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Development of a Knowledge Base Used by an Expert System to Assess the Air Quality in High-Rise Buildings

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Centre d'études pour l'industrialisation de la construction

FINAL REPORT

Development of a knowledge base used by an expert system to assess the air quality in high-rise buildings

by

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Disclaimer

This study was conducted by the Centre d'études pour l'industrialisation de la construction (CEPIC) for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretation and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part IX of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

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1. INTRODUCTION

The problem of poor air quality in buildings has developed relatively recently due to, in a large extent the improved insulation and increased sealing of buildings for conservation of energy. This situation has produced problems concerning humidity, temperature, pollutants, air exchange and odors which describe the overall air quality of a building. A greater emphasis has therefore been placed on proper air quality and has lead to the need for this research project.

Differences among industrial, commercial and residential buildings are too great to permit a generalization of the problems encountered in indoor air quality and the possible corresponding solutions. Residential highrise buildings have been singled out for this research project for various reasons. Many residential buildings have been renovated to provide increased insulation, however, the associated air quality improvements have not been considered and as such many problems have recently developed for which the building manager is not capable of solving. Also, the standards and codes associated with residential buildings are more similar in nature than those of industrial or commercial buildings, which normally require greater specialization. An expert system as the one proposed here, will provide the user with an aid to solve such problems.

The principal elements if this research project are as follows:

- an aid for the identification of possible problems in indoor air quality
- a means to identify the source of the problems, i.e. an expert system
- an aid to define the nature and severity of the air quality problem
- produce a set of solutions associated with the air quality problems in highrise residential buildings

The knowledge base data for indoor air quality was gathered primarily from the following pieces of literature provided by the Canada Mortgage and Housing Corporation :

- Indoor Air Quality Test Protocol For Highrise Residential Buildings. Buchan, Lawton, Parent Ltd. Ottawa, Ontario. April 1990.
- Field Investigation Survey of Air Tightness, Air Movement and Indoor Air Quality in B.C. Highrise Apartment Buildings. Avalon Mechanical Consultants Ltd. Victoria, British Columbia. July 1991.
- Enquete sur le terrain portant sur l'etancheite a l'air, le mouvement de l'air et la qualite de l'air interieur des tours d'habitation au Quebec. CMA Chalifour, Marcotte & Ass. Inc. Quebec. septembre 1991

- Field Investigation Survey of Air Tightness, Air Movement and Indoor Air Quality in Highrise Apartment Buildings Prairie Region. Wardrop Engineering Inc. Winnipeg, Manitoba. November 1991.

- Field Investigation Survey of Air Tightness, Air Movement and Indoor Air Quality in Highrise Apartment Buildings Atlantic Region. BFL Consultants Limited. St.John's, Newfoundland. April 1991.

Texts on this subject were also consulted for information.

This report presents the results of the research and the **EXPAIR** expert system developed for indoor air quality problems in highrise residential buildings. This work was accomplished at École de technologie supérieure de l'Université du Québec with a grant from Canada Mortgage and Housing Corporation. The team from l'ÉTS was represented by Professor Edmond T. Miresco, Hugo Windish and Jacqueline Gruia-Gray as research assistant.

In recognition of the fact that this work was undertaken in a relatively short period of time and within limited funds, we feel that the **EXPAIR** system is indicative of an independent expert system with a knowledge base of indoor air quality. However, it is possible that the information gathered could be elaborated by an expert in indoor air quality.

We are confident that you will find this report and the **EXPAIR** expert system to your satisfaction and a solution to the predicament presented to us. We look forward to your remarks and those of the experts verifying the program and its knowledge base.

2. INDOOR AIR QUALITY ELEMENTS

2.1 General Building Information

The major groups of information associated with indoor air quality are presented in the following table:

INFORMATION	PURPOSE
Year of construction	To present the user with choices relating to heating, ventilation, etc. relevant to year of construction
Year of renovation	If renovation occurred, to present above applicable to year of renovation
Availability of building information	For possible solutions
Heating Information	Possible combustion products
Ventilation information	Mechanical systems, possible pollutants, air exchange problems, etc.
Humidifiers	Pollutants, odors, temperature, humidity problem
Basement / Holes	Possible radon problems, fungus, etc.
Building equipment	Possible problems areas

2.2 Problems related to the indoor air quality

The major problems groups associated with indoor air quality are:

- POLLUTANTS
- AIR EXCHANGE
- BUILDING TIGHTNESS
- TEMPERATURE
- HUMIDITY
- OUTDOOR CONCENTRATION
- ODORS

These problems are described through a selection of symptoms and physical findings which are presented bellow.

2.3 List of symptoms

This a list of the symptoms which may affect the air quality in the buildings:

- Temperature
    - Too hot
    - Too cold
- Humidity
    - Too dry
    - Too humid
- Odors
- Human symptoms
    - Difficulty breathing
    - Irritated respiratory passage
    - Coughing
    - Sneezing

- Irritations to eyes, nose or throat
- Headaches
- Fatigue
- Nausea
- Skin rashes
- Faintness
- Blurred vision
- Watery eyes

2.4 List of physical findings

This a list of the physical findings which may be involved in affecting the air quality in the buildings:

- Organic
    - Mould
    - Fungi or fungal growth
    - Bacteria
- Diffusers
    - Dirt around them
    - Chalky deposits around them
- Damp spots
- Renovations
    - New furnishing
    - New carpeting
    - Painting
- Use of insecticides
- Building maintenance
    - New equipment
- Flooding
- Drafts

- Seasons
- Occupants activities

2.5 Locations affected by air quality

An important factor in assessing the air quality in the building is the location of the problem. In residential highrise buildings two groups are identified:

- Building common areas
- Individual units

2.6 Building common areas

- Garage
    - Outdoor
    - Indoor
        - Ventilated
        - Non ventilated
- Corridors
- Entrance
- Pool, sauna and gymnasium
    - Roof top
    - Basement
- Elevators
- Garbage room
- Laundry room
    - Each floor
    - Basement
- Building basement

- Stairs

2.7 Individual units

- Floors
- Segments of buildings
- Common areas nearby

3. EXPERT SYSTEM CHARACTERISTICS

The main flow diagram of information for assessing the air quality in building is shown below:

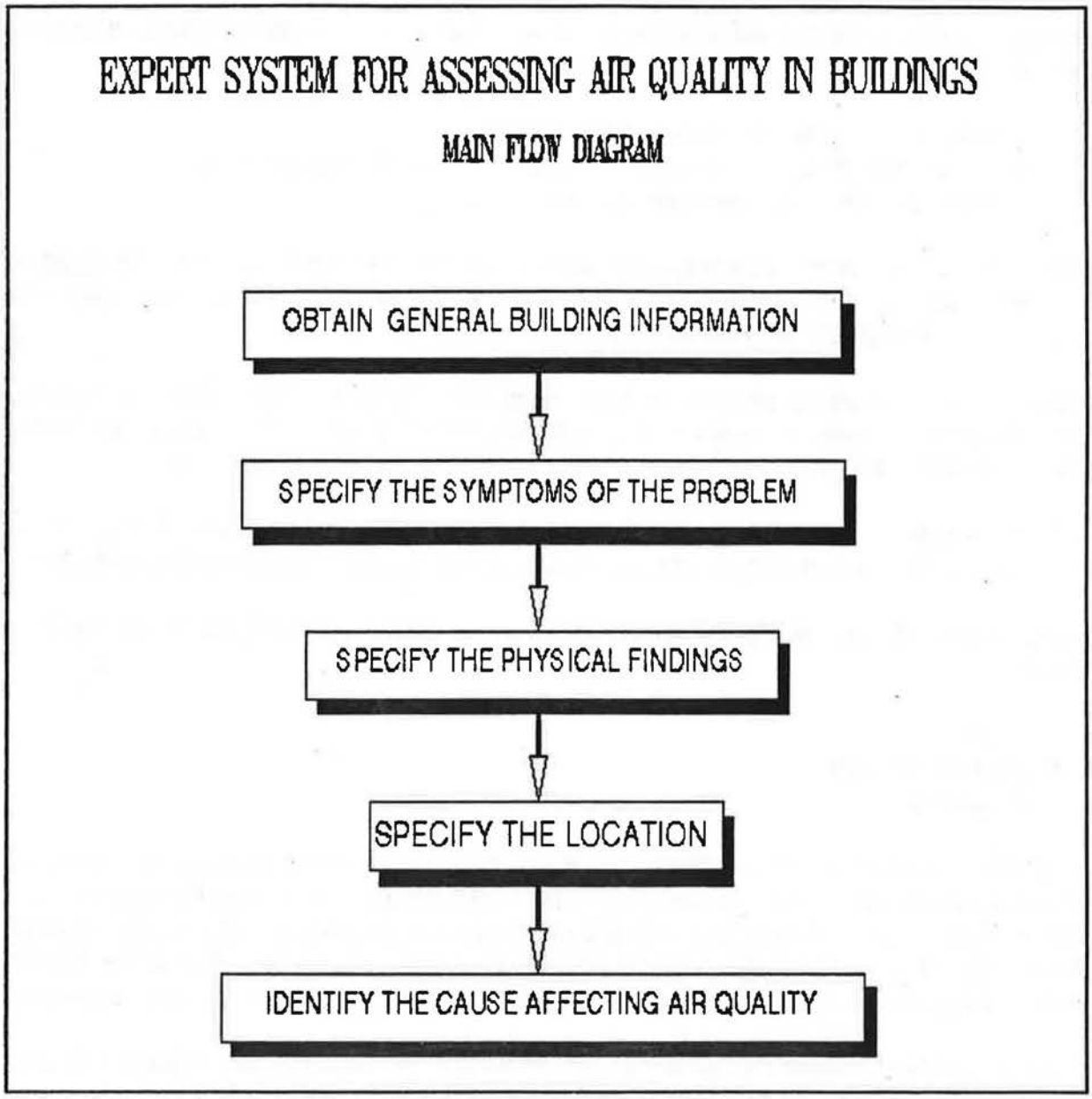


Figure 1

3.1 The principal elements of the knowledge base

The knowledge required for indoor air quality in highrise residential buildings is a highly diversified information. The knowledge base of the system contains the information in blocks of sequences. The order of these blocks follows some preestablished rules. The combination of these rules represents the reasoning of our expert system.

The most elementary level of information in our knowledge base is called a "graphical object". These graphical objects are:

- **a node**, which represents an action to be done,
- **an arrow**, which represents a relation between two nodes (actions) and
- **a decision node**, which generates the rules.

The graphical objects in the knowledge base are organized so they can be easily manipulated by the inference engine. Like any other knowledge base, ours contains an ensemble of rules, each rule having its own graphical representation.

In addition to the graphical objects, the knowledge base contains different kind of elements, called "attributes". These attributes help to represent the information on the computer screen, group some blocks and provide additional information about each particular node.

All the knowledge is entered in graphical mode and stored so it can be retrieved in graphical mode as well. The user that inputs the knowledge, will make use of these graphical objects.

In order to asses the air quality in highrise building, the user must supply the following three elements:

- locations
- physical findings
- symptoms

The location is the place in the residential highrise building where, or close to where, the problem is located. In certain situations this location will provide a more specific solution to the problem. For example: if there is mould and damp spots in the pool area the solution may be different than if these problems were located in the mechanical room. Below we list the locations in highrise residential buildings which will be concentrated on for this knowledge base.

The elements which indicate that an indoor air quality problem exists are described by physical findings and symptoms. A physical finding is discernible by touch, sight or smell where as a symptom is usually an uncomfortable feeling described by tenants. Both are most often established from complaints by the tenants. The table below lists the physical findings and symptoms associated with the problems of indoor air quality. These form the elements of the knowledge base for the **EXPAIR** expert system.

TABLE 1

LOCATIONS	PHYSICAL FINDINGS	SYMPTOMS
POOL	STALE AIR	DRY EYES
GARAGE	FUNGUS	DRY NOSE
GARBAGE ROOM	SLIME	DRY THROAT
MECHANICAL RM.	MOULD	COUGHING
LAUNDRY ROOM	FLOODING	SNEEZING
INDIVIDUAL UNITS	DAMP SPOTS	RESPIRATORY ALLERGIES
	PUDDLES	ALLERGIES DURING POLLEN SEASON
	STUFFINESS	RESPIRATORY PROBLEMS
	DRAFTS	EYES,NOSE,THROAT IRRITATION
	HOT/COLD SPOTS	HEADACHES
	ODOR	FATIGUE
	DIRT AROUND DIFFUSERS	NAUSEA
	CHALKY DEPOSITS AROUND DIFFUSERS	SKIN RASHES
	NEW FURNISHINGS	HEART PALPITATION
	CONSTRUCTION / RENOVATION	CHEST PAINS
	CLEANING FLUIDS STORED	FAINTNESS
	CLEANING OF CARPETS	WATERY EYES
	NEW PAINT	BLURRED VISION
	NEW BUILDING PRODUCTS	

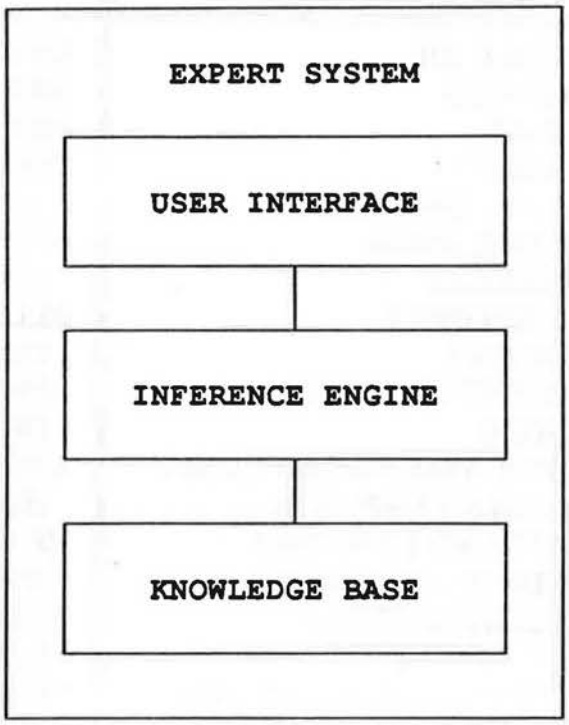
Certain special information also represented by the knowledge base are existing equipment in the building and pollutant testing. These elements are described in detail in the next section.

To further improve the accuracy and detail of the solutions provided for the indoor air quality problems, information concerning the equipment associated with indoor air quality is also required. The knowledge base includes details concerning this type of equipment.

Certain problems can be further specified through the application of certain simple tests. The knowledge base also supports the possibility to apply these tests for proper solutions.

The expert system for indoor air quality has been appropriately named **EXPAIR**. It serves as an aid to the user for the identification and resolution of indoor air quality problems in highrise residential buildings.

The expert system implements a simple and visual approach that corresponds to the needs of the user perfectly. **EXPAIR** integrates all the components of an expert system with the ability to produce a hard copy report. Its structure is:



3.2 The principal characteristics of EXPAIR

The principal characteristics of the **EXPAIR** expert system are as follow:

- The expert system is programmed in C++ language which functions on the MS-DOS operation system.
- The inference engine is adapted from recognized elements and standards in the domain of artificial intelligence, in such a way as to permit the manipulation of rules according to the available documentation and experiences with respect to indoor air quality in residential highrise buildings.
- The knowledge base of the expert system was developed from studies performed for the Canada Mortgage and Housing Corporation on indoor air quality in highrise residential buildings throughout Canada along with available literature on the subject. Usual problems associated with indoor air quality problems were cited and practical solutions were provided.

- The **EXPAIR** system is divided into three sections where information must be entered, with subsections included in certain circumstances.

- The knowledge base may be updated or modified as new information or data presents itself due to the versatility of the inference engine of the expert system.

- The expert system is able to save particular information in separate files for access at a later date. This may be necessary should the user desire to perform a test suggested by the system or try a solution rendered by the expert system.

- The communication interface between the user and the expert system operates in a manner that is simple and analogous to what is considered standard. The user must merely point to and select items from the messages or questions provided in the form of windows with the use of a mouse. One click selects the item and a double click processes the selection.

- The performance and ergonomy of the expert system regards the needs of the user. In addition, the system is developed in a manner to allow users not familiar with computers to apply it to their problems without any complications.

3.3 The main components of EXPAIR

The main components of the knowledge base of **EXPAIR** expert system are:

- NETWORKS
- VARIABLES
- DIALOGS

3.3.1 Networks

NETWORKS represent certain elements of the knowledge base expressed by NODES and logical links that form paths. The NETWORKS use the VARIABLES and DIALOGS as components in the COMMANDS of the NODES. The description and the function of each NETWORK is presented in the **EXPAIR** user manual.

Nodes and paths are triggered by the inference engine according to their position (which was selected by the developer of the knowledge base). Should the user select a VARIABLE in one of the DIALOG screens, the value of the variable will change from **0** to **1** and be transmitted to the inference engine. The path to be followed in a NETWORK will be dictated by the logic imposed by the user.

The inference engine translates the logic as follows. A network must have a MAIN network. The logic in the network must start with a START node. The inference engine traverses the network from left to right following the arrows. When a fork in encounted, the "higher" path which was not visited is followed. In other words, the first path from a fork is followed. If a solution is found, the results are displayed. If not, it will go until the end of this path, it will return to the fork and will follow the second (the "lower") path and so on. The logic must be structured in such a way, that eventually a solution will be found, since the inference engine will follow all the paths and will not stop if there is no solution.

Each node encountered has a particular function. There are three types of nodes, and each node has options and commands. If there is a command associated with a node, the inference engine will execute this command. A command could be such as *Print a message*, *Display a Dialog*, *Perform a logic test*, etc.

3.3.2. The Nodes

A network has three types of nodes (START, SOLUTION and NORMAL). Each node has attributes and commands. Even though when defining a node, the node window will feature all the choices, only some attributes or commands are allowed for each type of node. The node are:

START — It marks the beginning of a network. Every new network must have a START node. The attributes will not affect this node and the command, if present, will be ignored.

SOLUTION — It mark a point in the logic where a solution is found. The command of this node is executed and if the result is not null (usually when the value is **1**), the execution stops. If the result is null, the execution continues until another solution node is encountered.

NORMAL — Defines the nodes following the start node. This node may use an attribute and a command The command is always required.

3.3.3 The Attributes of nodes

The ATTRIBUTES of the nodes and their functions are:

IF — It is used to select between two paths (two possibilities of logic). The command associated with this node is evaluated. If the results of the command is TRUE (value **1**), the nodes following this node will be executed. If the result is FALSE (value **0**) the path which has an arrow of type ELSE will be executed. (The notion of ELSE arrow will be explained below).

PAUSE This type of node creates a pause in the expert system and offers the user a choice. When the execution is "paused", the user can click the button **Next** to continue or **Previous** to go back to the last node encounted with the attribute **MARK**. This attribute is usually used to allow the user the time to read a message.

MARK This attribute "marks" a return point accessible when the **Previous** button was used. This stops the backward direction of the flow. All the nodes which were visited between the **Previous** button and the **Mark** will be revisited again, like a loop.

BRN This attribute marks the beginning of a loop. (not required by this knowledge-base).

TRN This attribute marks the end of a loop. (not required by this knowledge-base).

3.3.4 The COMMANDS of the nodes

The COMMAND of the nodes defines the 'rule' being followed by the expert system when the user triggers the path on which the node is located.

The commands are followed by sentences, words or variables which define the knowledge base of the expert system.

Each COMMAND line is limited to a maximum space of 48 characters. It is therefore common for the command to be continued in another node linked to it. The following COMMANDS define what is to be done with the sentence, words or variables which follow it.

The COMMANDS are:

OR is commonly succeeded by one or more variables. This type of COMMAND is commonly used with an IF attribute. If one or more of the variables stated in this node are triggered by the user, the path succeeding this node will be followed. If one variable is TRUE, the result of the command is TRUE.

AND is commonly succeeded by one or more variables. This type of COMMAND is commonly used with an IF attribute. If one or more of the variables stated in this node are triggered by the user, the path succeeding this node will be followed. If all variables are TRUE, the result of the command is TRUE.

EQ This type of COMMAND is commonly used with an IF attribute. If the value of two variables triggered by the user are EQUAL, (result TRUE) the path succeeding this node will be followed.

NE This type of COMMAND is commonly used with an IF attribute. If the value of two variables triggered by the user are NOT EQUAL (result TRUE), the path succeeding this node will be followed.

GE This type of COMMAND is commonly used with an IF attribute. If the value of a variable triggered by the user is GREATER than or EQUAL to the other variable (result TRUE), the path succeeding this node will be followed.

GT This type of COMMAND is commonly used with an IF attribute. If the value of a variable triggered by the user is GREATER than the other variable (result TRUE), the path succeeding this node will be followed.

LE This type of COMMAND is commonly used with an IF attribute. If the value of a variable triggered by the user is LESS than or EQUAL to the other variable (result TRUE), the path succeeding this node will be followed.

LT This type of COMMAND is commonly used with an IF attribute. If the value of a variable triggered by the user is LESS than the other variable (result TRUE), the path succeeding this node will be followed.

CALL This type of COMMAND will execute another NETWORK name as a command. The nodes and paths associated with the network will then be followed by the expert system. This node is triggered by being on a path that is being followed.

DIALOG This type of COMMAND will be used with a DIALOG name. The screen associated with the DIALOG will appear in the expert system when the path containing this node is triggered.

MESSAGE This type of COMMAND will displays the characters associated with this command on the screen and on the file.

SMESSAGE This type of COMMAND will displays only on the screen the characters associated with this command.

PMESSAGE This type of COMMAND will displays the characters associated with this command only on the file.

3.3.5 The arrows

The arrows indicate the normal flow of logic by connecting the nodes. Even though the logic could be represented with only one type of arrow, there are cases when the inference engine must be instructed to follow a path issued from a logical test. For instance, the result of a node with **IF** attribute could be TRUE or FALSE. If the connection of these two paths is only made with

a normal arrow, it will be impossible to distinguish which is the TRUE path and which is the FALSE one.

To avoid this problem, the TRUE path is connected by a normal arrow, while a FALSE path must be connected by an **ELSE** arrow.

3.3.6 The variables

Variables are symbolic codes assigned to the information of the knowledge base. These codes are assigned by the programmer and when used, they should be similar to the actual word being coded. The list of variables is presented in the **EXPAIR** manual.

Each variable is given a value based on the binary system. As such, a value of **0** is normally the default value of the variable. If the variable is selected by the user, the value of the variable will change to **1**. This is the main way by which the selection is acknowledge by the inference engine.

3.3.7 The DIALOGS

The dialogs are windows in which all information input required by the system are presented. The user can define any dialog.

In the case of **EXPAIR**, the existing dialogs are designed for:

- LOCATIONS,
- PHYSICAL FINDINGS,
- SYMPTOMS,
- EQUIPMENT
- MEASURED FINDINGS (tests).

The description of each DIALOG is found in **EXPAIR** manual.

The information provided in each line of the DIALOG screen are defined by the following three types of fields which are provided in the input screen:

LABEL: Permits the text which is introduced in the space below to be seen in the DIALOG screen as comments or messages only.

BOOLEAN: Permits the text which is introduced in the space below to be seen in the DIALOG screen as a selection for the user with [ ] in front of it. The value (0 or 1) will be transmitted to inference engine as a selection changing the value of the variables involved.

NUMBER: Accepts a numerical value to be assigned to a variable.

As well, the DIALOG has three specific attributes for each field. These are described below.

TEXT: Provides the space to describe the LABEL, BOOLEAN or NUMBER chosen above.

VARIABLE: Provides the name of the variables (identification) that is required to be triggered by this selection.

WIDTH: Allows the user to vary the number of characters available on the line. This also matches the width of the shaded areas in the text of the BOOLEAN and NUMBER types.

3.4 The solutions provided

The solutions to the indoor air quality problems are provided to the user on four levels which will appear depending on the information provided by the user. The accuracy of the location, physical findings and symptoms provided by the user will dictate the level of the solution.

Level 1:

This is a detailed solution particular to a location, physical findings and symptoms. The evidence of this type of solution is found at the top of the SOLUTION SCREEN where the particular location is stated followed by its associated specific solutions.

ex: Location: Pool
*** Solution ***

Level 2:

This is a general solution particular to a location, physical findings and symptoms. The evidence of this type of solution is found at the top of the SOLUTION SCREEN where the particular location is stated followed by its associated general solutions.

ex: Location: Pool
*** General Solution ***

Level 3:

This is a detailed solution non specific to a location, associated with particular physical findings and symptoms. The evidence of this type of solution is found at the top of the SOLUTION SCREEN where the location is stated as ANY LOCATION followed by its

associated specific solutions.

ex: Location: Any Location
*** Solution ***

Level 4:

This is a general solution non specific to a location, associated with particular physical findings and symptoms. The evidence of this type of solution is found at the top of the SOLUTION SCREEN where the location is stated as ANY LOCATION followed by its associated general solutions.

ex: Location: Any Location
*** General Solution ***

If the user has specified the location of a problem for which the problem is non specific to the location, the Level 2 solution will appear for the stated location followed by the Level 3 and Level 4 solutions. It should be noted that the Level 4 solution is often similar to the Level 2 solution. Also, the user must indicate a location even if the exact location is unknown.

3.5 Special windows feature

To further improve the accuracy and detail of the solutions provided by the expert system, information concerning the existing equipment related to indoor air quality is required. An 'equipment window' will appear during the input of information, asking the user if certain equipment exists in the building. Again, the user simply must click with the mouse on the correct answer. This information is then used in the inference engine to provide solutions related to possible problems with existing equipment or the necessity for the installation of non existing equipment for proper indoor air quality. This feature is not present as yet throughout the **EXPAIR** expert system.

Certain problems can further be identified through the application of simple tests. Since the user of an expert system does not require to be an expert, only simple tests that can be easily performed by the user are suggested. The specific tests used and their applications are described in the following table.

POLLUTANT	TEST	SPECIFICATIONS
FORMALDEHYDE	PFI Passive Dosimeter 7 day sampler	Place sampler at complaint areas or at pollutant source, when fresh air rate is low. Requires analysis from professional lab.
CARBON DIOXIDE	GASTEC or DRAGER DETECTOR TUBE/HAND PUMP	Place tube at pollutant source, when heavily occupied,fresh air rate is low, or when combustion products can be produced.
CARBON MONOXIDE	GASTEC or DRAGER DETECTOR TUBE/HAND PUMP	Place tube at pollutant source, complaint area,stairwells linked to source, elevators linked to source, or exhausts when fresh air rate is low or when combustion products can be produced.

It should be noted that due to the flexibility of the **EXPAIR** inference engine, other tests can be included should the proper equipment be possessed by the user.

This is another point at which the user could justify employing the "save" feature of the expert system to stop the program without losing the information already inputed. This permits the user to perform the required test and return to the system at a later date with the result. NOTE: This feature does not as yet work in this version. The test window will furnish the user with the normal range for this pollutant. Should the result of the test be positive, the solutions suggested will not include those for a negative result. If the user should elect not to perform the test indicated by the expert system, the solution provided will include solutions for negative and positive results.

3.6 The expair expert system applied to other situations

Due to the versatility of the inference engine of the expert system developed in this research project, many possibilities are available for applications in other domains. The knowledge base data bank would be modified to hold the specific information.

4. KNOWLEDGE BASE DATA

The following table contains most of the information stored in our knowledge base. The physical findings and the symptoms are presented alphanumerically to avoid repetitions. The description of these codes is presented in the legend following the table.

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
POOL	B,C,D,E,F,G	1,2,3	-Clean mouldy area and regrout -replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
POOL	general	general	-implement cleaning/maintenance program
LAUNDRY	B,C,D,E,G	1,2,3	-remove mould and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check connection of dryer exhaust: -unblock -clean -reconnect -seal ducts
LAUNDRY	general	general	-implement cleaning/maintenance program

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
GARBAGE ROOM	A,B,C,F	1,2,3	-remove mould -clean and disinfect containers -clean an disinfect chutes -clean and disinfect rooms on each floor -install door closers and gaskets on hoppers -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
MECHANICAL ROOM	A,B,C,E,F	1,2,3	-check A/C for malfunction -check humidifier for malfunction -check exhaust fans: -turn on -clean -unblock -seal ducts
INDIVIDUAL UNITS	A,B,D,E,F,G	1,2,3	-remove mould -check A/C unit for malfunction -check humidifier for malfunction -clean humidifier -check bathroom exhaust fan -clean bathroom exhaust fans -install bathroom exhaust fans -check refrigerator for malfunction: -unblock drain -remove rotten food -clean

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
INDIVIDUAL UNITS-WALLS COMMON WITH GARBAGE ROOM OR LAUNDRY ROOM	A,B,F	1,2,3	-clean and disinfect containers -clean and disinfect chutes -clean and disinfect rooms on each floor -install door closers and gaskets on hoppers -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans -remove mould and replace damaged materials check equipment for malfunction -check humidity setting -install humidifier -check connection of dryer exhaust: -unblock -clean -reconnect -seal ducts
INDIVIDUAL UNITS-AROUND WINDOWS	A,B,F	1,2,3	-remove mould -caulk around windows -check exterior facade for leaks and seal
ANY LOCATION	K,J	4,8,9,10,11,12 , 13,14,15	PERFORM FORMALDEHYDE TEST -remove offensive materials and increase ventilation for one week and take new measurements -apply impermeable barrier over pressed wood
ANY LOCATION	K,J,L	4,8,9,10,11,12 , 13,14,15	PERFORM FORMALDEHYDE TEST -use other cleaning agents

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
ANY LOCATION	J,M	4,8,9,10,11,12 , 13,14,15	PERFORM FORMALDEHYDE TEST -allow adhesives/carpets to dry and increase ventilation for one week and take new measurements
ANY LOCATION	general for above section	general for above section	-reduce temperature and relative humidity: 20C and 30%RH
ANY LOCATION	N	4,6,9,10,11,12 , 13,16,17,18	-allow paint to dry and increase ventilation during drying period
ANY LOCATION	J,P	4,6,9,10,11,12 , 13,16,17,18	-allow new building product to dry and increase ventilation during drying period
ANY LOCATION	J,L,P	4,6,9,10,11,12 , 13,16,17,18	-use other cleaning agents
ANY LOCATION	general for above section	general for above section	-complicated measurements are required; call your consultant
ANY LOCATION	H,I	1,2,3,4,5,6,7	-clean dirt from diffusers -clean filter system -install filter system -clean ducts -seal ducts -check location of air intake: -to be greater than 2m above ground -proximity to dust -accumulation of debris

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
ANY LOCATION	H,I,J	1,2,3,4,5,6,7	-seal off construction zone -clean dirt from diffusers -clean filter system -install filter system -clean ducts -seal ducts -check location of air intake: -to be greater than 2m above ground -proximity to dust -accumulation of debris
ANY LOCATION	NONE	1,2,3,6	-install "no smoking" signs in common areas
ANY LOCATION	general for above section	general for above section	-if above solutions fail to provide positive results: complicated measurements are required; call your consultant
ANY LOCATION	F	8,10,16	-PERFORM DETECTOR TUBE TESTS -check location of air intake and move if: -located less than 2m above ground -close to traffic -near garbage containers -near garage entrance/exit -near another buildings exhaust -check air intake for debris, rodents, nests and remove and install screen to prevent reoccurrence

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
INDIVIDUAL UNIT	F	8,10,16	PERFORM DETECTOR TUBE TEST -check gas appliances for malfunction -change to electric appliances -check hood exhaust for malfunction -seal ducts of hood exhaust -install exhaust hood -check for open windows near: -close to traffic -near garbage containers -near garage entrance/exit -near another buildings exhaust
INDIVIDUAL UNIT	Q	8,10,16	-increase rate of ventilation
ANY LOCATION	NONE	8,10,16	-PERFORM DETECTOR TUBE TEST -check garage ventilation system for malfunction -install garage ventilation -install CO sensors to control exhaust fans
ANY LOCATION	R,S	8,10,16	-check location of air supply vent with respect to occupant furniture -reduce rate of air supply as per specifications -system may require balancing-call consultant
CORRIDORS	R,S	8,10,16	-check roof hatch/stair well doors to be closed -reduce rate of air supply as per specifications -system may require balancing-call consultant

LOCATION	PHYSICAL FINDINGS	SYMPTOMS	SOLUTIONS
POOL	D,E,F,G	1,2,3	-Remove water and replace damaged materials -check equipment for malfunction -check humidity setting -install humidifier -check exhaust fans: -turn on -clean -unblock -seal ducts -install exhaust fans
ANY LOCATION	F,T	8,10,16	-increase air supply/rate of air exchange -check ducts/diffusers for obstructions and remove -verify duct connections to garage and garbage room on plans and redirect if required
INDIVIDUAL UNITS	F,T	8,10,16	-check exhaust hood for obstructions,dirt,proper connections -install hood -clean air filters -install air filters -verify corridor pressurization -open windows

LEGEND:

SYMPTOMS		PHYSICAL FINDINGS	
1	dry eyes	A	fungus
2	dry nose	B	mould
3	dry throat	C	slime
4	coughing	D	damp spots
5	sneezing	E	flooding
6	respiratory allergies	F	odour
7	allergies during pollen season	G	puddles
	respiratory problems	H	dirt around diffusers
8	irritation(eyes, nose, throat)		
9	headaches	I	chalky deposits around
	fatigue		diffusers
10	nausea	J	construction/
11	skin rashes		renovation
12	heart palpitations	K	new furnishings
13	chest pains	L	cleaning fluids stored or
14	faintness		applied
15	watery eyes	M	steam cleaning
16	blurred vision	N	new paint
17		P	new building
18			products(sealants)
		Q	stuffiness
		R	hot/cold spots
		S	drafts
		T	stale air

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As outlined in the introduction, the purpose of this research project was to produce an aid for the identification of possible indoor air quality problems and a set of solutions associated with them. The resolution of these indoor air quality problems in a quicker, more efficient and less expensive manner will improve the quality of life for tenants and owners.

Following the research performed on indoor air quality in highrise residential buildings and the subsequent adaptation to an expert system, **EXPAIR**, we arrive at these conclusions:

- The problems and solutions associated with indoor air quality in highrise residential buildings have been successfully applied to an expert system developed for that purpose.

- The amount of information comprising this knowledge base is relatively small in comparison to most knowledge bases. However, the information can be easily detailed by specialists in air quality.

- The expert system was developed to permit the user to edit the knowledge base and logic and modify it as required.

- New knowledge bases can be applyed to other situations requiring similar expert systems, using the same interface provided by **EXPAIR**.

- The **EXPAIR** system is a simple tool, accessible to most of the computer users under the most popular operation system, MS-DOS.

- The present version of **EXPAIR** has the capacity for expansion with the availability of 'equipment windows' throughout the system.

Even though this work was undertaken in a relatively short period of time and within very limited funds, we were able to prove that a knowledge base of indoor air quality and a versatile expert system can be successfully accomplished.

5.2 Recommendations

Below are our recommendations to further the accuracy of the **EXPAIR** expert system.

- Allow the experts or consultants in the domain of indoor air quality to use the system and provide their comments.
- Provide the expert system to users in the field such as building managers and owners.

The information gathered to meet the requirements of the knowledge base of the expert system may not be complete, since the information was acquired solely from literature.

However, we do feel that an effective system was developed if the time and budget limitations are taken into account. One of the main advantages of this system is its adaptability to other situations and possibility for expansion of the present system.