Chapter 1 Needs and Trends In Building and HVAC System Design Tools

Modern building and HVAC systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. Economical considerations and environmental issues also need to be taken into account. These factors, as well as an increase in design liability and a requirement to complete designs quickly, have placed unprecedented pressure on designers. Computers are seen as an important design tool that can reduce some of the strain. This chapter provides a short overview of the use of computers, and advances made in software development in the building and HVAC field.

The trend in the development of new computer tools is towards integrated and expert design tools. This is a big step towards optimal, energy efficient building design. However, it was found that only a few designers make use of these tools. This chapter also identifies the reasons for this and highlights some of the aspects that need attention. One of the main reasons is that in general there is a big difference in what designers require and what is available. Complexity of the tools seems to be the biggest stumbling block. The remainder of this study is based on these findings.

1.1 INTRODUCTION

Modern buildings and their Heating, Ventilation and Air-conditioning (HVAC) systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. This must be accomplished within certain constraints.

Typical constraints are economical considerations such as installation and operating costs, ease of maintenance, flexibility, and spatial requirements, as well as environmental issues such as the reduction and banning of certain refrigerants and noise pollution [1,2,3,4,5]. Consequently, building and HVAC design is a complex task consisting of various interactive factors that requires experts from different disciplines. According to Kennington [6] this complexity is one of the main reasons why the building industry has made little progress in improving energy efficiency.

Researchers believe that it is possible to obtain savings of around 30 % through the use of new and better design techniques and tools. Most of these savings are based on an integrated system design approach. This consists of finding the optimum interaction between the various factors and their constraints [7,8,9,10,11].

In order to make a living, designers are usually required to complete their designs quickly. This leaves hardly any time for optimising their design. In the last decade designers have therefore increasingly turned to computer design tools. Numerous design applications have been developed for this purpose. Most of the widely used software only focuses on one or two design aspects, such as load calculations, energy consumption estimation, duct design, pipe design, etc. [12]. Existing software therefore lacks the required continuity and integration to be truly useful in optimal design [6,11,13].

Researchers have only recently begun to look at integrating different design tools. This integration can be grouped into two main, but overlapping, categories. The first category deals with the development of software dedicated towards integrating HVAC system and building thermal simulation. The second category focuses on the transfer of data between design applications. This is done through the use of a central database.

These developments have a tremendous potential for saving energy. To be truly effective however, these tools must be widely accepted and used by the design community. Currently, designers are finding it difficult to exploit even the basic computer tools available to them. Complexity of existing tools and their integration into the design process seem to be the biggest barriers. New tools must therefore be designed in close co-operation with designers so that their requirements can be addressed.

A need therefore exists for design tools that are user-friendly and easy-to-use. These tools should be able to provide answers quickly and calculations should require the minimum amount of input so as to be useful during the initial design stages. Based on this, they should be able to give quantitative answers regarding the influence of design decisions. These elementary design tools must further be able to transfer data to more complex and detailed design tools. Detailed calculations can then be made after the initial design has been finalised.

1.2 ECONOMIC IMPORTANCE OF BUILDING DESIGN

Buildings form an important part of the modern lifestyle. It is not surprisingly also one of the largest industry sectors worldwide [6,11]. Buildings, especially commercial buildings, are further one of the biggest consumers of energy. In developed countries, buildings account for between 30 and 40 % of the energy consumed [14,15]. Another alarming fact is that their energy consumption seems to be on the rise.

A report of the American Council for an Energy Efficient Economy showed that commercial buildings had the highest growth in energy consumption during the mid 1980s [16]. This corresponds with data adapted and corrected for inflation by Kreider and Rabl [5], as shown in Figure 1.1.

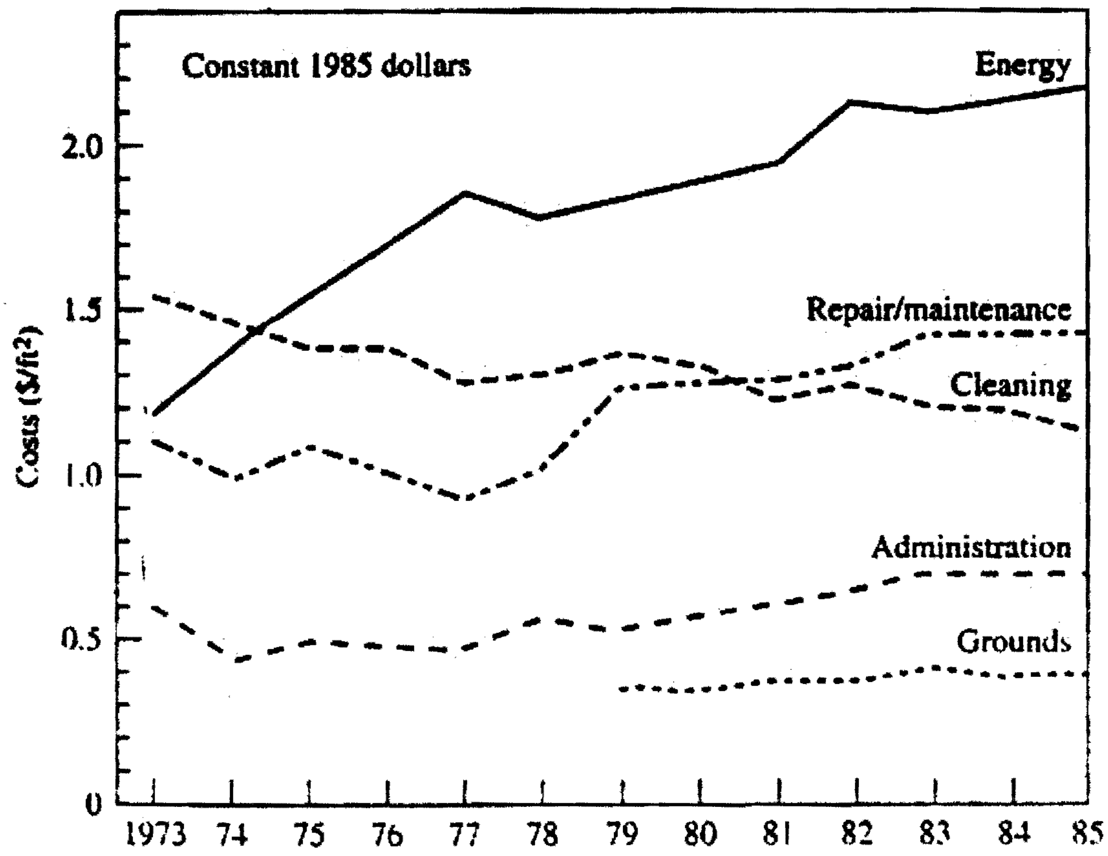

Figure 1.1 – Average office building operating cost per floor area corrected for inflation $\$1/ft^2=\$10.76/m^2$ [5]

In general most of this energy is used to maintain acceptable comfort levels within buildings. Of this, lighting and HVAC systems form the largest consumption items. Studies indicate that air-conditioning is responsible for between 10 and 60 % of the total building energy consumption, depending on the building type [17,18].

Maintaining high standards of indoor comfort is an economically sound goal. Research shows that indoor comfort and productivity can be linked [19,20]. These studies indicate that the economic gain with a small increase in productivity outweighs energy savings obtained by reducing the indoor comfort levels. A balance between energy efficiency and indoor comfort must thus be obtained.

Energy efficiency and comfort further impacts on the life-cycle cost of the building. A building with an ineffective HVAC system or high running cost is also unlikely to be leased or sold easily. Figure 1.2 illustrates the effect that the different role players have on the building life-cycle cost. The client's brief, if very complex, has an enormous impact on the cost. However in general the architect/engineering team has the greatest influence [21].

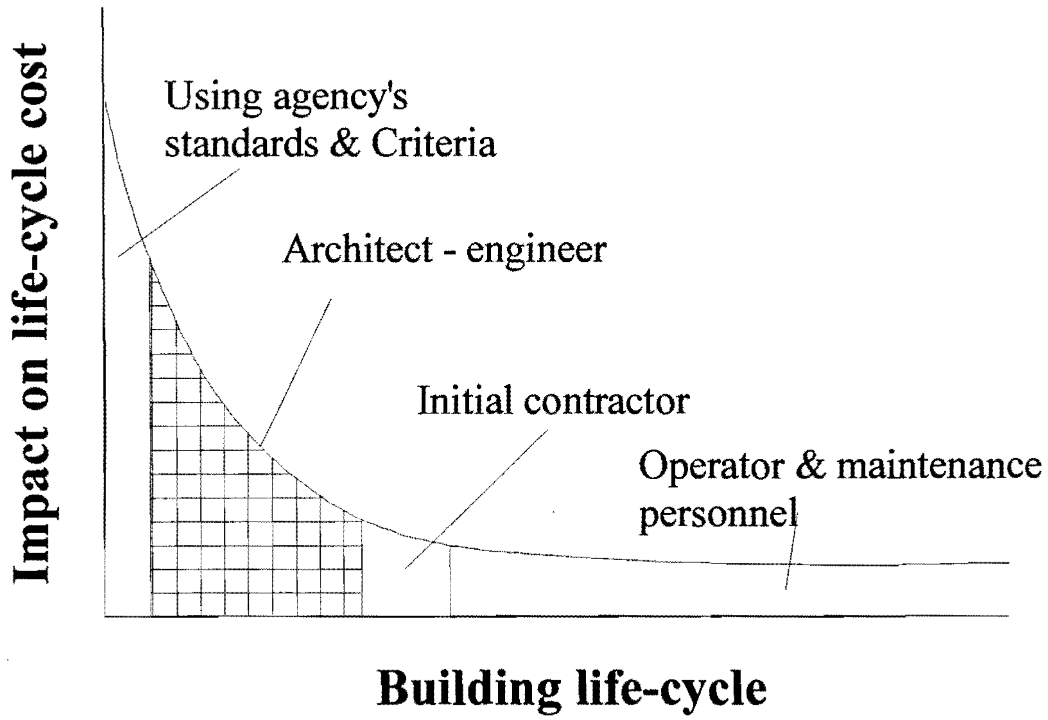

Figure 1.2 - The impact different role players have on building life cycle cost [21].

The importance of architectural and engineering design decisions is further compounded by the relatively long life of buildings. The replacement cost of the total value of buildings in the US during the 1980s was estimated to exceed the Gross National Product (GNP) by 20 to 40% [5]. Existing buildings can thus obviously not be replaced too often. It is therefore not surprising that the design of comfortable, energy efficient buildings is receiving a lot of attention. Research in this field tends to be focused on computer software applications aimed at reducing energy consumption.

1.3 COMPUTER APPLICATION IN DESIGN

It has long been known that computers are better at performing repetitive calculations rapidly, accurately, and tirelessly. Modern design tools are however required to do more than this [22]. Typical requirements of new design tools are to:

- suggest possible solutions,
- compare various designs,
- optimise design solutions,
- analyse economical aspects,
- size the various components,
- compute the performance, and
- verify compliance with, and draw attention to possible conflicts with local regulations.

The availability of relatively cheap and powerful desktop computers has opened up a new treasure chest of design capabilities. Small consulting firms now have access to computing power previously accessible only to research institutions and large companies. This, coupled with enhanced graphic capabilities, has drastically increased the use of computers. A wide variety of design applications are currently available for HVAC and building design. They range from complicated finite element applications to simple electronic nomographs. Their typical applications can be classified into the following groups [22,23]:

1.3.1 Building thermal and energy analysis

These applications are used to calculate the peak heating and cooling loads of buildings. This in turn is used to determine the required HVAC system size. They vary in complexity and accuracy from simple steady-state calculations to finite difference methods. ASHRAE [23] lists what factors to take into consideration when selecting such a design tool. These packages form the link between architect/engineer, buildings thermal shell and system size.

Some of the advanced applications incorporate energy calculations and estimation of installed HVAC and lighting systems. These applications mostly originated during the energy crisis were they formed part of government sponsored research into energy efficient building design, as well as energy audit and retrofit programs. Most of these incorporate some sort of pre-specified HVAC systems. They are however mainly used by research and/or government institutions.

1.3.2 Equipment selection and simulation

ASHRAE [23] identifies three types of equipment related programs. The first group consists of equipment selection programs. These programs are essentially electronic catalogues. Given certain design criteria, these programs will locate a suitable component model number. They are usually distributed by equipment manufactures.

The second group consists of equipment optimisation programs. These programs display a range of possible equipment alternatives. Given design criteria, the program aids the designer in finding the best solution.

The third group consists of equipment simulation programs. They are used to calculate the full- and part-load performance, perform system diagnostics, and for training purposes. Simulation programs can also closely be linked to the above energy analysis programs and integrated computer applications.

1.3.3 System design and sizing

A large number of programs are available for designing and sizing HVAC systems. The most prominent of these are duct and piping system design programs. There are basically two main needs in ducting and piping design, namely sizing and flow distribution. Sizing and system selection forms part of any new system design while flow distribution is required for calculation of flow if the duct sizes and fan characteristics are known.

Some of the programs also perform heat gain calculations, produce a bill of quantity, and perform stress analyses. Duct and pipe sizing are closely related to drafting tools. Quite a few of these programs can therefore be used in conjunction with computer aided design packages.

1.3.4 Computer-aided design (CAD)

Computer-aided design (CAD) systems are tools used for drafting and to some extent as a component database. Drafting forms an important communication media. It conveys pertinent information such as the physical size, as well as the relation of various components to one another. This, coupled with the component database, gives designers a powerful tool for conveying their ideas to the rest of the design team.

One of its most important benefits is that drawings can quickly be created or changed. Small changes do not require a completely new set of drawings to be made. Some of the more advanced CAD programs allow the user to extract material and component data for reports and specifications.

1.3.5 Acoustic calculations

Acoustic analysis is another design area that has benefited from the computer age. According to ASHRAE [23], the analysis of noise in HVAC systems is straightforward. It is however laborious due to the amount of computations involved.

1.3.6 Building regulation and code analysis

These software packages form part of a new generation of design aids. They are especially indispensable in countries with strict building regulations and codes. Designers use them as a quick and easy method for determining whether a new building complies with local codes and regulations. Most of the building regulations and codes analysed by this kind of software are energy related. A typical application is checking whether a proposed construction has a lower overall heat transfer coefficient (U-value) than a specified value.

1.3.7 Administrative and productivity tools

These tools typically consist of word processing, spreadsheet, project scheduling, and accounting applications. Administrative and productivity tools, along with CAD applications, are of the more popular computer tools used by architectural and engineering firms [24].

Except for spreadsheet applications, these tools are not directly linked to the actual building design. They are more likely to be used for the day to day management of projects and company administration.

In summary, it can be seen that there is a wide range of possible applications for computers in the building design field. Converting existing mainframe computer applications so that they can be used on PC based computers, and providing existing programs with user-friendly interfaces are some of the areas receiving a lot of attention. New development in this field tends to be toward integrated building design tools and knowledge-based systems.

1.4 INTEGRATED BUILDING DESIGN TOOLS

Integrated building design systems (IBDS) are seen as the next generation of building design tools. There are two main driving forces behind this development. Firstly, existing software lacks the capability to deal with the complex nature of building design. Secondly, there exists a need for sharing information and for rapid feedback between the various design professions [6,7,11].

By integrating the design tools, a better analysis can be made of the effect that various sub-components will have on the building as a whole. Integrated tools will also allow rapid feedback of analysis results to the various design disciplines. The influence of different design decisions can therefore be investigated quickly. A better understanding of the dynamic component interaction and improved communication will enhance the chances of reaching an optimal design solution.

It is believed that integrated design tools will lead to more energy efficient and environmentally friendly buildings. Two different but overlapping categories of integrated tools can be identified. The first kind focuses more on the physical interaction and analysis between different sub-systems and the second kind focuses more on the exchange of data and information between different building design disciplines.

The basic idea behind the second category is to provide designers with a "toolbox" filled with different design software. These tools all share a central database reducing the need for entering the same data into different applications. Ideally, design tools of the first category will form part of the "toolbox" of the second category. The literature however refers to both types as integrated design tools. They will therefore be discussed separately in more detail.

1.4.1 Integrated building and sub-systems design tools

Ever since the energy crisis of the seventies, researchers have discovered that the efficiency of a building can closely be linked to the interaction of its sub-systems. They found that there is a huge potential for energy savings when closely related system interaction is optimised. Probably the best example of this is the interaction between the building envelope, HVAC system, and its controller.

Numerous energy analysis and system simulation tools have been developed as so-called "integrated" design tools. Some of the tools available include DOE-2 [25], AXCESS[26], COMTECH[27], HAP E-20[28], BLAST[29], TAS[30], TRACE[31], HVACSIM+[32], TRNSYS[33], and QUICKcontrol [34].

The main benefit of these tools is that they give the user an indication of the expected energy consumption of building and HVAC system combination. Different HVAC and control systems or energy savings strategies can be compared and analysed. Combined with economics analysis, they are powerful tools in selecting the best solution for each building. Another benefit of the economic analysis is to convince building developers to invest money in energy savings schemes.

Most of the integrated design tools are difficult and cumbersome to use, and cater more for the research community. Another drawback is that they can require long calculation times, which is unacceptable for use in design. It should also be noted that most tools are not fully integrated [35]. They do not solve the building and HVAC system simultaneously at each time step. This means a real-life situation is usually not correctly modelled [8]. There are however a few, for example QUICKcontrol, that perform an integrated simulation and are still relatively easy to use.

It is hoped that improvements in computing power and more user-friendly operating systems like Windows® will help to make this type of program more accessible. Other practical problems, such as the difficulty of adding or adapting models and numerical instability must also be addressed. Organisations that specialise in building and system simulations and act as consultants for building designers, is one solution. Another is to use systems, which uses a standard for data and information exchange. Users can therefore easily adapt models to suit their needs.

1.4.2 Integrating building design tools

Computer tools already support many of the different building design discipline functions. The information required by these tools frequently overlaps. Current available software however lacks the ability to transfer data between different tools or design disciplines. This is seen as a major obstacle in efficient building design. In order to solve this problem, the concept of integrated building design systems (IBDS) has emerged.

There are two approaches followed in the development of IBDS. The first is the project-driven approach. This is based on pre-specified design scenarios and data requirements. These systems are therefore limited in scope and application. The second, and more popular, is the object-driven approach. The basic idea of the object-driven approach is to use a central database.

The central database contains all the information required to describe the different design objects. This information is structured according to an internationally accepted standard such as the ISO Draft International standard 10303 [36]. New software tools, based on the same standard, can easily be added. This method of data transfer has it origins in the Computer Integrated Manufacture (CIM) community.

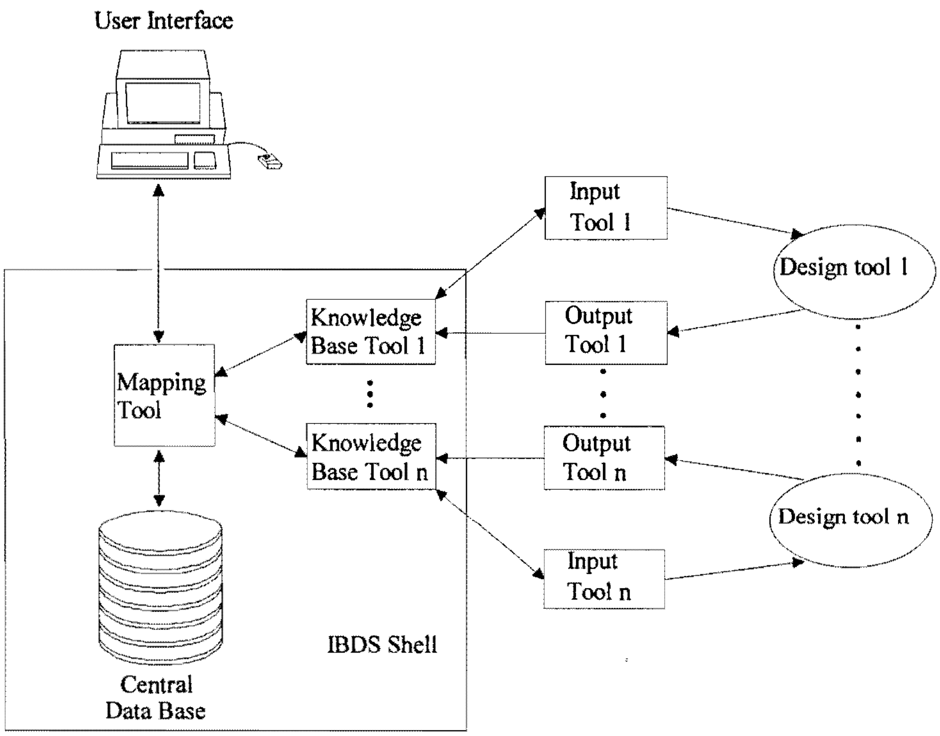

Figure 1.3 – Typical IBDS structure (Adapted from [13])

A mapping tool converts and channels the available information so that the different design tools can access it. This method of transferring data allows for the use of existing software, without the need for significant reprogramming. An added advantage is that designers still use tools that they are familiar with, reducing the need for extra training.

IBD systems are further structured so that any tool can be accessed at any time. Information required by a tool, which is not yet available, can be estimated or added by the designer. Information and results will automatically be updated as improved data is obtained or calculated from a different tool. This open structure does away with rigid or prescriptive design paths that can stifle design creativity.

Some examples of IBD systems are COMBINE (Computer Models for the Building Industry in Europe) as part of the ECjoule program [6,7], AEDOT (Advanced Energy Design and Operation technologies) for the U.S. Department of Energy [37], IISABRE (Intelligent Integrated System for the Analysis of the Building theRmal Environment) developed by the

HVAC Division of Tsinghua University [38], and BDA (Building Design Advisor) developed by the Lawrence Berkley National Lab [39].

The use of a central database has some practical problems. Different design professionals are usually contracted from various consulting firms. Communication between designers customarily consists of regular meetings and the exchange of paper drawings. A survey of thermal simulation tool users further indicates that there is nothing to suggest that electronic communication between firms fits the way they would like to communicate in the future [40]. Updating and exchanging database information is thus hampered.

Improvements in the World Wide Web may in the long run benefit the exchange of electronic data. There will no doubt still be some compatibility problems if designers us different IBD systems. It is therefore believed that these systems will mostly benefit building researchers or other multi-disciplinary institutions.

1.5 EXPERT SYSTEMS

Most of the existing "design tools" perform calculations, simulations and quantitative analyses. It is still up to the designer to present a design solution to be evaluated. They are consequently seen as Decision Support Systems (DSS) rather than true design tools [23,41]. Expert systems or Knowledge Based Systems (KBS) on the other hand are capable of making decisions similar to those made by human experts.

These systems use heuristic strategies, developed by humans, to solve specific classes of problems [42]. Decisions and suggestions made by these systems are based on facts, if-then rules, and models. The rules and information used by the program are gained from various experts in the field. These programs can thus be seen as an attempt to capture the knowledge and reasoning of human experts. The architecture of a typical expert system is shown in Figure 1.4.

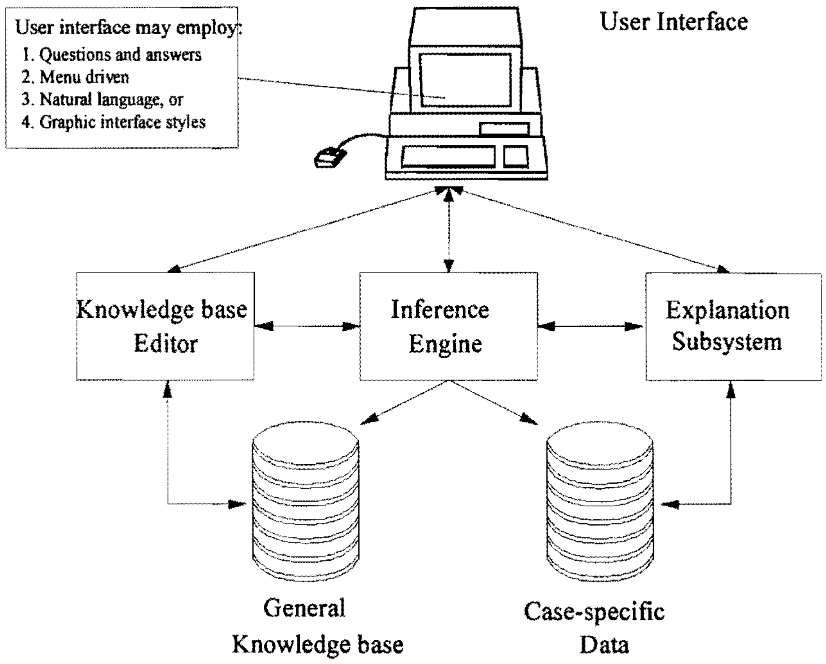

Figure 1.4 – Architecture of a typical expert system (Adapted from [42]).

The system gains problem specific information via the user interface. The inference engine processes this information. The if-then rules and known facts are applied to determine a solution for the problem at hand. These systems are also usually open for inspection. The user may at any stage inquire as to the logic or reasoning followed by the tool. These queries are handled by the explanation subsystem.

Unlike a human expert, these systems cannot learn from experience. Expert systems are limited to the heuristic rules programmed into the general knowledge base. Reasoning and decision making capability are therefore fixed to the information explicitly defined in the knowledge base. Decisions made by these systems are further only as effective as the experts used to compile the rules.

Creating the knowledge base is another problem facing developers of these systems. Gaining and extracting knowledge from human experts and defining it in "if-then" rules is not a simple task. Experts are frequently unaware of the knowledge they have and of the way in which they use it. An additional aspect to take into consideration is that experts may have different and sometimes conflicting sets of rules.

Another inherent trap of using expert systems is that these tools can soon become outdated. This is due to continuous development in the field of building and HVAC systems. Certain rules may become invalid as advances in technology are made and new techniques develop. They also tend to promote building uniformity. This is undesirable from an aesthetic and individualistic perspective [43].

Hall and Deringer [44] provide an extensive overview of research and development done on KBSs in the HVAC field. Typical applications of knowledge-based systems in building and HVAC design are (as adapted from [23,44,45]):

- Building envelope design [46, 47],
- structural design [48],
- building layout design [45],
- system diagnostics [49],
- system selection [50,51],
- control and monitoring [52], and
- building regulation and design code testing [53].

1.6 PROBLEMS WITH EXISTING COMPUTER TOOLS

There are huge design efficiency and energy savings benefits to be gained by using computer tools. This potential is however still largely untapped. Few building designers exploit the full potential of the building design and simulation tools available to them. According to McElroy [54], the use of computers in building design tends to be restricted to CAD and steady state calculations. This lack of widespread use can be attributed to various inherent problems with existing tools.

The main problem identified from the literature is that existing software is complex and difficult to use. The results obtained from existing integrated building and HVAC simulation tools also tend to be either too detailed or too simple to be of practical use to designers [6,15]. In general, these tools are perceived as being too expensive, time consuming or complex to be applied on general design problems [54].

Existing tools also do not always fit well into the current design practices. A typical example being thermal building simulation tools. These tools can greatly aid architects in designing energy efficient buildings, but they require detailed building information. To use the program, the architect must thus already have completed his design. At this stage it is too late for the thermal analysis to be effective in optimising the building thermal characteristics.

Other socio-economic reasons also influence the use of computer design tools. Program vendors do not accept any liability due to decisions made based on results obtained from their tools. Designers are therefore cautious to use methods not proven to be at least as safe and well tried as their traditional methods. According to Batty and Swann [55], some designers also see computers as a threat to their expertise and knowledge, and therefore their salary.

1.7 NEW DESIGN TOOL REQUIREMENTS

Tools that have the capability of improving the general quality of buildings are of no value if they are not applied in the design of new buildings. A workshop held on next generation building simulations tools also indicated that new tools should focus on benefiting practising designers [56]. The problems that designers' experience with existing tools consequently need to be addressed. Simplification of existing tools is probably the single most important requirement.

Complexity of design tools is born out of a growing gap in what researchers and scientists offer as design tools, and what is really used in practice [38]. Researchers and scientists are more technically orientated and require powerful and accurate models that adequately represent real world complexity. Designers on the other hand are more interested in simple, straightforward and intuitive tools.

This gap is especially evident in the user interface and language used to specify input parameters [11,13]. Models that are accurate and represent the real world complexity are more likely to require a user that has a significant understanding of the underlying modelling principals and implementation details. Designers can however be overwhelmed by the amount of information required by some of these tools. This is especially true during the initial stages of design when certain aspects are either still unknown or not yet designed.

Simplifying the data input structure and providing default design values could greatly reduce the complexity of a program. A simple input structure aids designers in providing the required data and default values can be used when the required information is not yet available or if quick estimates are required. Closely related to the simplification of input data is the time required to learn and use the program effectively.

Time is of immense value to designers. Describing and preparing data for thermal building simulation programs can take several days. Designers can however not afford to spend that much time doing this. The same holds true for calculation time and interpreting results. According to Richards [57], errors of up 20 % may be acceptable if the tool answers "what if" questions in minutes rather that hours.

An 80 % accuracy is still within design limits considering the influence that workmanship during construction, and actual utilisation of the building have on the final performance of the building. Reducing accuracy in order to save time and decrease complexity is thus a viable solution.

Language difference between scientists and designers is another barrier. An architect, not well versed in building thermal characteristics for example, will find it difficult to specify the thermodynamic properties of a building. The construction material used can however easily be defined. In doing so, some of the thermal characteristics are inherently specified.

Communication and the exchange of data between different design experts is another important aspect in optimal building design. For various practical reasons it is believed that IBD systems will not be used in the near future, but the idea of transferring data between various design applications is still worth pursuing. Where possible, the data structure of a new tool must therefore still conform to an accepted standard. These tools can then be provided with a means of importing and exporting a standard data file format.

The socio-economic aspects of design tool usage must also be taken into consideration. High on this list is the need for practical verification of all new design tools. This will ensure greater confidence in the use of design tools. Designers also need to be educated about the benefits and limitations of using these tools [55]. Marketability of design tools must also be considered. According to Stevens [24], tools that can be used to impress clients and therefore serve as a marketing tool are more likely to be used by designers.

Most of these requirements are not new. They were first identified during the third International Congress on Building Energy Management (ICBEM) in Lausanne [58]. According to Holm [59], these requirements are however too vague. Tools satisfying these requirements are not guaranteed to succeed. To be truly effective new software must also be developed in close co-operation with the designers it is intended for.

1.8 STUDY OBJECTIVES

It is believed that practical, easy to use design tools can be obtained by addressing the identified design tool requirements. Thermal efficiency of buildings and the selection of HVAC systems are two areas that can benefit from simplified tools. These aspects have a large influence on the socio-economic success of a building, but do not receive the necessary attention due the complexity and the time required for analysing the various options sufficiently.

Thermal characteristics of a building are mainly influenced by architectural design decisions made during the preliminary design stages. A need thus exists for a simplified analysis tool suited for architectural use. The first objective of this study is to develop such a design tool. This consisted mainly of:

- Simplifying input complexity by identifying and focusing on critical parameters.
- Defining input parameters in architectural terms.
- Verifying that the tool provides answers of suitable accuracy.
- Developing a simple means of comparing and rating design efficiency.
- Evaluation of design tool suitability by practising designers.

HVAC system selection ideally consists of a detailed integrated system and building performance analysis of all the systems being considered. It is however impractical and very time consuming. A simplified preliminary selection tool can aid designers in reducing the number of systems to consider to two or three. The need for detailed analysis can thus be significantly reduced. The second objective of this study is to develop such a tool.

Bloom [60] states that "communication or the lack thereof is one of the prime areas of conflict. At least four of the 15 failure factors are as a result of poor communication during the design stage". A secondary objective of the selection tool is thus to aid the designer in determining the owner's true requirements and expectations of the HVAC system performance.

1.9 CONCLUSION

Designers are increasingly pressured to design buildings with high standards of energy efficiency, performance and comfort. Computers are seen as an important modern design tool that can help lighten some of the designers' burdens. A myriad of computer applications already exists, ranging from complex finite-element applications to simple electronic nomographs. New development in this field tends to be in the areas of integrated building design and knowledge based systems.

Researchers and scientists can develop tools with the potential to greatly enhance the quality of buildings. These tools will however fail if they are not widely accepted and used by designers. Only a few building designers currently exploit the full potential of computer design tools. The general use of computers seems to be restricted to CAD and steady state calculations. This can mainly be attributed to the complexity of, and time required, for using the existing tools.

New computer design tools should address the requirements of building designers if they are to succeed in benefiting the building industry. It is important that new design tools be developed in close co-operation with building designers. In general the requirements for new design tools are:

- The tool should be simple and straightforward to use.
- It should provide default values for unknown variables. This will be especially valuable during the preliminary design stage.
- Time required to learn and use the software must be as short as possible (minutes rather than hours).
- Output should be simple yet informative.

- It should use a language familiar to designers.
- The tool must be verified and tested by designers.
- New tools should make provision for easy data transfer between different design tools.

Most of these requirements are not new. It is however clear from the literature that these items have still not been addressed to the satisfaction of designers. There is therefore still considerable scope for improvement in making design tools accessible to designers. This study addresses some of the needs by developing new simplified building and HVAC design tools for building designers.

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