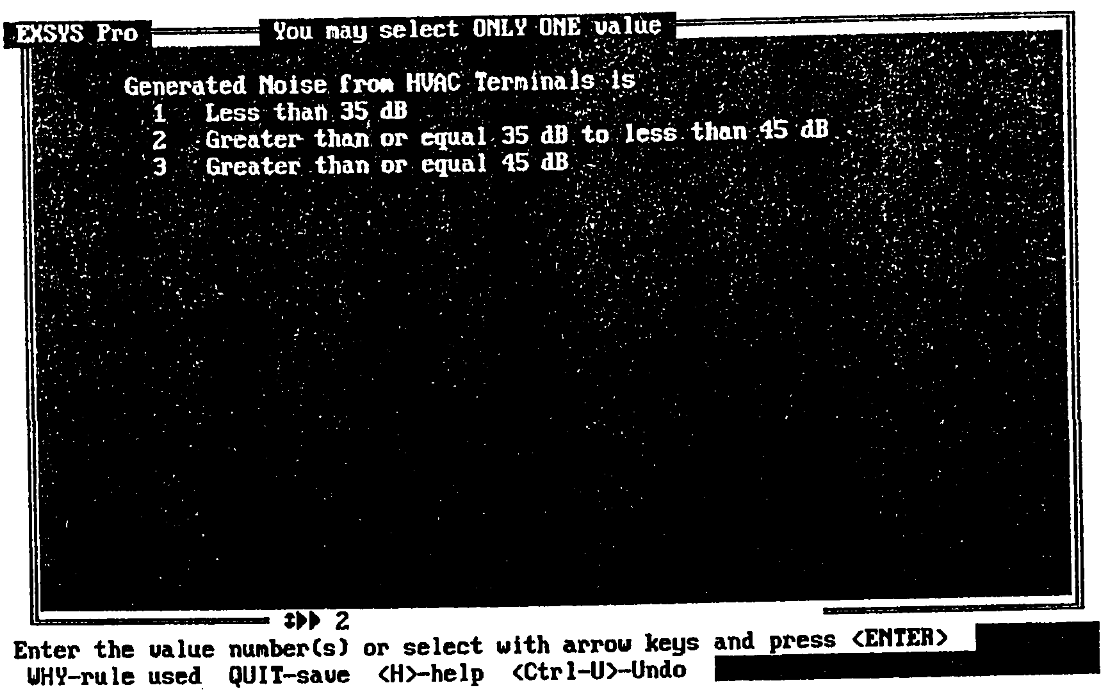

Plate 4.11 Generated Noise from HVAC terminals

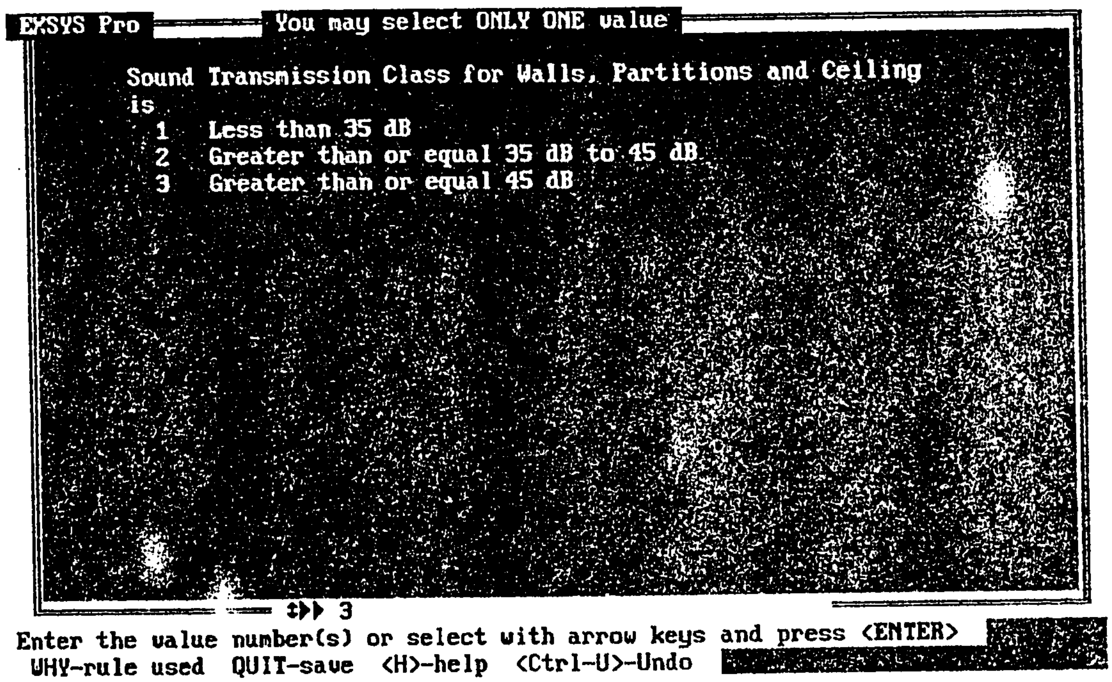

Plate 4.12 Sound Transmission Class for walls, partitions and ceiling

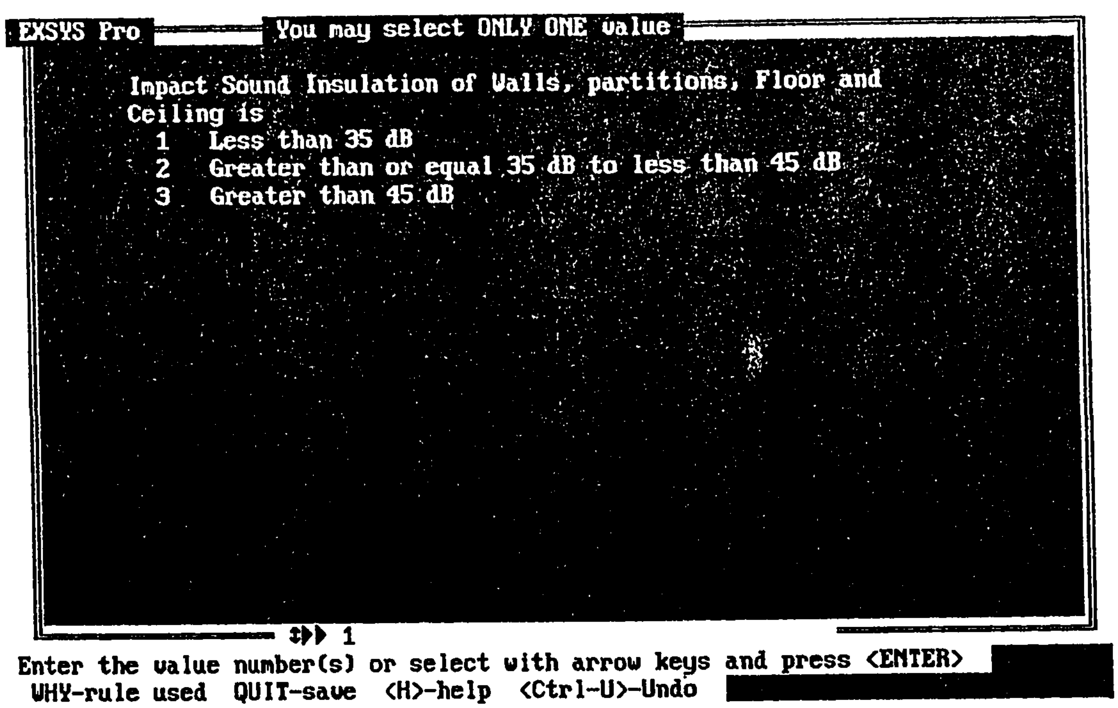

Plate 4.13 Impact Sound Insulation for walls, partitions, floors and ceiling

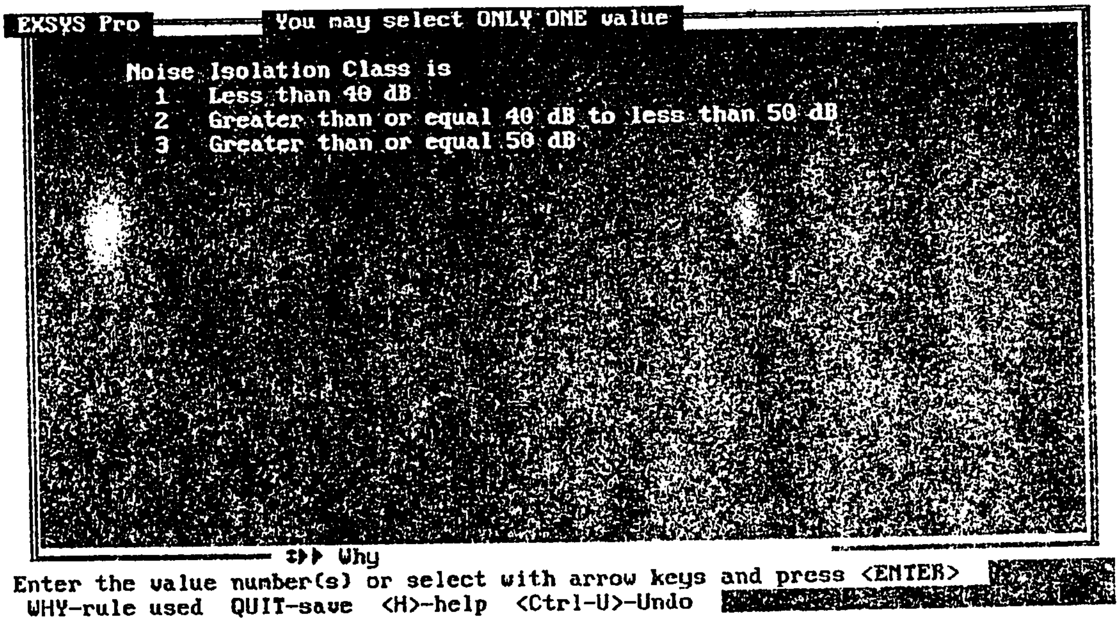

Plate 4.14 Related Information of Nose Isolation Class

If you would like to get more information about any variable, type *"WHY"*. You will find the one of the rules that fire this variable and other explanations about the terms used in this variable. An example is shown in Plate 4.15

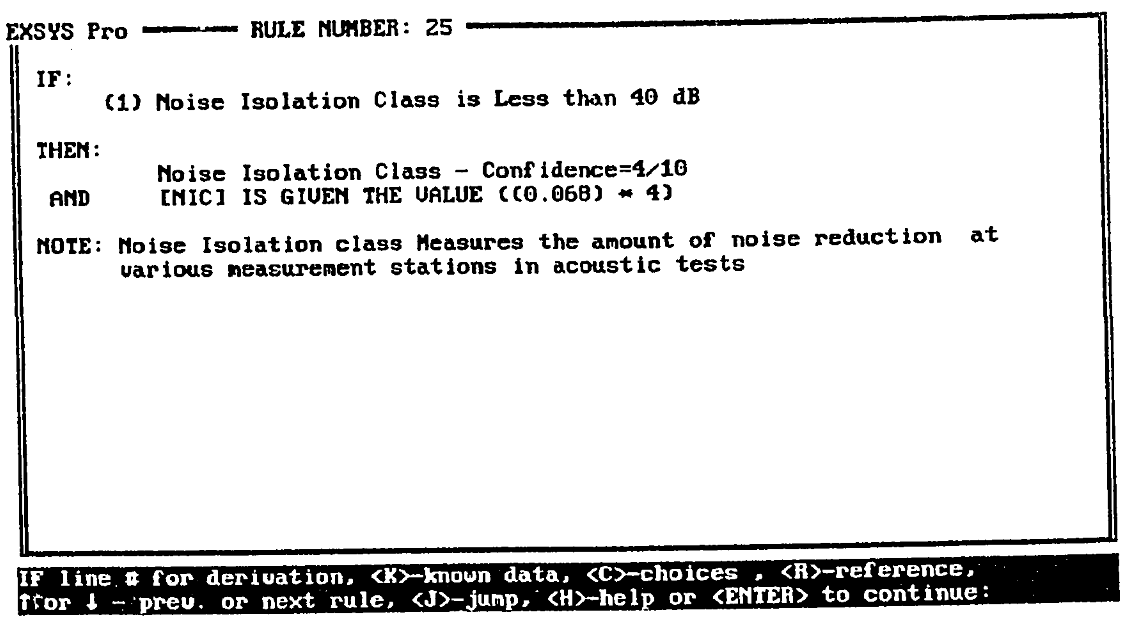

Plate 4.15 More information about the variable

If you would like to get the reference for this information, type *"R"*.

```
EXSYS Pro ──── RULE NUMBER: 25 ────────────────────────
IF:
    (1) Noise Isolation Class is Less than 40 dB

THEN:
       Noise Isolation Class - Confidence=4/10
 AND   [NIC] IS GIVEN THE VALUE ([0.068] * 4)

NOTE: Noise Isolation class Measures the amount of noise reduction  at
      various measurement stations in acoustic tests

REFERENCE: D. A.. arris, A. E. Palmer / M. S. Lewis, D. L. Munson, G.
           Meckler and R. Gerdes, "Planning and Designing the Office
           environment," Van Nostrand Rinhold Company, New York (1981).

Press any key to continue:
```

Plate 4.16 The references of the related information about the variable

```
EXSYS Pro ═══ You may select ONLY ONE value ═══
   Noise Isolation Class is
     1  Less than 40 dB
     2  Greater than or equal 40 dB to less than 50 dB
     3  Greater than or equal 50 dB

═══════════ ⇕▶ 2
Enter the value number(s) or select with arrow keys and press <ENTER>
 WHY-rule used  QUIT-save  <H>-help  <Ctrl-U>-Undo
```

Plate 4.17 Nose Isolation Class

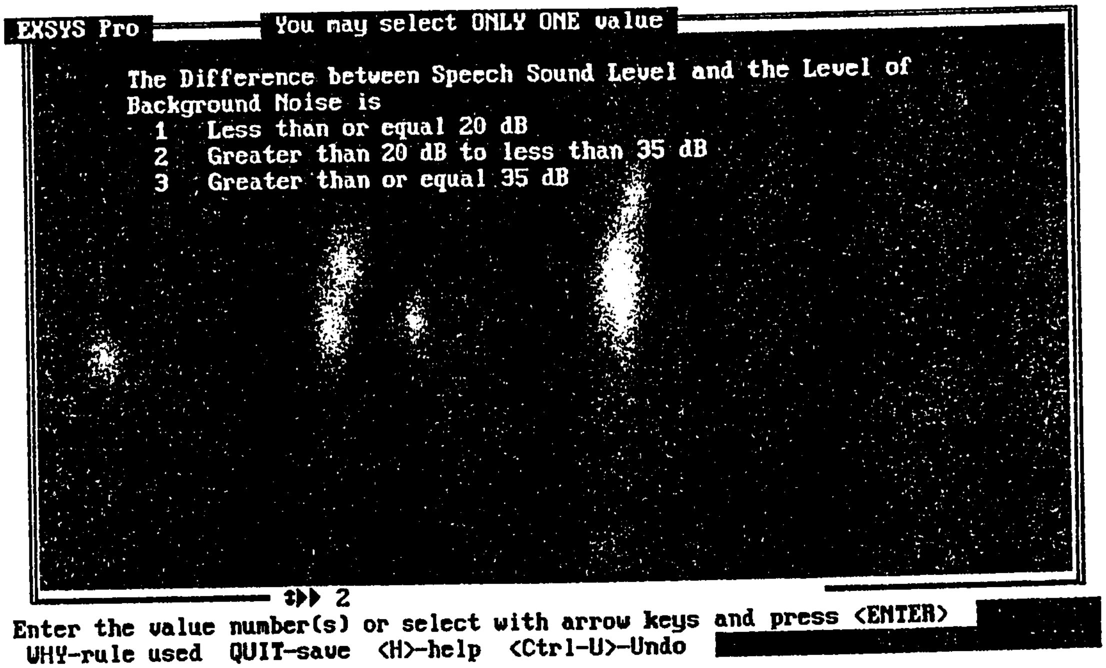

Plate 4.18 The Difference between Speech Sound Level and the level of Background Noise

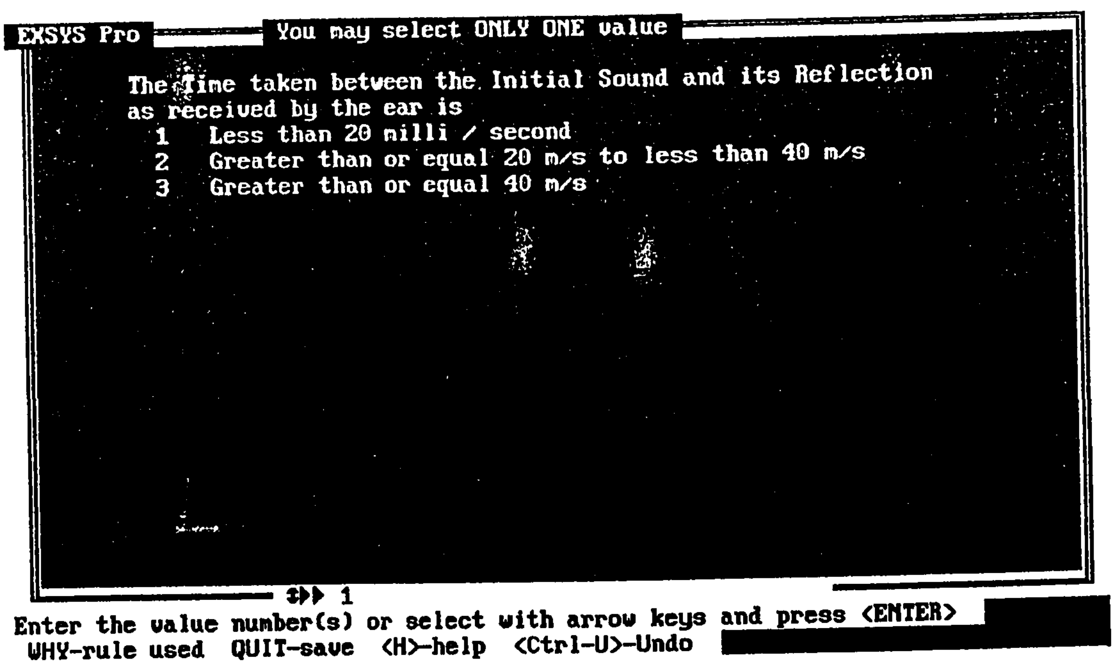

Plate 4.19 The time taken between the Initial Sound and its Reflection

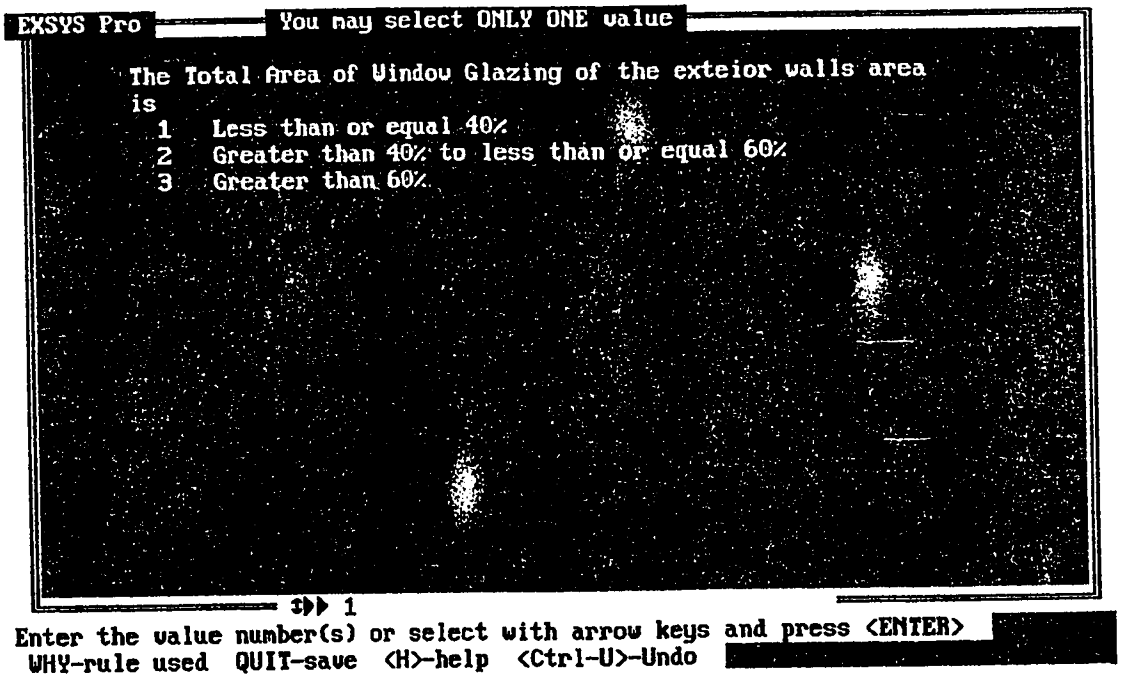

Plate 4.20 The total area of Window Glazing

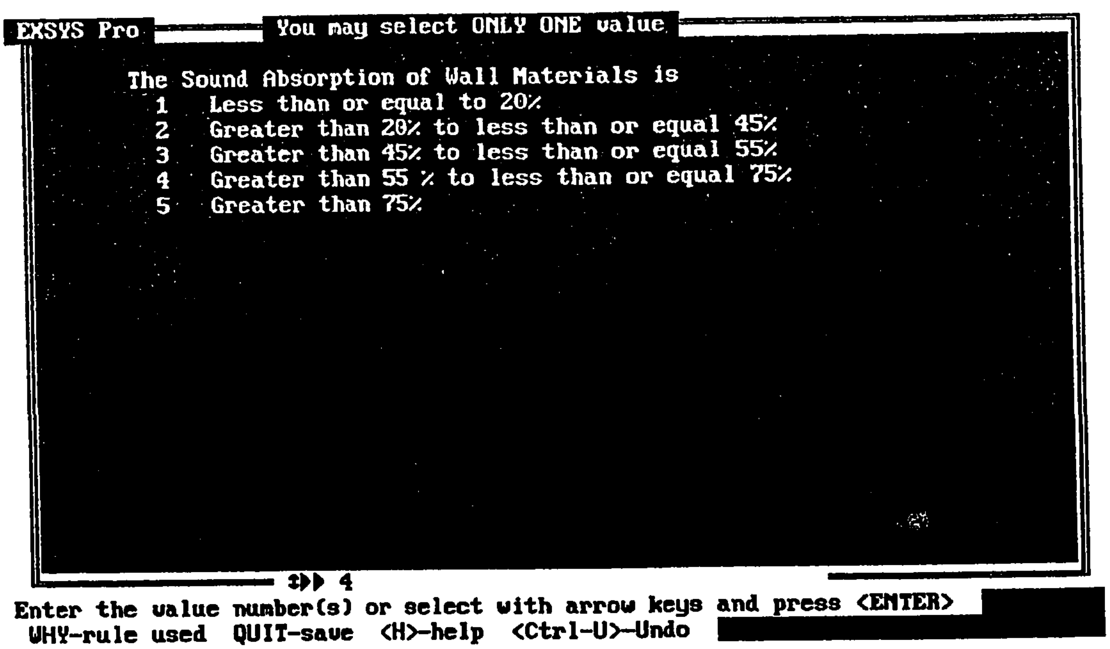

Plate 4.21 Sound Absorption of wall materials

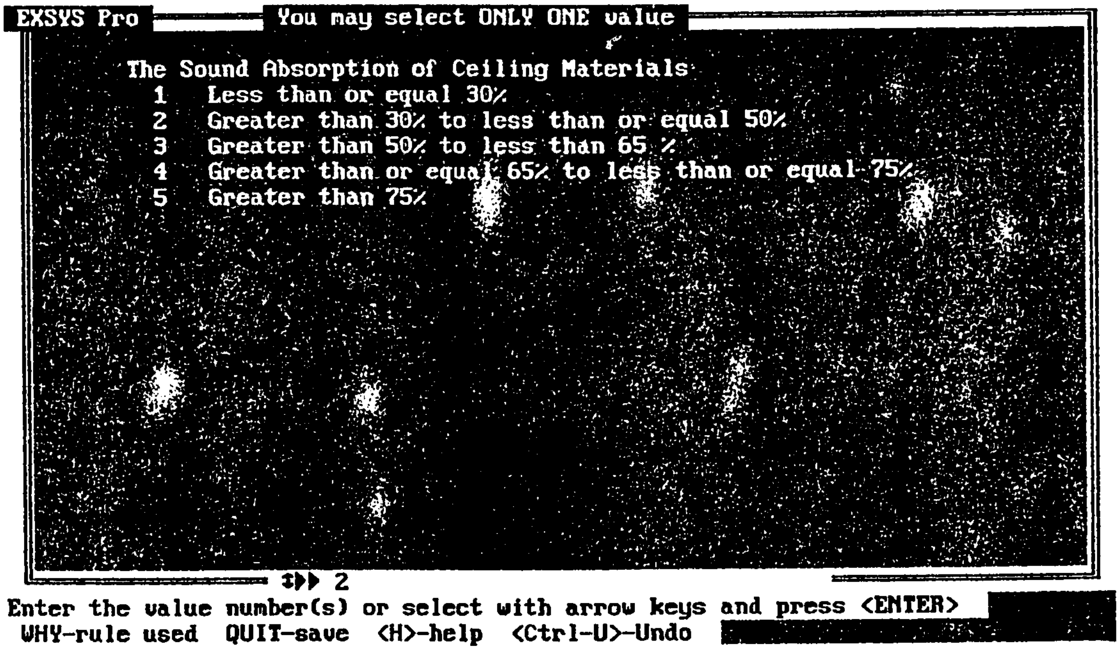

Plate 4.22 Sound Absorption of ceiling materials

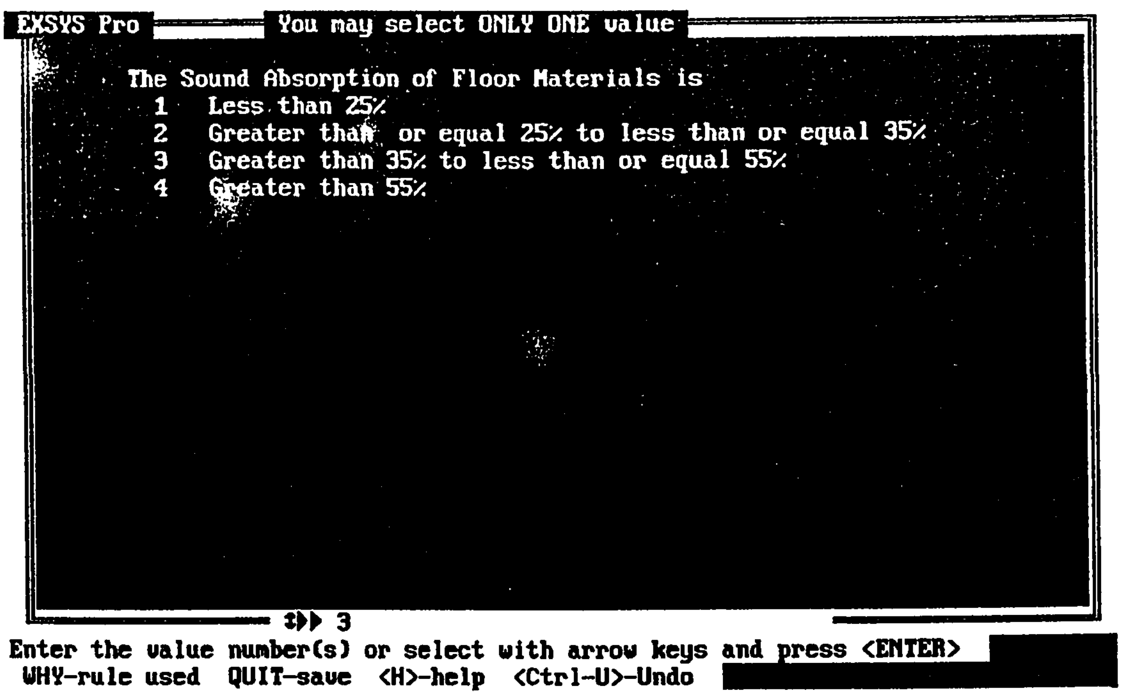

Plate 4.23 Sound Absorption of floor materials

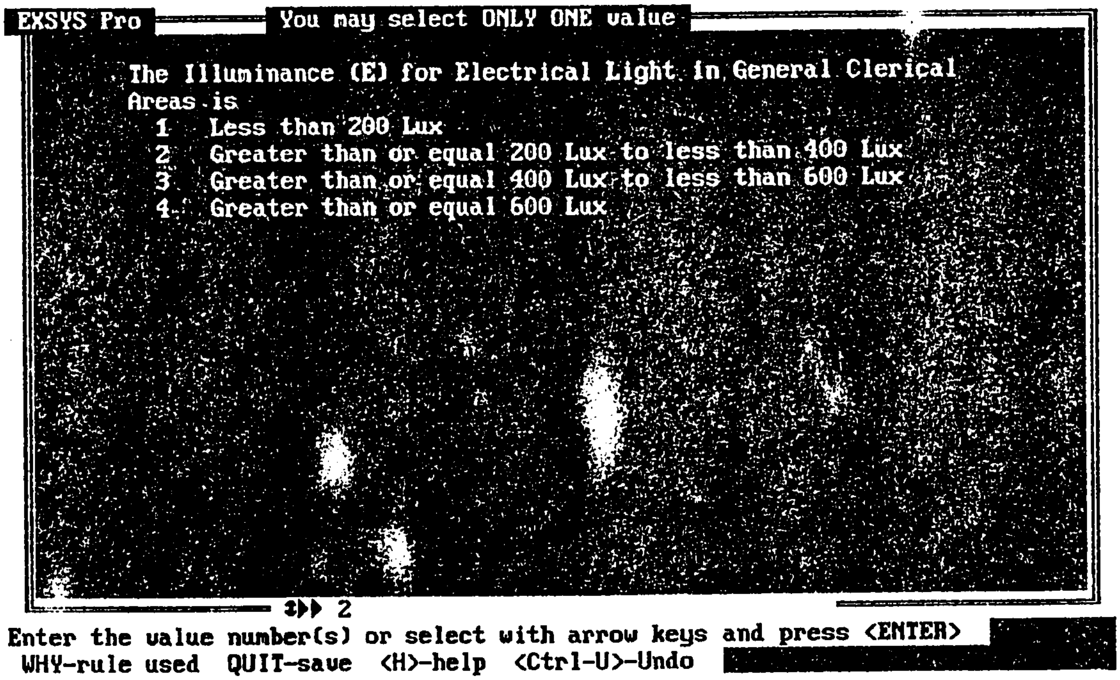

Plate 4.24 The Illuminance of Electrical Light in G.C.A.

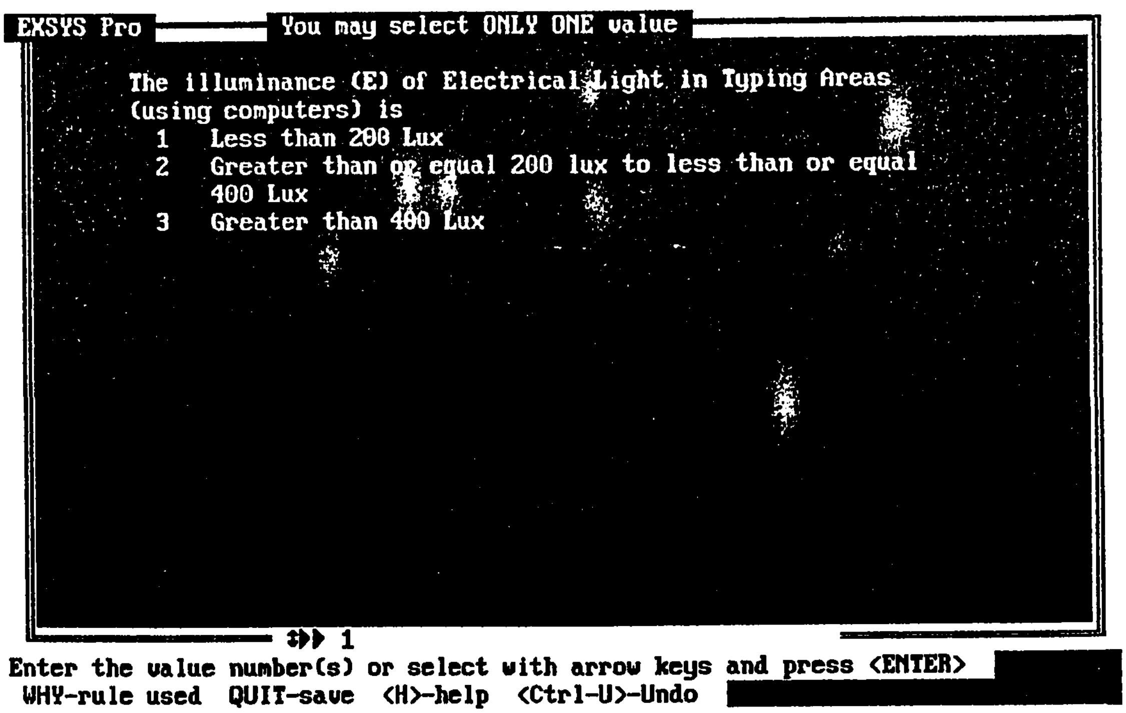

Plate 4.25 The Illuminance of Electrical Light in T.A.

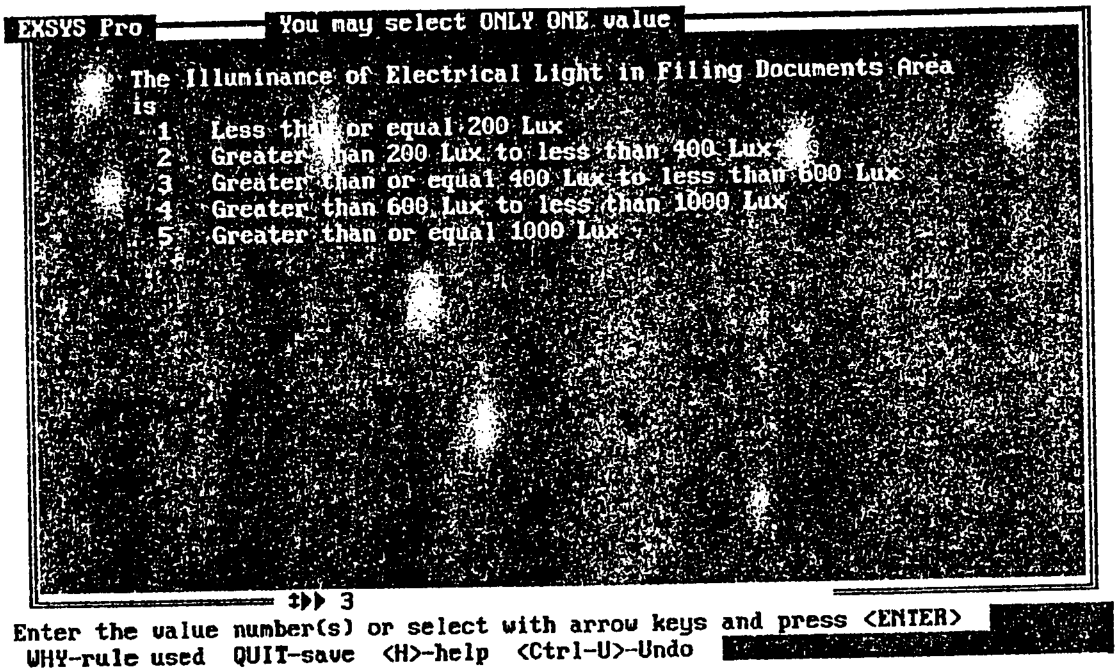

Plate 4.26 The Illuminance of Electrical Light in F.D.A.

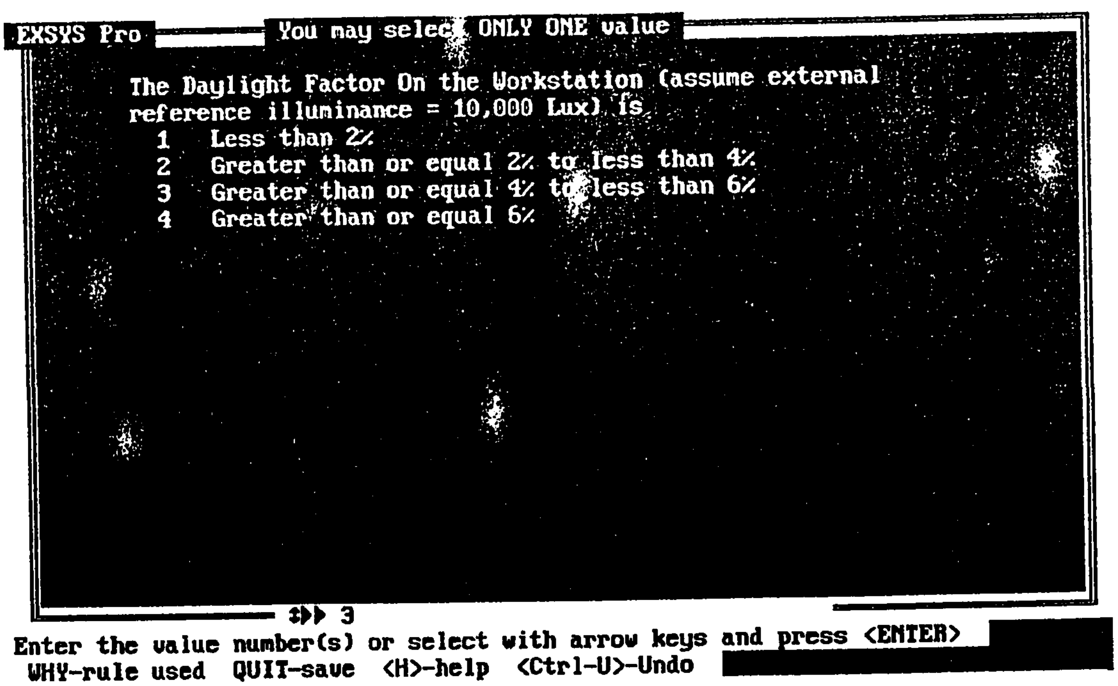

Plate 4.27 Daylight Factor on the workstation

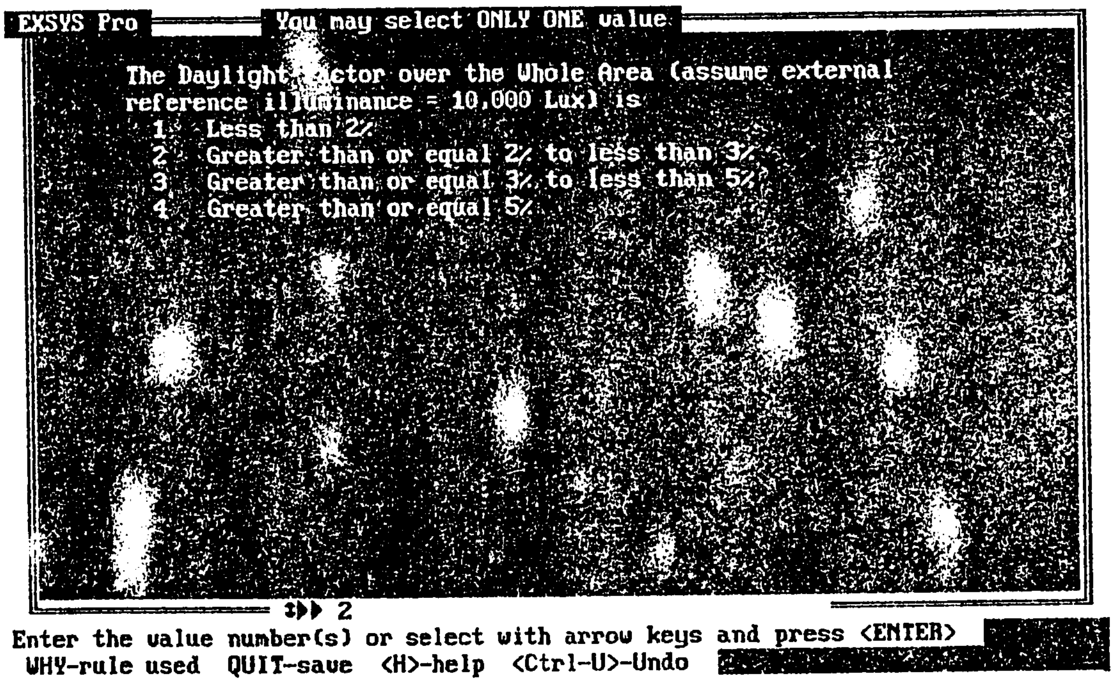

Plate 4.28 Daylight Factor over the whole area

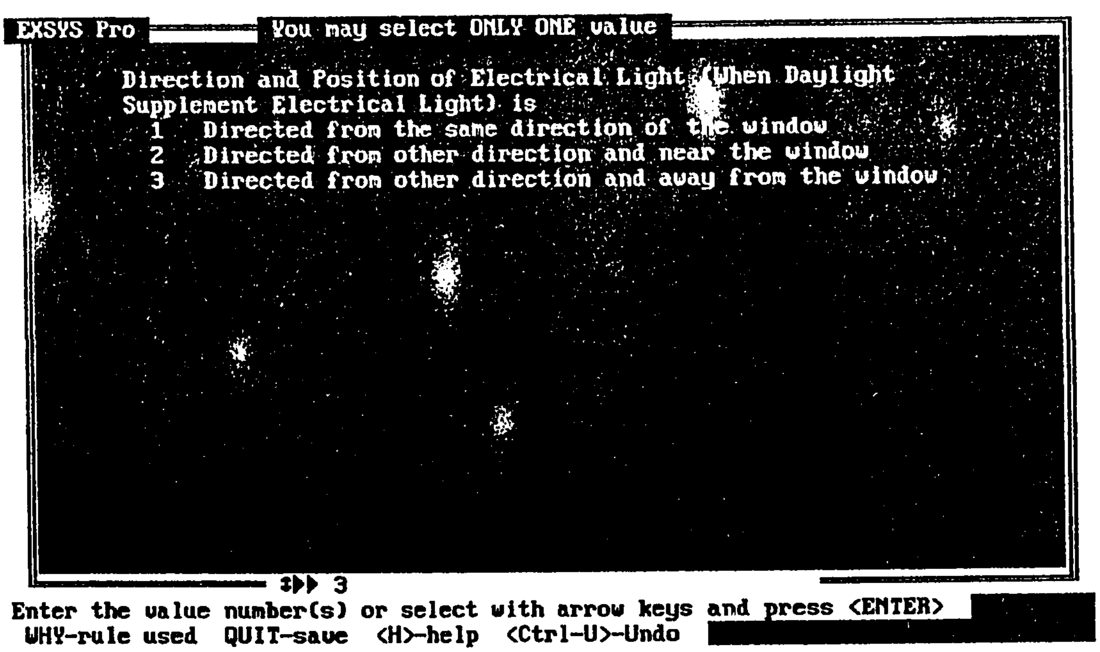

Plate 4.29 Direct and Position of Electrical Light

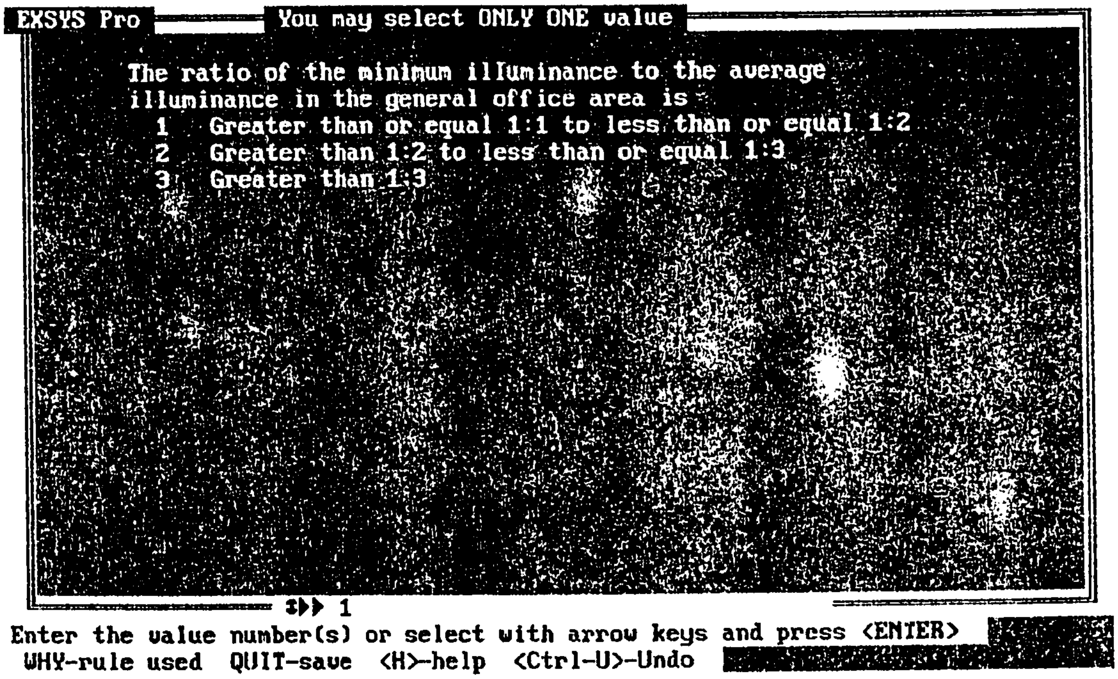

Plate 4.30 The ratio of the (E min.) to the (E. average) in G.O.A.

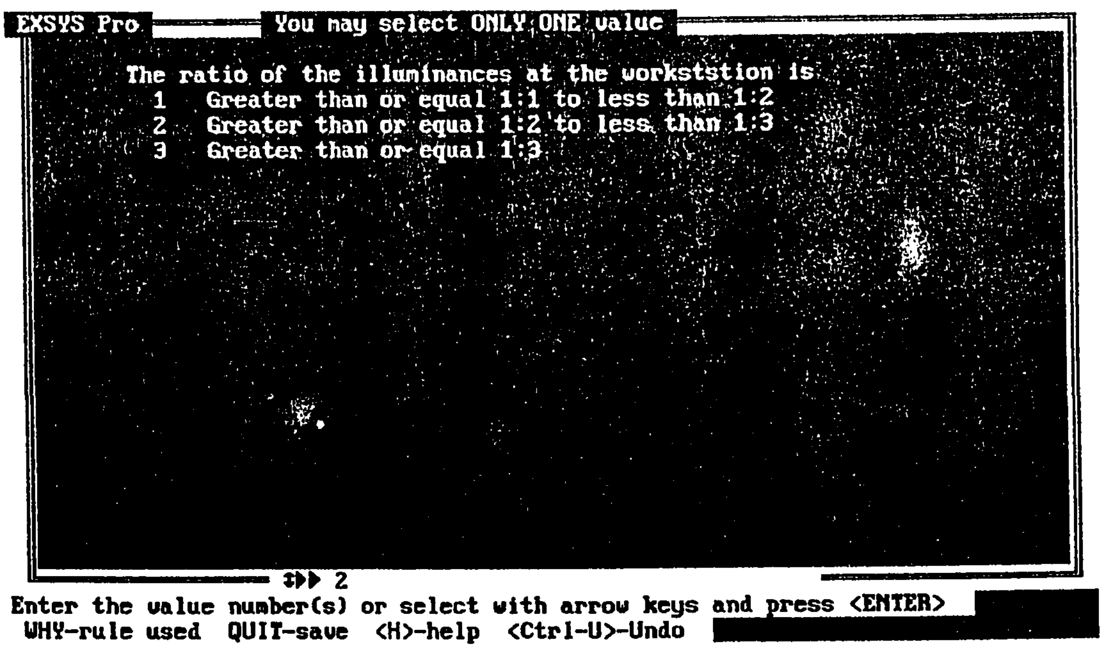

Plate 4.31 The ratio of the Illuminances at the workstation

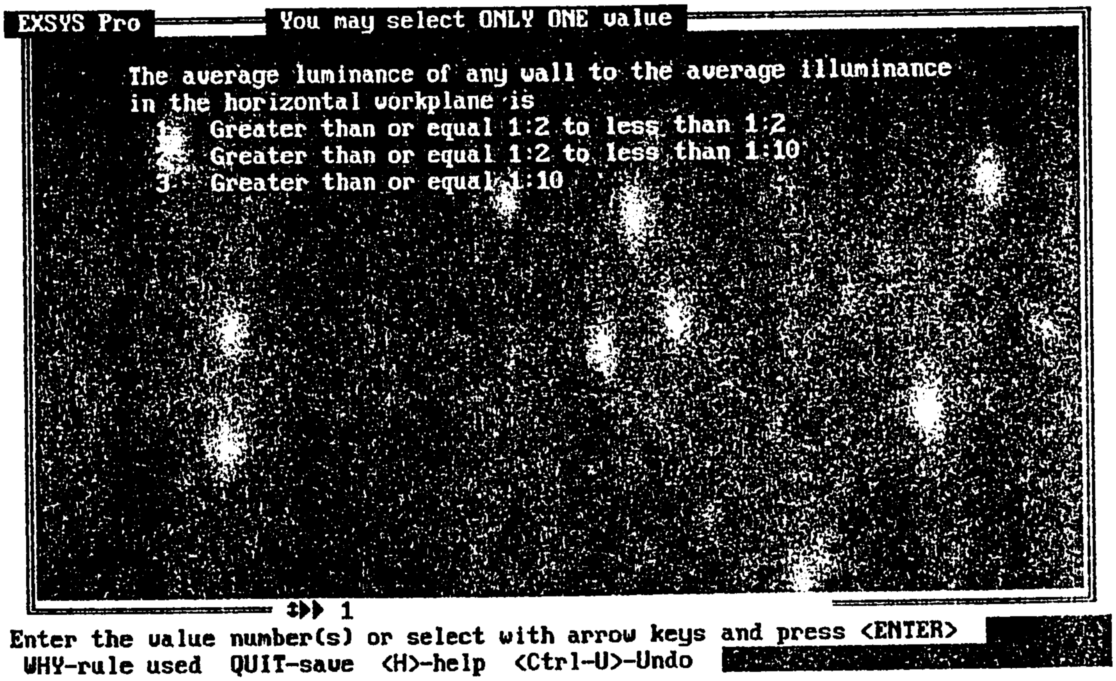

Plate 4.32 The ratio of the (E min.) to the (E. average) in H.W.

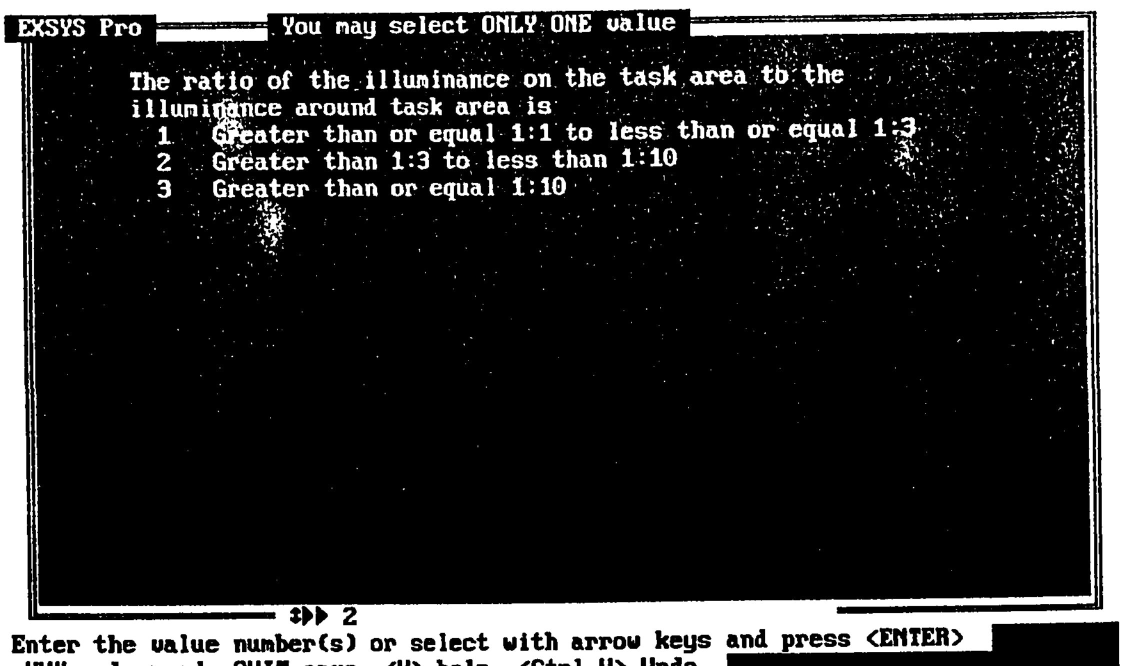

Plate 4.33 The ratio of (E) on T.A to (E) around T.A.

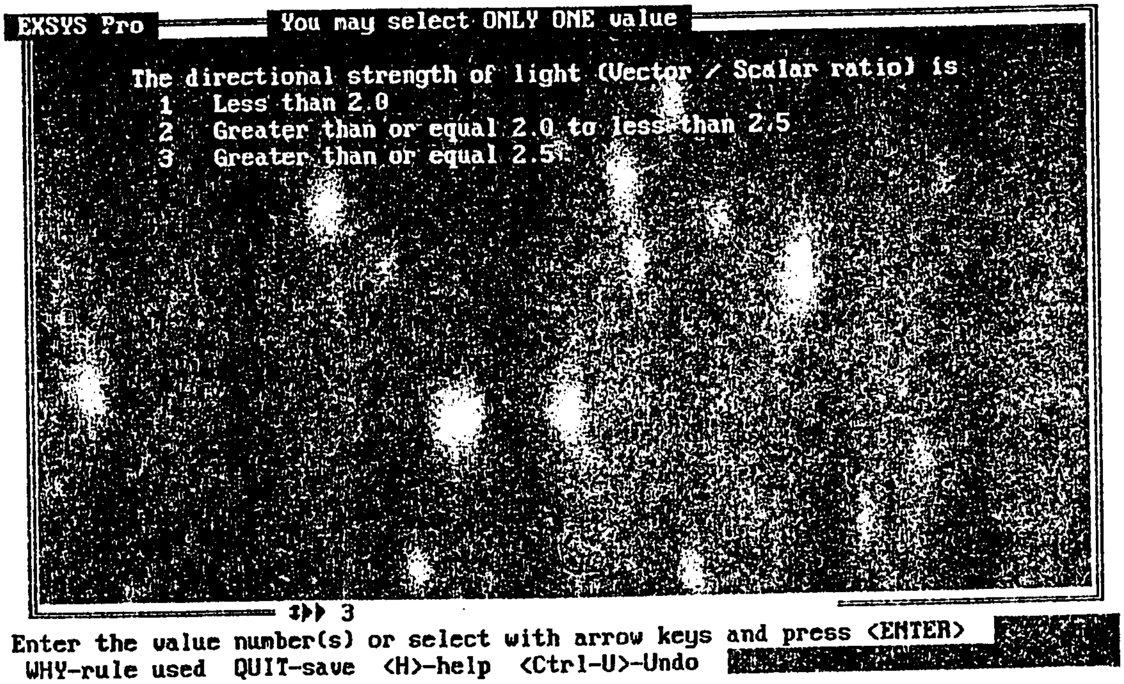

Plate 4.34 Directional Strength of Light

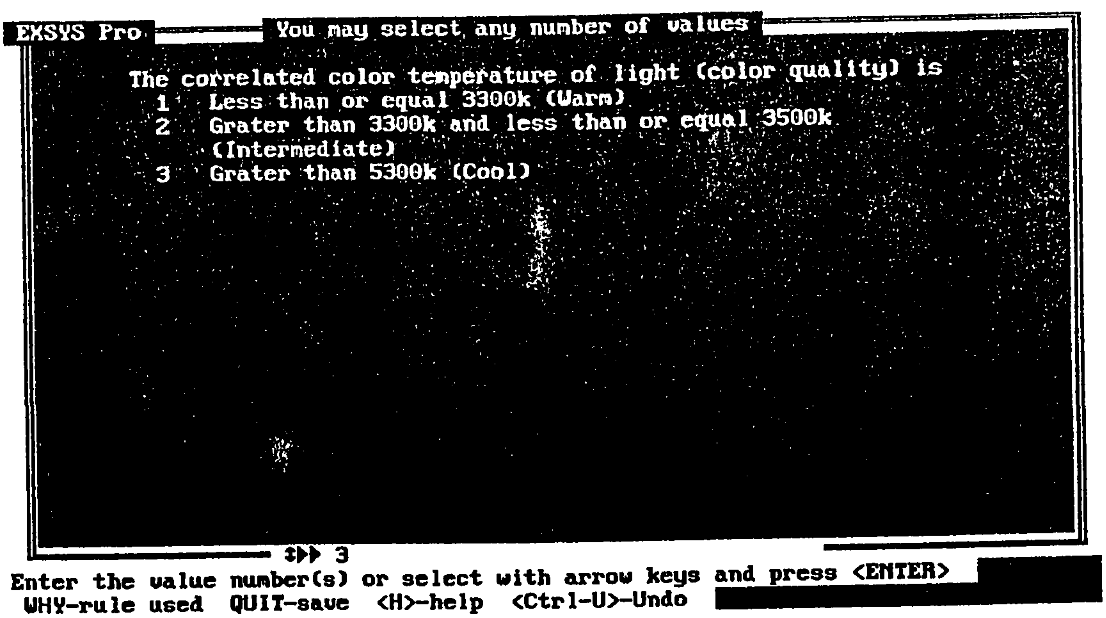

Plate 4.35 Correlated Color Temperature of Light

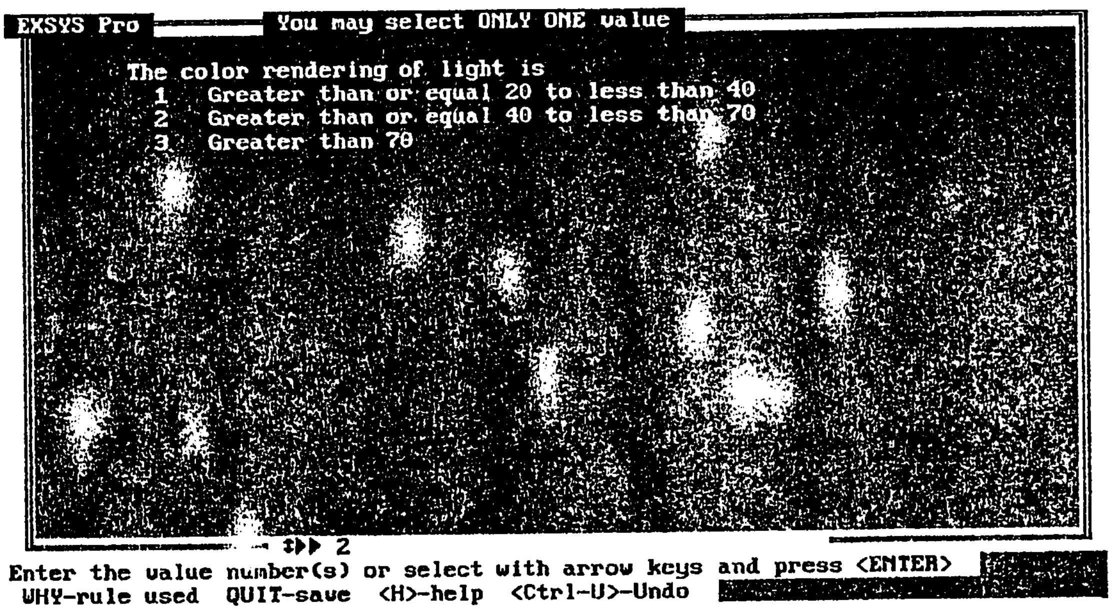

Plate 4.36 Color Rendering of Light

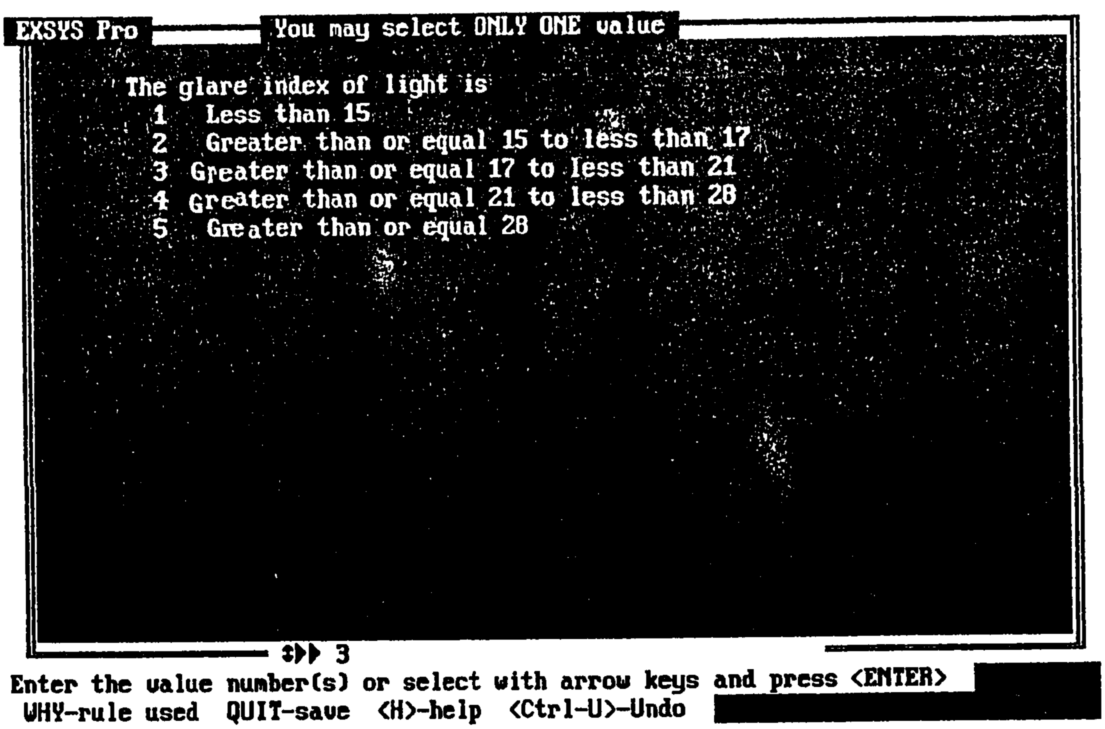

Plate 4.37 Glare Index of Light

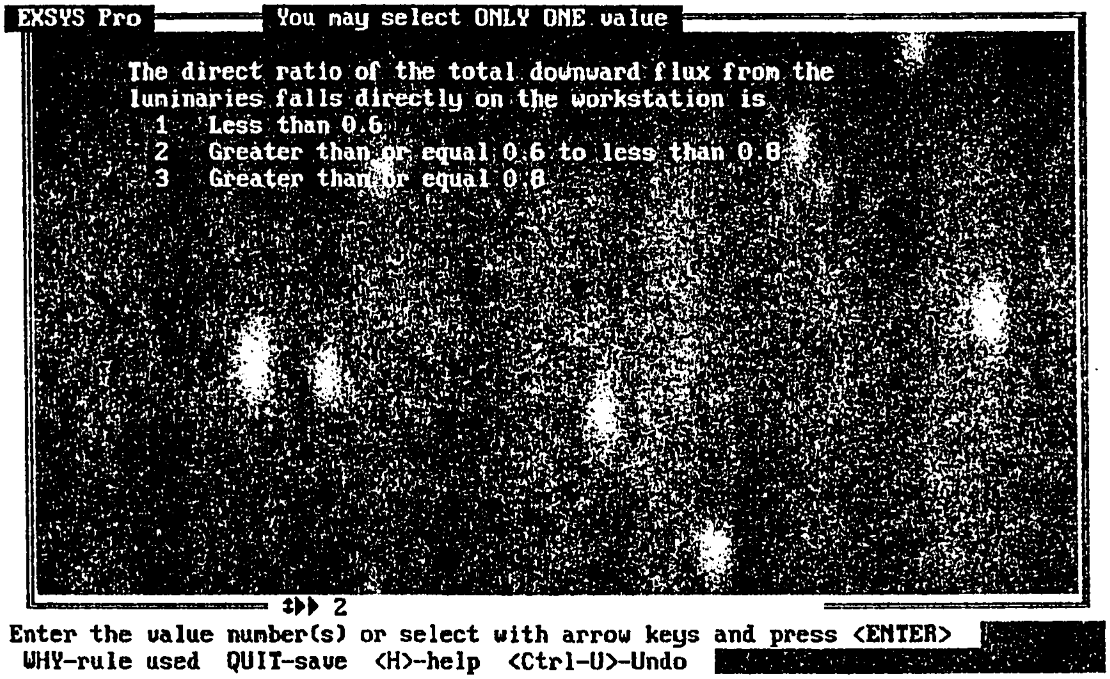

Plate 4.38 Total Downward Flux

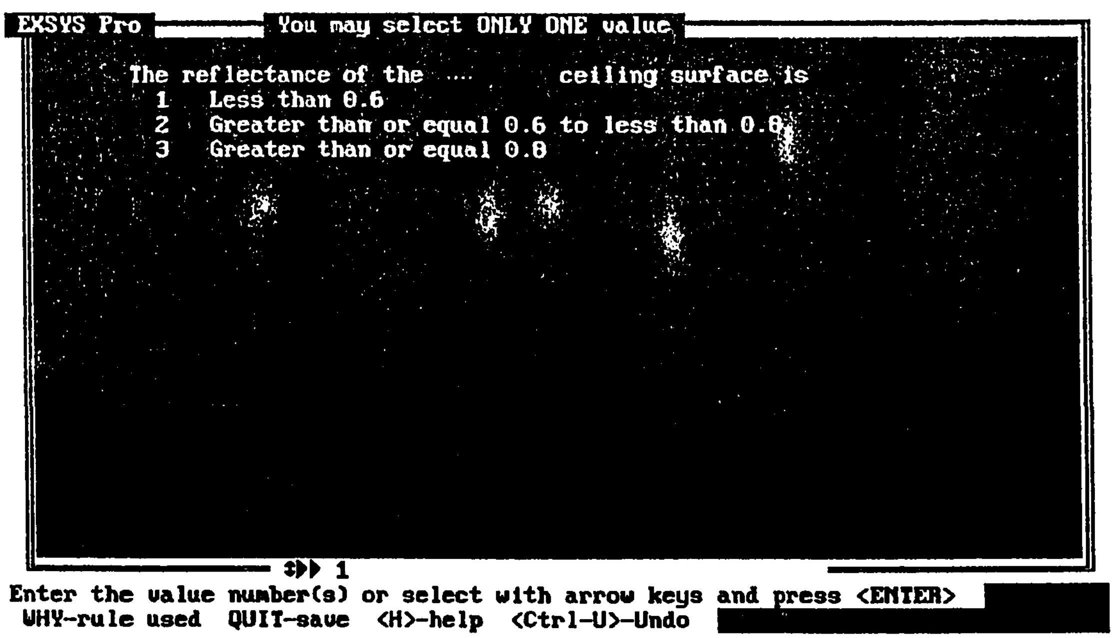

Plate 4.39 Reflectance of Ceiling Surface

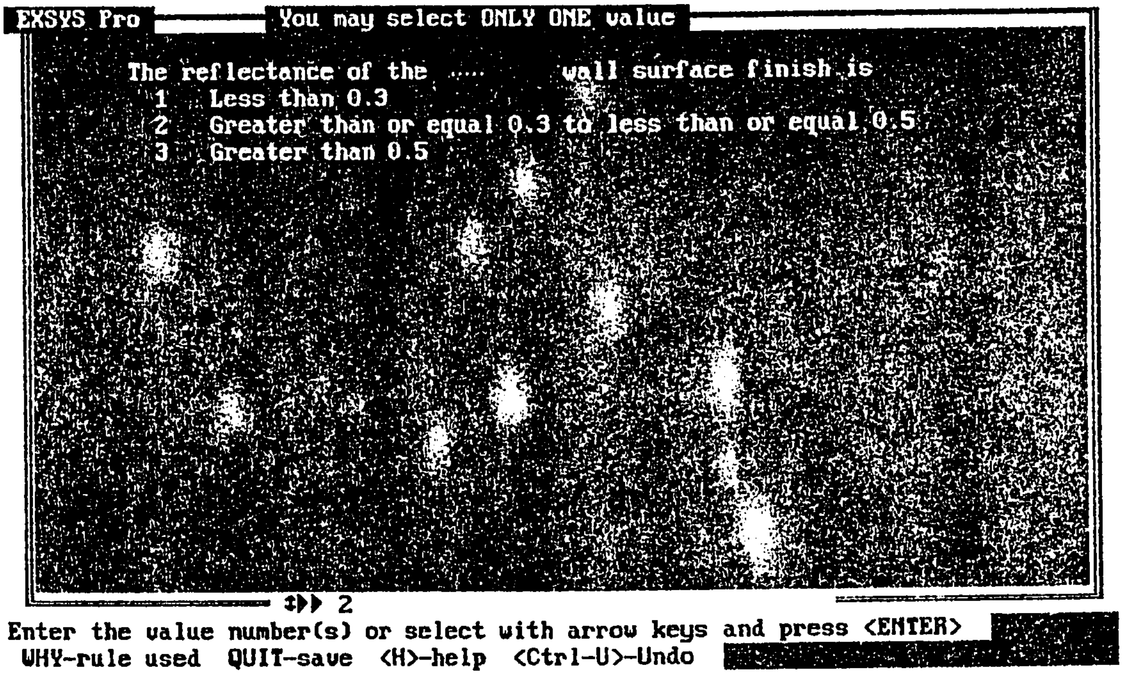

Plate 4.40 Reflectance of Wall Surface

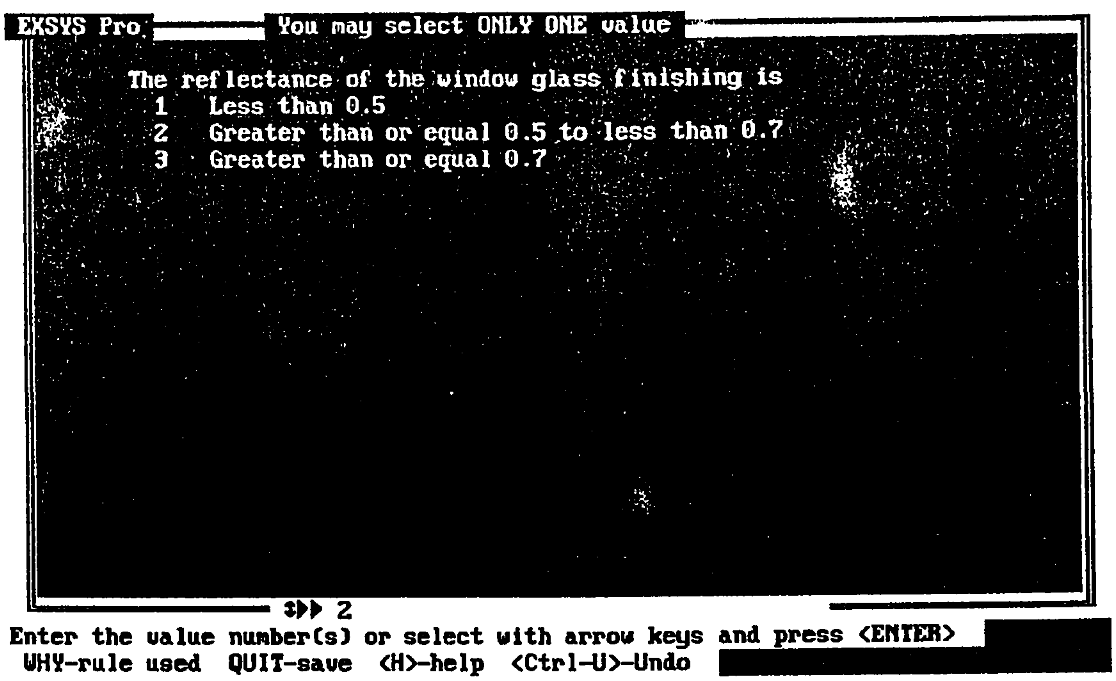

Plate 4.41 Reflectance of Window Glass

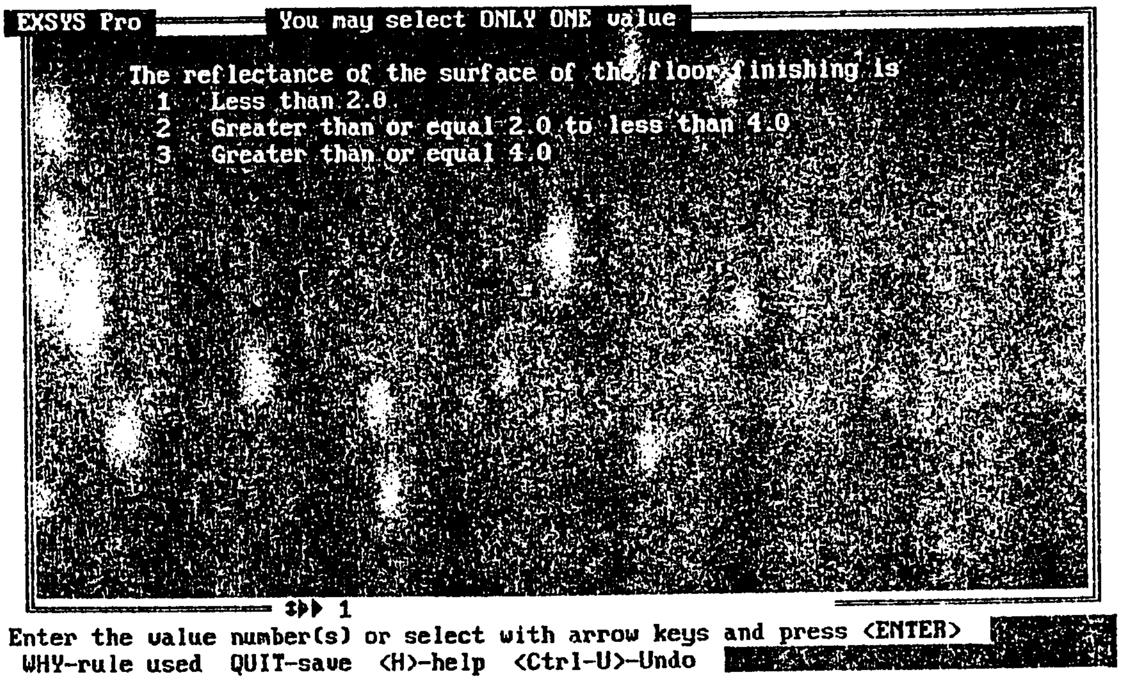

Plate 4.42 Reflectance of Floor Surface

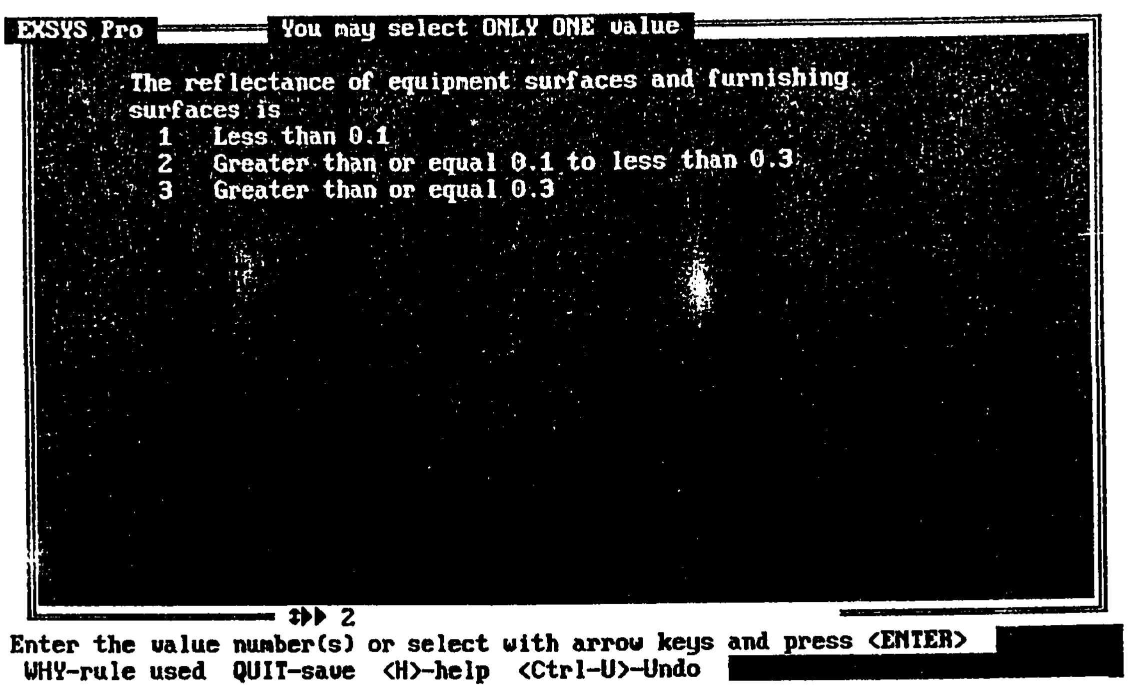

Plate 4.43 Reflectance of equipment and furniture Surfaces

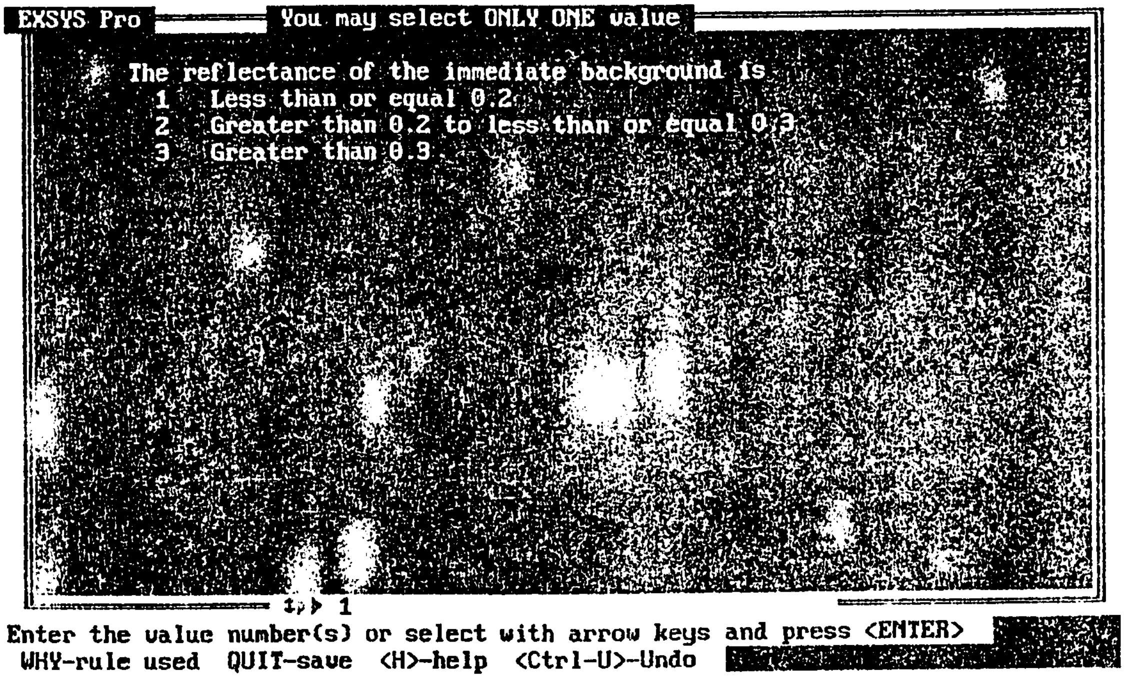

Plate 4.44 Reflectance of Immediate Background

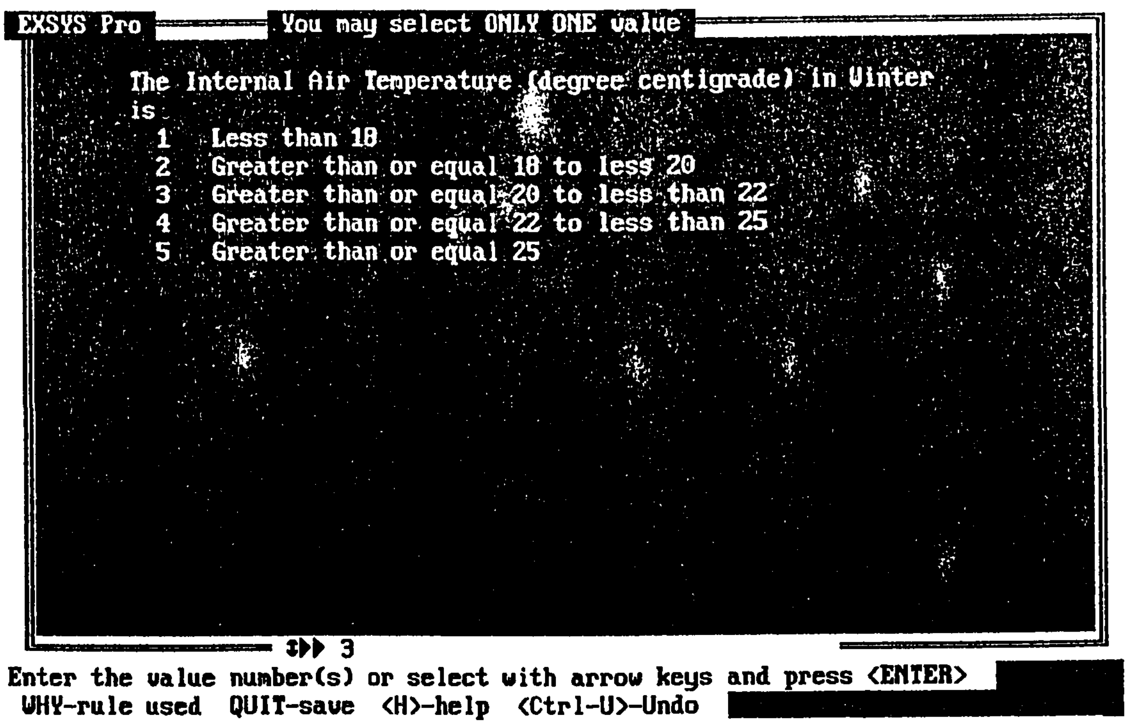

Plate 4.45 Internal Air Temperature in Winter

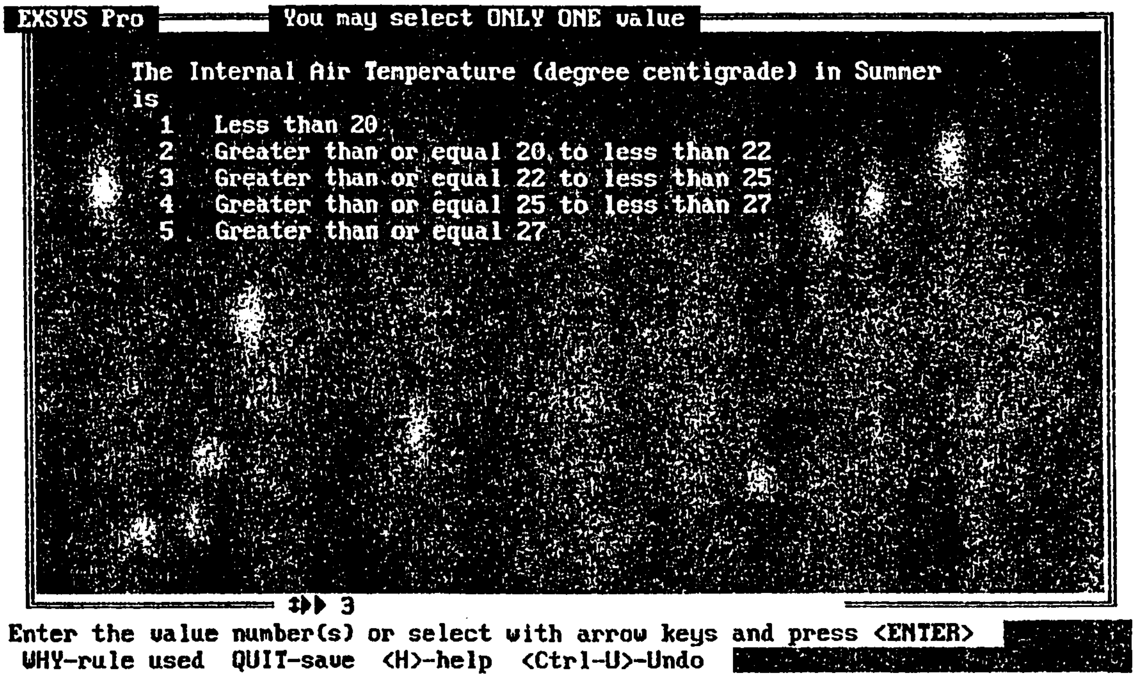

Plate 4.46 Internal Air Temperature in Summer

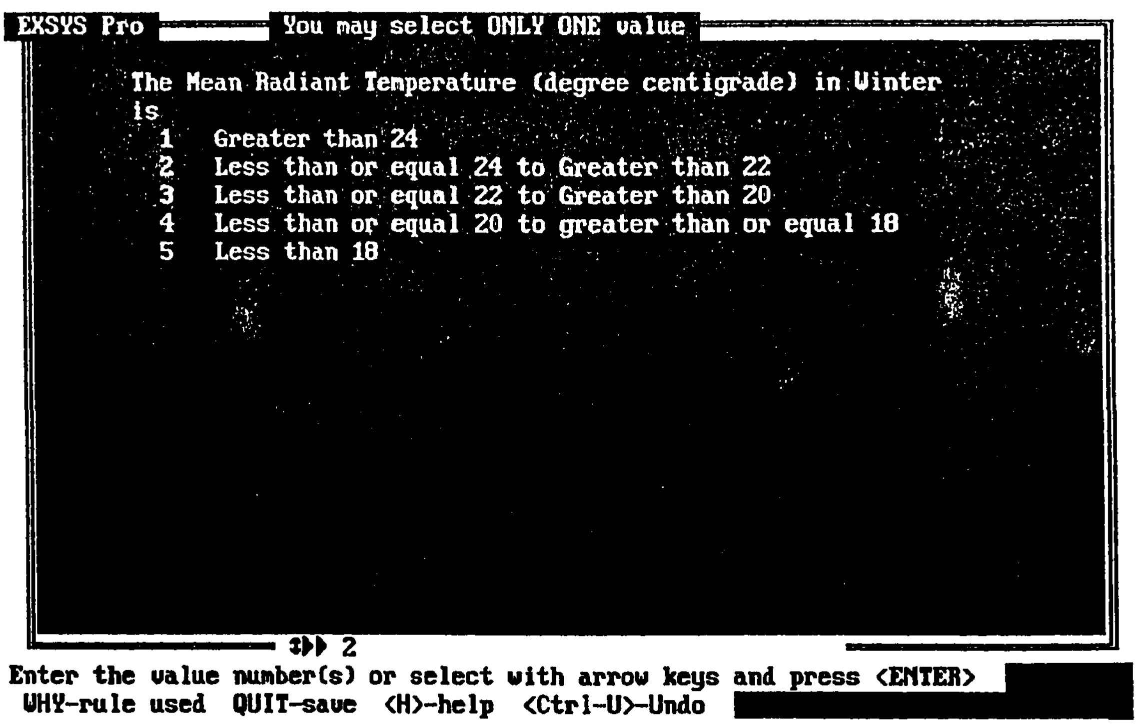

Plate 4.47 MRT in Winter

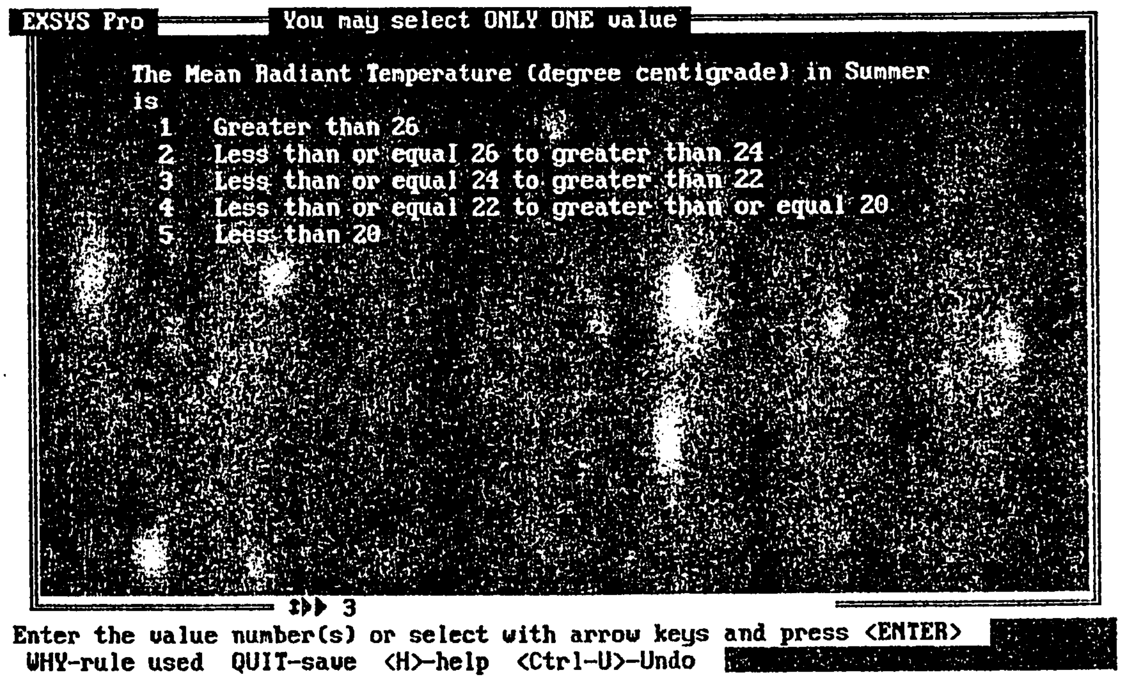

Plate 4.48 MRT in Summer

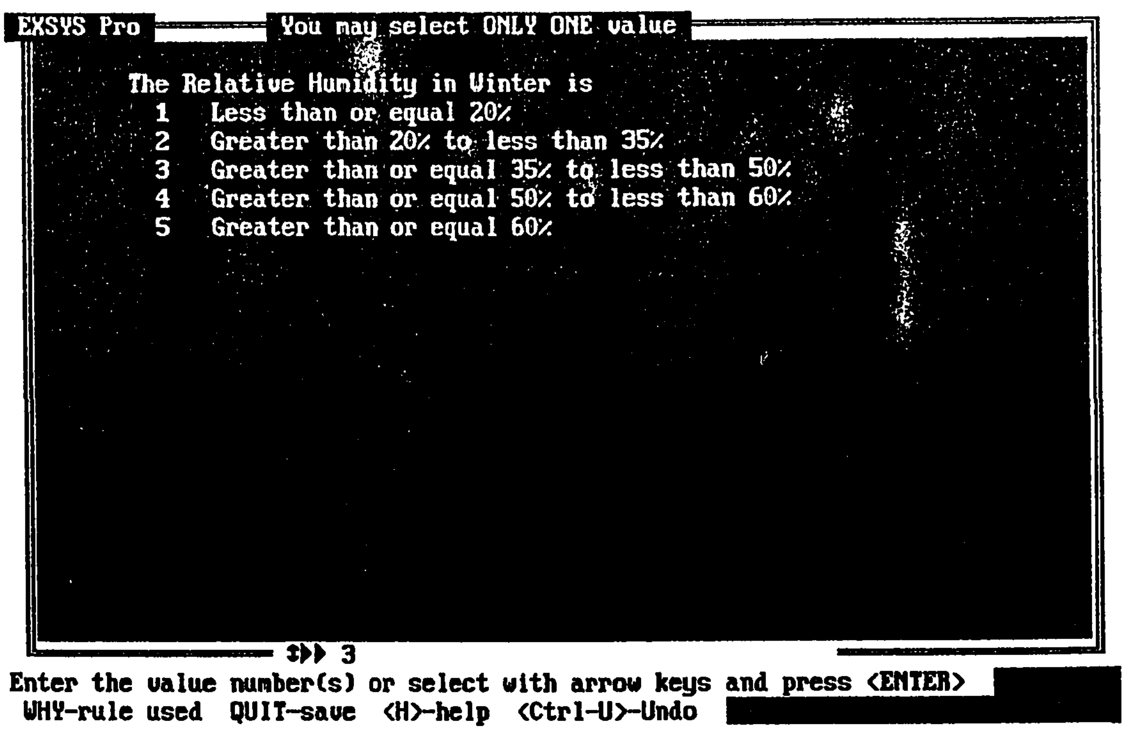

Plate 4.49 RH in Winter

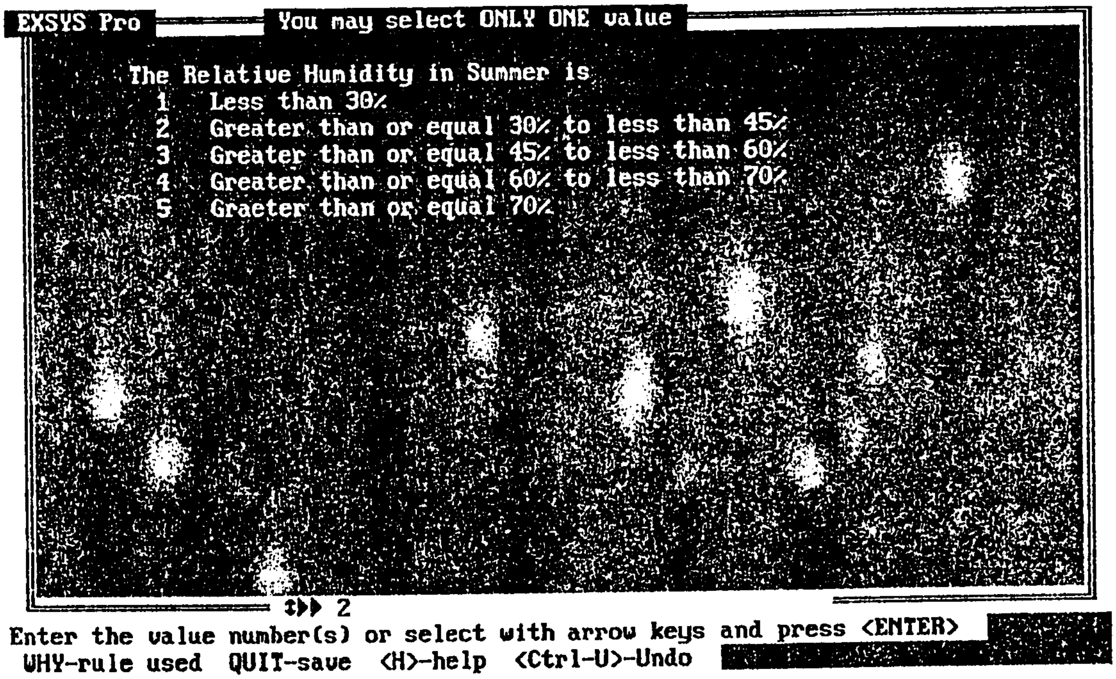

Plate 4.50 RH in Summer

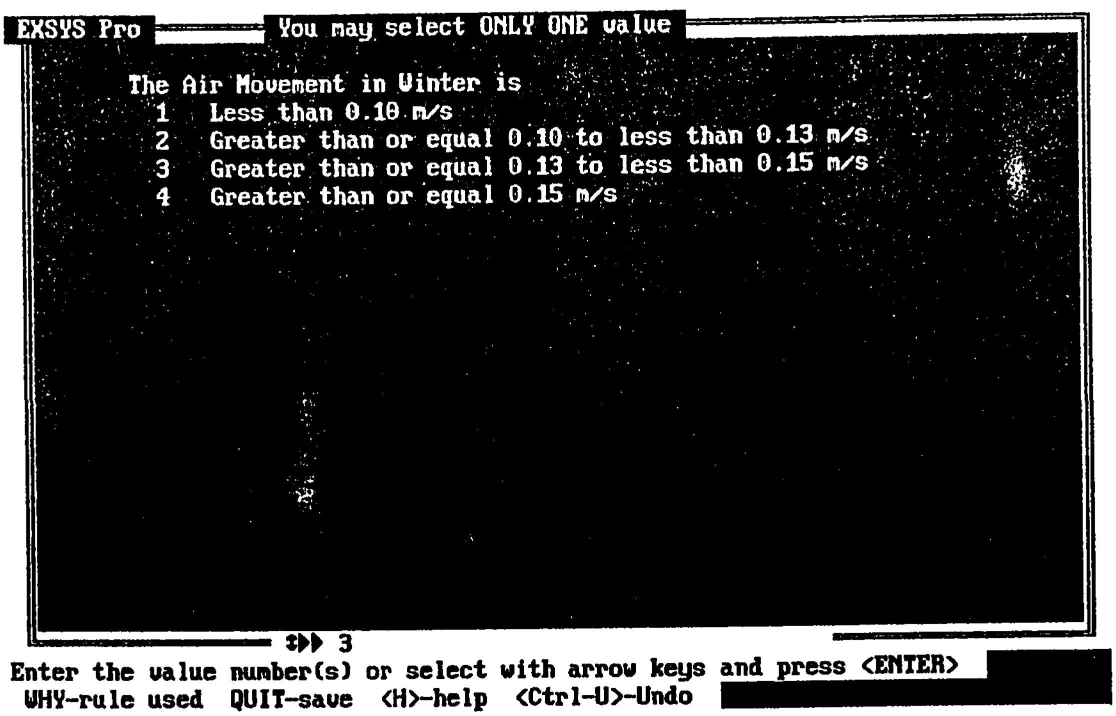

Plate 4.51 Air Movement in Winter

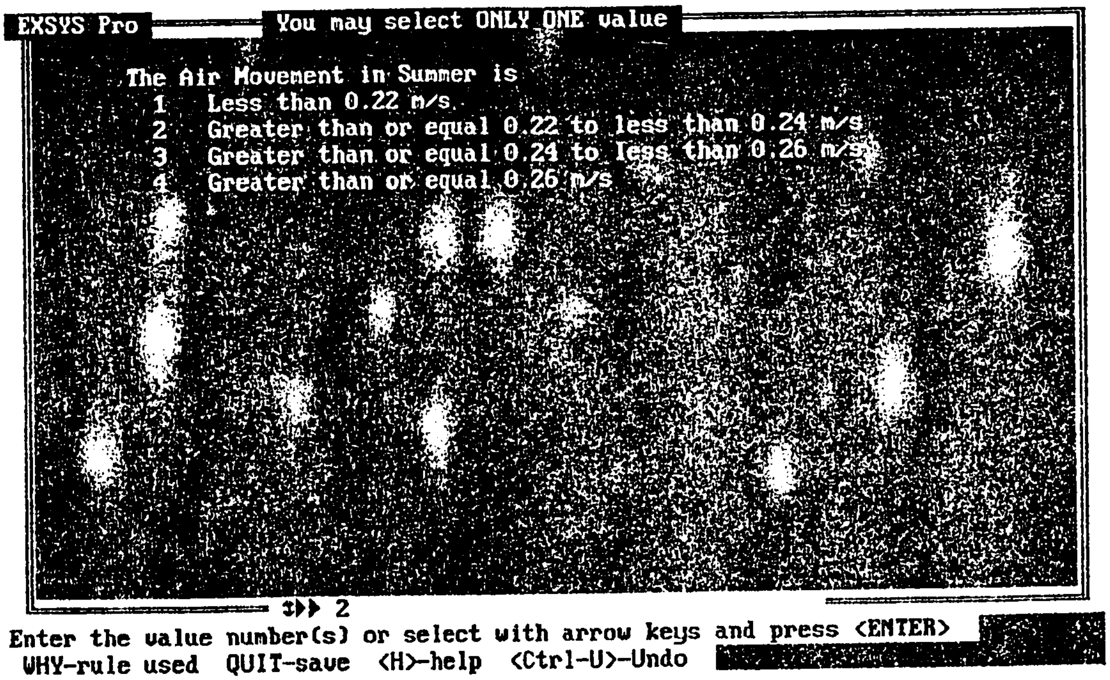

Plate 4.52 Air Movement in Summer

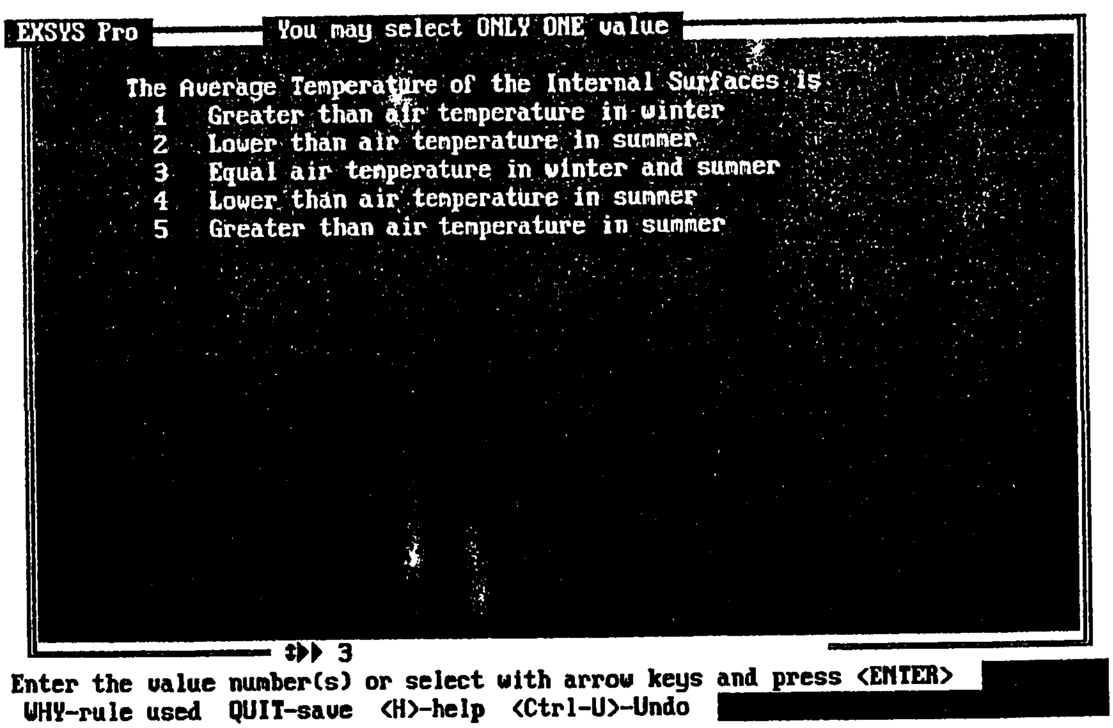

Plate 4.53 Average Temperature of Internal Surfaces

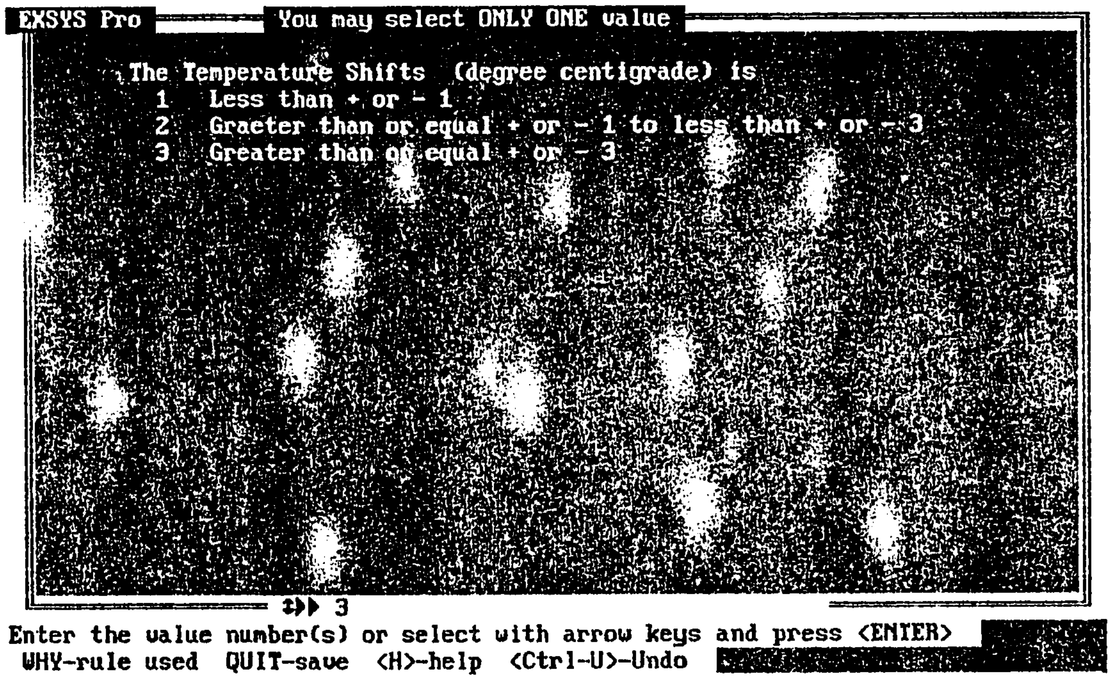

Plate 4.54 Temperature Shifts

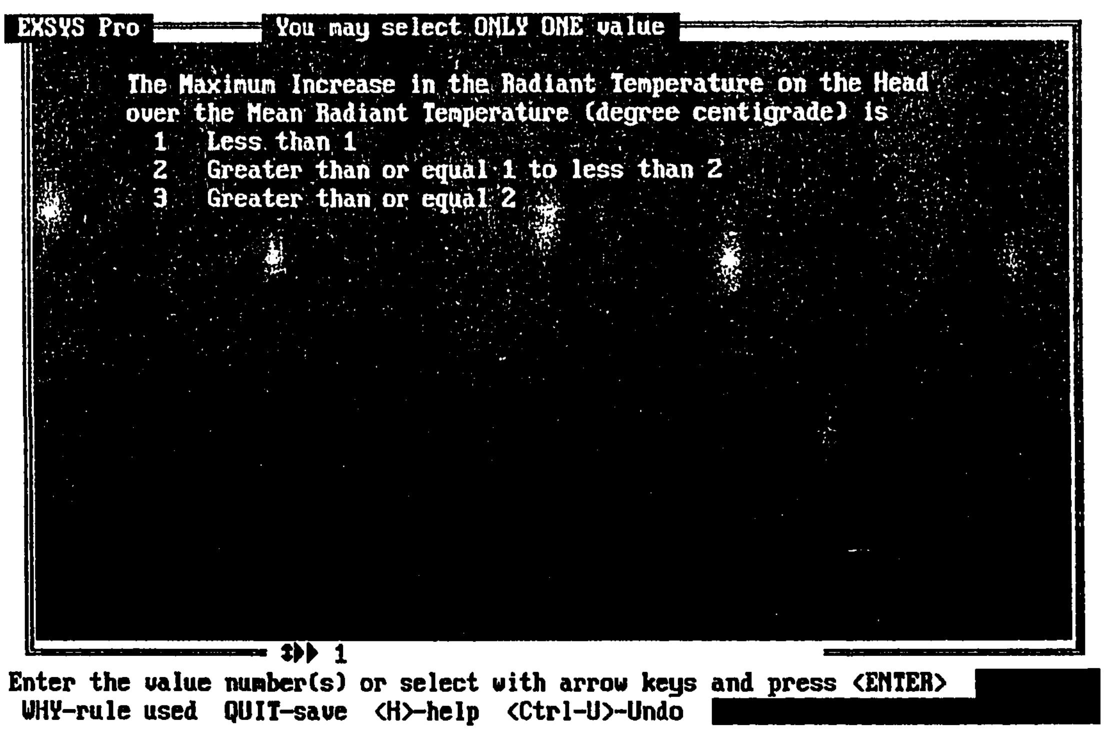

Plate 4.55 Max. increase of Radiant Temperature on the head over the MRT

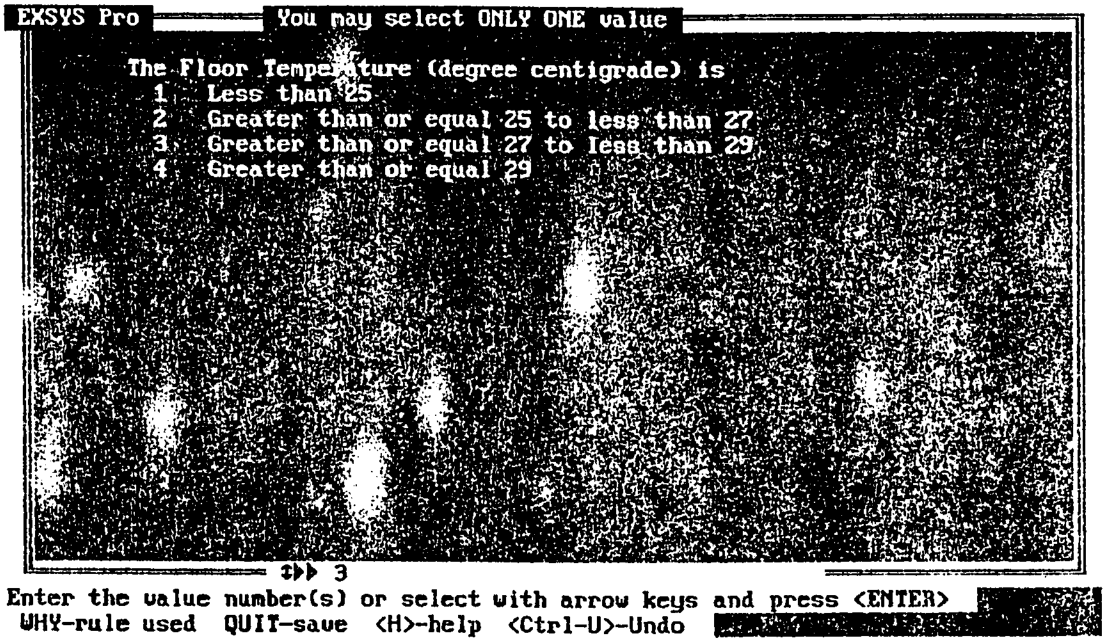

Plate 4.56 Floor Temperature

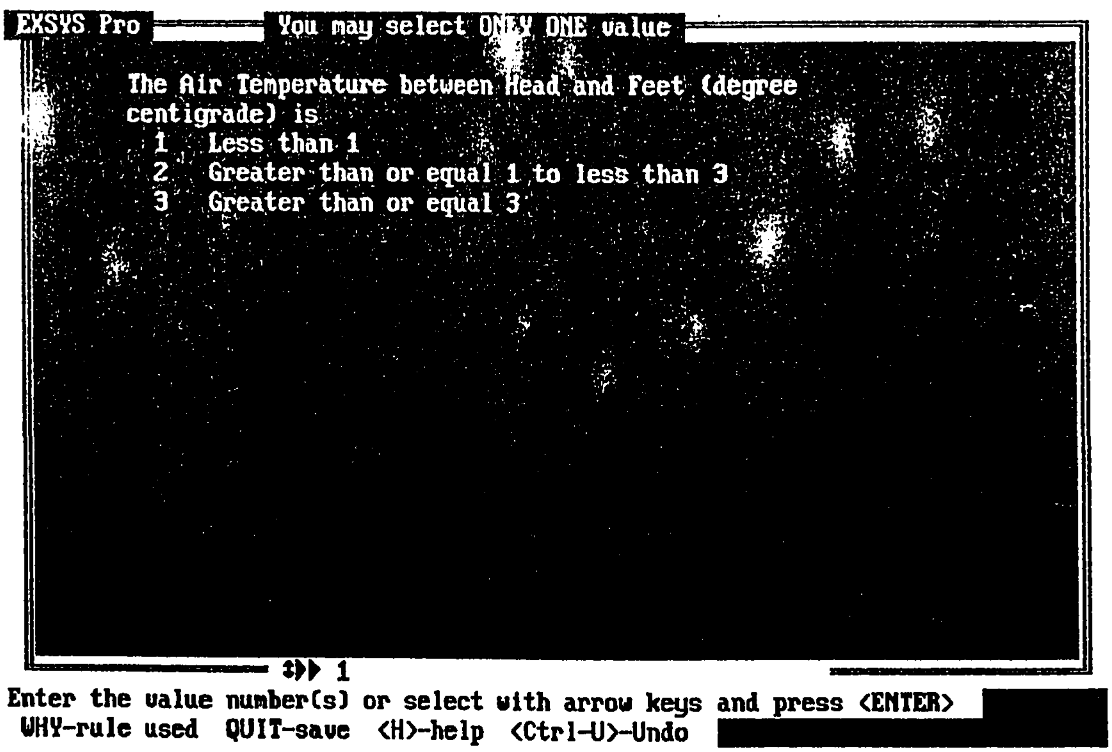

Plate 4.57 Air Temperature difference between head and feet

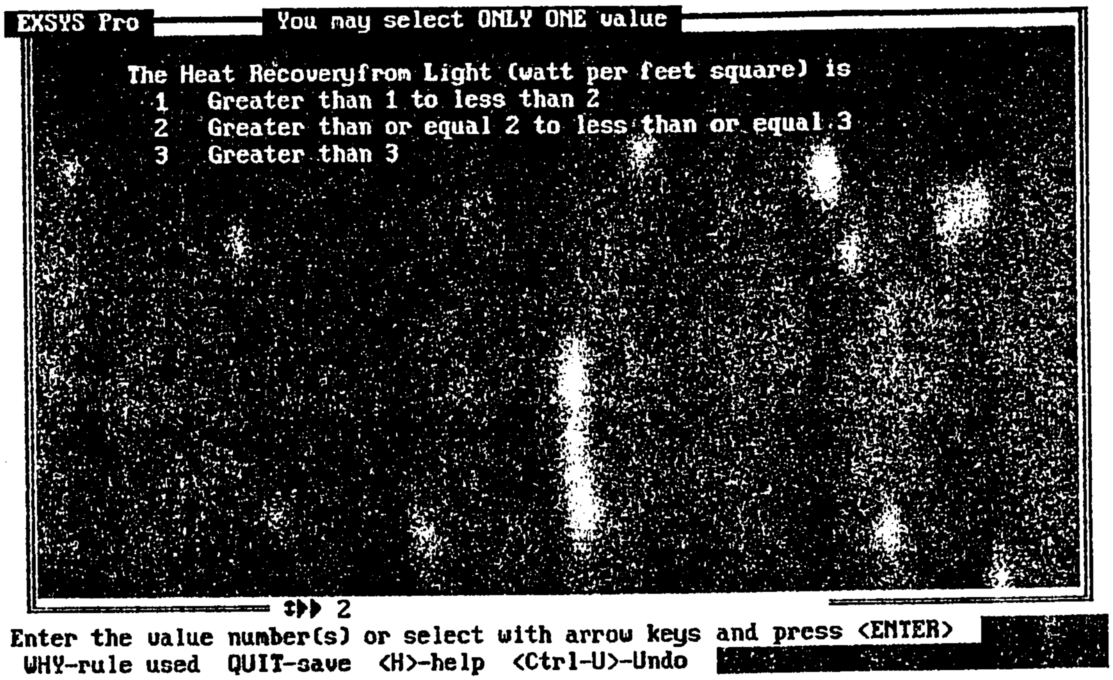

Plate 4.58 Heat recover from light

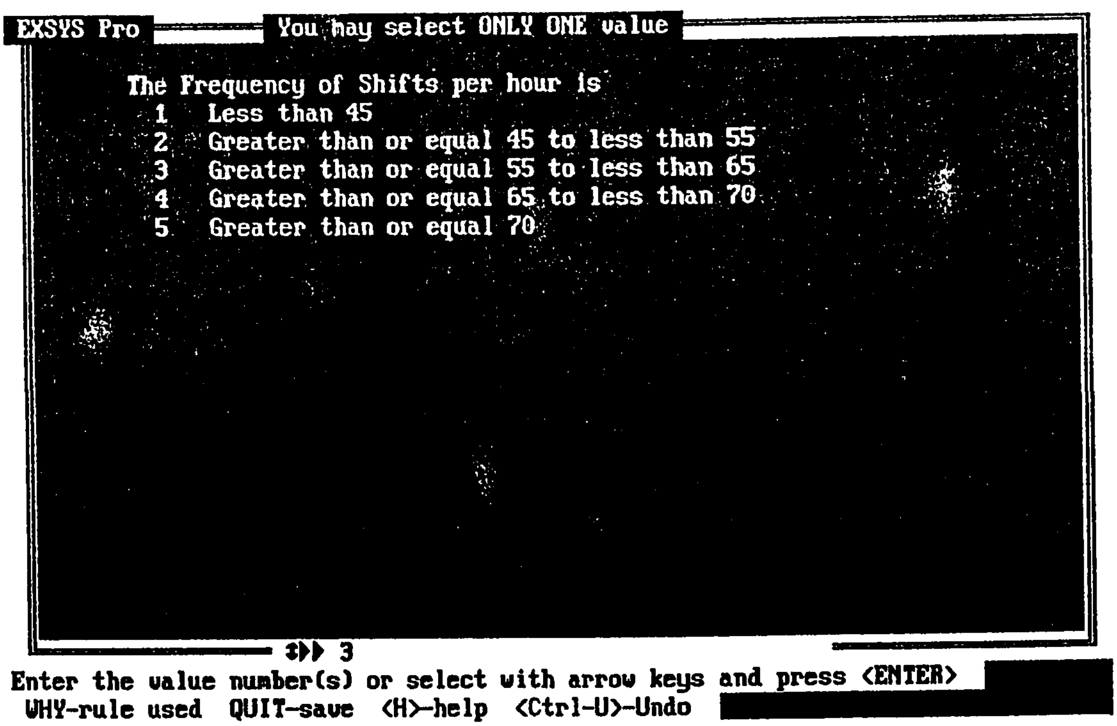

Plate 4.59 Frequency Shifts

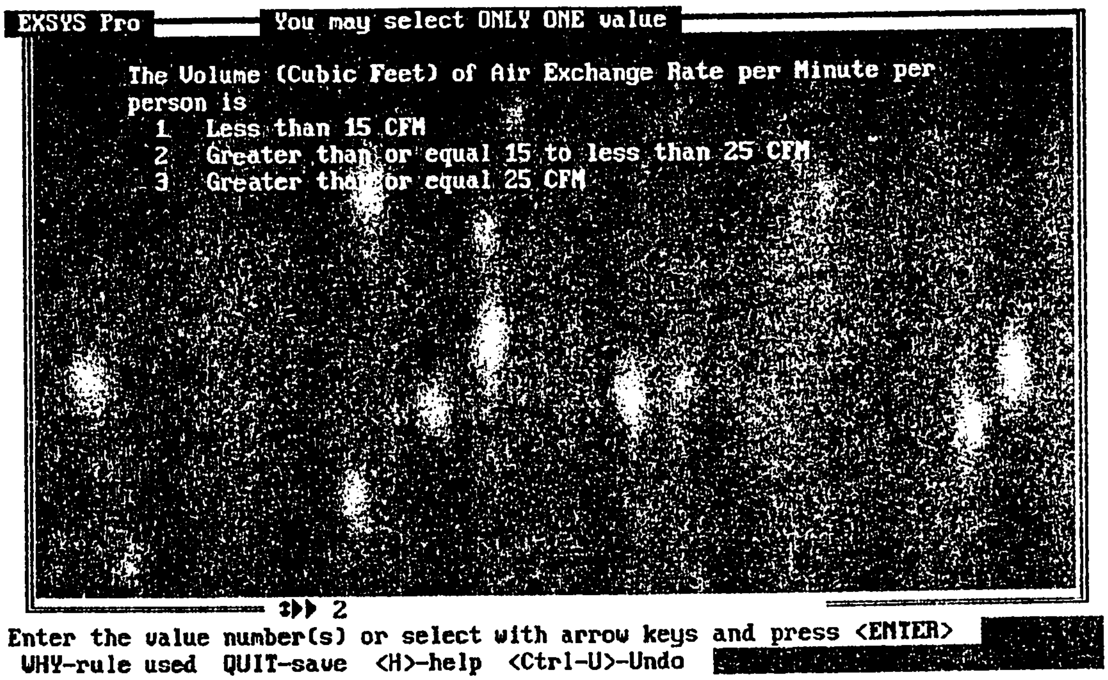

Plate 4.60 Volume of Air Exchange Rate

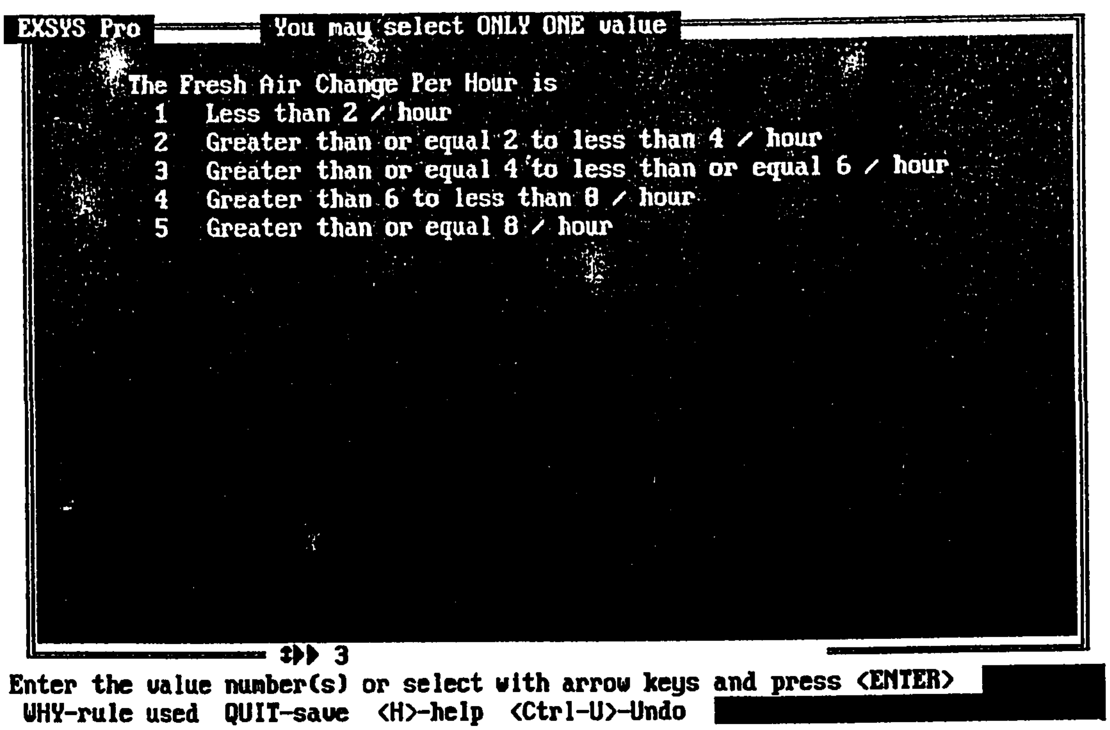

Plate 4.61 Fresh Air Change

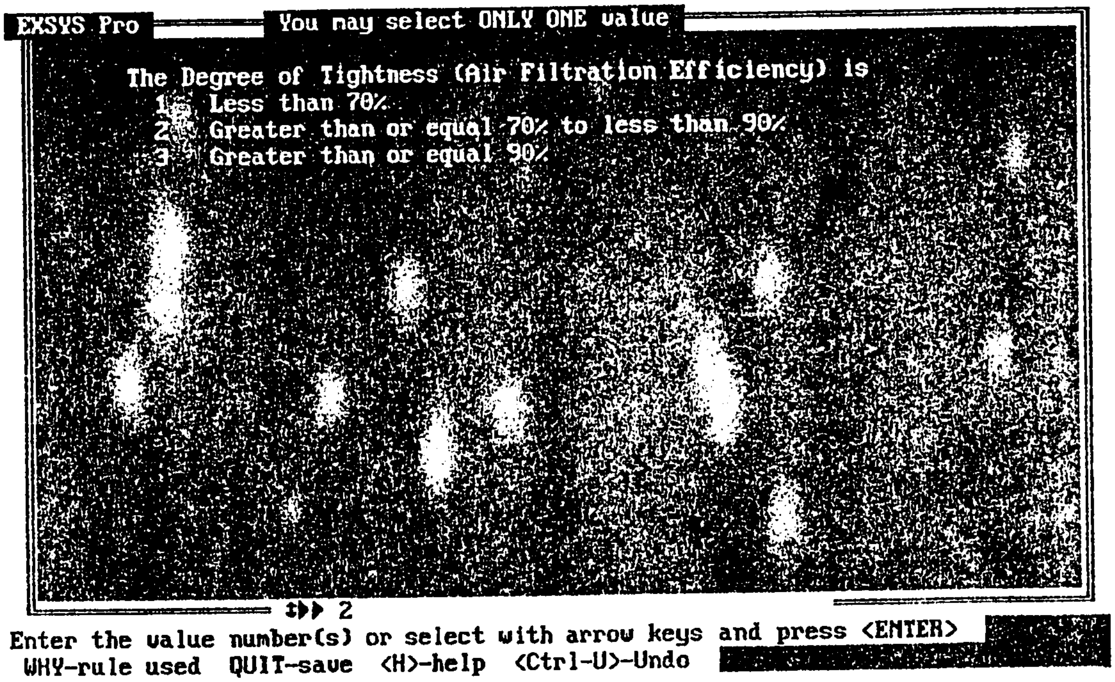

Plate 4.62 Degree of Tightness

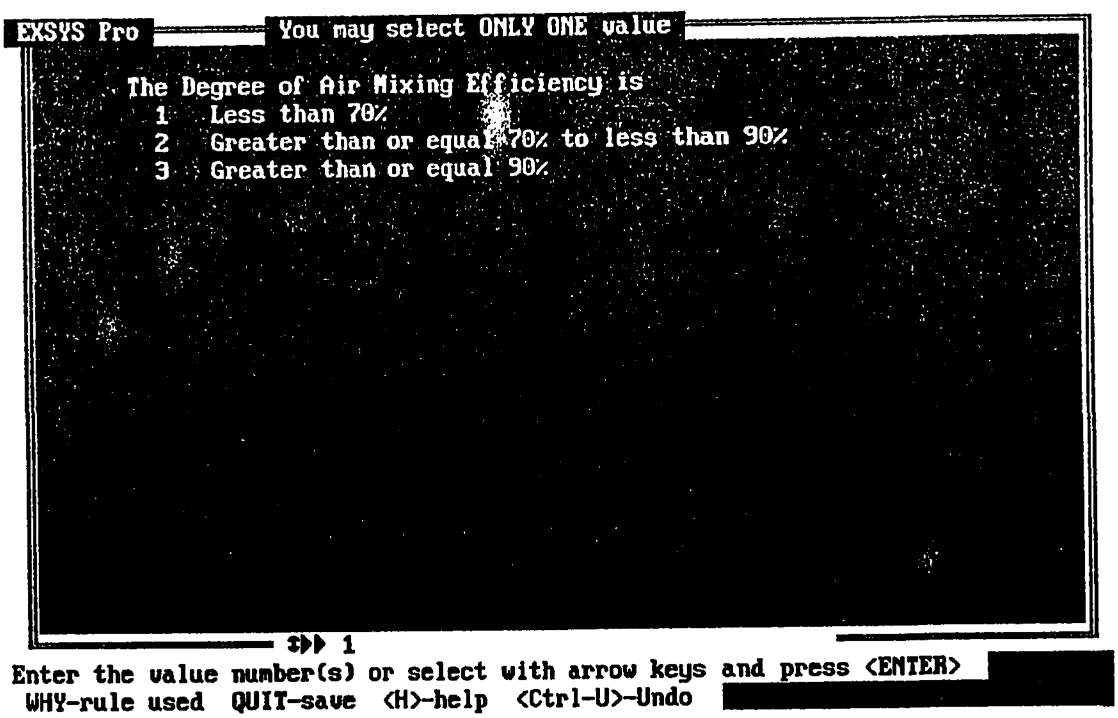

Plate 4.63 Degree of Air Mixing Efficiency

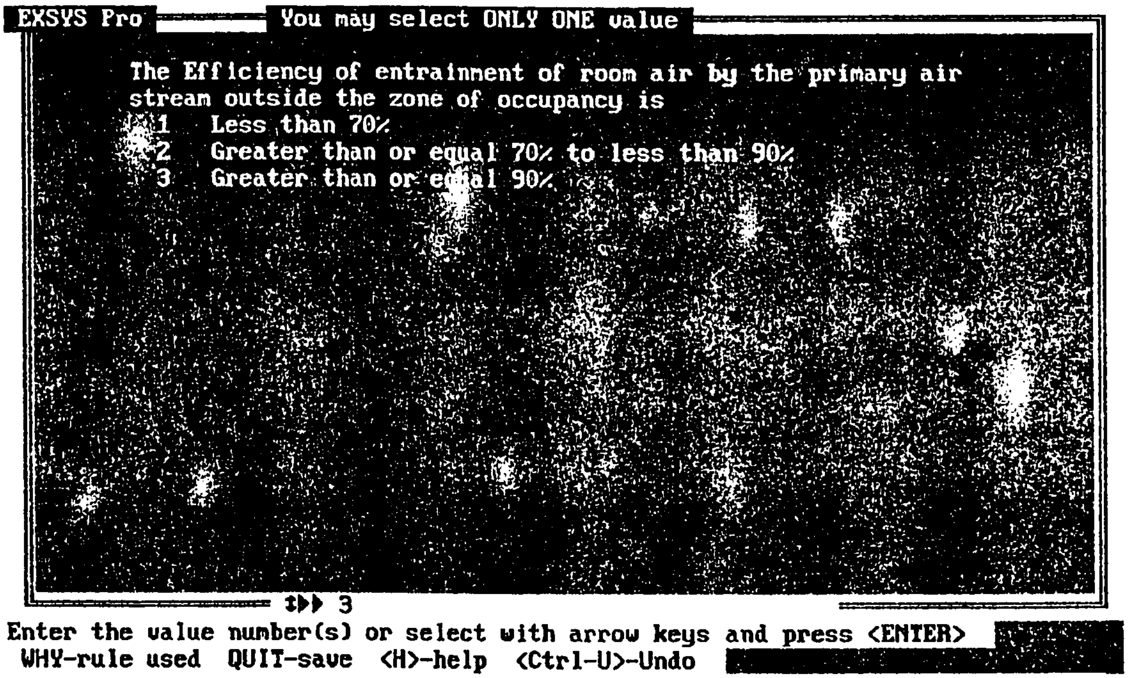

Plate 4.64 Efficiency of Entrainment of Room Air

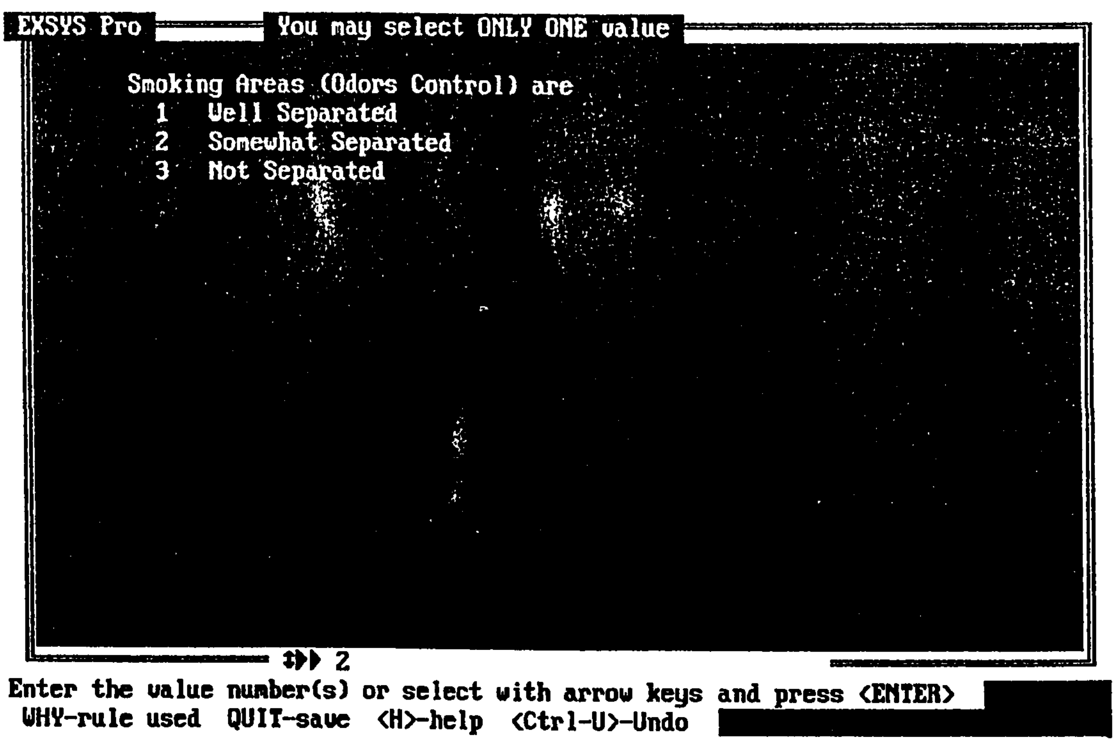

Plate 4.65 Smoking Areas

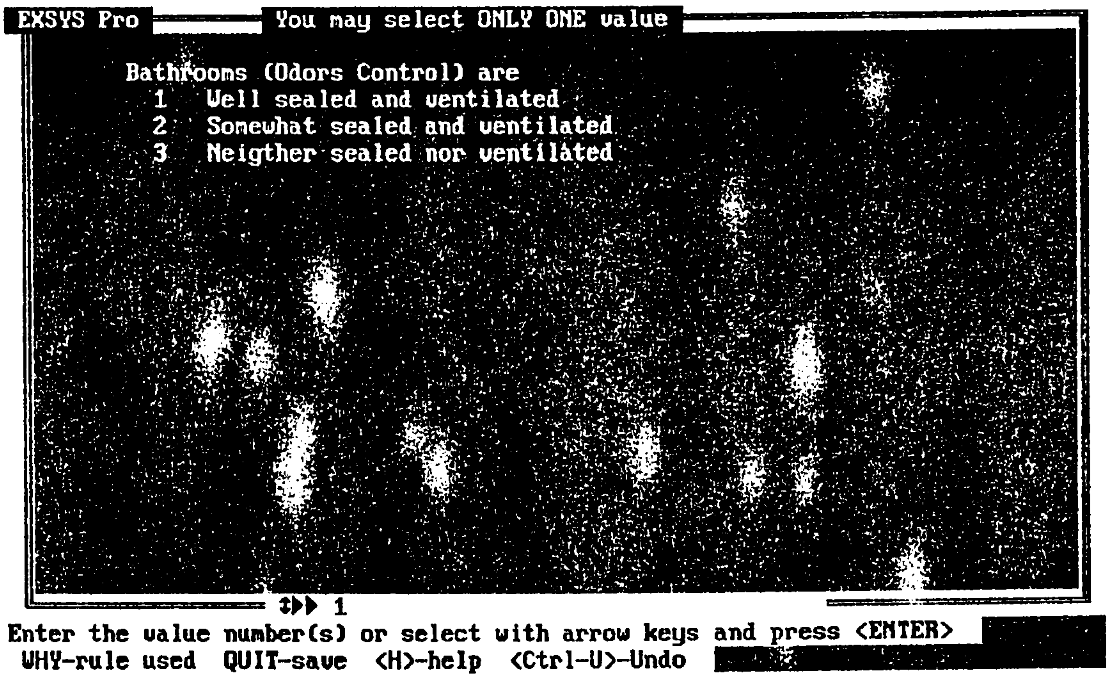

Plate 4.66 Bathrooms

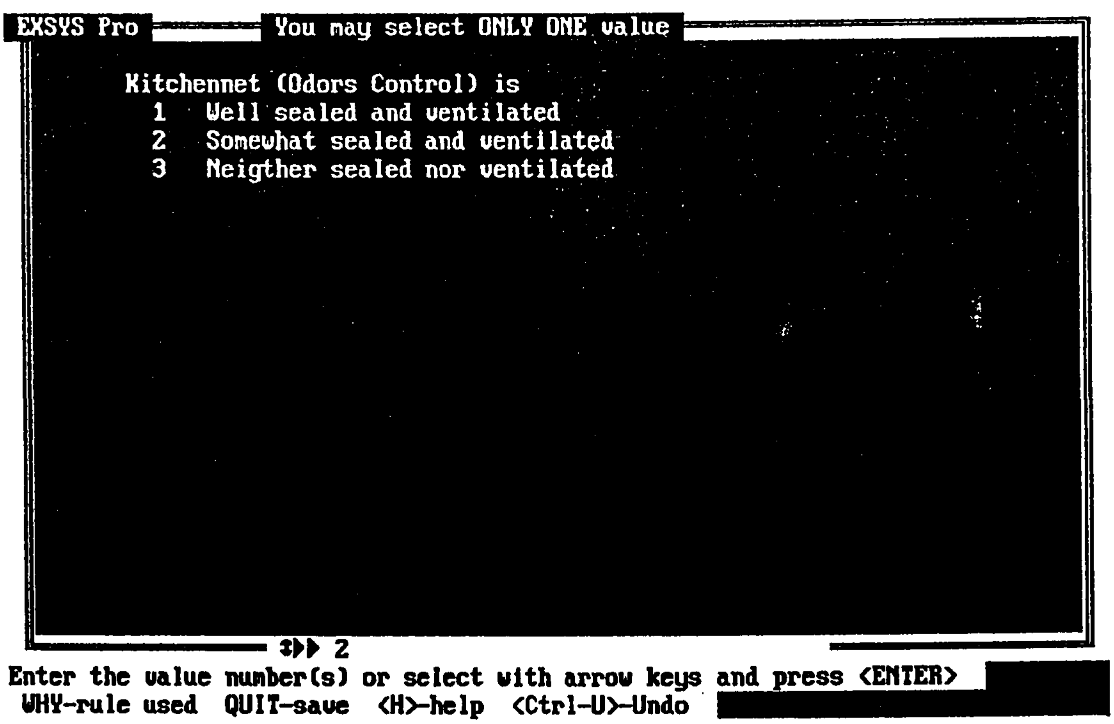

Plate 4.67 Kitchenette

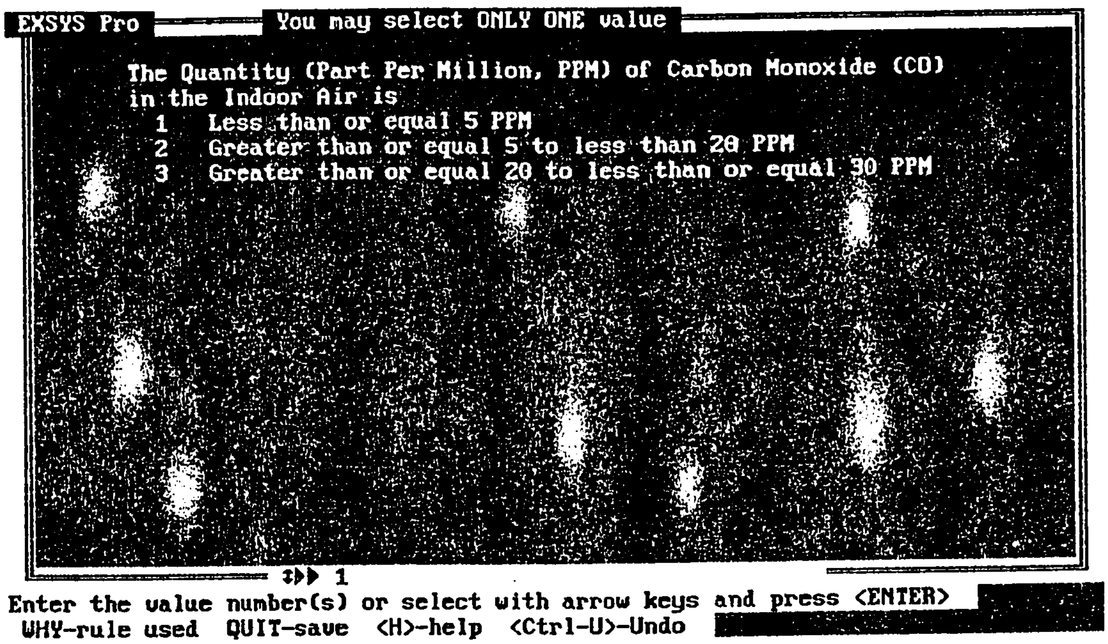

Plate 4.68 Quantity of (CO)

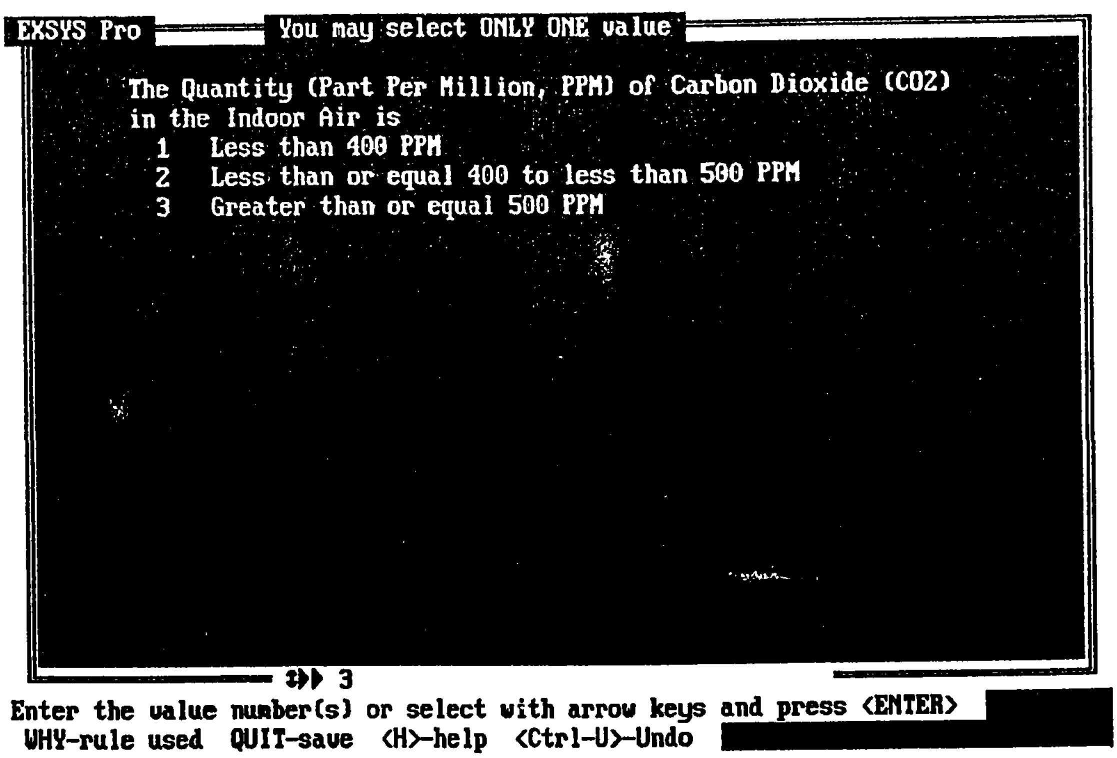

Plate 4.69 Quantity of (CO2)

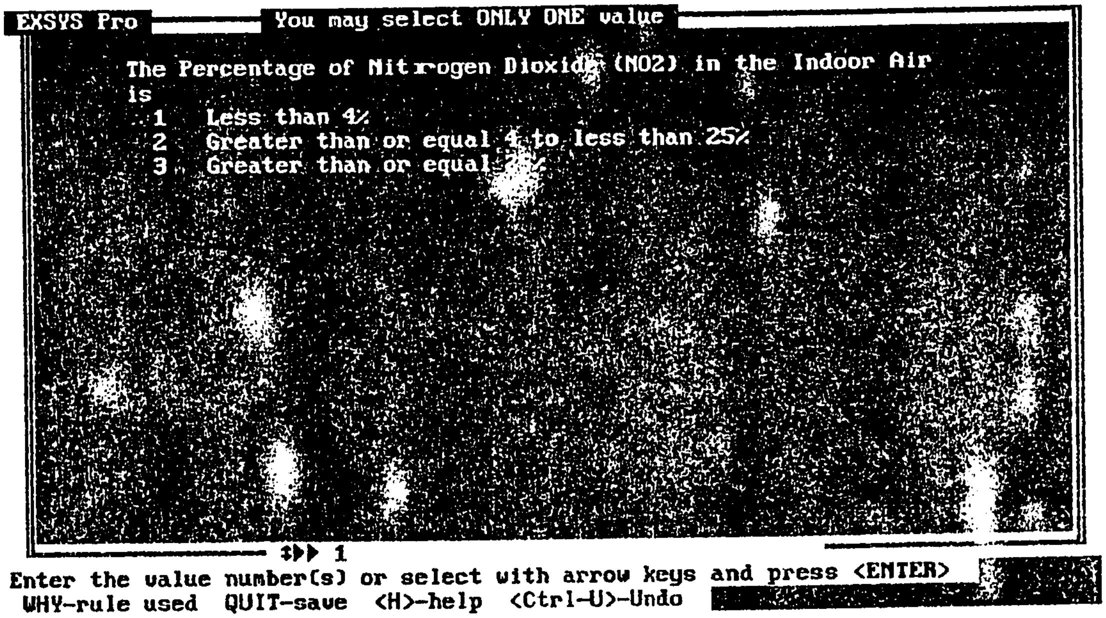

Plate 4.70 Quantity of (NO2)

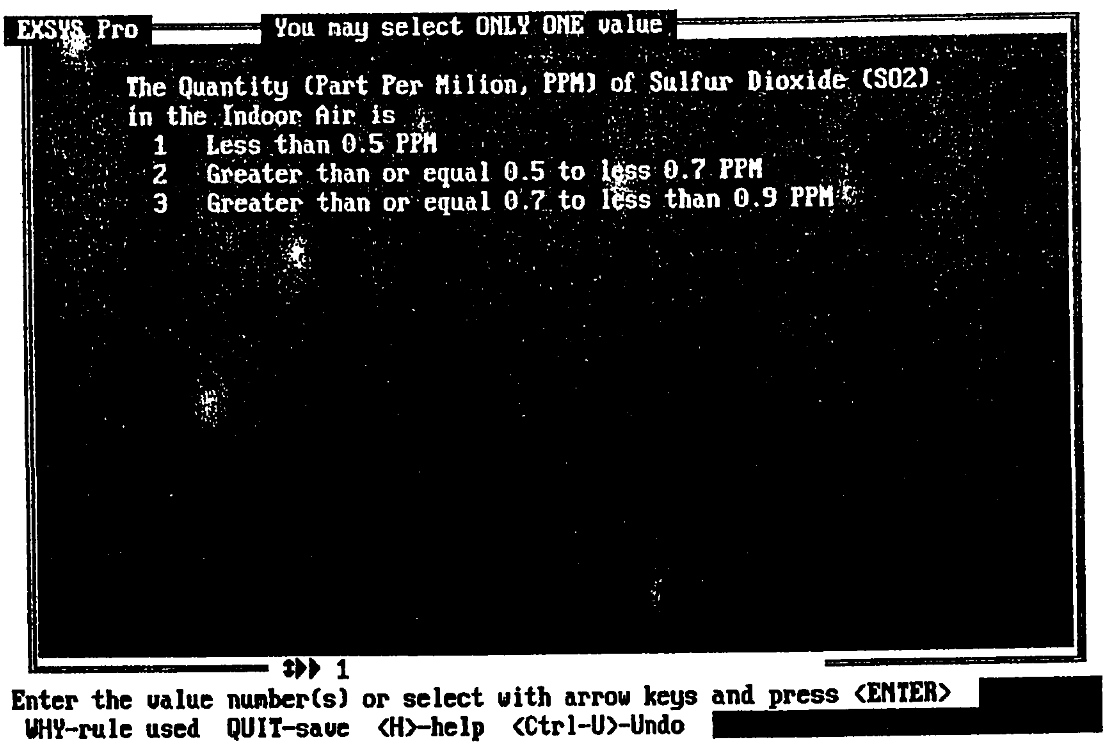

Plate 4.71 Quantity of (SO2)

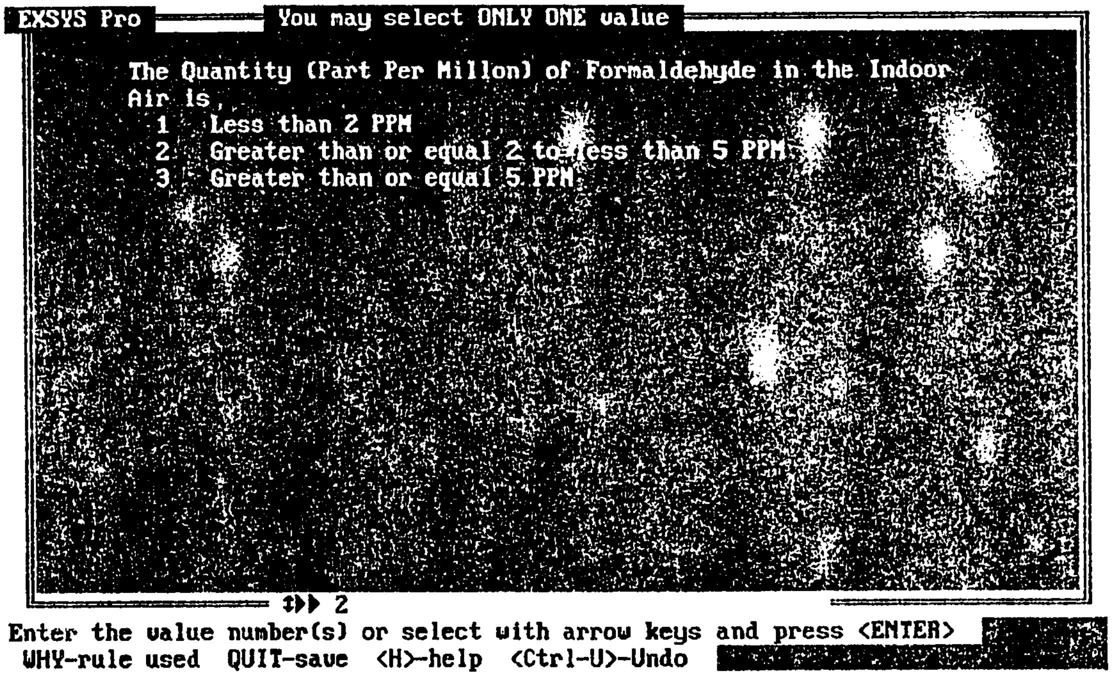

Plate 4.72 Quantity of Formaldehyde

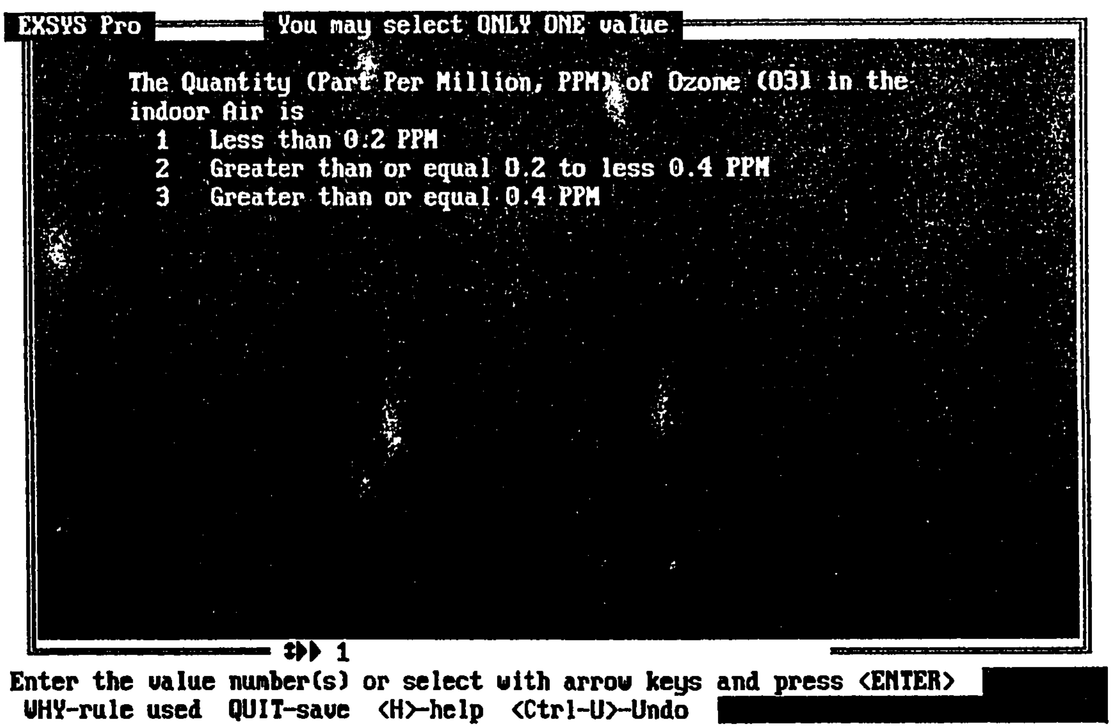

Plate 4.73 Quantity of (O3)

8. Now, all the variables have been assigned and this the time to get the results.

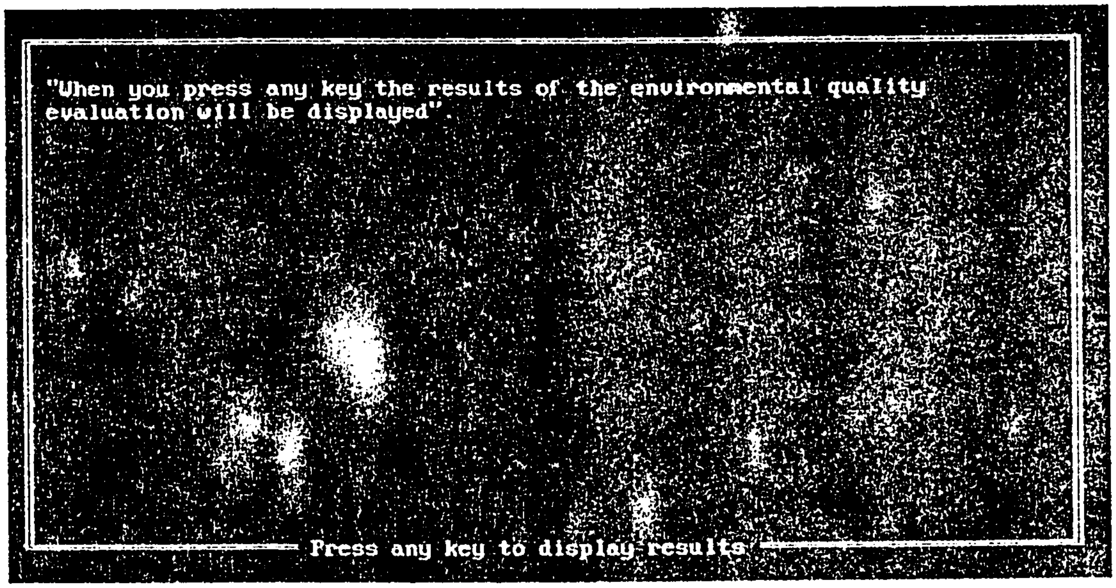

Plate 4.74 Starting of Results

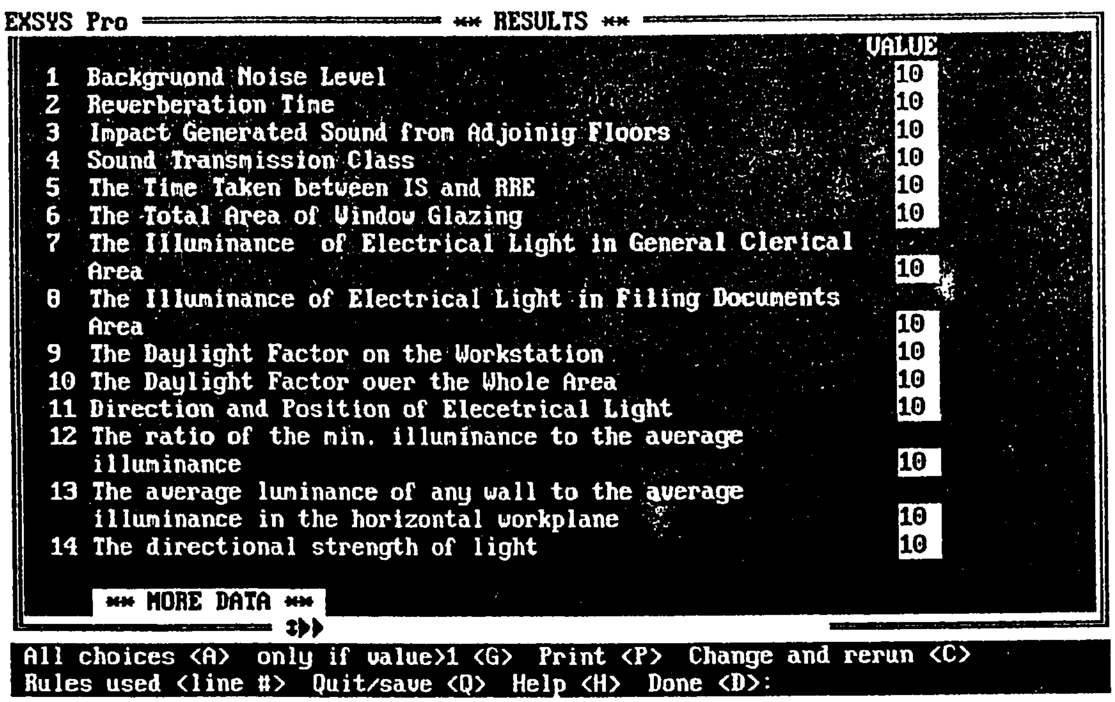

Plate 4.75 Results

EXSYS Pro ═══ ** RESULTS ** ═══

	VALUE
15 The correlated color temperture of light	10
16 The glare index of light	10
17 The Internal Air Temperature in Winter	10
18 The Internal Air Temperature in Summer	10
19 The Mean Radiant Temperature in Summer	10
20 The Relative Humidity in Winter	10
21 The Air Movement in Summer	10
22 The Maximum increase in RT over MRT	10
23 The Floor Temperature	10
24 Air Temperature between Head and Feet	10
25 Frequency of Shifts	10
26 Fresh Air Change	10
27 Entrainment of Room Air	10
28 Odors Control from Bathrooms	10
29 CO in the Indoor Air	10
30 NO2 in the Indoor Air	10
31 SO2 In the Indoor Air	10
32 Ozone in the indoor Air	10

** MORE DATA **

All choices <A> only if value>1 <G> Print <P> Change and rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Done <D>:

Plate 4.76 Results

EXSYS Pro ═══ ** RESULTS ** ═══

	VALUE
33 Speech Interference Level of workplace	7
34 Speech Interference Level of Typing Areas	7
35 Generated Noise from HVAC Terminals	7
36 Noise Isolation Class	7
37 The Difference between SSL and BNL	7
38 The Sound Absorption of wall Materials	7
39 The Sound Absorption of Ceiling Materials	7
40 The Sound Absorption of Floor Materials	7
41 The Illuminance (E) of Electrical light in typing Areas	7
42 The ratio of the illuminances at the workstation	7
43 The ratio of the illuminance on the task area to the illuminance around task area	7
44 The color rendering of light	7
45 The direct ratio of the total downward flux	7
46 The reflectance of the paint of wall surface finish	7
47 The reflectance of the window gloss finishing	7
48 The reflectance of equipment and furnishing surfaces	7
49 The Mean Radiant Temperature in Winter	7

** MORE DATA **

All choices <A> only if value>1 <G> Print <P> Change and rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Done <D>:

Plate 4.77 Results

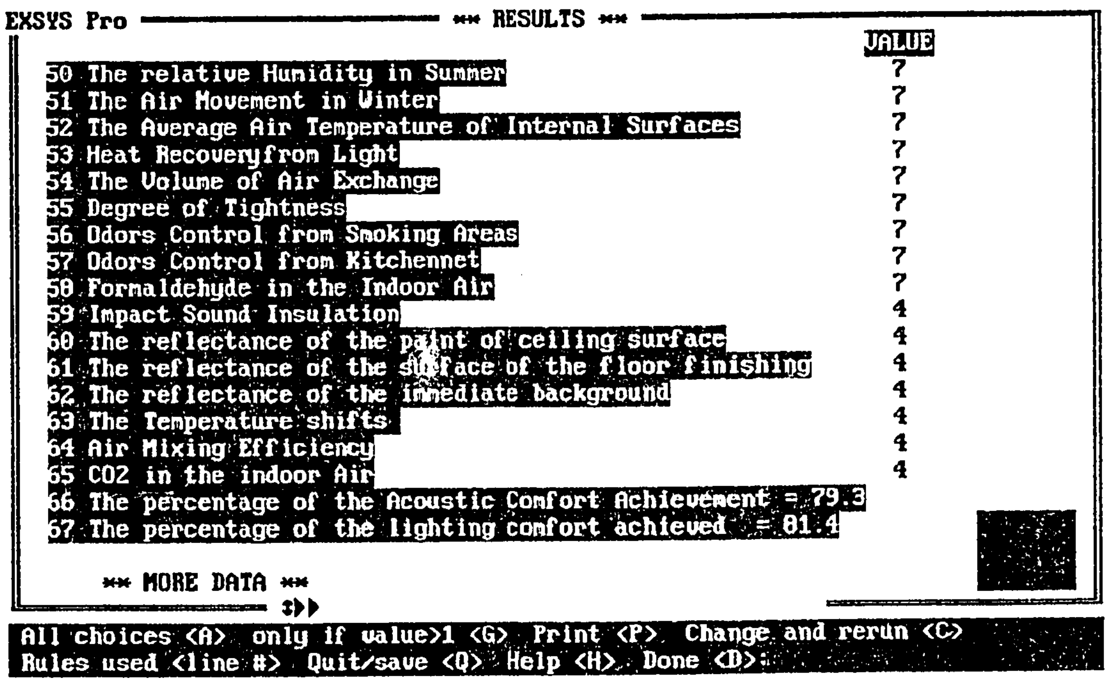

Plate 4.78 Results

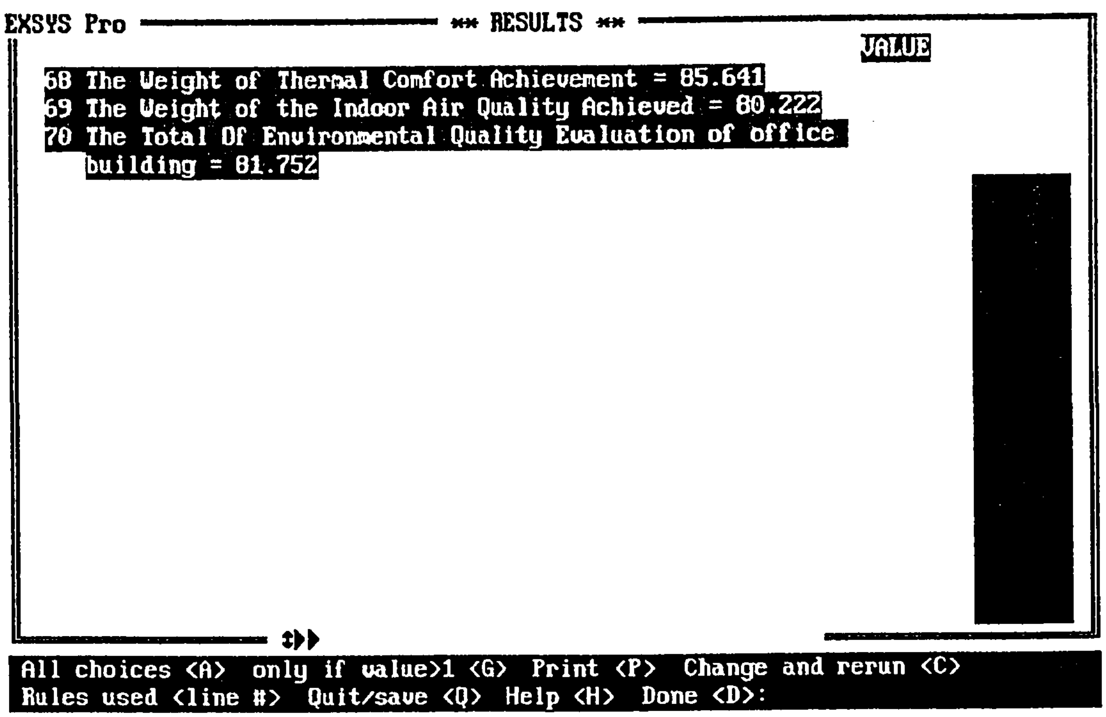

Plate 4.79 Results

9. If we would like to present all the inputs, type *"A"* to illustrate all the choices

```
EXSYS Pro ============ ** CHANGE INPUT DATA ** ============

1  Background Noise Level (using Noise Criteria - NC curve)
   is Greater than or equal 35 dB to Less than 45 dB
2  Reverberation Time is Greater than or equal 0.8 Second to
   Less than 1.2 Second
3  The Speech Interference Level of Workplace is Greater
   than or equal 30 dB  to less than 40 dB
4  Speech Interference Level of Typing Areas is Greater than
   or equal 30 dB to less than 40 dB
5  Impact Generated Sound (using NC curve) from Adjoining
   Floors is Less than 20 dB
6  Generated Noise from HVAC Terminals is Greater than or
   equal 35 dB to less than 45 dB
7  Sound Transmission Class for Walls, Partitions and
   Ceiling is Greater than or equal 45 dB
8  Impact Sound Insulation of Walls, partitions, Floor and
   Ceiling is Less than 35 dB
9  Noise Isolation Class is Greater than or equal 40 dB to
   less than 50 dB

     ** MORE DATA **
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.80 All Choices of the Variables

```
EXSYS Pro ============ ** CHANGE INPUT DATA ** ============

10 The Difference between Speech Sound Level and the Level
   of Background Noise is Greater than 20 dB to less than 35
   dB
11 The Time taken between the Initial Sound and its
   Reflection as received by the ear is Less than 20 milli /
   second
12 The Total Area of Window Glazing of the exteior walls
   area is Less than or equal 40%
13 The Sound Absorption of Wall Materials is Greater than 55
   % to less than or equal 75%
14 The Sound Absorption of Ceiling Materials Greater than
   30% to less than or equal 50%
15 The Sound Absorption of Floor Materials is Greater than
   35% to less than or equal 55%
16 The Illuminance (E) for Electrical Light in General
   Clerical Areas is Greater than or equal 200 Lux to less
   than 400 Lux
17 The illuminance (E) of Electrical Light in Typing Areas
   (using computers) is Less than 200 Lux
     ** MORE DATA **
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.81 All Choices of the Variables

```
EXSYS Pro ══════════ ** CHANGE INPUT DATA ** ══════════

 18 The Illuminance of Electrical Light in Filing Documents
    Area is Greater than or equal 400 Lux to less than 600
    Lux
 19 The Daylight Factor On the Workstation (assume external
    reference illuminance = 10,000 Lux) is Greater than or
    equal 4% to less than 6%
 20 The Daylight Factor over the Whole Area (assume external
    reference illuminance = 10,000 Lux) is Greater than or
    equal 2% to less than 3%
 21 Direction and Position of Electrical Light (When Daylight
    Supplement Electrical Light) is Directed from other
    direction and away from the window
 22 The ratio of the minimum illuminance to the average
    illuminance in the general office area is Greater than or
    equal 1:1 to less than or equal 1:2
 23 The ratio of the illuminances at the workststion is
    Greater than or equal 1:2 to less than 1:3
 24 The average luminance of any wall to the average
    illuminance in the horizontal wo
                    ↕▶▶
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.82 All Choices of the Variables

```
EXSYS Pro ══════════ ** CHANGE INPUT DATA ** ══════════

 24 The average luminance of any wall to the average
    illuminance in the horizontal workplane is Greater than
    or equal 1:2 to less than 1:2
 25 The ratio of the illuminance on the task area to the
    illuminance around task area is Greater than 1:3 to less
    than 1:10
 26 The directional strength of light (Vector / Scalar ratio)
    is Greater than or equal 2.5
 27 The correlated color temperature of light (color quality)
    is Grater than 5300k (Cool)
 28 The color rendering of light is Greater than or equal 40
    to less than 70
 29 The glare index of light is Grater than or equal 17 to
    less than 21
 30 The direct ratio of the total downward flux from the
    luminaries falls directly on the workstation is Greater
    than or equal 0.6 to less than 0.8
 31 The reflectance of the paint of ceiling surface is Less
    than 0.6
     ** MORE DATA **
                    ↕▶▶
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.83 All Choices of the Variables

```
EXSYS Pro ──────────── ** CHANGE INPUT DATA ** ────────────

32 The reflectance of the paint of wall surface finish is
   Greater than or equal 0.3 to less than or equal 0.5
33 The reflectance of the window gloss finishing is Greater
   than or equal 0.5 to less than 0.7
34 The reflectance of the surface of the floor finishing is
   Less than 2.0
35 The reflectance of equipment surfaces and furnishing
   surfaces is Greater than or equal 0.1 to less than 0.3
36 The reflectance of the immediate background is Less than
   or equal 0.2
37 The Internal Air Temperature (degree centigrade) in
   Winter is Greater than or equal 20 to less than 22
38 The Internal Air Temperature (degree centigrade) in
   Summer is Greater than or equal 22 to less than 25
39 The Mean Radiant Temperature (degree centigrade) in
   Winter is Less than or equal 24 to Greater than 22
40 The Mean Radiant Temperature (degree centigrade) in
   Summer is Less than or equal 24 to greater than 22

   ** MORE DATA **
                 ↕▶▶
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.84 All Choices of the Variables

```
EXSYS Pro ──────────── ** CHANGE INPUT DATA ** ────────────

41 The Relative Humidity in Winter is Greater than or equal
   35% to less than 50%
42 The Relative Humidity in Summer is Greater than or equal
   30% to less than 45%
43 The Air Movement in Winter is Greater than or equal 0.13
   to less than 0.15 m/s
44 The Air Movement in Summer is Greater than or equal 0.22
   to less than 0.24 m/s
45 The Average Temperature of the Internal Surfaces is Equal
   air temperature in winter and summer
46 The Temperature Shifts  (degree centigrade) is Greater
   than or equal + or - 3
47 The Maximum Increase in the Radiant Temperature on the
   Head over the Mean Radiant Temperature (degree
   centigrade) is Less than 1
48 The Floor Temperature (degree centigrade) is Greater than
   or equal 27 to less than 29
49 The Air Temperature between Head and Feet (degree
   centigrade) is Less than 1
   ** MORE DATA **
                 ↕▶▶
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.85 All Choices of the Variables

```
EXSYS Pro ─────────── ** CHANGE INPUT DATA ** ───────────

50 The Heat Recoveryfrom Light (watt per feet square) is
   Greater than or equal 2 to less than or equal 3
51 The Frequency of Shifts per hour is Greater than or equal
   55 to less than 65
52 The Volume (Cubic Feet) of Air Exchange Rate per Minute
   per person is Greater than or equal 15 to less than 25
   CFM
53 The Fresh Air Change Per Hour is Greater than or equal 4
   to less than or equal 6 / hour
54 The Degree of Tightness (Air Filtration Efficiency) is
   Greater than or equal 70% to less than 90%
55 The Degree of Air Mixing Efficiency is Less than 70%
56 The Efficiency of entrainment of room air by the primary
   air stream outside the zone of occupancy is Greater than
   or equal 90%
57 Smoking Areas (Odors Control) are Somewhat Separated
58 Bathrooms (Odors Control) are Well sealed and ventilated
59 Kitchennet (Odors Control) is Somewhat sealed and
   ventilated
    ** MORE DATA **
Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.86 All Choices of the Variables

```
EXSYS Pro ─────────── ** CHANGE INPUT DATA ** ───────────

60 The Quantity (Part Per Million, PPM) of Carbon Monoxide
   (CO) in the Indoor Air is Less than or equal 5 PPM
61 The Quantity (Part Per Million, PPM) of Carbon Dioxide
   (CO2) in the Indoor Air is Greater than or equal 500 PPM
62 The Percentage of Niterogen Dioxide (NO2) in the Indoor
   Air is Less than 4%
63 The Quantity (Part Per Milion, PPM) of Sulfur Dioxide
   (SO2) in the Indoor Air is Less than 0.5 PPM
64 The Quantity (Part Per Millon) of Formaldehyde in the
   Indoor Air is Greater than or equal 2 to less than 5 PPM
65 The Quantity (Part Per Million, PPM) of Ozone (O3) in the
   indoor Air is Less than 0.2 PPM

Enter number of line to change, <O> for original data, <R> to run the data,
<H> for help
```

Plate 4.87 All Choices of the Variables

10. If the final results do not satisfy our needs we have to return to user inputs to make results comparison (see Fig. 5.8)

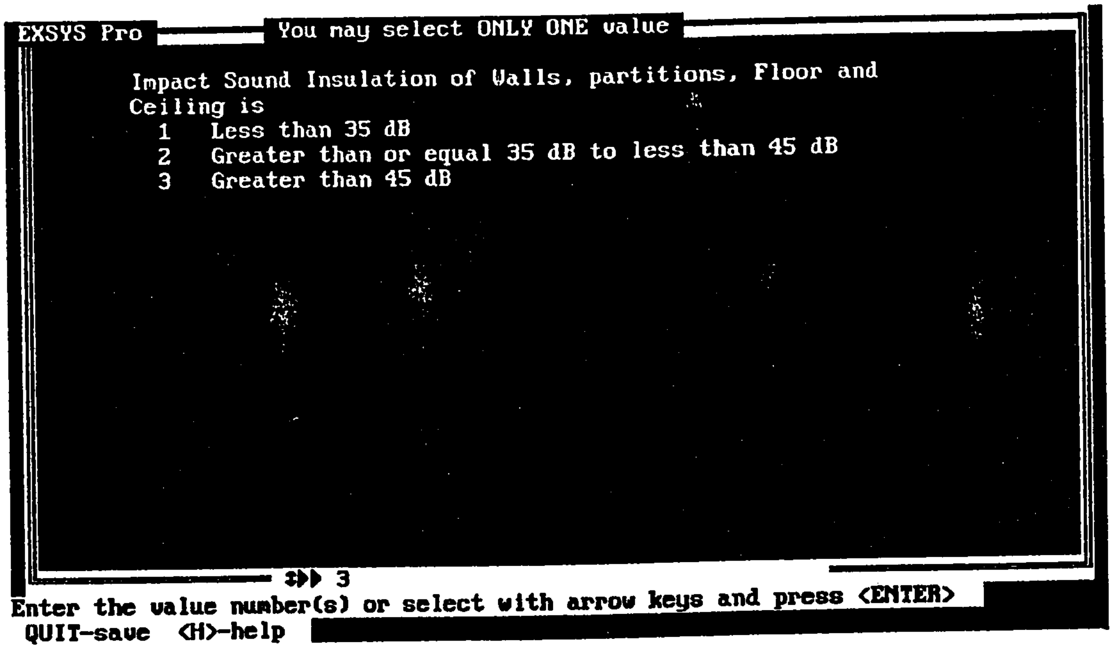

Plate 4.88 Change Data Input of Impact Sound Insulation.

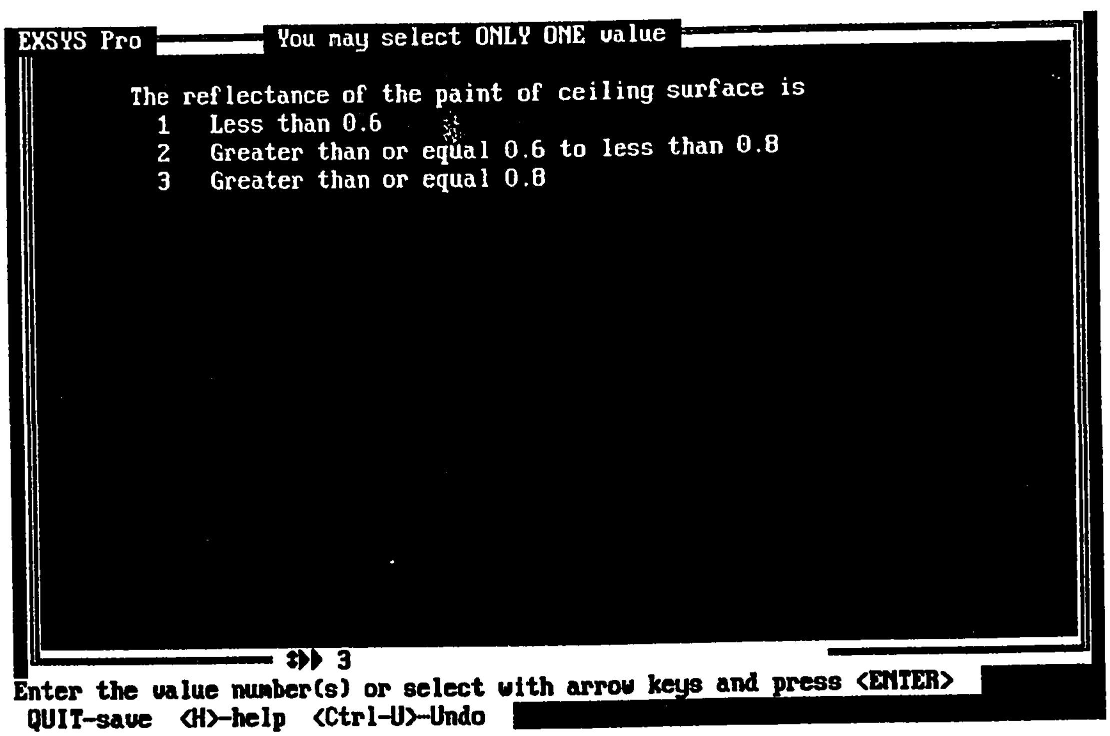

Plate 4.89 Change Data Input of Reflectance of ceiling surface.

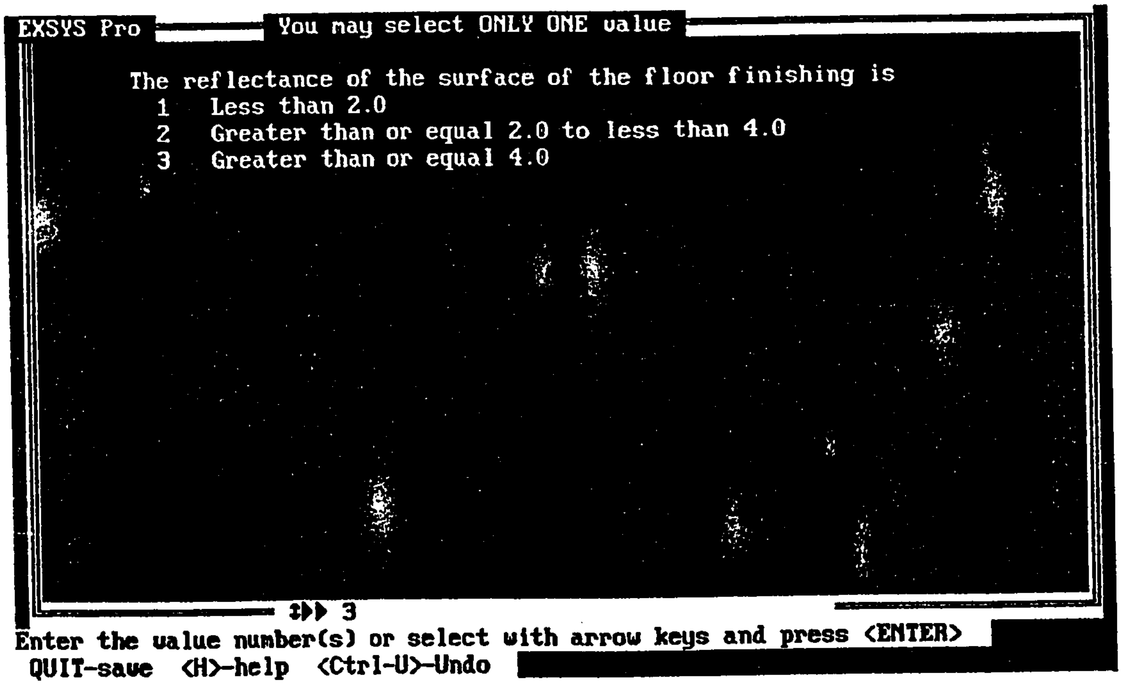

Plate 4.90 Change Data Input of Reflectance of floor surface.

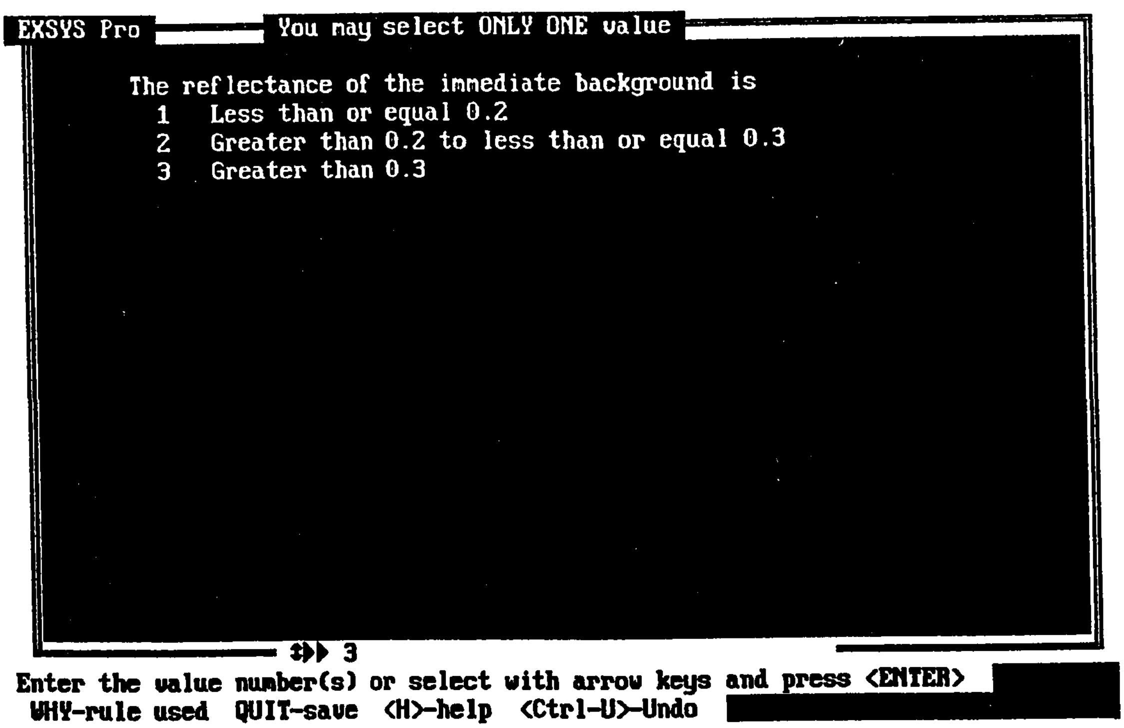

Plate 4.91 Change Data Input of Reflectance of immediate background

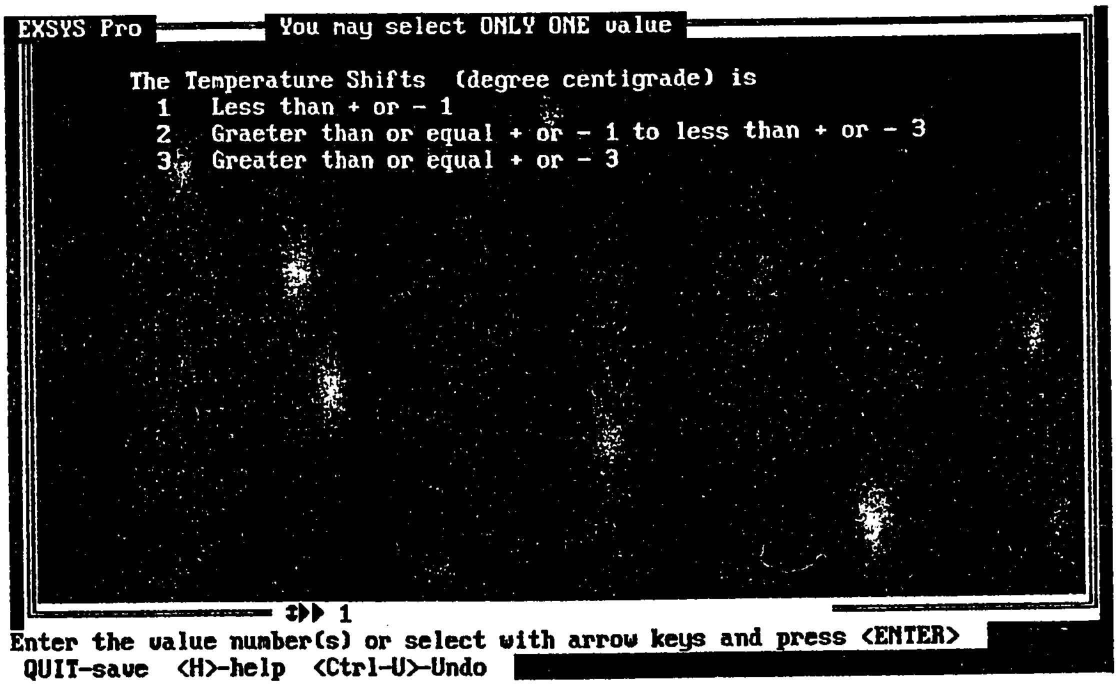

Plate 4.92 Change Data Input of Temperature Shifts.

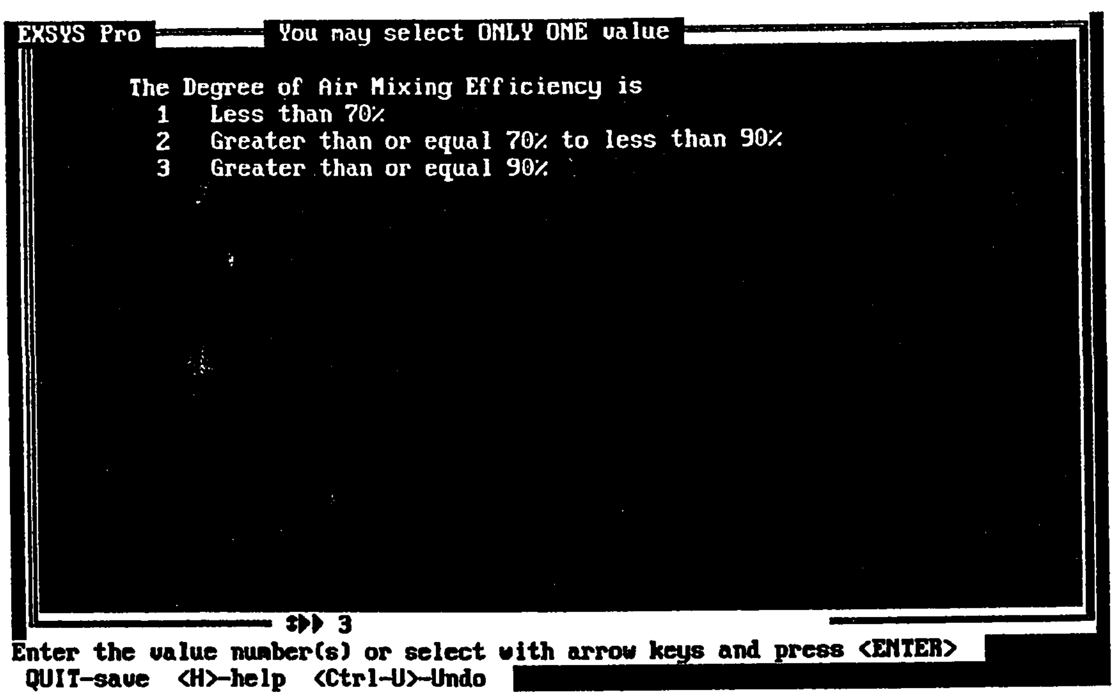

Plate 4.93 Change Data Input of Air Mixing Efficiency

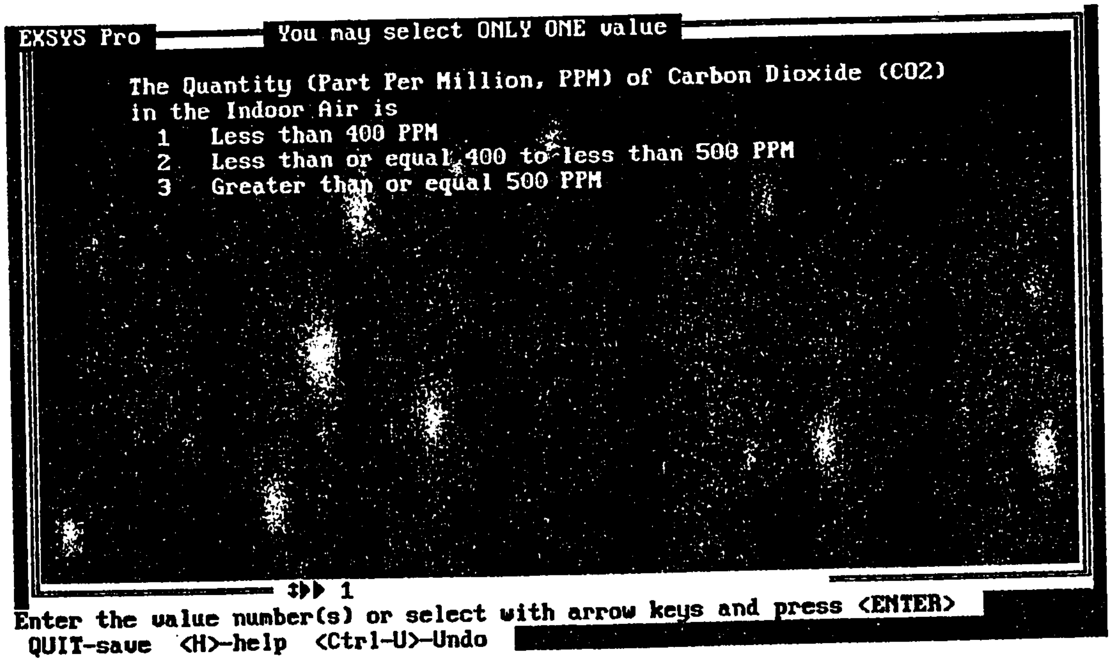

Plate 4.94 Change Data Input of Quantity of (CO2).

11. When you change the selected choices press "R" to rerun the inputs. The new results as well as the previous results will appear on the screen.

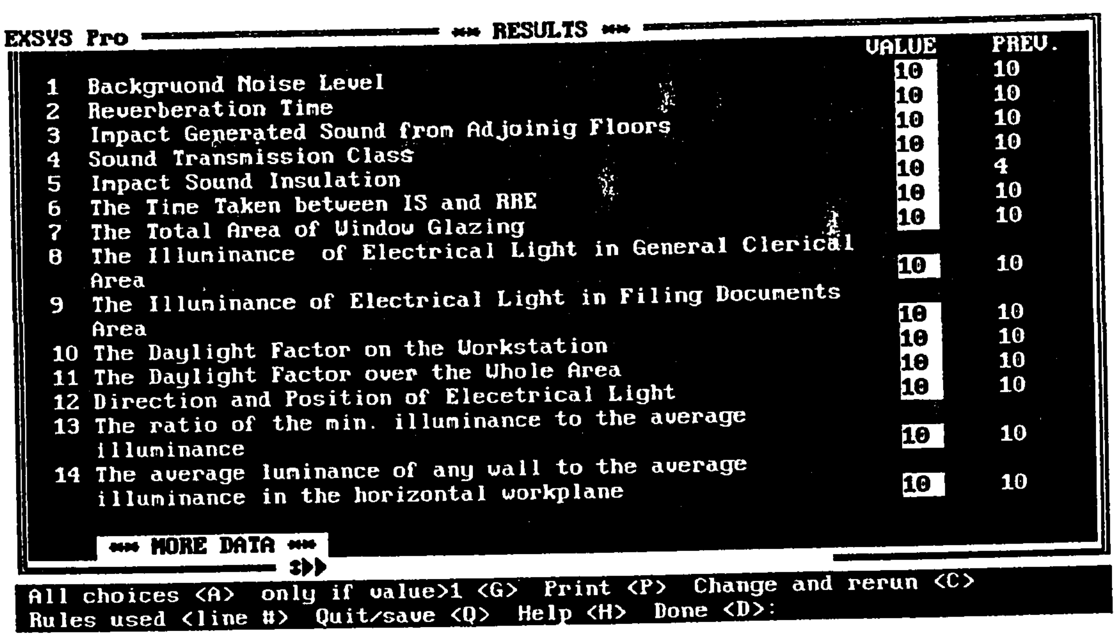

Plate 4.95 Enhanced Results

EXSYS Pro — ** RESULTS **

	VALUE	PREV.
15 The directional strength of light	10	10
16 The correlated color tenperture of light	10	10
17 The glare index of light	10	10
18 The reflectance of the paint of ceiling surface	10	4
19 The reflectance of the surface of the floor finishing	10	4
20 The reflectance of the immediate background	10	4
21 The Internal Air Temperature in Winter	10	10
22 The Internal Air Temperature in Summer	10	10
23 The Mean Radiant Temperature in Summer	10	10
24 The Relative Humidity in Winter	10	10
25 The Air Movement in Summer	10	10
26 The Maximum increase in RT over MRT	10	10
27 The Floor Temperature	10	10
28 Air Temperature between Head and Feet	10	10
29 Frequency of Shifts	10	10
30 Fresh Air Change	10	10
31 Air Mixing Efficiency	10	4
32 Entrainment of Room Air	10	10

** MORE DATA **

All choices <A> only if value>1 <G> Print <P> Change and rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Done <D>:

Plate 4.96 Enhanced Results

EXSYS Pro — ** RESULTS **

	VALUE	PREV.
33 Odors Control from Bathrooms	10	10
34 CO in the Indoor Air	10	10
35 CO2 in the indoor Air	10	4
36 NO2 in the Indoor Air	10	10
37 SO2 In the Indoor Air	10	10
38 Ozone in the indoor Air	10	10
39 Speech Interference Level of workplace	7	7
40 Speech Interference Level of Typing Areas	7	7
41 Generated Noise from HVAC Terminals	7	7
42 Noise Isolation Class	7	7
43 The Difference between SSL and BNL	7	7
44 The Sound Absorption of wall Materials	7	7
45 The Sound Absorption of Ceiling Materials	7	7
46 The Sound Absorption of Floor Materials	7	7
47 The Illuminance (E) of Electrical light in typing Areas	7	7
48 The ratio of the illuminances at the workstation	7	7
49 The ratio of the illuminance on the task area to the illuminance around task area	7	7

** MORE DATA **

All choices <A> only if value>1 <G> Print <P> Change and rerun <C>
Rules used <line #> Quit/save <Q> Help <H> Done <D>:

Plate 4.97 Enhanced Results

```
EXSYS Pro ──────────── ** RESULTS ** ────────────
                                                          VALUE   PREV.
50 The color rendering of light                             ?       ?
51 The direct ratio of the total downward flux              ?       ?
52 The reflectance of the paint of wall surface finish      ?       ?
53 The reflectance of the window gloss finishing            ?       ?
54 The reflectance of equipment and furnishing surfaces     ?       ?
55 The Mean Radiant Temperature in Winter                   ?       ?
56 The relative Humidity in Summer                          ?       ?
57 The Air Movement in Winter                               ?       ?
58 The Average Air Temperature of Internal Surfaces         ?       ?
59 Heat Recoveryfrom Light                                  ?       ?
60 The Volume of Air Exchange                               ?       ?
61 Degree of Tightness                                      ?       ?
62 Odors Control from Smoking Areas                         ?       ?
63 Odors Control from Kitchennet                            ?       ?
64 Formaldehyde in the Indoor Air                           ?       ?
65 The Temperature shifts                                   4       4
66 The percentage of the Acoustic Comfort Achievement =
   83.38

   ** MORE DATA **
All choices <A>  only if value>1 <G>  Print <P>  Change and rerun <C>
Rules used <line #>  Quit/save <Q>  Help <H>  Done <D>:
```

Plate 4.98 Enhanced Results

```
EXSYS Pro ──────────── ** RESULTS ** ────────────
                                                          VALUE   PREV.
67 The percentage of the lighting comfort achieved   = 88.6
68 The Weight of Thermal Comfort Achievement = 85.641
69 The Weight of the Indoor Air Quality Achieved = 88.112
70 The Total Of Environmental Quality Evaluation of office
   building = 86.918

All choices <A>  only if value>1 <G>  Print <P>  Change and rerun <C>
Rules used <line #>  Quit/save <Q>  Help <H>  Done <D>:
```

Plate 4.99 Enhanced Results

CHAPTER 5

SUMMARY AND RECOMMENDATION

This chapter presents the summary of the study and the recommendations.

5.1 SUMMARY

5.1.1 SUMMARY OF THE STUDY

Office buildings are built to host a group of people conducting economic activities. The environment of the building must be set in a quality level helping occupants in performing their activities with comfort. This study revealed the methods by which experts evaluate facility planning, lighting, acoustic, thermal and indoor air quality factors in office buildings. Questionnaires were developed and 50 experts from academic and practicing sectors were interviewed.

This study simulated the experts' knowledge and developed an integrated expert system for evaluating the environmental quality of office building

5.1.2 SUMMARY OF THE FINDINGS

The findings obtained by this study could be summarized as follows:

1. The office workplace is the most important element in the office building from the environmental quality point of view. The office workplace has assigned a weight 9.58 out of 10 point scale.

2. In the office workplace the lighting quality has assigned the highest weight (9.56 out of 10 point scale). Indoor air quality, thermal and acoustic have assigned 6.61, 6.35 and 5.56 respectively.

3. The function that integrates the environmental quality factors in one equation is:

Total EQE = (1.89 * [Acoustic] + 2.29 * [Thermal] + 2.39 [Indoor Air Quality] + 3.44 * [Lighting])

4. The acoustical quality variables were ranked as follows:

Rank 1

- Speech Interference Level of Typing area
- The Time Taken between the Initial Sound and its reflection as received by the ear
- Sound Absorption of Ceiling Materials

Rank 2

- Background Noise Level
- Impact Generated Sound from adjoining Floors
- Noise Generated from HVAC

- Speech Interference Level of Workplace Area
- Sound Transmission Class for walls, partitions, floors and ceiling
- Impact Sound Insulation of walls, partitions and ceilings
- Noise Isolation Class
- The Difference between Speech Sound Level and the level of background noise level

Rank 3

- Reverberation Time
- The Total Area of Window glazing
- Sound Absorption of Wall Materials
- Sound Absorption of Floor Materials

5. The lighting quality variables were ranked as follows:

Rank 1

- The Glare Index of Light
- The ratio of the Illuminances at the Workstation

Rank 2

- Illuminance (E) for Electrical Light in General Areas
- The ratio of the minimum illuminance to the Average Illuminance in the General Office area
- The Average Luminance of any Wall to the Average Illuminance in the Horizontal Workplace
- The ratio of the illuminance on the task Area to the Illuminance around task Area

- The Direct ratio of the Total Downward Flux from the Luminaries falls directly on the Workstation
- The Reflectance of the Paint of Ceiling Surface

Rank 3

- The Reflectance of the Paint of the Wall Surface
- The Reflectance of the Window Glass Finishing
- The Reflectance of the Paint of the Floor Finishing
- The Reflectance of Equipment and furnishing Surfaces
- The Reflectance of the Immediate Background
- The Directional Strength of light (Vector/Scalar Ratio)
- The Correlated Color Temperature of Light
- The Color Rendering of Light
- Direction and Position of Electric Light
- Daylight Factor over the whole Areas
- Daylight Factor on the Workstation

Rank 4

- Illuminance (E) for Electrical Light in Types Areas (using computers)
- Illuminance (E) for Electrical Light in Filing of documents Areas

6. The thermal quality variables were ranked as follows:

Rank 1

- Temperature Shifts

- Maximum Increase in the Radiant Temperature on the Head over the Main Radiant Temperature

Rank 2

- Air Temperature
- Mean Radiant Temperature
- Relative Humidity
- Air Movement
- The Average Temperature of the Internal Surfaces
- Floor Temperature
- Air Temperature Between Head and Feet
- Frequency Shifts

Rank 3

- Heat Recover from Light

7. The indoor air quality variables were ranked as follows:

Rank 1

- Odors from smoking Areas

Rank 2

- Air Exchange Rate (Fresh Air Make up)
- Air Change Per Hour
- Air Filtration Efficiency
- Air Mixing Efficiency
- The Efficiency of entrainment of Room Air by the primary stream outside the zone off occupancy
- Odors from Bathrooms
- Odors from Kitchenette
- Carbon Dioxide in indoor Air in the general office area

Rank 3

- Carbon Monoxide in indoor Air in the general office area
- Nitrogen Dioxide in indoor Air in the general office area
- Sulfur Dioxide in indoor Air in the general office area
- Formaldehyde in indoor Air in the general office area
- Ozone in indoor Air in the general office area

8. It was possible to develop a unified system for environmental quality evaluation of office buildings in an integrated approach simulating the methods that the expert using them for office environment.

9. The ESEQE was tested under certain conditions for the environmental quality variables and the results were figured out and they are totally the same results came from the manual evaluation using experts methods under the same conditions of the variables.

5.2 RECOMMENDATIONS

5.2.1 STUDY RECOMMENDATIONS

The architects are advised to use the ESEQE model for the environmental quality evaluation of office buildings in tropical areas. The model speeds and simplifies the evaluation process. ESEQE users will benefit from such a model in producing more reliable and acceptable designs for office buildings. Some of these benefits are listed below:

- ESEQE model allows the user to preserve the experts' valuable knowledge and provides a new way to preserve knowledge.
- ESEQE model helps the user to understand how an expert system goes about solving a problem, or otherwise applying knowledge.
- ESEQE model saves the time and money by avoiding costly mistakes and bad decisions.
- With knowledge readily available, good decision could be made quickly.

5.2.2 FUTURE STUDIES

Going through the development cycle of ESEQE model the following points could be future studies:

1. The ESEQE model could be enlarged to comprise other factors of office building evaluation like space allocation, envelope design, structural design, building integrity etc., so that it can promise of a marketable nature.
2. The amount of knowledge involved in a system is the feature that gives it real power. So it is recommended to build a well structured data base "Office Building Evaluation", that can be incorporated to the system.
3. The structure and idea of ESEQE model could be used to evaluate any type of buildings after adjusting the ranges of scales and the weight to be suitable for the type of the building.

AN INTERVIEW

Dear Interviewee,

The Architectural Engineering Department of the College of Environmental Design at King Fahd University of Petroleum and Minerals is currently engaged in a study relevant to the Environmental Quality Evaluation (EQE) of Air Conditioned Office Buildings in the arid region of Saudi Arabia. This is to assess how well office buildings meet the needs of their occupants. The knowledge we obtain will be useful in developing an expert system for EQE of office buildings during the design stage.

We would appreciate your effort in filling out the questionnaire as carefully as possible. Your response will improve the efficiency of the study and help us to develop a valuable and valid expert system for EQE of office buildings.

Thank you for your cooperation.

Very truly yours,

Dr. Ali Ali Shash Phone (03) 860-3590

Mr. Rabee M. Reffat Phone Office (03) 860 3275
House (03) 860 5106

P. O. Box 1717 - KFUPM - Dhahran - 31261 - Saudi Arabia

Introduction

Dear Interviewee:.......................................

The Architectural Engineering Department of the College of Environmental Design at King Fahd University of Petroleum and Minerals is currently engaged in a study relevant to the Environmental Quality Evaluation (EQE) of Air Conditioned Office Buildings in the arid region of Saudi Arabia. This is to attain how well the office buildings meet the needs of its occupants. The knowledge we obtain will be useful in developing an expert system for EQE of office buildings during the design stage.

The following is a brief description about the interview contents. The **Office Building Elements** have been classified into ten major elements: Reception Areas, Office Workplace, Core System (elevators, staircases, bathrooms, etc.), Meeting Areas (conference room, lectures room, etc.), Rest Areas (dining hall, cafeteria, etc.), Circulation Areas (corridor's, lobbies, etc.), Special Facilities (computer room, library, audio visual room, etc.), General services (mechanical and electrical rooms), Storage, and Parking Areas.

The **Environmental Quality Factors** are Lighting, Acoustic, Thermal, and Indoor Air Quality. **Lighting comfort** will be assessed from light quantity, electrical light and daylight, color quality, glare comfort, and directional quality point of view. **Acoustic comfort** will be assessed from background noise level, noise criteria, speech privacy and speech intelligibility, noise from equipment point of view. **Thermal comfort** will be assessed from air temperature, mean radiant temperature, relative humidity, air movement, temperature shifts, activity level, and clothing factor point of view.

Indoor air quality will be assessed from ventilation comfort, fresh air exchange rate, indoor air pollutants, odors, rate of air movement, humidity, and air temperature point of view.

The questions to be discussed during the interview concerned with the EQE are divided into six parts:

Part I Facility Planning

The purpose of this part is to determine the importance of each office building element among various elements of the office building from an environmental comfort point of view.

Part II Environmental Quality of Office Building Design

The main purpose of this part is to determine the importance of each Environmental Quality (EQ) factor among various factors of EQ for each office building element.

Parts III, IV, V, VI

The purpose of these parts is to determine how the influential effect of each performance criteria will be used for evaluating EQ factors. Also, to figure out how the scales (subjective and objective) could be used for evaluating the performance criteria of the EQ factors of office buildings.

Part III	Lighting Comfort.
Part IV	Acoustic Comfort.
Part V	Thermal Comfort.
Part VI	Indoor Air Quality.

Personal experience and the expert respondent will be reordered under eight headings:
1, 2, 3, 4, 5, 6, 7, and 8.

We would appreciate your participating in one or more from the above mentioned parts depending your area of expertise.

Thank you for your cooperation.

Personal Information

Name:......................................

Date:..

Company:.................................

Address:..................................

1. Which of the following is(are) your area(s) of expertise?

- ☐ Lighting design
- ☐ Acoustical design
- ☐ Thermal design
- ☐ Indoor air quality
- ☐ Architectural design (office buildings)

2. Please indicate the education degrees you have been awarded?

- ☐ BS., Major :...
- ☐ Master degree, Major :..
- ☐ Professional degree, Major :...............................
- ☐ Ph.D. degree, Major :..
- ☐ Others (please specify) ....

3. **How many years have you been practicing your expertise?**

- ☐ Less than 5 years
- ☐ 5 to less than 10 years
- ☐ 10 to less than 15 years
- ☐ 15 to less than 20 years
- ☐ 20 years and above

4. **To how many office buildings have you applied your expertise in designing?**

- ☐ Less than 5 office buildings
- ☐ 5 to less than 10 office buildings
- ☐ 10 office buildings and more

5. **In how many office buildings have you successfully applied your expertise?**

- ☐ Less than 20%
- ☐ 20% to less than 40%
- ☐ 40% to less than 60%
- ☐ 60% to less than 80%
- ☐ 80% to 100%

6. **To which of the following areas have you applied your expertise?**

- ☐ Projects (office buildings)
- ☐ Books
- ☐ Reports
- ☐ Articles
- ☐ Experimental work

7. **What are the methods you always use to evaluate the Lighting Comfort, Acoustic Comfort, Thermal Comfort, Indoor Air Quality Comfort, Facility Planning of office buildings design?**

- ☐ Your own experience
- ☐ Your own checklist
- ☐ Your own computerized program
- ☐ Software (please specify,.......................................)
- ☐ Others (please specify,...)

8. **How important is it in using an integrated approach to conduct EQE of office buildings?**

- ☐ Extremely important
- ☐ Major important
- ☐ Important
- ☐ Somewhat important
- ☐ Not important

FACILITY PLANNING

The main purpose of the following questions is to determine the weight of each office building element among various elements of the office building from an environmental comfort (Lighting, Acoustics, Thermal, and Indoor Air Quality) point of view. A paired comparison method is being used to find out the weights by determining the importance of each office building element compared to other elements. The importance should be assessed from an environmental quality point of view as illustrated in the following example:

	NO.	Office Building Elements The importance OF	TO	Level of importance H 7	6	5	M 4	3	2	L 1
Ex. 1		A	B	X						
			C							
			D							
Ex. 2			E				X			
			F							
			G							
Ex. 3			H							X
			I							
			J							

Ex.1 **A is of extremely high importance compare to B**
Ex.2 **A is equally as important as E**
Ex.3 **A is much less important than H**
Where A, B, C, D, E, F, G, H, I and J are the office building elements.

The importance of each office building element compared to other office building elements from an Environmental Comfort point of view

	Office Building Elements		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
A	**Reception Areas**	Office Workplace							
		Core System							
		Meeting Areas							
		Rest Areas							
		Circulation Areas							
		Special Facilities							
		General Services							
		Storage							
		Parking Areas							
B	**Office Workplace**	Core System							
		Meeting Areas							
		Rest Areas							
		Circulation Areas							
		Special Facilities							
		General Services							
		Storage							
		Parking Areas							

H = Much more important than. M = Equally important as, L = Much less important than.

The importance of each office building element compared to other office building elements from an Environmental Comfort point of view

	Office Building Elements		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
C	Core System	Meeting Areas							
		Rest Areas							
		Circulation Areas							
		Special Facilities							
		General Services							
		Storage							
		Parking Areas							
D	Meeting Areas	Rest Areas							
		Circulation Areas							
		Special Facilities							
		General Services							
		Storage							
		Parking Areas							
E	Rest Areas	Circulation Areas							
		Special Facilities							
		General Services							
		Storage							
		Parking Areas							

H = Much more important than. M = Equally important as, L = Much less important than.

The importance of each office building element compared to other office building elements from an Environmental Comfort point of view									
	Office Building Elements		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
F	Circulation Areas	Special Facilities							
		General Services							
		Storage							
		Parking Areas							
G	Special Facilities	General Services							
		Storage							
		Parking Areas							
H	General Services	Storage							
		Parking Areas							
I	Storage	Parking Areas							

H = Much more important than. M = Equally important as, L = Much less important than.

Please assign weight for each office building element from 10 point's scale compared to other office building elements from its importance in the environmental quality (lighting, acoustics, thermal, and indoor air quality) point of view.

Office Building Elements	**Weight**
Reception Areas	
Office Workplace	
Core System	
Meeting Areas	
Rest Areas	
Circulation Areas	
Special Facilities	
General Services	
Storage	
Parking Areas	

10 is most important, 1 is least important

ENVIRONMENTAL QUALITY OF OFFICE BUILDINGS

The main purpose of the following questions is to determine the weight of each Environmental Quality (EQ) factor (lighting, acoustic, thermal, indoor air quality) compared to other EQ factors for each office building element. A paired comparison method is being used to find out the weights by determining the importance of each environmental quality factor compared to other factors for each space (office element) in the office building.

The importance of each Environmental Quality (EQ) factor compared to other EQ factors for each office building element

Office Building Elements	Environmental Quality factors		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
A. Reception Areas	**Lighting Comfort**	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							
B. Office Workplace	**Lighting Comfort**	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							

***H** = Much more important than.* ***M** = Equally important as,* ***L** = Much less important than.*

The importance of each Environmental Quality (EQ) factor compared to other EQ factors for each office building element									
Office Building Elements	**Environmental Quality factors**		**Level of importance**						
	The importance		**H**			**M**			**L**
	OF	**TO**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
C. Core System	**Lighting Comfort**	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							
D. Meeting Areas	**Lighting Comfort**	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							

H = Much more important than. M = Equally important as, L = Much less important than.

The importance of each Environmental Quality (EQ) factor compared to other EQ factors for each office building element

Office Building Elements	Environmental Quality factors		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
E. Rest Areas	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							
F. Circulation Areas	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							

H = Much more important than. M = Equally important as, L = Much less important than.

The importance of each Environmental Quality (EQ) factor compared to other EQ factors for each office building element

Office Building Elements	Environmental Quality factors		Level of importance						
	The importance		H			M			L
	OF	TO	7	6	5	4	3	2	1
G. Special Facilities	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							
H. General Services	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							

H = Much more important than. M = Equally important as, L = Much less important than.

The importance of each Environmental Quality (EQ) factor compared to other EQ factors for each office building element

Office Building Elements	Environmental Quality factors: The importance OF	TO	H 7	6	5	M 4	3	2	L 1
I. Storage Areas	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							
J. Parking Areas	Lighting Comfort	Acoustic Comfort							
		Thermal Comfort							
		Indoor Air Quality							
	Acoustic Comfort	Thermal Comfort							
		Indoor Air Quality							
	Thermal Comfort	Indoor Air Quality							

H = Much more important than. M = Equally important as, L = Much less important than.

Please assign weight from 10 point's scale for each Environmental Quality (EQ) factor (lighting comfort, acoustic comfort, thermal comfort, indoor air quality) compared to others for each office building element.

Office Building Elements	Assigned weight for each EQ factor compared to other factors for each office building element.			
	Lighting Comfort	Acoustics Comfort	Thermal Comfort	Indoor Air Quality
Reception Areas				
Office Workplace				
Core System				
Meeting Areas				
Rest Areas				
Circulation Areas				
Special Facilities				
General Services				
Storage				
Parking Areas				

10 is most important and 1 is least important

LIGHTING DESIGN

The main purpose of the following questions is to determine how the influential effect of each performance criteria will be used for evaluating lighting comfort of office workplace in the open plan office buildings (managerial work). A second purpose of these questions is to determine how the scales (Quantitative and / or Qualitative) could be used for evaluating the performance criteria of the lighting comfort of office workplaces.

The influential effect of each performance criteria will be used for evaluating Lighting Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Lighting Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
1.	**Illuminance**						<200 Lux				
	(Electrical light ,						≥ 200 < 400 Lux				
	alone)						≥ 400 < 600 Lux				
A.	**General**						≥ 600 < 800 Lux				
	Clerical						≥ 800 Lux				
B.	**Typing Computer work**						<200 Lux				
							≥ 200 < 400 Lux				
							≥ 400 < 600 Lux				
							≥ 600 < 800 Lux				
							≥ 800 Lux				

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The influential effect of each performance criteria will be used for evaluating Lighting Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Lighting Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
C.	**Filing of Documents**						<200 Lux				
							≥ 200 < 400 Lux				
							≥ 400 < 600 Lux				
							≥ 600 < 800 Lux				
							≥ 800 Lux				
2.	**A. Daylight Factor**						< 2%				
	on the Workstation						2 - 3 %				
	(Assume External Reference Light = 10,000 Lux)						3 - 5 %				
							5 - 7%				
	Daylight supplement Electrical Light						> 7%				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges		Scales of Comfort: Comfort.	Reason.	Uncomfor.
2	**A. Daylight Factor** over the whole area (Assume External Reference Light = 10,000 Lux) Daylight supplement Electrical Light						< 2%				
							2 - 3 %				
							3 - 5 %				
							5 - 7%				
							> 7%				
3.	**Direction and position of Electrical light when it is supplem-ented by Daylight**						Directed from the same direction of the window				
							Directed both from other direction and near the window				
							Directed both from other direction and away from the window				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
4.	The ratio of minimum Illuminance to the average Illuminance in the general office area						$< 1:1$				
							$\geq 1:1$ - $< 1:2$				
							$\geq 1:2$ - $< 1:3$				
							$\geq 1:3$ - $< 1:4$				
							$\geq 1:4$				
5.	The ratio of the average illuminances at the workstation						$< 1:1$				
							$\geq 1:1$ - $< 1:2$				
							$\geq 1:2$ - $< 1:3$				
							$\geq 1:3$ - $< 1:4$				
							$\geq 1:4$				

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The influential effect of each performance criteria will be used for evaluating Lighting Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Lighting Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
6.	The Average Luminance of any wall to the average Illuminance in the horizontal working plane						< 2:3				
							≥ 2:3 - < 1:2				
							≥ 1:2 - < 1:10				
							≥ 1:10 - < 1:25				
							≥ 1:25				
7.	The ratio of the on the task area to the Illuminance around the task area						< 1.0 : 1.0				
							≥ 1:1 - < 1:2				
							≥ 1:2 - < 1:3				
							≥ 1:3 - < 1:10				
							≥ 1:10				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
8.	**Direction Strength Vector / Scalar Ratio**						< 1.5				
							≥ 1.5 - < 2				
							≥ 2.0 - < 2.5				
							≥ 2.5 - < 3.0				
							≥ 3.0				
9.	**Color Quality Correlated Color Temperature (CCT)**						≤ 3300 k (Warm)				
							≥ 3300 - < 5300 k (Intermediate)				
							≥ 3500 k (Cool)				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort		
									Comfort.	Reason.	Uncomfor.
10	**Color Rendering Index (Ra)**						≥20 - < 40				
							≥40 - < 60				
							≥60 - < 80				
							≥80 - < 90				
							≥90				
11	**Glare Index**						< 10				
							≥10 - < 16				
							≥16 - <22				
							≥22 - < 28				
							≥28				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
12	**The Direct Ratio of the Total Downward Flux from the Luminaries falls Directly on the Working Place**						< 0.2				
							≥ 0.2 - < 0.4				
							≥ 0.4 - < 0.6				
							≥ 0.6 - < 0.8				
							≥ 0.8				
13	**The Reflectance of the Paint of the Ceiling or any other Surface finish**						< 0.8				
							≥ 0.8				

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NO.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
14	**The Reflectance of the Paint of the Wall or Surface Finish**						< 0.5				
							≥ 0.5				
15	**The Reflectance of the of the window gloss finishing**						< 0.6				
							≥ 0.6				
16	**The Reflectance of surface of the Floor Finishing**						< 0.3				
							≥ 0.3 - < 0.6				
							≥ 0.6				

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The influential effect of each performance criteria will be used for evaluating Lighting Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Lighting Comfort of office buildings.

N O.	Performance Criteria	Influential Effect					Scales of lighting Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
17	**The Reflectance of Equipment Surfaces and Furnishing Surfaces**						< 0.2				
							≥ 0.2 - < 0.4				
							≥ 0.4 - < 0.6				
							≥ 0.6				
18	**The Reflectance of the Immediate Background**						< 0.3				
							> 0.3 - ≤ 0.5				
							> 0.5 - ≤ 0.7				
							> 0.7				

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ACOUSTIC DESIGN

The main purpose of the following questions is to determine how the influential effect of each performance criteria will be used for evaluating acoustic comfort of office workplace in open plan office buildings (managerial work). A second purpose of these questions is to determine how the scales (Quantitative and / or Qualitative) could be used for evaluating the performance criteria of the acoustic comfort of office workplace.

The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
1.	**Background Noise Level** Noise Criteria (NC Curve)						< 20 dB				
							≥ 20 - < 35 dB				
							≥ 35 - < 45 dB				
							≥ 45 - < 60 dB				
							≥ 60 dB				
2.	**Reverberation Time**						< 0.4 Sec.				
							≥ 0.4 - < 0.8 Sec.				
							≥ 0.8 - < 1.2 Sec.				
							≥ 1.2 - < 1.6 Sec.				
							≥ 1.6 Sec.				

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The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
3.	**Impact Generated Sound from Adjoining Floors** (Using NC Curve)						< 20 dB				
							≥ 20 - < 40 dB				
							≥ 40 - < 60 dB				
							≥ 60 - < 80 dB				
							≥ 80 dB				
4.	**Generated Noise from HVAC Terminals** (Using NC Curve)						≥ 20 - < 35 dB				
							≥ 35 - < 45 dB				
							≥ 45 - < 55 dB				
							≥ 55 - < 65 dB				
							≥ 65 dB				

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NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
5.	**Speech Interference Level (SIL) A. Workplace**						< 30 dB				
							≥ 30 - < 40 dB				
							≥ 40 - < 50 dB				
							≥ 45 - < 60 dB				
							≥ 60 dB				
5.	**Speech Interference Level (SIL) B. Typing**						< 40 dB				
							≥ 40 - < 50 dB				
							≥ 50 - < 60 dB				
							≥ 60 - <70 dB				
							≥ 70 dB				

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NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
6.	**Sound Transmission Class (STC)** For Walls, Partitions, Floor and Ceiling						< 20 dB				
							≥ 20 - < 35 dB				
							≥ 35 - < 45 dB				
							≥ 45 - < 60 dB				
							≥ 60 dB				
7.	**Impact Sound Insulation of Walls, Partitions, and Ceiling**						< 20 dB				
							≥ 20 - < 35 dB				
							≥ 35 - < 45 dB				
							≥ 45 - < 60 dB				
							≥ 60 dB				

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The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
8.	**Speech Privacy Noise Isolation Class (NIC')**						< 30 dB				
							≥ 30 - < 40 dB				
							≥ 40 - < 50 dB				
							≥ 50 - < 60 dB				
							≥ 60 dB				
9.	**The Difference Between Speech Sound Level and the Level of Background Noise**						< 10 dB				
							≥ 10 - < 25 dB				
							≥ 25 - < 35 dB				
							≥ 35 - < 45 dB				
							≥ 45 dB				

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The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.											
NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
10	The Time Taken Between the Initial Sound and its Reflection is Received by the Ear						< 20 milli / second				
							≥ 20 - < 40 m/s				
							≥ 40 - < 50 m/s				
							≥ 50 m/s				
11	The Total Area of Window Glazing						< 40 %				
							≥ 40 - < 60 %				
							≥ 60 - < 80 %				
							≥ 80 %				

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The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
12	**Sound Absorption of Wall Materials**						< 10 %				
							≥ 10 - < 30 %				
							≥ 30 - < 50 %				
							≥ 50 - < 70 %				
							≥ 70 %				
13	**Sound Absorption for Ceiling Materials**						< 10 %				
							≥ 10 - < 30 %				
							≥ 30 - < 50 %				
							≥ 50 - < 70 %				
							≥ 70 %				

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The influential effect of each performance criteria will be used for evaluating Acoustic Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Acoustic Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Acoustic Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort		
									Comfort.	Reason.	Uncomfor.
14	**Sound Absorption of Floor**						< 10 %				
							≥ 10 - < 30 %				
							≥ 30 - < 50 %				
							≥ 50 - < 70 %				
							≥ 70 %				

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THERMAL COMFORT

The main purpose of the following questions is to determine how the influential effect of each performance criteria will be used for evaluating thermal comfort of office workplace in open plan office buildings (managerial work). A second purpose of these questions is to determine how the scales (Quantitative and / or Qualitative) could be used for evaluating the performance criteria of the thermal comfort of office workplace.

The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
1	**Air Temperature**						< 18 C				
							$\geq 18 - < 20$ C				
	A. In Winter						$\geq 20 - < 22$ C				
							$\geq 22 - < 24$ C				
							≥ 24 C				
	Air Temperature						< 20 C				
							$\geq 20 - < 22$ C				
	B. In Summer						$\geq 22 - < 25$ C				
							$\geq 25 - < 27$ C				
							≥ 27 C				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
2	**Mean Radiant Temperature (MRT)** A. In Winter						> 24 C				
							> 22 - ≤ 24 C				
							> 20 - ≤ 22 C				
							> 18 - ≤ 20 C				
							≤ 18 C				
	Mean Radiant Temperature (MRT) In Summer						> 26 C				
							> 24 - ≤ 26 C				
							> 22 - ≤ 24 C				
							> 20 - ≤ 22 C				
							≤ 20 C				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
3.	**Relative Humidity (RH)** **A. In Winter**						< 20 %				
							≥ 20 - < 35 %				
							≥ 35 - < 50 %				
							≥ 50 - < 60 %				
							≥ 60 %				
	B. In Summer						< 30 %				
							≥ 30 - < 45 %				
							≥ 45 - < 60 %				
							≥ 60 - < 70 %				
							≥ 70 %				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
4	**Air Movement**						< 0.10 m/s				
							≥ 0.10 - < 0.13 m/s				
							≥ 0.13 - < 0.16 m/s				
	A. In Winter						≥ 0.16 - < 0.18 m/s				
							≥ 0.18 m/s				
	B. In Summer						< 0.22 m/s				
							≥ 0.22 - < 0.24 m/s				
							≥ 0.24 - < 0.26 m/s				
							≥ 0.26 - < 0.28 m/s				
							≥ 0.28 m/s				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
							Ranges		Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
5	**The Average Temperature of the Internal Surfaces**						Greater than air temperature in Winter				
							Lower than air temperature in Winter				
							Equal air temperature in Winter and Summer				
							Lower than air temperature in Summer				
							Greater than air temperature in Summer				
6.	**Temperature Shifts**						$< \pm 1$ C				
							$\geq \pm 1 - < \pm 2$ C				
							$\geq \pm 2 - < \pm 3$ C				
							$\geq \pm 3 - < \pm 4$ C				
							$\geq \pm 4$ C				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
7	**Asymmetry** (Maximum increase in the Radiant Temp. On the Head over the Main Radiant Temp.						0.0 - <1 C				
							≥ 1 - <1 C				
							≥ 2 - < 3 C				
							≥ 3 - < 4 C				
							≥ 4 C				
8	**Floor Temperature**						<25 C				
							≥ 25 - <27 C				
							≥ 27 - < 29 C				
							≥ 29 - < 31 C				
							≥ 31 C				

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NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
9	**Asymmetry Air Temperature Differences Between Head and Feet**						0.0 - < 1 C				
							≥ 1 - < 1 C				
							≥ 2 - < 3 C				
							≥ 3 - < 4 C				
							≥ 4 C				
10	**Heat Recovery From Light**						< 1 w/ ft^2				
							≥ 1 - < 2 w/ ft^2				
							≥ 2 - < 3 w/ ft^2				
							≥ 3 - < 4 w/ ft^2				
							≥4 w/ ft^2				

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The influential effect of each performance criteria will be used for evaluating Thermal Comfort of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Thermal Comfort of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Thermal Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
11	**Frequency of Shifts**						< 45 / Hour				
							≥ 45 - < 55 / Hour				
							≥ 55 - < 65 / Hour				
							≥ 65 - < 75 / Hour				
							≥ 75 / Hour				

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INDOOR AIR QUALITY

The main purpose of the following questions is to determine how the influential effect of each performance criteria will be used for evaluating indoor air quality comfort of office workplace in open plan office buildings (managerial work). A second purpose of these Questions is to determine how the scales (Quantitative and / or Qualitative) could be used for evaluating the performance criteria of the indoor air quality comfort of office workplace.

The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
1.	**Air Exchange Rate** (Fresh Air Make up) CFM is Cubic Feet / Minute						< 5 CFM				
							≥ 5 - < 15 CFM				
							≥ 15 - < 25 CFM				
							≥ 25 - < 35 CFM				
							≥ 35 CFM				
2.	**Fresh Air Rate** (Air Changed per hour)						< 2 / Hour				
							≥ 2 - < 4 / Hour				
							≥ 4 - < 6 / Hour				
							≥ 6 - < 8 / Hour				
							≥ 8 / Hour				

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort		
									Comfort.	Reason.	Uncomfor.
3.	**Air Filtration Efficiency** (Degree of Tightness)						< 30 %				
							≥ 30 - < 50 %				
							≥ 50 - < 70 %				
							≥ 70 - < 90 %				
							≥ 90 %				
4.	**Air Mixing Efficiency**						< 30 %				
							≥ 30 - < 50 %				
							≥ 50 - < 70 %				
							≥ 70 - < 90 %				
							≥ 90 %				

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
5.	**Air Diffusion (Air Velocity)** A. In Winter						< 0.10 m/s				
							$\geq 0.10 - < 0.13$ m/s				
							$\geq 0.13 - < 0.16$ m/s				
							$\geq 0.16 - < 0.18$ m/s				
							≥ 0.18 m/s				
	B. In Summer						< 0.22 m/s				
							$\geq 0.22 - < 0.24$ m/s				
							$\geq 0.24 - < 0.26$ m/s				
							$\geq 0.26 - < 0.28$ m/s				
							≥ 0.28 m/s				

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation			
							Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I		Comfort.	Reason.	Uncomfor.
6.	**Odors**									
A	**(Smoking Areas)**						Smoking area is separated and well Sealed			
							Smoking area is Somewhat separated and Sealed			
							Smoking area is not separated			
B	**(Bathrooms)**						Bathrooms are well ventilated and taped			
							Bathrooms are Somewhat ventilated and taped			
							Bathrooms are not well ventilated and taped			
C	**(Cooking Areas)**						Cooking Areas are well ventilated and taped			
							Cooking Areas are Somewhat ventilated and taped			
							Cooking Areas are not well ventilated and taped			

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
		E.I	M.I	I	S.I	N.I	Ranges	Other Ranges	Scales of Comfort: Comfort.	Reason.	Uncomfor.
7.	**Indoor Air Pollutants**						< 5 PPM				
							≥ 5 - < 10 PPM				
							≥ 10 - < 20 PPM				
A.	**Carbon Monoxide (CO)**						≥ 20 - < 30 PPM				
							≥ 30 PPM				
B.	**Carbon Dioxide CO_2**						< 400 PPM				
							≥ 400 - < 500 PPM				
							≥ 500 - < 600 PPM				
							≥ 600 - < 700 PPM				
	PPM is Part Per Million						≥ 700 PPM				

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
7	**Indoor Air Pollutants**						< 20 %				
C.	**Nitrogen Dioxide NO_2**						≥ 20 % - < 25 %				
							≥ 25 % - < 30 %				
							≥ 30 % - < 35 %				
							≥ 35 %				
D.	**Sulfur Dioxide SO_2**						< 0.5 PPM				
							≥ 0.5 - < 0.7 PPM				
							≥ 0.7 - < 0.9 PPM				
							≥ 0.9 - < 1.1 PPM				
							≥ 1.1 PPM				

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The influential effect of each performance criteria will be used for evaluating Indoor Air Quality of office buildings and the scales (subjective and objective) could be used for evaluating the performance criteria of Indoor Air Quality of office buildings.

NO.	Performance Criteria	Influential Effect					Scales of Indoor Air Quality Comfort Evaluation				
							Ranges	Other Ranges	Scales of Comfort		
		E.I	M.I	I	S.I	N.I			Comfort.	Reason.	Uncomfor.
E.	**Formaldehyde**						< 2 PPM				
							≥ 2 - < 4 PPM				
							≥ 4 - < 6 PPM				
							≥ 6 - < 9 PPM				
							≥ 9 PPM				
F.	**Ozone (O_3)**						< 0.2 PPM				
							≥ 0.3 - < 0.4 PPM				
							≥ 0.4 - < 0.5 PPM				
							≥ 0.5 - < 0.6 PPM				
							≥ 0.6 PPM				

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28 April 94 SPSS for MS WINDOWS Release 5.0

Number of valid observations (listwise) = 18.00

Variable	Mean	Std Dev	Minimum	Maximum	N	Label
STORAGE	3.04	1.43	.50	5.00	18	
PARKING AREAS	3.55	1.78	1.00	6.00	18	
GENERAL SERVICES	4.57	2.25	1.00	10.00	18	
REST AREAS	5.68	2.54	1.50	10.00	18	
CORE SYSTEM	5.93	2.78	1.50	10.00	18	
CIRCULATION	6.23	2.12	2.50	10.00	18	
SPECIAL FACILITIES	7.39	2.68	1.50	10.00	18	
RECEPTION AREAS	7.55	1.82	2.80	10.00	18	
MEETING AREAS	7.85	2.42	2.80	10.00	18	
WORKPLACE	9.58	.86	6.60	10.00	18	

Number of valid observations (listwise) = 18.00

Variable STORAGE

Mean	3.044	Std Dev	1.431
Kurtosis	-.946	S.E. Kurt	1.038
Skewness	-.068	S.E. Skew	.536
Range	4.500	Minimum	.50
Maximum	5.00		

Valid observations - 18 Missing observations - 0

- -

Variable PARKING AREAS

Mean	3.550	Std Dev	1.779
Kurtosis	-1.301	S.E. Kurt	1.038
Skewness	.130	S.E. Skew	.536
Range	5.000	Minimum	1.00
Maximum	6.00		

Valid observations - 18 Missing observations - 0

- -

Variable GENERAL SERVIVES

Mean	4.572	Std Dev	2.254
Kurtosis	.497	S.E. Kurt	1.038
Skewness	.592	S.E. Skew	.536
Range	9.000	Minimum	1.00
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Variable REST AREAS

Mean	5.683	Std Dev	2.544
Kurtosis	-1.077	S.E. Kurt	1.038
Skewness	-.043	S.E. Skew	.536
Range	8.500	Minimum	1.50
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Number of valid observations (listwise) = 18.00

Variable CORE SYSTEM

Mean	5.933	Std Dev	2.776
Kurtosis	-1.290	S.E. Kurt	1.038
Skewness	-.227	S.E. Skew	.536
Range	8.500	Minimum	1.50
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Variable CIRCULATION AREAS

Mean	6.228	Std Dev	2.116
Kurtosis	-.464	S.E. Kurt	1.038
Skewness	-.101	S.E. Skew	.536
Range	7.500	Minimum	2.50
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Variable SPECIAL FACILITIES

Mean	7.389	Std Dev	2.676
Kurtosis	-.490	S.E. Kurt	1.038
Skewness	-.711	S.E. Skew	.536
Range	8.500	Minimum	1.50
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Variable RECEPTION AREAS

Mean	7.550	Std Dev	1.825
Kurtosis	1.174	S.E. Kurt	1.038
Skewness	-.838	S.E. Skew	.536
Range	7.200	Minimum	2.80
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Number of valid observations (listwise) = 18.00

Variable MEETING AREAS

Mean	7.850	Std Dev	2.424
Kurtosis	-.128	S.E. Kurt	1.038
Skewness	-.981	S.E. Skew	.536
Range	7.200	Minimum	2.80
Maximum	10.00		

Valid observations - 18 Missing observations - 0

- -

Variable OFFICE WORKPLACE

Mean	9.583	Std Dev	.856
Kurtosis	8.908	S.E. Kurt	1.038
Skewness	-2.794	S.E. Skew	.536
Range	3.400	Minimum	6.60
Maximum	10.00		

Valid observations - 18 Missing observations - 0

Number of valid observations (listwise) = 16.00

Variable	Mean	Std Dev	Minimum	Maximum	Valid N	Label
ACOUSTIC	5.26	3.53	1.40	10.00	16	
THERMAL	6.35	3.32	1.60	10.00	16	
INDOOR AIR QUALITY	6.61	3.62	1.00	10.00	16	
LIGHTING	9.56	1.31	5.00	10.00	16	

Number of valid observations (listwise) = 16.00

Variable ACOUSTIC

Mean	5.256	Std Dev	3.527
Kurtosis	-1.705	S.E. Kurt	1.091
Skewness	.280	S.E. Skew	.564
Range	8.600	Minimum	1.40
Maximum	10.00		

Valid observations - 16 Missing observations - 0

- -

Variable THERMAL

Mean	6.350	Std Dev	3.316
Kurtosis	-1.878	S.E. Kurt	1.091
Skewness	-.009	S.E. Skew	.564
Range	8.400	Minimum	1.60
Maximum	10.00		

Valid observations - 16 Missing observations - 0

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Variable INDOOR AIR QUALITY

Mean	6.612	Std Dev	3.618
Kurtosis	-1.698	S.E. Kurt	1.091
Skewness	-.399	S.E. Skew	.564
Range	9.000	Minimum	1.00
Maximum	10.00		

Valid observations - 16 Missing observations - 0

- -

Variable LIGHTING

Mean	9.563	Std Dev	1.315
Kurtosis	10.946	S.E. Kurt	1.091
Skewness	-3.271	S.E. Skew	.564
Range	5.000	Minimum	5.00
Maximum	10.00		

Valid observations - 16 Missing observations - 0

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	receptio	workplac	core	meeting	rest	circulat	special
1	9.00	9.00	7.00	9.00	9.00	7.00	10.00
2	8.00	10.00	4.00	7.00	4.00	7.00	6.00
3	8.00	9.00	4.00	10.00	6.00	5.00	7.00
4	9.50	9.90	7.50	9.50	7.00	6.50	9.50
5	2.80	10.00	1.50	2.80	1.50	2.80	1.50
6	6.60	6.60	3.30	10.00	8.30	3.30	10.00
7	6.00	10.00	1.50	7.00	2.50	2.50	8.00
8	7.00	10.00	5.00	8.00	6.00	5.00	9.00
9	9.00	10.00	10.00	10.00	8.00	6.00	10.00
10	10.00	10.00	8.00	10.00	8.00	8.00	10.00
11	9.00	10.00	8.00	10.00	8.00	9.00	10.00
12	6.00	10.00	8.00	5.00	5.00	8.00	4.00
13	8.00	10.00	3.00	9.00	4.00	6.00	7.00
14	6.00	9.00	7.00	6.00	5.00	10.00	7.00
15	7.00	10.00	8.00	3.00	2.00	9.00	4.00
16	8.00	10.00	8.00	6.00	3.00	6.00	4.00
17	10.00	10.00	10.00	10.00	10.00	6.00	6.00
18	6.00	9.00	3.00	9.00	5.00	5.00	10.00

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	general	storage	parking
1	3.00	5.00	1.00
2	6.00	3.00	3.00
3	3.00	2.00	1.00
4	2.20	1.50	3.00
5	1.50	1.50	2.80
6	6.60	3.30	1.60
7	1.00	.50	1.50
8	4.00	4.00	4.00
9	10.00	5.00	5.00
10	7.00	5.00	2.00
11	6.00	2.00	5.00
12	4.00	3.00	3.00
13	5.00	3.00	6.00
14	7.00	5.00	6.00
15	5.00	1.00	6.00
16	4.00	3.00	6.00
17	4.00	4.00	4.00
18	3.00	3.00	3.00

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	lighting	acoustic	thermal	indoor
1	10.00	1.60	3.30	8.30
2	10.00	1.60	6.60	1.60
3	10.00	1.40	2.90	7.10
4	8.00	2.00	8.00	10.00
5	10.00	8.00	10.00	4.00
6	5.00	1.70	3.40	10.00
7	10.00	2.50	2.50	2.50
8	10.00	2.00	4.00	10.00
9	10.00	6.60	3.30	1.00
10	10.00	4.00	10.00	2.00
11	10.00	6.70	1.60	3.30
12	10.00	10.00	10.00	10.00
13	10.00	10.00	10.00	10.00
14	10.00	10.00	10.00	10.00
15	10.00	6.00	6.00	6.00
16	10.00	10.00	10.00	10.00

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VITA

Rabee Mohamed Reffat Ahmed was born in Egypt, on June 21, 1967. He has acquired the degree of B.Sc. in Architectural Engineering with Honors from Assuit University in May 1989. Upon his graduation, he was selected to be an Assistant Lecturer at Assuit University.

Mr. Reffat was trained at Al- Haram Training Institution (The Arab Contractors, Osman Ahmed Osman) for three years while being undergraduate. He has pursued also his career as an Architect in the Egyptian Consultant Group (ECG) as a part time Architect from July 1989 to October 1992. Mr. Reffat was registered as a Master Student at Assuit University 1n 1990 in the Architectural Engineering Department and completed the course work with a general grade (89%). Then, he has awarded an Assistantship at KFUPM in October 1992 as a Master Student and. He has completed all the requirements for his M.Sc. at KFUPM where his GPA is 3.84 out of 4.0 (96%).

Mr. Reffat's work has been published in the World Conferences such as "The 22nd IHAS", Austria, October 1994, "Environments for Tourism", Nevada, USA, October 1994 and "PPD", Newcastle upon Tyne, UK, Dec. 1994. Mr. Reffat has acquired several milestones during his studying and working career. He participated in many short courses both at Assuit and KFUPM University and has the certificate of the English Language Center at KFUPM.

Mr. Reffat is a member of the Egyptian Syndicate of Engineers and the Egyptian Society of Architects.