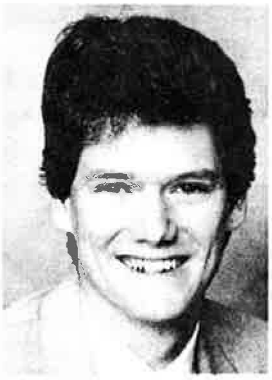
# BUILDING DAMPNESS: DIAGNOSING THE CAUSES

## How the BREDAMP system was developed

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*In our January/February issue last year, Jim Smith described the insights he had gained as the human expert being 'mined' by the knowledge engineers for an expert system to aid diagnosis of the causes of dampness in buildings. An overview of that BREDAMP project is presented here, explaining the background to the project and its objectives, and the way the expert system was created, discussing in detail the methods used to capture the depth of knowledge available.*

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*Dans notre numéro de janvier/février 1987, Jim Smith décrivait les connaissances qu'il avait acquises qui montrent bien que l'expertise humaine est exploitée par les ingénieurs de l'intelligence pour aider au diagnostic des causes de l'humidité dans les bâtiments. Les auteurs présentent ici une idée générale du projet BREDAMP: historique, objectifs, création, méthodes utilisées pour reprendre, dans toute leur profondeur, les connaissances disponibles.*

Expert systems in diverse areas have demonstrated the value of the technique by producing advice of a quality close to that offered by the foremost human experts in the field. Many large organizations have started to employ the technology in a wide range of applications (refs 1, 2, 3, 4).

## PROJECT OBJECTIVES

In 1984 BRE recognized that the construction industry, with its high reliance on specialist expertise, was ideally placed to exploit this new technology, and a research project was started.

It had three basic objectives. The first was to identify areas within construction which would benefit from the early application of the technology, considering factors such as costs, benefits, knowledge elicitation difficulties, hardware/software requirements and possible development problems. The second objective was to build demonstration expert systems in selected areas to gain practical experience. The final objective was to assess the overall success of the approach to identify areas of greatest potential and to define future research requirements.

The review study identified building defect diagnosis as an area where expert systems can be applied with considerable benefit. (Diagnosis has in fact been the most popular application of expert systems, particularly in the medical field where a wealth of experience has accrued. Diagnostic problems also tend to be well suited to the 'goal-directed' reasoning mechanisms provided by most low cost microcomputer-based expert system 'shells'.) BRE therefore chose this area to develop its first prototype system, and selected the diagnosis of dampness and water ingress problems in building. The expert system would encapsulate knowledge from specialists in the BRE Advisory Service (BRAS).

## SELECTION FACTORS

The selection of this application was based on a range of factors, but the main considerations were:

- An important element of the work of BRAS is the provision of diagnostic advice relating to dampness and water ingress problems in buildings. Expertise within BRAS in this area is concentrated in the knowledge and experience of just a few individuals. These experts have to deal with numerous routine enquiries which considerably restrict the time they have available to deal with the more complex problems that are presented. It was hoped that an expert system would enable non-specialists in the field to give first level advice to routine enquiries, thereby freeing the specialists to tackle the interesting and demanding problems more befitting their skills.
- The diagnosis of dampness is representative of many defect diagnosis problems. Lessons learnt in the development of an expert system in this subject area could be readily applied elsewhere.
- The BRAS expert was particularly enthusiastic about the project. This was important since the extraction of the knowledge from the specialist is often the most difficult aspect of developing an expert system and demands a high degree of co-operation and commitment of time.
- The expert system could be used as a training aid within BRAS. The system would enable newcomers to the service to gain experience of the questions which have to be asked for any particular problem without having to formulate the questions in the light of their site experience. In particular, the facility for asking the system to justify its reasoning would provide a foundation for asking the questions and hence some understanding of why they were asked, rather than doing it by rote.
- A fully developed microcomputer-based expert system would have considerable commercial potential. It would enable consulting architects and surveyors to make preliminary assessments of problems before coming to the BRAS for a site visit. This use of an expert system is in line with the BRE desire to sponsor 'technology transfer' to the industry.
- Human expertise is not permanent – staff leave organizations for many reasons taking their specialist knowledge with them. The expert system would act as an archive for dampness diagnosis knowledge, thereby providing a means of capturing and storing some limited, but possibly very valuable, expertise of the current BRAS staff.

## THE DAMPNESS PROBLEM

### BRE and the Building Research Advisory Service

The Advisory Service has always been subject to sudden losses of expertise when staff retire since, although the information could be written up, the ability to make judgements about uncertainties could not, and it departed with the retiring expert. In addition, when new staff enter the advisory service it takes as long as two years to produce a fully fledged advisory officer who can stand on his own even if he already had experience in his field and in laboratory work.

The expert system was seen as a means of keeping the expertise when staff departed and of training new personnel to ask the relevant questions in the right order more quickly than they would otherwise have learned to do.

The field of dampness was chosen because the officer concerned had the necessary expertise and had written up much of the subject of diagnosis in the form of lecture notes, and he was also interested in computers.

The project was envisaged in a number of phases, the first of which was to get a system to simulate the abilities of the officer to a limited extent, and from then on to refine it with field tests and amendments until ultimately it would diagnose not only the type of dampness but also the defect in the building which caused or permitted it.

### Types of dampness problem

There are 14 types of dampness, eight of which are associated with the presence of HYGROSCOPIC SALTS which are capable of absorbing water from the air in sufficient quantities that the dampness and the associated stains and disruption of paint films and plasterwork spread.

The types of dampness are:

1. CONDENSATION. The deposition of moisture from the atmosphere, either internal or external, on a cold surface.
2. RAIN PENETRATION. The passage of rainwater through a structure intended to exclude it.
3. BUILT-IN WATER. The presence of water which has been enclosed within the structure during the building process. This includes water from the weather, i.e. rain, snow, hail, frost and dew. It also includes CONSTRUCTION WATER, i.e. water used in the building process for mixing concrete, mortar and plaster.
4. PIPE LEAKAGE. The leakage of water from water supply or central heating systems or drains.
5. SPILLAGE. The spillage of water from industrial or domestic activities. In dwellings and some other buildings, this includes the effects of excess washing water.
6. SEEPAGE. The passage of water from the ground through structures wholly or partly below the ground level.

The following are all associated with hygroscopic salts.

7. RISING DAMP. The slow rise of water from the ground up walls, whether internal or external, due to defective or missing damp-proofing precautions.
8. CHIMNEY DAMP. The presence of brown dampness stains, on or near a chimney or near where a chimney used to be, that come and go with the weather and do not respond to the conventional treatments for rain penetration.
9. CONTAMINATED SAND. The presence of sea sand in mortar and concrete mixes.
10. CALCIUM CHLORIDE. The presence of calcium chloride used as a protection against frost in mortar mixes or as a quick-setting agent in concrete mixes.
11. COMPOSITION FLOORS. Magnesium oxychloride floors which have broken down into chlorides.
12. INDUSTRIAL CONTAMINATION. The presence of salts from industrial processes, usually discontinued ones.
13. ANIMAL CONTAMINATION. The presence of salts from animal waste, either directly as in a stable or indirectly as from a leaky drain.
14. FLOODING. The presence of large quantities of water, in the lower regions of the building, which has come from waterways that have failed to carry away excess rainfall for some reason. There are often large deposits of silt or mud containing salts.

## SYSTEM DEVELOPMENT

### Choice of computer hardware

BRE recognized that, if in the future a fully developed version of BREDAMP was to be made widely available to consulting architects and surveyors, it would need to run on the most popular personal computers. Most professional personal computers in the UK are based on the Intel 8088/86 family of microprocessors and run under the PC/MS-DOS operating system. With these considerations in mind an IBM XT personal computer was selected for the development of BREDAMP. This hardware supported most of the available commercial Expert System shells and gave BRE great flexibility in choosing appropriate software.

### Choice of expert system shell

After a detailed survey of commercially available expert system shells the SAVOIR package from ISI Ltd was selected for BREDAMP development. This decision was based on several technical considerations:

(a) Savoir was similar in philosophy to an earlier ISI shell – MicroExpert – that BRE had used to build a pre-prototype version of BREDAMP. The experience with MicroExpert could be exploited when using Savoir.
(b) BREDAMP needed to represent and reason with uncertain information and Savoir supported this facility.
(c) Savoir provided a mechanism to enable external Pascal procedures to be linked with the shell run-time intepreter. This enabled BRE to develop user display software tailored to the requirements of BREDAMP.
(d) Savoir provided elements of procedural programming to control the inference process, and to generate report and display output at appropriate points in the investigation.

### Knowledge acquisition

The development of BREDAMP took place in the latter half of 1985 and this paper is being written about a year later. In the meanwhile the authors have been continuing their studies of the methodology of expert systems and several of the comments that follow are made with the benefit of hindsight.

Although the alternative methods of knowledge acquisition have not been fully defined the following broad categories can be discerned.

- Unstructured interviews
- Structured interviews
- Fast prototyping
- Machine induction
- Expert codes his own rules

The first two of these and the last are self-explanatory. By fast prototyping we mean the preparation of an embryonic but relevant system which is then used to prompt the domain expert into providing additional information. This is coded to produce an enhanced system and this in turn prompts the release of further information. Machine induction is a process in which sets of cases are analysed automatically to produce rules.

In the process of acquiring the knowledge at least two people are usually involved, namely the domain expert and the knowledge engineer. In the case of BREDAMP there were three: the expert, the knowledge engineer, and the computer coder. This team composition has the advantage that it enables the knowledge engineer to develop rapport with the expert, and this helps to generate a more productive environment.

*The structure of the system.* It had been recognized that there were a number of possible causes of dampness and that these could be selected by the application of appropriate rules. This is an ideal type of domain to represent as an expert system. The goals of the system relate to the fourteen PRE-DEFINED diagnoses (listed above). A further goal of condensation on pipes emerged during the knowledge acquisition. It was also recognized that the diagnoses would have to yield probabilities for each goal since the symptoms of dampness often lead to the cause lying between two or three possibilities. SAVOIR is a very suitable shell for such a system.

*The methodology adopted.* At the start of the work it was recognized that the domain expert was extremely cogent about the subject of dampness in buildings. Little difficulty was expected in getting him to provide the necessary information, nor was any encountered. Moreover he was keen to see his own expertise represented in a form that would enable it to be used directly by others. Thus he was positively motivated. (Readers will appreciate that there will be many cases where the experts are concerned about parting with knowledge and may see that doing so may weaken their competitive position, either internally or externally.)

The method of knowledge acquisition adopted is now described. For each of the fifteen dampness causes at least two interviews were held, although for convenience some of the simpler causes were taken in groups. The first unstructured interview sought to ascertain, for the chosen cause, the factors that confirm or deny the possibility of that cause being the source of trouble in a building. For example it was found that for Rising Damp,

- Occurrence is limited to ground floors and basements
- The evidence is a stain (in a band) at bottom of wall
- That the dampness grows gradually at no more than one and a quarter inches (32 mm) per year
- The inside of the affected component is wetter than the surface.

The second interview was more structured. In advance the knowledge engineer drew up a table of representative conditions, such as that shown in Table 1. He first checked that he had properly interpreted the expert's information about relevant factors and then asked him for his assessment of the probability of dampness being due to this particular cause for each case.

By considering many combinations of the symptoms, a sufficiently large set of these artificial case studies was generated to cover a full range of high or low probabilities for the cause under examination. In turn this enabled the appropriate factors to be calculated for the uncertainty knowledge statements. For more complex causes it was natural to break down the overall problem into sub-goals. For example, rain penetration is clearly two sub-problems of penetration through a roof or a wall. Penetration through a roof could be further sub-divided according to the type of roof covering.

Once the relationships for a particular goal (or cause) had been obtained they were coded and a self-contained sub-system was developed for each cause. Each sub-system was demonstrated to the expert, who was invited to comment on the suitability of the questioning and the appropriateness of the assessed probability. This enabled each cause to be 'fine-tuned'. Once all sub-models were available they were merged to form the total system.

*Some by-products.* Once the system was complete, two important observations were made, namely that

- the user will be interested in the confidence that is associated with the offered diagnosis
- the knowledge-base should be carefully verified.

The interest in a confidence assessment lies in the fact that a user will respond differently to an assessment in a range 80–100 percent in comparison with a range of 89–91 percent. If the range

*Table 1 Case studies for part of Rising Damp*

| Case | 1 | 2 |
|---|---|---|
| Stain present | Y | Y |
| Height of stain | 9 inches | 12 inches |
| Age of building | 8 years | 8 years |
| Inside wetter than outside | Don't know | Yes |
| Probability of rising damp | ? | ? |

is wide he will probably decide to conduct further, inexpensive, tests and consult the system again. With the narrow range he will probably conclude that further data would not improve the diagnosis and that he should adopt physical remedies, on the assumption that this is indeed the cause of the problem.

The problem of verifying the knowledge base was noted and a series of trial consultations was conducted, in the presence of the expert, to enable him to comment on their appropriateness. These trials were supplemented by tests carried out by colleagues of the expert who had volunteered for this task. We believe that this procedure was prudent but may not have been sufficiently exhaustive. However, field trials are now being undertaken to further this verification. It is hoped in future to develop a procedure by which the expert system itself is used as a simulator. Such an arrangement could, for example, generate characteristics such as a plot of rising damp probability *vs* age of building. It seems likely that data in this summarized graphical form can be quickly scanned by the expert to detect errors, whereas a complete assessment of all combinations of responses would be quite impractical.

*Rule induction – a postscript.* The authors have an interest in the use of rule induction even though it was not adopted in the development of BREDAMP. For this reason they have used part of the BREDAMP domain, together with input from the domain expert, to explore the potentials of rule induction. Their conclusions from this investigation indicated that, although the induced relationships (and thus potential rules) were seldom satisfactory, the process of using the rule induction program had forced the expert to define variables that had not emerged in the normal interview processes. It seems, therefore, that rule induction may play an important role in prompting the release of knowledge though the rules induced will be of little direct use.

| | | |
|---|---|---|
| PROBABILITY rd_dpc_faulty | | |
| rd_salt_test_positive | LS 100 | LN 0.01 |
| moisture_test_positive | LS 4 | LN 0.2 |
| straight_strain | LS 0.1 | LN 1.4 |
| PRIOR 0.5 | | |

*Fig. 1. A probability statement about Rising Damp for SAVOIR*

Purpose of building
Age
Number of storeys
Type of roof
Angle of pitch
Where dampness is seen
Shape of stain

*Fig. 2. The preliminary questions*

Question stain_shape 'What is the shape of the stain?'
1 A crescent in the corner of a wall
2 A horizontal band on a wall
3 A complete circle
4 Roughly semi-circular
5 A three-quarter circle
6 An irregular patch
7 A vertical band down a wall
8 A band across the ceiling

*Fig. 3. A SAVOIR question illustrating detail in an expert's knowledge*

## Overall plan and coding of the system

*Plan.* Two important decisions, taken before coding commenced, influenced the choice of shell and the overall plan of the system. These were:

i) the system should always work through a short set of preliminary questions before embarking on the investigation of likely causes: and
ii) all causes should be examined.

Decision (i) seems obvious but needs explanations. Expert systems, whether written in an artificial intelligence language such as PROLOG or with a shell such as SAVOIR, investigate their knowledge bases by searching methods, the most common being that known as backward chaining. This can easily result in a user being asked detailed questions about an unlikely cause of his problem immediately a consultation is started. Some control over the searching method is needed to avoid this and a few shells such as SAVOIR provide this. Figure 2 summarizes these preliminary questions, which are just the set an expert would ask before considering possible causes. Figure 3 shows one of the questions in full and this illustrates the depth of detail which reflects a true expert's knowledge.

Decision (ii) represented a cautious approach to the use of expert systems. We have coded the system so that it will drop the investigation of a cause when the related probability falls to a very low value, but we have not stopped the investigations of remaining causes when the probability of one is found to be very high. The system will continue checking through the remaining causes.

A decision related to this was that the order in which causes of dampness would be investigated was to be derived from the statistics of the Advisory Service of BRE. Examination of several hundred site investigation reports yielded an order of likelihood for the goals and a prior probability for each goal.

To complete the overall plan it was agreed that the system should provide the user with help at all stages and would display (and optionally print) a report on each cause. SAVOIR provides basic help facilities such as explanations and amplifications of questions, but extra facilities were added to allow re-starts, exits and a display of current status of all goals.

*Coding.* The system was written and, wherever possible, tested in separate modules corresponding to the initial preliminary questions and investigation of each goal. Of course, the one strength of expert systems is their ability automatically to find the cross-connections when a particular symptom occurs in several knowledge statements relating to separate goals. Hence it was sometimes necessary to test some goals together, but the modularity was still maintained in the source form of the knowledge.

SAVOIR provides three forms of knowledge statement and a question statement. All can have preconditions which, if satisfied, allow the knowledge to be processed or the question asked and, if not satisfied, provide alternative values for the result. Results are stored in variables just as in a programming language. There are two types of variable, designated CONDITION and PROBABILITY. The former can have the value TRUE/FALSE/UNKNOWN, the second stores two values of the probability. These are the maximum and minimum possible values attainable by a variable according to the answers given to *as yet unasked* questions. As the system works through its questions, these values are updated according to the user's answers, converging when all related questions have been answered.

The two forms of knowledge statement allow rules or uncertain expression between variables – typically between question variables and sub-goals, or between sub-goal variables and the final goals. The uncertain form uses the Bayes theorem (ref. 5) to allow for the effect of evidence of various symptoms to be weighted together. Figure 1 shows one example of a sub-goal of

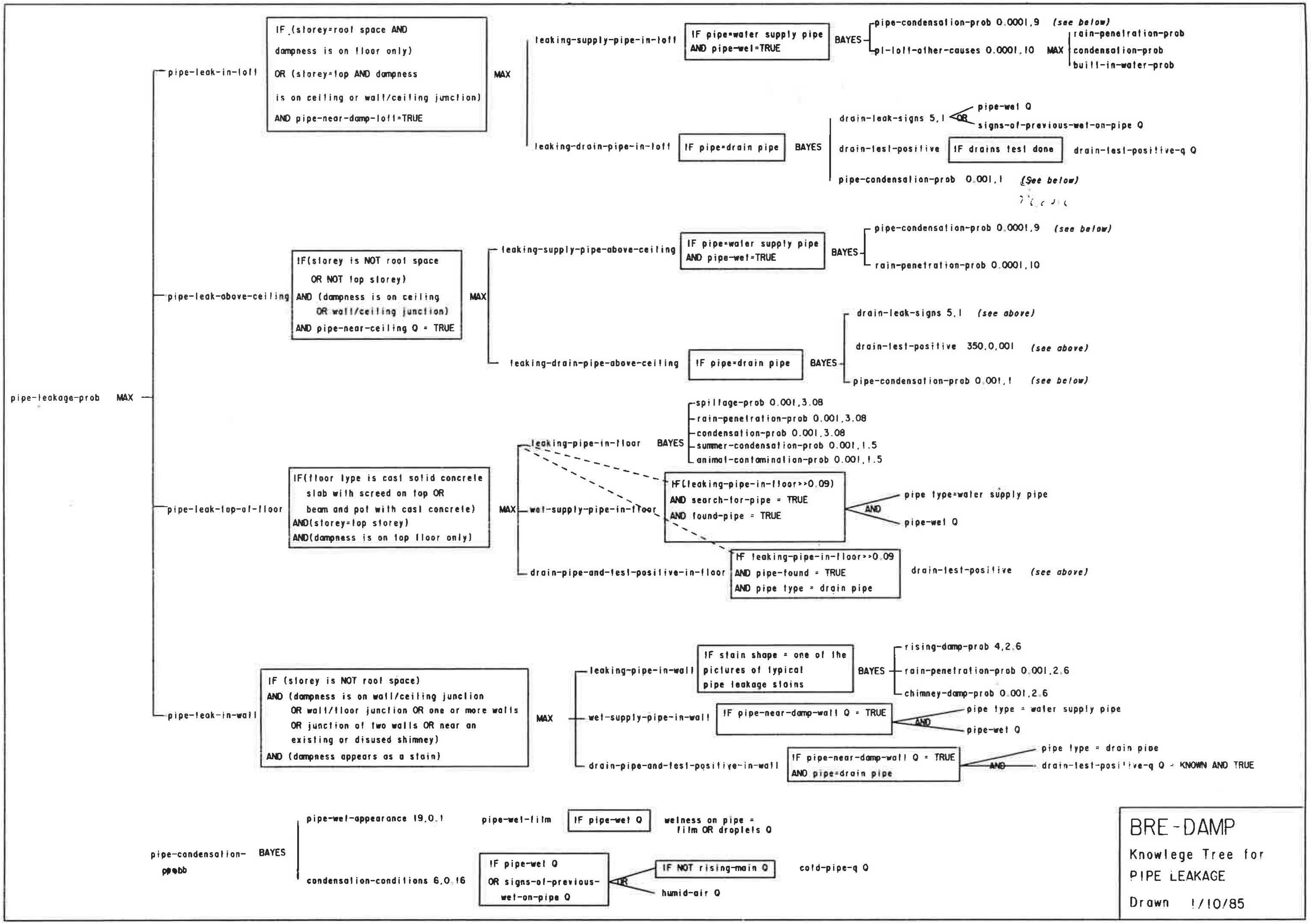


Fig. 4. Knowledge diagram for pipe leakage

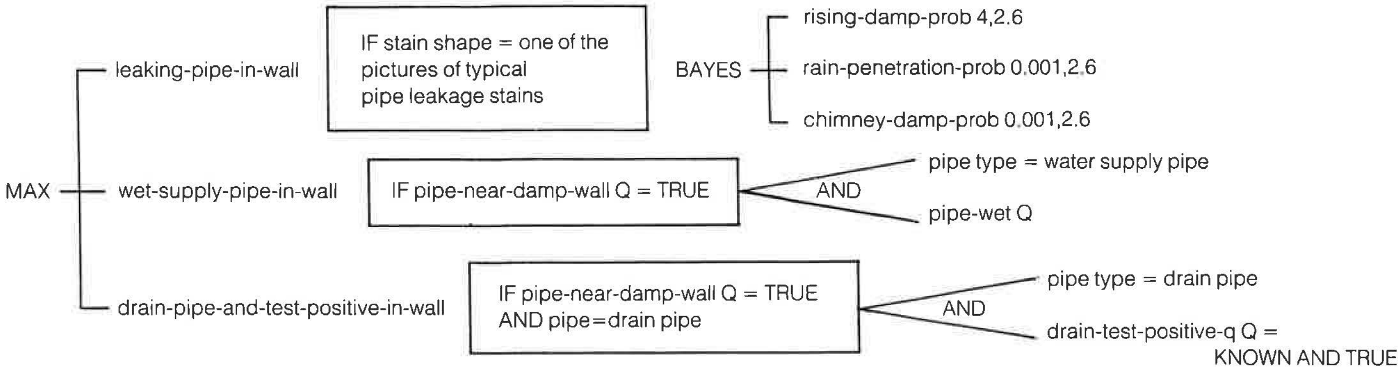


*Fig. 5. Part of the knowledge diagram of figure 4*

rising damp due to a faulty dampproof course. The numbers after LS are weighting factors applied to the PRIOR probability of the likelihood of this sub-goal if each piece of evidence is confirmed as true. The numbers after LN are used if the evidence is not true.

The weighting factors were derived from the artificial case studies generated during the knowledge acquisition process. The final factors ensure that the expert system gives the same final probability to the overall cause, i.e. rising damp in this case, as the expert did for all the combinations of evidence considered in the case studies.

*System statistics.* Some figures describing the system size and the effort needed to create it may be helpful. The knowledge acquisition and overall planning took 30 man days of effort including the time of the expert. The coding and testing took 45 man days. The knowledge base contains approximately 4000 lines of text but much of this is for display purposes. The knowledge is represented by 143 questions and 171 'rules', expressed as either CONDITIONS or PROBABILITY statements. The system runs on an IBM PC microcomputer with 512k bytes memory and with one floppy disc drive. The response time between questions is approximately 3 seconds.

### Knowledge diagrams

The process of eliciting knowledge and coding it into a reliable system poses many difficulties. The expert is unlikely to express his knowledge in a form which resembles the coding, the knowledge engineer may not interpret and record the expert's ideas correctly, the coding may be at fault and the expert may overlook some facets of his own knowledge. All workers in expert systems recognize these difficulties, and to aid in all the above steps, diagrammatic representations of the knowledge are often used, sometimes produced automatically from the knowledge base.

We chose to create, using a CADraughting package, more detailed knowledge diagrams. Figure 4 shows a reduced version of the whole diagrams for one of the more complex goals, figure 5 is an enlarged part of figure 4. Features of the diagrams are that the goal is on the left, the variable names were made meaningful and the logical relationships between variables are indicated by AND, OR, BAYES, MAX or MIN, the last three indicating uncertainty operations. The truth of each goal is ascertained by chaining backwards from the questions on the right-hand side, but where a rectangular box appears the conditions in that box must be true before the backward chaining search goes down any branch.

The value of these diagrams was twofold. Firstly, they enabled the coding to be discussed with the expert in a detailed manner, providing an invaluable check on the whole process of converting his knowledge to coding statements. Secondly, the ability of the eye to scan rapidly across the diagram provided an opportunity for the expert to see the scope of the knowledge he had expressed. This led on several occasions to the identification of missing lines of reasoning.

## HISTORY OF BREDAMP

1983. A simple dampness diagnosis expert system was developed by BRE using the ISI MicroExpert shell. This system only considered rain penetration and chimney damp.

1984. BRE converted the MicroExpert model to the more powerful SAVOIR shell and added built-in water dampness to its repertoire. The expert system became known as BREDAMP.

1985. BRE commissioned Professor Geoffrey Trimble and Dr Roger Allwood of Loughborough University to develop BREDAMP into a full prototype embracing all 14 possible types of dampness.

1986. BRE commissioned Loughborough University to carry out a field assessment of BREDAMP performance to identify future research and development needs.

## CONCLUSIONS

BREDAMP has already shown itself to be a useful tool and we are confident that, with some refinement after the completion of current field trials, it will be a very reliable, practical system. It may well prove to be a precursor of a family of systems offering advice to professionals engaged in building and acting as an accumulating reservoir of the experience we currently lose every time an old hand retires.

## ACKNOWLEDGEMENTS

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