Knowledge-Based Design Assistant to Overcome Moisture-Induced Problems

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ABSTRACT

Diagnosis of building envelope failures and design to overcome these problems require expertise and knowledge from many different disciplines. The present work is aimed at developing a systematic methodology to represent the knowledge required in the diagnosis and design processes to resolve the moisture-induced problems. The symptoms, causes, effects, and remedial measures for commonly encountered problems are grouped for each building envelope component. Sample rules for diagnosis and design have been extracted from available literature and well-established methods. Information on most commonly used construction types, material properties, and building code requirements are also made part of the knowledge base. A data base of design weather data is interfaced to the knowledge base for establishing the context of the problem. Psychrometry information and the computation of temperature and vapor pressure profiles are incorporated in the knowledge base for verifying the possibility of condensation due to vapor diffusion. This system will be a useful tool to novice designers, renovation contractors, building inspectors, and other professionals involved in the design and retrofitting of building envelope components.

INTRODUCTION

Building envelope problems are caused by many factors such as improper selection and design of materials, inadequate construction details, climatic conditions, and poor workmanship. The uniqueness of building defects makes the diagnostic process difficult and often building science experts are required to perform the investigation (Fielding 1987). Research reports and documents from many sources (CMHC 1988; Amney and Jessop 1984; Beall 1989; Building Research Establishment Digest 1981) are available for diagnosing the causes of various building envelope failures and design methods to overcome these problems. The number of parameters to be considered in the investigation is large and requires expert knowledge, hence it is difficult for the designer to thoroughly analyze a problem situation.

Knowledge-based system techniques can be used to develop computer programs that can capture the expertise and knowledge required to solve some of the difficulties in automating the diagnostic and design processes. Diagnostic problem-solving has been one of the most popular applications of rule-based system techniques, where the heuristics applied to diagnosis can be represented using simple production rule forms. Knowledge-based system techniques for solving building envelope failure diagnosis problems is an emerging concept with great potential for automating the process of information handling and enabling a wider distribution of the accumulated expertise. This has been demonstrated by a number of recent prototype systems such as DAMP (Sachdeva 1985), AIRDEX (Persily 1986), BREDAMP (Allwood etal. 1988), and WINDEKS (Ruberg and Cornick 1988). DAMP, AIRDEX, and BREDAMP address the dampness problems in general, and WINDEKS addresses the moisture problems in windows. The primary objective of these systems is to capture the expertise available and required for solving diagnostic

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problems encountered in specific situations. However, the use of knowledge-based system techniques can be better realized by developing software tools that incorporate the expertise in diagnosis as the basis for new designs as well. Such an approach will assist the designer in both the diagnostic and design processes.

The objective of the present research is to unify and integrate the knowledge and information required in the diagnostic and design processes relating to moisture-induced problems in building envelope components. A prototype knowledge-based system has been developed to demonstrate the feasibility and advantages of this methodology. The details of diagnostic and design processes, knowledge representation, and implementation of the prototype system will be discussed in the following sections.

DIAGNOSTIC AND DESIGN PROCESSES

The diagnosis of building envelope failures in general consists of the following three stages: (i) collection of symptoms and observations, (ii) establishing the causes, and (iii) proposing remedial measures. The uniqueness of each building, its location, climatic conditions, and occupancy, etc., affect the interpretation of any given symptom. Additional information on materials used, their properties and construction detailing is required before making meaningful conclusions on the cause of the problem. Many case studies on the diagnosis of specific building envelope failures have been researched to develop generalized procedures to assist in the investigation process. But the applicability of these techniques is limited and must be carefully used in practice. In the context of moisture-induced problems, the most common causes are condensation and bulk transport of moisture. There are a variety of symptoms for moisture-induced problems. For example, the rotting of exterior cladding, mold and mildew, deterioration of insulation material, staining of inner surface, and discoloration, etc., may be some of the external symptoms. The frequency of occurrence of the problem and the materials affected can be used to establilsh the nature of the problems and the corresponding remedial measures. Hence it is possible to develop a knowledge base of diagnostic rules to determine the causes for certain categories of problems.

Design of building envelope components is usually done at the preliminary stages of a building project, and often the lack of information, time constraints, and priorities of the owner influence the decisions on the selection of materials and construction systems. These decisions, along with the building code requirements and constructability aspects, become the constraints with which the detailed design is carried out. Hence the quality of the final design can be greatly improved by making knowledgeable decisions at the preliminary design stage. In the present study, an attempt is made to consider some of these requirements in detail by performing a check on the compatibility of materials, verifying the possibility of interstitial condensation, and applying design rules to avoid moisture-induced problems. The knowledge required for building diagnostics may also be applied to check new designs for satisfactory performance (Building Research Board, 1985). A knowledge base of diagnostic rules, once developed, may be used for such design verifications.

KNOWLEDGE REPRESENTATION AND IMPLEMENTATION

The knowledge required in diagnosis and design can be represented as structural and functional descriptions corresponding to design data and heuristics (Sugaya, 1987). Such an approach to building envelope problems consists of the following information: (i) design weather data, (ii) indoor design conditions, (iii) construction types, (iv) material properties, (v) computational procedures, (vi) building code regulations, and (vii) heuristics and experiential knowledge. A prototype system has been implemented by developing a framework to integrate all these types of information. The scope of design and diagnosis in the present work is limited to moisture-induced problems, in particular to avoid interstitial condensation.

Figure 1 shows the software architecture of the prototype implementation. Knowledge representation for this system consists of structured assertions using frames and instances, production rules, procedural functions, and a data base interface. Design weather data for any given location can be obtained from the Supplement to the National Building Code of Canada (NRC 1985) and these are stored in spreadsheet data files. There are about 10 such files classified according to provinces and territories in Canada. By specifying the city name for the building in the problem context, the outdoor temperatures, relative humidity, and degree-days for design can be retrieved. This facility permits the maintenance and updating of the weather data information independently of the knowledge base.

The construction types and material properties data essentially provide the information for wall and roof types to be used in design. Details of 17 wall and roof types are currently available in the prototype and this information has been obtained from the AIA (1982). Structured assertions of the construction types are defined by frames with the necessary slots and specifying instances of this frame to consist of the values describing the characteristics of each type. Thus the user may easily add new construction types to the knowledge base. Figure 2 shows the frame "BASIC-WALL-TYPE" and an example of its instance "BRICK-ON-CONCRETE-BLOCK-WALL" for defining a wall type. The slot "NAME-OF-COMPONENTS" specifies a list of various materials used for each layer of the wall assembly. The value "INSULATION" in this list corresponds to the location of insulation, and the system will find an appropriate insulation material and thickness to satisfy the design requirements. Most commonly used building materials corresponding to each function such as cladding, structure, insulation, and vapor barrier, and their properties for thermal and vapor resistance, cost, and thickness are currently available in the prototype system. The material properties representation is similar to that of the construction types as described above. During the diagnostic or design process, the user can select any of the available construction types, define a new construction type using the materials available, or specify new materials and their properties. Thus the knowledge base can be easily extended by the user, depending on the necessity.

The diagnosis and design in the prototype system require the computation of temperature and vapor pressure profiles across the envelope assembly. A procedure to calculate these gradients is implemented using the simple static condenstaion analysis (Fazio and Gowri 1988). These procedures are developed separately and are interfaced with the knowledge base to advise on the location of the problem, if encountered. Such an approach is found to be useful in the preliminary design stage of verifying the proper location and combination of materials in an assembly (Szokolay 1988).

The building code requirements, design heuristics, and experiential knowledge are represented using the production rule form. Basic information required in diagnosis consists of observations, symptoms, frequency of occurrence, and materials affected for a failure problem. Representative knowledge for the prototype system is acquired from CMHC (1988) and Mattar and Morstead (1985), which provide the symptoms, causes, effects, and solutions to commonly encountered moisture-related problems. Figure 3 shows an example of a production rule for determining one possible cause of moisture problems. This rule is executed when staining due to condensation is observed in the exterior panel of a wall assembly during the winter season. The possibility of air leakage and poor insulation value for the envelope assembly are inferred as the causes for the problem, and the user is informed of the remedial measures. A number of such general rules for making recommendations on remedial measures are present in the system.

The design process is broken down into an alternative generation stage and an evaluation stage. The design alternative generation stage examines all the basic wall and roof types, the corresponding insulation materials, etc., to obtain a combination of materials to meet the thermal resistance requirements and be free from condensation problems. ASHRAE Standard 90A-1980 ASHRAE 1980 specifications are incorporated in the knowledge base to establish the thermal resistance requirements for the envelope components. The design alternative generation process considers the rules for diagnosis to make sure that a feasible alternative is free of interstitial condensation problems. Also, a list of recommendations to be considered in the choice of that alternative is generated and provided to the user.

The production rules present in the prototype are grouped according to each envelope component and for the diagnosis and design separately. Each group is attached to a sponsor whose state may be enabled to disabled appropriately to consider the rules required during a consultation session. Figure 4 shows the sponsor hierarchy used in the present implementation. Meta-rules are attached to the "TOP-SPONSOR" to activate the child sponsors such as for diagnosis or design and for walls, roof, or a combination of envelope components and so on. A commercially available knowledge-based system development tool (Gold Hill Inc. 1987) is used in the present work. The reasons for selecting this tool and the evaluation process are reported in Gowri et al. (1988).

USER INTERFACE

A screen tool kit of predefined frames and utilities provided by the development environment is used in creating a menu-driven window user interface. Both the design and diagnosis options take the user through a number of questions to adequately describe the context of the problem.

These are limited to basic design data such as the city name, geometry, and other details of the envelope components. Each input request appears in a temporary window, optionally with a list of possible answers from which to choose. The user response is added to the assertion base and the inference mechanism decides the course of the consultation process. A sequence of user input required in the design of a building envelope assembly is given below: (i) the province and city name of the building, (ii) area of external walls, roof, and fenestration, (iii) preference of basic wall and roof types, (iv) priorities on performance attributes.

The results of a design are displayed as shown in Figure 5. This design screen consists of a command line at the top of the screen, a status line at the bottom, and the rest of the screen is filled with windows for displaying the user input, design context, and the details of suggested alternatives. The command line provides icons for pop-up menus to modify the user input parameters, obtain explanations and recommendations, and perform other operations for saving/printing the results, etc. The design context window provides the quantitative performance requirements for the design. The suggested design details window provides the construction type, materials used, and the performance characteristics of the suggested envelope components. A similar screen facility is also provided for diagnosis.

CONCLUSION AND FURTHER RESEARACH

A knowledge-based system framework has been developed to demonstrate the feasibility of assisting in both the diagnosis and design of building envelope components. This approach reduces the difficulties of information handling and facilitates the use of expert knowledge in the design and diagnostic processes. A software tool of this nature will enable successful technology transfer and dissemination of available expertise in a form that can be easily used by the industry.

The prototype system attempts to address the moisture-induced problems to a limited extent. Further research is being carried out to extend the knowledge base for considering other causes of building envelope problems and performance attributes such as structural, fire, and acoustic resistances. Efforts are made to formalize the building envelope design process and to assist in the preliminary design stages (Fazio et al. 1989). These techniques will help the designers to make knowledgeable decisions in the selection of materials, construction types, and design alternatives.

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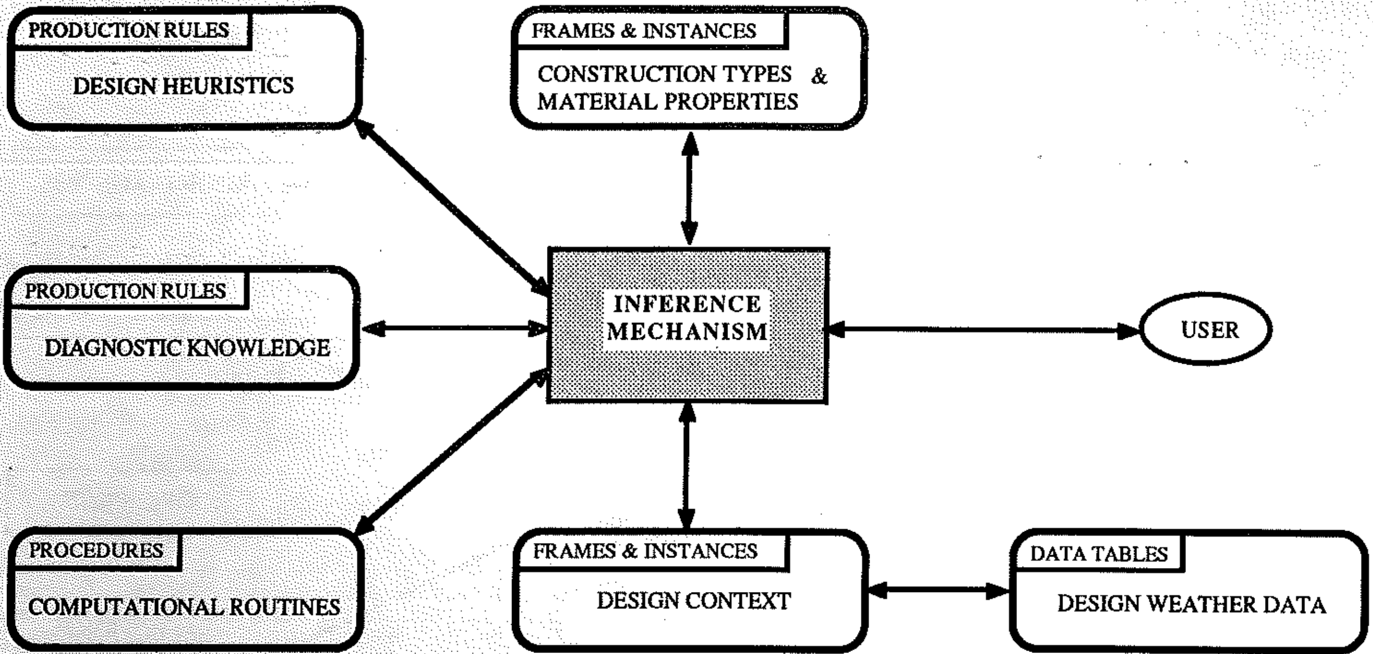

Figure 1. Software architecture of the knowledge-based system

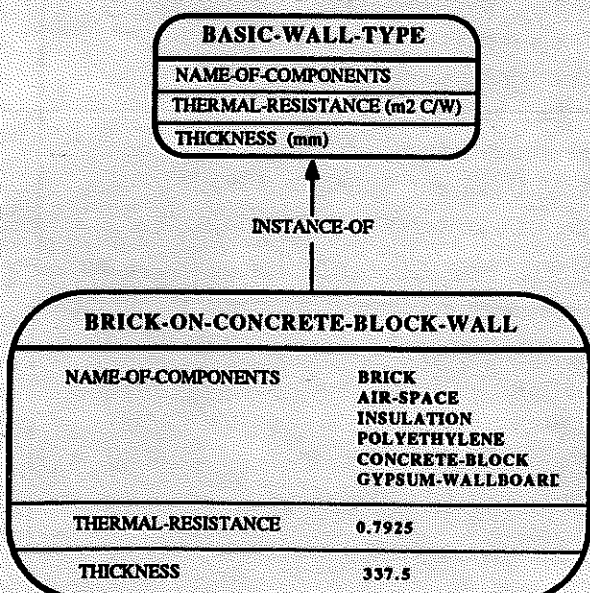

Figure 2. Example of an instance of "basic-wall-type" frame

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(DEFINE-RULE WALL-DEFECT-1
    (:dependency   T
     :direction    :FORWARD
     :sponsor      WALL-DIAGNOSIS)
    (INSTANCE DESIGN-CONTEXT IS CONTEXT-INFORMATION
        WITH  FAILURE-LOCATION              EXTERIOR-PANEL
        WITH  FAILURE-TYPE                  STAINING
        WITH  FREQUENCY-OF-OCURRENCE SEASONAL-WINTER
        WITH  CONDENSATION-LOCATION    OUTER-LAYER)
  THEN
    (INSTANCE DESIGN-CONTEXT IS CONTEXT-INFORMATION
        WITH  CAUSE  (AIR-LEAKAGE  POOR-INSULATION))
    (INSTANCE RECOMMENDATION IS POPUP-FORM
        WITH  CONTENTS
              ((" A possible solution is to seal the interior and maintain a  ")
               (" continuous air barrier.  Also the insulation value of the   ")
               (" wall assembly may be increased to avoid condensation.       ")))
)
```

Figure 3. Example of a production rule

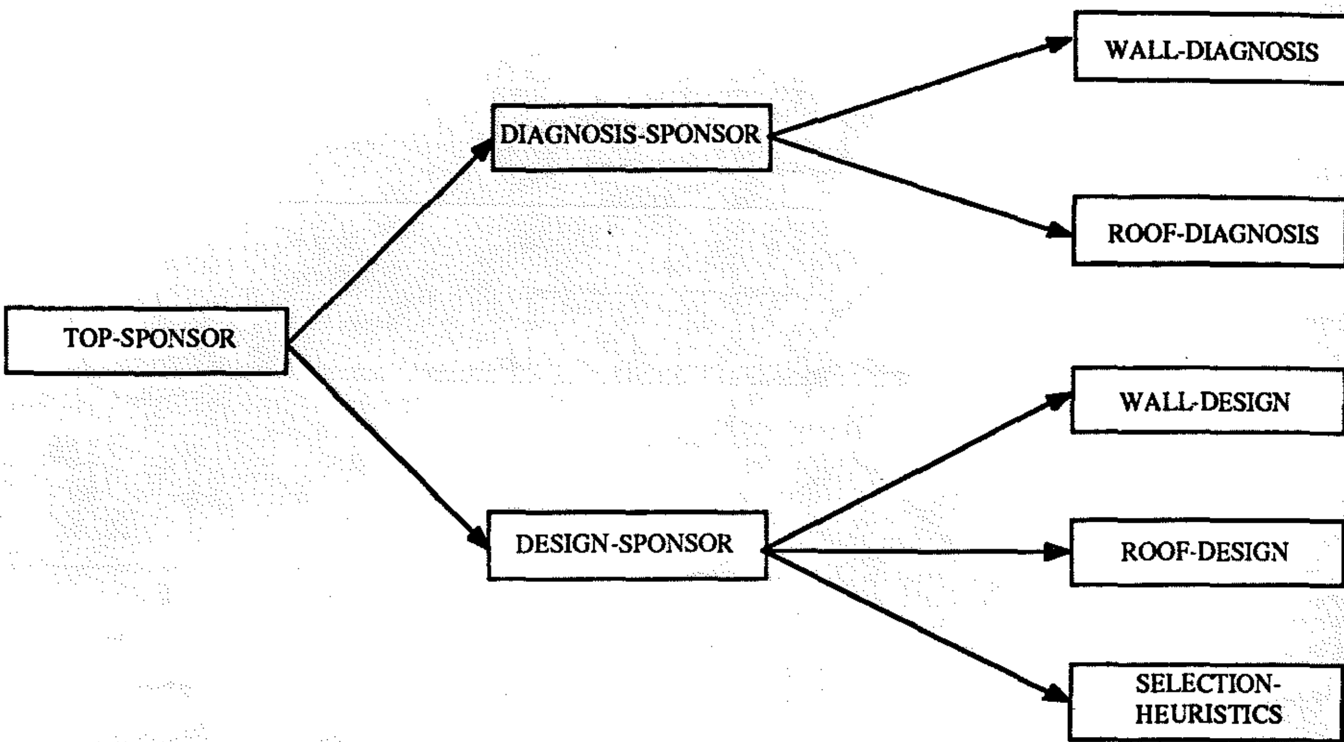

Figure 4. Sponsor hierarchy for rule grouping

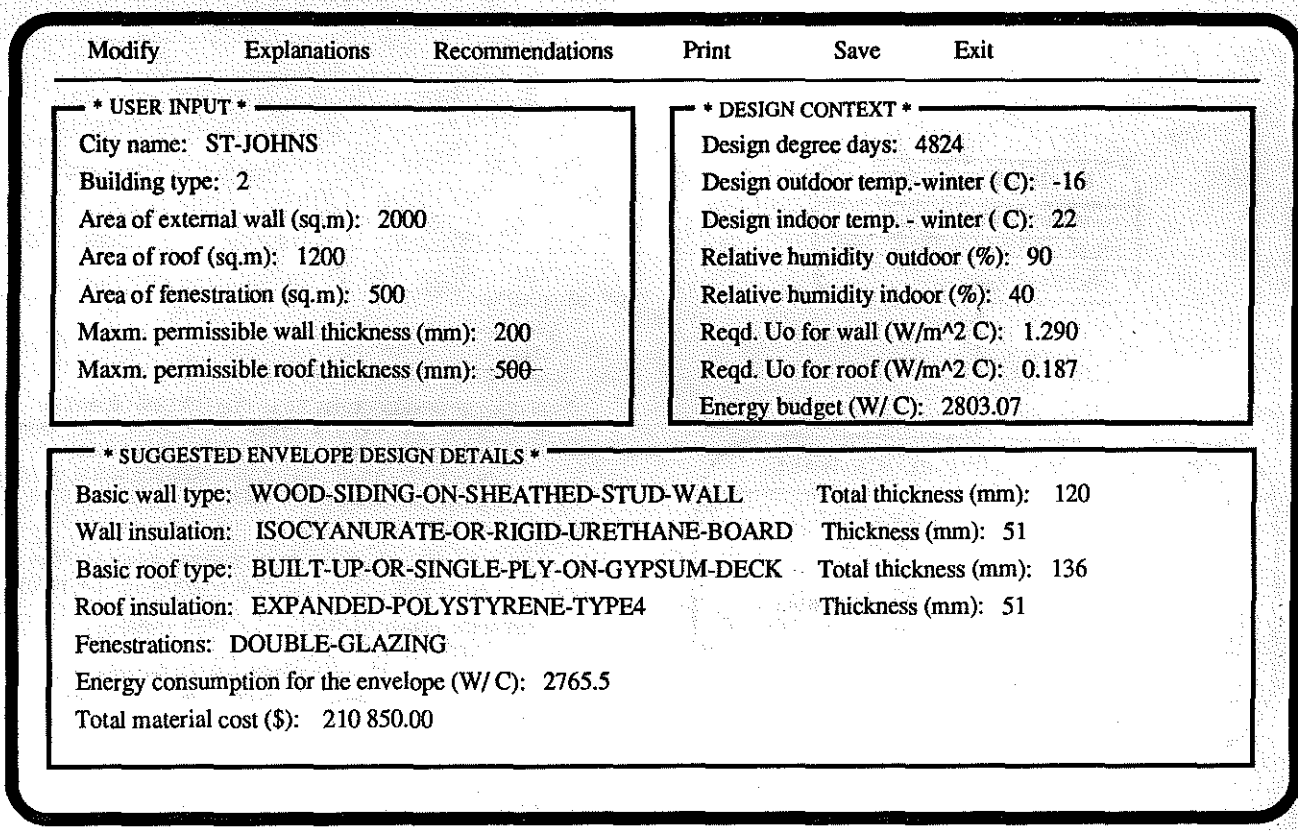

Figure 5. Example of a design screen