1

Prologue

1.1 Introduction

We are entering a new decade where the environment and pollution are some of our biggest concerns, but we are still burning a dwindling amount of irreplaceable fossil fuel for our energy needs (Clarke & Maver, 1991:25). Atomic energy did not live up to its expectations mostly because of its negative environmental impact and 'Green' politics. The search for an economically viable source of environmentally friendly energy has not produced any likely candidates. Therefore, there must be more awareness of environmental issues in engineering. Unfortunately economic and technical issues are still the major factor behind most engineering decisions (Beck, 1993:10). There is however, potential to reduce energy consumption in buildings (Clarke & Maver, 1991:25).

1.2 Potential Impact and Trends

Buildings have been identified as one of the largest users of energy. Buildings account for approximately 40% of the energy used in developed countries. Of this approximately 50% is used for air-conditioning. From these figures one can make an assumption that approximately 10% of the global energy supply is used to air condition buildings. This makes the efficiency of air-conditioning systems a global concern (Rousseau & Mathews, 1993:439).

Energy savings of around 30% is said to be possible with better designing of buildings, air-conditioning and control systems (Rousseau & Mathews, 1993:439). UK Department of Energy suggested that better designed new buildings can reduce energy consumption by 50% and that the retrofit of old buildings with better designed systems can improve their energy consumption by 25% (Clarke & Maver, 1991:25). A reduction of approximately 2.5% in global energy consumption can be expected if the optimistic figures in reduction in energy consumption in new and retrofitted buildings are used.

Several companies and institutes started design philosophies that reduce the energy consumption of office buildings. The US-based Pacific Gas & Electric initiated the Advanced Customer Technology Test (ACT^2). With this they plan to reduce the energy consumption index from 1050 $MJ/m^2/yr$ for a base case design to 300 $MJ/m^2/yr$ for a super-efficient designed building. The Energy Edge Building is Bonneville Power Administrations program to reduce the energy consumption of buildings by 30%. They hope to achieve an energy consumption index of approximately 503 $MJ/m^2/yr$. Natural Resources, Canada's C-2000 program, used the Integrated Design Approach (IDA) to design a building with a predicted energy consumption index in the low 300 MJ/m^2/yr range. An energy consumption index in the low 300 MJ/m^2/yr range is also the target of the Energy Efficient Office of the Future (EOF) program of the Building Research Establishment (BRE) based in the UK (Todesco, 1997: 43).

Integrated Design Approach (IDA) is a system designed to reduce the cooling load and equipment size by using high insulation level, equipment with the highest efficiency and the extensive use of day lighting. Emphasis is also placed on the commissioning of the building to ensure that the equipment operates as designed. Pilot programs that used IDA have shown that reductions of 30% to 50% on energy use compared to ASHRAE Standards 90.1 is possible without difficulty or expense. The IDA process is graphically represented in Figure 1 (Todesco, 1997:45).

The cost of an HVAC system design using this approach is less or very close to that of a base case system (Todesco, 1997:45). This is due to the interaction between all the elements in the design. The positive effect of higher cost of the insulation and lighting is a lower cooling load. This in turn leads to a smaller cooling system that in turn costs less (Todesco, 1997:53). In light of global environmental concern, this type of design philosophy should be the way of the future.

Sustainable design is used in the building industry as a method to design buildings that reduce the environmental impact of a building (Beck, 1993:10). A key point of the sustainable design approach is IDA (Beck, 1993:11). The emphasis of the design is also on reducing the energy and water use. The use of nontoxic and environmentally friendly materials are also advised. Although there is a growing awareness of environmental issues, most decisions are still made on economic bases. Fortunately a design that reduces energy and water also reduces energy cost and sometimes life-cycle costs. Beck (1993:10-11) states that environmental friendly designs first costs may be higher but also agree with Todesco (1997:53) that this is not always the case.

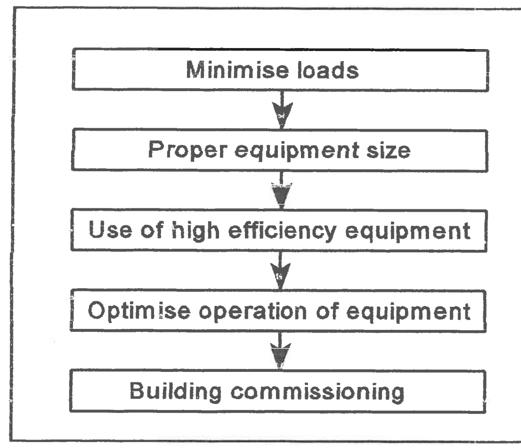

Figure 1 Process flow of IDA

There is also a move to integration of building systems via Integrated Building Management Systems (IBMS or BMS) (Clark & Metha, 1997:481). The BMS can manage the building automation, information processing and communication (Arkin & Paciuk, 1997:471). BMS could react quickly to changes in the building and adjust energy consumption accordingly. BMS can also minimise the energy cost of a building in controlling the maximum electricity demand by selectively reducing lighting levels in perimeter zones, reducing HVAC loads, reducing lift speeds or even stopping a number of lifts (Clark & Metha, 1997:485). It should also be possible to alter the HVAC load by either predicting occupancy or monitoring the building access control system (Clark & Metha, 1997:481). Integrated management systems could also be used to prevent sick building syndrome (Arkin & Paciuk, 1997:471).

Sick building syndrome is the worst case aftermath of a building designed for aesthetic reasons with a disregard for the energy efficiency of the HVAC system. The end result is a building that has high energy costs and a high level of tenant complaints (Blaine, 1993:29).

1.3 Definition of the Problem

Even though IDA and BMS show potential to reduce energy consumption, HVAC systems have been shown in studies to be the one factor mostly mentioned by tenants as the reason why they have relocated. Owners are realising that the HVAC system is one of the important elements that govern the renting and resell value of their buildings (Linford, 1997:77).

There are unfortunately still some problems experienced in the design of energy-efficient green buildings. One of these is that the performance of an HVAC system cannot easily be described because of the complex interaction of all the components (Rousseau & Mathews, 1993:441; Clarke & Maver, 1993:25). This leads to the designer overdesigning the HVAC system. This system then runs at a less efficient setpoint which increases the energy usage (Rousseau & Matthews, 1993:440).

The design of an HVAC system is complex (Rousseau & Mathews, 1993:442; Tseng, Harmon & Edwards, 1993:959). It requires time which most HVAC system designers usually don't have a lot off because in practice they are often forced to work on a number of projects simultaneously. There is then little time to optimise the design to reduce energy consumption (Rousseau & Mathews, 1993:442). The complexity of the design process poses another problem. Engineering and construction experience is needed to make an intelligent analysis of a building and HVAC system. Linford (1997:79) also states that a recently graduated mechanical engineer will not clearly understand the complex nature of an HVAC system and how each of its components interacts. Linford's (1997:79) experience showed that three to five years of experience needs to be acquired. This is then followed with a lifetime of acquiring experience that adds to the engineer's knowledge base (Linford, 1997:79).

One of the key items of the IDA design philosophy is correct sizing of the equipment to design better and more efficient buildings (Todesco, 1997:45). One method to achieve this is by using a computerised load simulation program. These programs can calculate the necessary loads and can show if a system is applicable for a building. The program can also calculate the yearly energy use which can be used to make design changes to a building to reduce its energy consumption (Barat, 1991:100). Load calculation programs are already in their third to fourth generation (Clark & Maver, 1991:26). Programs like New Quick (TEMMI) are easy to use because they have a good human computer interface. It is a design tool that simulates the building, air-conditioning system and the control system as a unit ((Mathews,Van Heerden & Arndt, 1999:429-449). This integration of a design tool is also advised by Rousseau and Mathews (1993:449).

Unfortunately most energy models need large amounts of input data of which some are difficult to obtain and for which some technical HVAC background is needed (Clark & Maver, 1991:31) (Barat, 1991:100). Most of these inputs are not available in the brief and preliminary stages of the design (Clark & Maver, 1991:26). There are also time constraints usually involved in the brief and preliminary design stages.

The selection of an HVAC system also requires experience that makes it difficult for persons with limited technical experience to select a system (Linford, 1997:79). A selected HVAC system is needed to calculate the life-cycle and energy cost.

Another problem is that HVAC engineers are not included in the early stages of the design of the building when the customer/developer and the architect meet. The engineers can give valuable insets for the architect on how his design affects the energy needs of the building and what materials to use to improve the efficiency of the building. Information about space requirements and aesthetics of a selected cooling system can also be given (Beck, 1993:11). This information includes the space requirement of ducts, plant rooms, cooling towers or wall-mounted units (Gupta, 1997:55). The developer can then also see what effects each design has on initial cost and life-cycle cost of the building. Nothing in the design of the building must be done that does not make economical sense, although saving energy is morally and politically correct (Linford, 1997:78-79).

1.4 Aim

A simplified simulation program for use in the brief and preliminary stages may be of help to consultant engineers, sales representatives, and architects to overcome some of the problems mentioned above. Such a program will have to give a reasonable answer while using sketchy input data. It will also have to give an idea of the cooling load, help with system selection and must give preliminary values for life-cycle cost, energy cost and space needed for a selected cooling system.

The purpose of this thesis is to lay a foundation for the creation of an expert system that will help consultant engineers, sales representatives and architects to size, select and budget HVAC systems in the preliminary and brief design stages. The first step in creating the program is to define an ideal program. This is done by analysing the needs of the users and the inputs that are available. Once this is done several characteristics can be defined which give a general feeling of how the interface will look. Some characteristics are unobtainable and in other cases certain trade-offs have to be made between them. This makes it important to set priorities between characteristics.

The ideal program consists of three modules. The modules are the load calculation module, the system selection module and the cost calculation module. All the modules should be able to work on their own and should also form a unit where each module result is used as the next module input. The interaction of the modules is shown in figure 2.

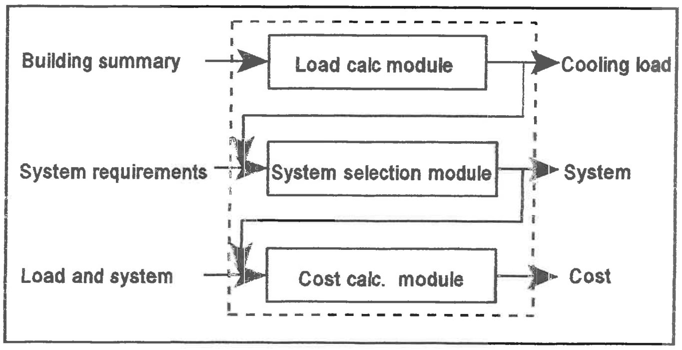

Figure 2 Module set-up and interaction

The program must be fast because of the time constraints, very simple to use, very user friendly and should be able to operate on a laptop computer. The interface of the program should make it possible to use the program in a meeting between the consultant engineer, architect and the developer or while the engineer is in contact with the developer over the phone. The needs of the developer and architect should real-time (in a meeting) be converted into realistic maximum cooling load, selected cooling system, life cycle cost, energy cost and space needed for the cooling system.

Another specification is that a person with a limited HVAC background (for example: sales representative) should be able to use this program. The program should give reasonable results from sketchy inputs and must assume more technical input from inputs that the person has entered. The selection module must be able to deduct the design specifications from the answers of several questions that the program asked. The cost module must be able to translate the calculated load and selected system into life-cycle and energy cost.

In Summary

- *The ideal package consists of the following:*
  - *Cooling load calculation module:*
    - *Inputs:* *Summary of the building*
    - *Output:* *Cooling loads required*
  - *System selection module:*
    - *Inputs:* *System requirements*
    - *Output:* *Selected system*
  - *Cost Calculation module:*
    - *Inputs:* *Cooling loads required*
    - *Selected system*
  - *Output:* *Costs of system:* *Initial cost*
    - *Running cost*
    - *Energy cost*
- *Characteristics of the ideal program:*
  - *All the modules must be very easy and fast to use.*
  - *The modules input must limit technical inputs.*
  - *The modules must be able to interact with each other.*
  - *The program must be fast enough to be used in a meeting.*
  - *The load calculations must be reasonably accurate.*

The development of the load calculation and system selection modules of this design tool for the brief and preliminary design stages are discussed in the next chapters. The aim of development was to get the modules as close to the ideal package as possible.

2

Expert System Development Method

2.1. Introduction

Computer programs make it possible to design better systems more effectively (Ahart, 1995:154). Computers have become affordable, more powerful and large inexpensive storage space plus CD ROM's make it easier to store large volumes of information (Ahart, 1995, p 154). This and the use of MS Windows 3.1 and MS Windows 95 have helped in the creation of a number of user-friendly HVAC design software (Smith, 1996:83). A system to develop an expert system will be discussed in this chapter. This system can be used for the development of most software (Wolfgram, Dear & Galbraith, 1987:16).

2.2. Stages of Development

The simplified cooling load calculation and selection modules were designed and implemented using a system for the development of expert system software (Wolfgram, Dear & Galbraith, 1987:141). The development system consists of a number of stages with different goals that have to be achieved.

Stage 1: Identification and Definition

This stage has to do with the identification and evaluation of the problem. This includes determining the problem domain, scope, potential users and the appropriateness of the application. The hardware and software needs must also be determined. The benefits and costs of the system are also determined. Project effort, which include things like duration of the project, time and cost, must also be evaluated. Knowledge discovery is the next stage after the problem has been defined. (Wolfgram, Dear & Galbraith, 1987:142-149).

Stage 2: Development of a Prototype

Knowledge discovery is the main aim of the second stage. The knowledge can be obtained from two primary sources, domain independent and domain dependent information. Domain independent information is usually public archival information in the form of books, journals, pamphlets, and articles. This information is used to become familiar with the problem. Domain dependent information consists of a report from internal research and development projects and information from the expert. This information is already more specified and mostly applicable to only a small domain. The information that the expert gives is important because it can contain situational data, relationships of problems, tendencies, starting point for trouble shooting, what to look for and procedural rules.

The knowledge acquisition process begins by familiarising oneself with the problem and with the jargon used by the expert. It is important to understand what the expert is saying. The next part of the process is to interview the expert about the problem and to find out how the expert typically solves the problem. It may happen that an expert omits information. This sometimes happens because the expert considers certain information as common knowledge. Other experts must then be interviewed to clarify the issue if there are discrepancies in the information that was obtained. In the last part of this stage the information must be analysed, validated and then coded.

The development of the prototype can start once all the information has been gathered and verified. A good understanding of the problem and the information is also essential in this stage. Microcomputers are usually used as a development platform of the prototype. A developed inference engine and knowledge base must be written from scratch if no development tools are used. A number of things must be considered when designing the prototype. This includes the amount, reliability, consistency, relationship of the data and methods of maintaining the data. It is preferable if the expert system can be shown in a descriptive visual model that clearly indicates the problem solving process. Hypotheses and procedural rules must also be considered. The construction of the system can now start after the prototype has been completed. (Wolfgram, Dear & Galbraith, 1987:150-152).

Stage 3: Construction

The prototype is completed in the construction stage by completing all the rules and interfaces of the expert system. Detailed "personal" and "private" knowledge of expert must be accurate at this stage of the project. The system must also be evaluated to determine if it is worth going on with the project. The full cost of the system must therefore be defined. The cost can typically be divided into software, hardware, and development. This will influence the decision to proceed with the project or not. The testing and evaluation stage of the system is used to determine the progress of the project. (Wolfgram, Dear & Galbraith, 1987:152-156).

Stage 4: Testing and Evaluation

The performance of the expert system is usually evaluated against a standard. This can be problematic if no clear standards are available. Objectivity is another problem in the evaluation of the systems because the analysis is subjected to personal interpretation. It is therefore very important to stay objective in this stage. The main evaluation criteria is user acceptance of the system. Performance, completeness and accuracy of the system must be evaluated. The effect and value adding benefits of the system must also be determined. It is important to consider the liabilities and the risk involved because of the use of the expert system.

Feedback in the development stage must be incorporated. Evaluation can be divided into formal and informal evaluations. Formal evaluations take the form of planned milestones while informal evaluation generally in the form of a general review. The user would typically like a system that is simplistic in the amount of computer expertise needed. Systems advice must be useful and it must be able to explain and justify its answer if problems arise. Response time is important because the user wants "natural" conversation without pauses of several minutes.

Critical performance and valuation check is done by executing several test scenarios for which the expert has solved or checked for correct answers and reasoning. Test for completeness and consistency is done by static testing while dynamic testing tests the reasoning of the system by using audit trails. Accuracy of 90% - 95% should be aimed at.

The results of the test must be evaluated against the time and money that the expert system cost. In short does the system improve productivity and is it effective? The liability risk of the expert is a very important consideration. It is critical to know what effect/cost an error of the expert system has.

It is preferable to have reasonable milestone evaluations during stages two and three to improve the chances of developing a successful expert system. It has been shown that long prototype and testing periods are preferable because it is easier to test working prototypes than prototypes on paper. It also makes it possible to test realistic problems. This type of development has the added advantage that it improves the moral of the development team. (Wolfgram, Dear & Galbraith, 1987:157-160).

Stage 5: Integration and Implementation

The expert system can be released after it has been successfully evaluated and tested. This stage also includes the training of users, completion of user guides and software documentation. It is also sometimes necessary to port the system to other hardware and software platforms. The system must also be promoted in the organisation. Its acceptance will depend on its ability to offer the organisation productivity gains. (Wolfgram, Dear & Galbraith, 1987:160-161).

Stage 6: Maintenance

This stage of the project is usually not done by the developer of the system. It is necessary to do maintenance on the system because no environment stays static. New knowledge that is discovered can enhance the domain and improve the heuristics of the system. Debugging to improve the code is also necessary and the user interface may also have to be improved. Changes in hardware and software may entail major changes to the system. Any problems must be located and new information must be evaluated and added to the knowledge base. (Wolfgram, Dear & Galbraith, 1987:161).

2.3. Implementation

The development of the cooling load calculation and selection module will be discussed in the next four chapters. It will follow the outline of the development method discussed in the previous section. Only the first four stages are applicable on the modules. The first three stages of the development of the simplified cooling load calculation method are in Chapter Three. The results of this module are then discussed in Chapter Four. Chapter Five similarly contains the first three stages of the development of the selection module while the results of the selection module are discussed in Chapter Six.

3

Simplified Load Calculation Module

3.1 Introduction

One of the key items of the IDA design philosophy, as discussed in the prologue, is the correct sizing of HVAC equipment (Todesco, 1997:45). The development of the first module, the load calculation, will be discussed in this chapter. The simplified cooling load calculation module was designed and implemented using the system discussed in the previous chapter (Wolfgram, Dear & Galbraith, 1987:141). The development system was simplified because the cooling calculation module on its own is not an expert system.

3.2 Stage 1: Identification and Definition

The problem has been discussed in detail in section 1.3 of the prologue. The aim of the program, as discussed in section 1.4 of the prologue, is to create a simplified cooling load calculation program for the brief and preliminary stages of HVAC design.

The cooling load calculation module on its own is not an expert system. It is simply a coded calculation method. In the selection of a cooling load calculation method, some of the simplifications and assumption however need some expert knowledge. The cooling load calculation method is a useful and integral add-on to the system selection module which will be discussed in Chapter Five.

The expert system development method was still followed because it gives a structured approach to the design of software. The potential users of the module, as highlighted in section 1.4 of the prologue, are consultants, architects, and sales representatives. People with limited technical knowledge must also be able to use the cooling load calculation module. The load calculation module must therefore be easy to use and must not require many inputs. The input must make use of easily understood multiple options. This will limits the user's inputs.

Consultant engineers must be able to guarantee the quality and reliability of the work done in a design (Marther, Mazzuchetti & Watson, 1994:18). The accuracy of the load calculation unit should therefore be in certain allowable tolerances. A tolerance of ± 10% was set as the aim for the simplified load calculation module in respect of electrical analogy model(Mathews, 1986:35-39; van Heerden & Mathews, 1996:223-228).

The hardware and software requirements were determined with the target group of users in mind. Microcomputers, better known as desktop computers, personal computers or PC, are widely used, mostly running Windows 3.11, 95 or 98 as their operating system. These operating systems offer a graphical, mouse-driven environment for which it is easy to write user-friendly programs. It is also relatively easy to produce a professional-looking product. Borland Turbo Pascal for Windows was selected as the development language because it was the language used by the research group in which this study was done. Pascal supports window programming and is an easy language to learn although window programming can get complicated and tedious. Rapid development language, like Delphi and Visual Basic, may have been a better option. The development of the prototype will be discussed in the next section.

3.3 Stage 2: Development of a Prototype

The development of a prototype starts with knowledge discovery. The knowledge used for this module comes mainly from domain independent sources like textbooks and articles. The basic components that affect the cooling load will be discussed next.

The heat transfer into and out of the building is affected by the materials used; the geometric factors such as size, shape, and orientation, by internal loads; and climatic factors. Thermal storage also affects the cooling load requirement. The main function of heat-loss and heat-gain calculations is to estimate the heating /cooling capacity required of the heating and air-conditioning components. The loads calculated can be divided into the following four categories:

- *Transmission.* Heat loss or heat gain due to a temperature difference across a surface.
- *Solar.* Heat gain due to transmission of solar energy through transparent surfaces.
- *Infiltration.* Heat loss or gain due to the infiltration of outside air.
- *Internal.* This is heat gain due to lights, people and equipment (Stoecker, W.F. & Jones, J.W.1982:63-64).

The next step is to consider a number of cooling load calculation methods to determine which will be the most appropriate for this application. First generation load calculation methods are very simple, well established and are reasonablely accurate although mistakes of up to 25% have been recorded. These textbook-based load calculation methods use empirical data from tables to calculate the heat transfer. The electrical analogy-type load-calculated method is ideally suited for integrated building simulations but is more complex and needs more technical input.

In the brief and preliminary design stages the inputs are mostly very sketchy or non existing. This makes it possible to consider the use of a textbook-based cooling load calculation method. An advantage of this type of method is that it uses tables to calculate the cooling load. This has the effect that the load calculation is very fast. This is becoming less of an advantage as the speed of computers increases. Tables also make it possible to limit very technical inputs to only one table option.

The users therefore do not have to worry about the specific thermal resistance of a sandwich material which is several layers of different material next to each other that form a boundary. The module can use the value in the table for the sandwich material that the user has chosen graphically. The use of a textbook-type method will limit the use of the module to the brief and preliminary design stage because it can only calculate the passive building load.

Five cooling load calculation methods were considered for the simplified load calculation module. Only textbook-based load calculations and thumb rule type of calculation methods were considered. Thumb rules are generally crude and fast methods to get approximate values fast.

CARRIER Cooling Load Calculation Method

The CARRIER method is a well-established table-based calculation method. The method is simple and fast to use. The large number of tables used can slow the calculation process down. CARRIER takes wall, floors, window, roof area and type into account. It also has a large number of insulation types for each of the above. Thermal storage is also taken into account. It also incorporates the effect of internal loads and people. The method further has typical bypass and fresh air volume for a number of building types. The method also clearly shows how to convert northern hemisphere tables to southern hemisphere tables. A major drawback of this method is the fact that the information is in British units. It will therefore be necessary to convert all these tables into SI units if this method is used. CARRIER method shares its negative points with other table-based methods in that it cannot calculate the passive performance of a building and outdoor and indoor set points are taken as fixed. The CARRIER method is discussed in detail in the CARRIER textbook (Carrier Air-conditioning Company, 1969:1.1-1.113).

ASHRAE CLTD Cooling Load Calculation Method

The ASHRAE CLTD method is another well-established table-based calculation method. The method is also simple and fast to use. Similar to the CARRIER method the large number of tables used can slow the calculation process down. An equivalent temperature difference method was developed by ASHRAE called the cooling-load temperature difference (CLTD) to incorporate the effect of thermal storage of commonly used walls and roofs. The CLTD method, like CARRIER, takes wall, floors, window, roof area, and type into account. It also has a large a number of insulation types for each of the above. It incorporates the effect of internal loads and people. The detail of the method is discussed in ASHRAE fundamentals' handbook. The CLTD has the same drawbacks as the CARRIER method in that it cannot calculate the passive performance of a building and the outdoor and indoor set points are taken as fixed (ASHRAE, 1992:66.33-66.49).

Simplified Thumb Rule Cooling Load Calculation Method

A thumb rule mentioned by sales representatives for window-mounted and small split units calculate the maximum cooling load by multiplying 500 - 600 BTU/hr with the floor area. This very simple calculation is popular for application where an HVAC system must meet the needs of a single office. They use their discretion to choose between the two values. They will typically use the higher value if there is more than one person in the office. The methods tend to overestimate the load but the sales representatives say that they rather over specify the unit to ensure the client is happy. This method is very simple and easy to implement but from an unknown source and accuracy.

Panasonic Cooling Load Calculation Method

This method is a simple and fast method to calculate a cooling load. The method was designed to calculate the load for the installation of unitary systems. The method uses a table to do the calculation. The method does not take the wall, floor and roof type into account.

Item		Quantity	Outside design deg. °C					(Quantity x factor) BTU/HR
			32	35	38	41	45	
			FACTOR					
1. Floor area		m²	24	32	52	76	100	
2. Room volume		m²	20					
3. Windows exposed to sun (use only the exposure with the largest result)	South latitude							
	N or E	m²	460	480	540	600	600	
	NW	m²	840	880	920	980	1040	
	W	m²	1140	1200	1260	1320	1380	
	NE or SW	m²	620	660	700	760	820	
4. All windows (not including item 3)		m²	120	160	220	280	340	
5. Wall exposed to sun (use only the exposure used in item 3)		m²	120	140	180	200	228	
6. All exterior walls (not including item 5)		m²	68	100	148	180	220	
7. Partitions (all interior walls adjacent to an unconditioned space)		m²	32	44	68	84	100	
8. Ceiling or roof	Ceiling (with unconditioned space above)	m²	24	32	52	76	100	
	Ceiling (no insulation)	m²	88	108	140	160	180	
	Ceiling (50 mm or more insulation)	m²	32	32	44	44	56	
	Roof (no insulation)	m²	184	212	236	264	288	
9. People (number of people)		no.	600					
10. Lights & electrical equipment in use		w	3					
Total cooling load							**BTU/HR =**	

Thumb Rule Cooling Load Calculation Method

This method consists of several empirical maximum and minimum cooling load values per floor area. There are different values for different types of buildings.

Type	Maximum (m^2/KW)	Minimum (m^2/KW)
Apartment building	9.253	13.219
Auditorium - theatres (Seats / KW)	5.123	6.261
Banks	5.816	6.609
Barber shops	5.287	6.609
Beauty parlours	5.287	6.609
Bowling alleys (KW / alley)	7.379	7.906
Churches (seats / KW)	5.123	7.115
Cocktail lounges	3.966	5.287
Computer rooms	2.115	3.966
Dental offices	5.287	6.609
Department stores	7.931	9.253
Dormitory	7.402	9.253
Dress shops	6.609	7.931
Factories	7.931	9.253
High-rise office buildings	7.402	8.460
Hospitals - nursing homes	6.874	7.931
Hotels	7.402	8.592
Libraries	6.609	7.402
Medical centres	9.253	10.839
Motels	7.402	8.460
Post offices	7.931	8.460
Residences	13.219	15.862
Restaurants	5.816	6.609
Schools	6.609	7.931
Shopping centres	7.931	9.253

The table above was converted to SI units and comes from Design and Estimating for Heating, Ventilating, and Air-conditioning by Rizzi (1980:353). This method does not take the wall, glass and roof type or area into account. It also only takes people into account for auditoriums and churches. This is an easy method to convert to a computer program.

Selection

The thumb rules methods were not seriously considered because of their questionable accuracy. The Panasonic method was designed for sizing of unitary systems and may not be appropriate for sizing of other systems and was therefore not selected. This left the two texts book methods that are very similar. The CARRIER method was selected because it clearly shows how to convert northern hemisphere tables into southern hemisphere tables. It, like the CLTD method, takes wall, floors, window, roof area and type into account. It however has a larger number of insulation types for each of the above. The wall, roof, window and floor tables also lend themselves to graphical selection. Like the CLTD method, thermal storage is also taken into account. So too is the effect of internal loads and people. The method further has typical bypass and fresh air volume for a number of building types. The table can easily convert from British units to SI units by a computer program. A number of simplifications were done to the method to reduce input and make some of the inputs easier. These simplifications will be discussed in the next section.

Prototype

The development of the prototype can be started with the cooling load calculation method selected. The prototype load was coded in Turbo Pascal for DOS running on Windows. Some simplification and assumptions were done to the basic CARRIER method to reduce the inputs that are necessary. They are:

- The whole building was taken as one zone.
- Only four walls can be specified in the north, south, east and west direction.
- Only one type of wall, thickness, and insulation can be selected for all four walls.
- Only four glass areas can be specified in the north, south, east and west direction.
- Only one type of glass and shading can be selected for all four glass areas.
- Only one floor area and type can be specified.
- Only one roof area and type can be specified.
- No indoor partitions can be specified.
- The internal load of the building must be given per footprint floor area. The floor area on the ground level is called the footprint area of the building.

The following assumptions were also made:

- It is assumed that the maximum load will be at 15h00.
- When the user selects a building type, the module uses tables to get typical values of:
    - Bypass factor.
    - Ventilation standards.
    - Heat gain from people
- The module calculates the mass of the building by using the mass of the material selected for the walls, glass, floor and the roof. This is used to select the storage factor.

This reduces the input that the program needs to:

- Building = What type of building is it
- Hemisphere = In which hemisphere is the building
- Latitude = At what latitude is the building situated
- Altitude = At what altitude is the building situated
- Month = For what month must the calculation be done
- Bypass factor = The bypass factor used. This is defined by the type of building
- People = Number of people in the building
- Input power = Internal power load in W/m^2 of footprint floor area
- Temperature inside = Inside design temperature (°C)
- RH inside = Inside design relative humiditie (%)
- Temperature outside= Outside temperature (°C)
- RH outside = Outside relative humiditie (%)
- Wall area (North) = Wall area of the northern side of the building (m^2)
- Wall area (West) = Wall area of the western side of the building (m^2)
- Wall area (South) = Wall area of the southern side of the building (m^2)
- Wall area (East) = Wall area of the eastern side of the building (m^2)
- Wall type = What type of wall is used
- Wall thickness = What is the thickness of the wall (mm)
- Wall insulation = What type and thickness insulation is used for the walls
- Glass area (North) = Glass area of the northern side of the building (m^2)
- Glass area (West) = Glass area of the western side of the building (m^2)
- Glass area (South) = Glass area of the southern side of the building (m^2)
- Glass area (East) = Glass area of the eastern side of the building (m^2)
- Glass type = What type of glass is used
- Shading type = What type of shading does the glass have
- Floor area = Footprint floor area of the building. This is the ground floor area (m^2)
- Floor type. = What type of floor is used (m^2)
- Floor thickness = What is the thickness of the floor (mm)
- Insulation = What type and thickness insulation is used for the floor
- Roof area = Roof area of the building (m^2)
- Roof type = What type of roof is used
- Roof thickness = What is the thickness of the roof (mm)
- Roof insulation = What type and thickness insulation is used for the roof

The simplified Carrier method used in the module will now be shown. The module uses the reduced inputs given above. The formulas, tables, constants and inputs used in the module will be given. First the formula will be shown after which each of the components that are not inputs will be discussed. It will typically take the form:

SF = Shading factor = f (Glass type, Shading type) see Table 16

Where the first part, for example SF, is the abbreviation that is used in the formula. The next part shows that, for example, the abbreviation SF stands for Shading factor. The last part shows that SF is a function of Glass type and Shading type and the information is in Table 16 of the CARRIER textbook. The discussion of the method will follow the general format of the " Air-Conditioning Load Estimate" form. (Carrier Air-conditioning Company, 1969:1-124)

Solar Gain - Glass

q_1 = Glass area (north) * SHG * SF * SLF (1)
q_2 = Glass area (west) * SHG * SF * SLF (2)
q_3 = Glass area (south) * SHG * SF * SLF (3)
q_4 = Glass area (east) * SHG * SF * SLF (4)

where
SHG = Peak solar heat gain thru.glass = f (Latitude, Month, Hemisphere) (W/m^2) see Table 6
SF = Shading factor = f (Glass type, Shading type) see Table 16
SLF = Storage load factor = f (Exposure, Building weight, Hemisphere, Time) see Table 10

Solar and Transmission Gain - Walls and Roof

q_5 = Wall area (north) * ETD * TC (5)
q_6 = Wall area (west) * ETD * TC (6)
q_7 = Wall area (south) * ETD * TC (7)
q_8 = Wall area (east) * ETD * TC (8)

where
ETD = Equivalent temperature difference = f (Wall weight, Exposure, Time, Hemisphere) (°C) see Table 19
TC = Transmission coefficient (W/m^2)(°C) = f (Wall type, Wall thickness, Wall insulation) see Table 21, 22, 23, 24
and
q_9 = Roof area (east) * ETD * TC (9)

where
ETD = Equivalent temperature difference = f (Roof weight, Time) (°C) see Table 20
TC = Transmission coefficient (W/m^2)(°C) = f (Roof type, Roof thickness, Roof insulation) see Table 27, 28

Transmission Gain - Except Wall and Roof

q_{10} = Total glass area * TC (10)

where
Total glass area = Glass area (north) + Glass area (south) + Glass area (east) + Glass area (west)
TC = Transmission coefficient = f (Glass type) (W/m^2)(°C) see Table 33

q_{11} = Floor area * TC * (Temperature outside - Temperature inside) (11)

where
TC = Transmission coefficient = f (Floor type, Floor weight, Floor insolation) (W/m^2)(°C) see Table 29

Internal Loads

q_{12} = People * HG (12)

where
HG = Heat gain from people = f (Building type, Inside temperature, Type of heat gain) (W) see Table 48

q_{13} = Input power * Footprint floor area (13)

Storage

q_{14} = - Footprint floor area * TS * ST (14)

where
TS = Temperature swing = f (Building type) (°C) see Table 4
ST = Storage factor = f (Building type, Building weight, Glass ratio) (W/m^2)(°C) see Table 13

Sensible Heat

q_{15} = People * VS * 1230 * (Temperature outside - Temperature inside) * BF (15)

where
VS = Ventilation standards = f (Building type) (m^2/minute) see Table 45
BF = Bypass factor = f (Building type) see Table 62

Latent Heat

q_{16} = People * HG (16)

where
HG = Heat gain from people = f (Building Type) (W) see Table 48

q_{17} = People * VS * 30 000 * Difference in humidity ratio * BF (17)

where
VS = Ventilation standards = f (Building type) (m^2/minute) see Table 45
BF = Bypass factor = f (Building type) see Table 62

Outdoor Air Heat

q_{18} = People * VS * 30 000 * Difference in humidity ratio * (1 - BF) (18)

where
VS = Ventilation standards = f (Building type) (m^2/minute) see Table 45
BF = Bypass factor = f (Building type) see Table 62

q_{19} = People * VS * 1230 * (Temperature outside - Temperature inside) * (1 - BF) (19)

where

VS = Ventilation standards	= f (Building type) (m^2/minute)	see Table 45
BF = Bypass factor	= f (Building type)	see Table 62

Total

The total cooling load is the total of all the individual loads.

$$q_{Total} = q_1 + q_2 + \ldots + q_{18} + q_{19} \text{ (W)} \quad (20)$$

Outputs

The following outputs are given by the prototype after the calculation was completed:

- The total cooling load.
- The bypass factors that ware used.
- The ventilation standard that was used.
- The building weight that was calculated.

The prototype was not tested against other systems. Some very informal tests showed that the prototype answers for the cooling load were in the correct range. The completion of the module will be discussed in the next section.

3.4 Stage 3: Construction

The completion of the module mainly constituted the conversion from a Dos-based program to a Windows-based program. The DOS prototype needed little modification to form the load calculation section of the module. The main input and output section however still had to be coded for Window.

One of the pivotal ideas of the module is simplicity. This extends to the user's interface that should preferably use only one input window and one output window. Multiple option inputs are also preferable because this limits the type of input that is possible and speeds up the entering process. A related point is the minimisation of keyboard inputs. This and mouse-driven input selection processes improve the entering speed. Graphical selections of more technical inputs also improve entering speed. Simplified menu options are in line with the idea of simplicity.

The second key design idea is understandability. This and simplicity create an easy-to-use module. The inputs must typically be as non-technical as possible. Graphical selection mentioned above helps to achieve this requirement. A way to check this requirement is by eliminating inputs that the user will not understand. In other words, any input that the user will not understand must not be asked. The output window should give all the assumptions made. It should also give a summary of all the input to summarise at a glance what inputs were used. This feature can be used to check the program in the construction phase.

One input screen, Figure 3, and one output screen, Figure 4, were used to meet the above-mentioned specifications.

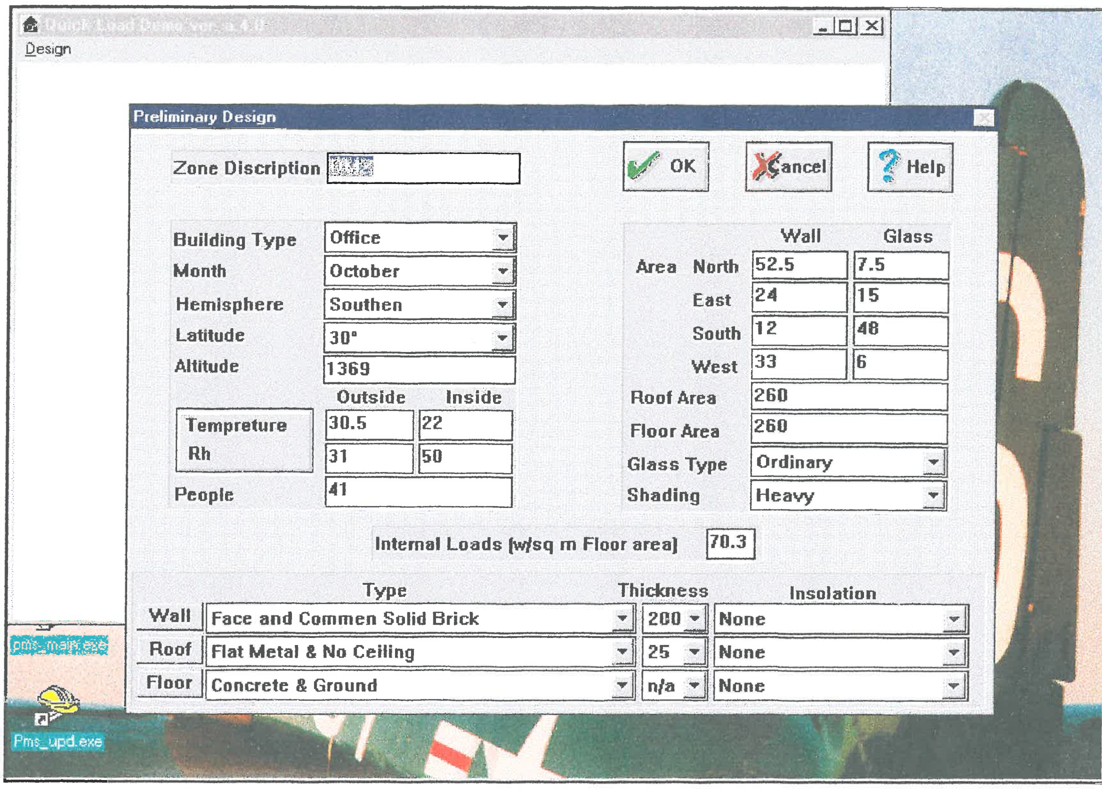

Figure 3 Input Screen

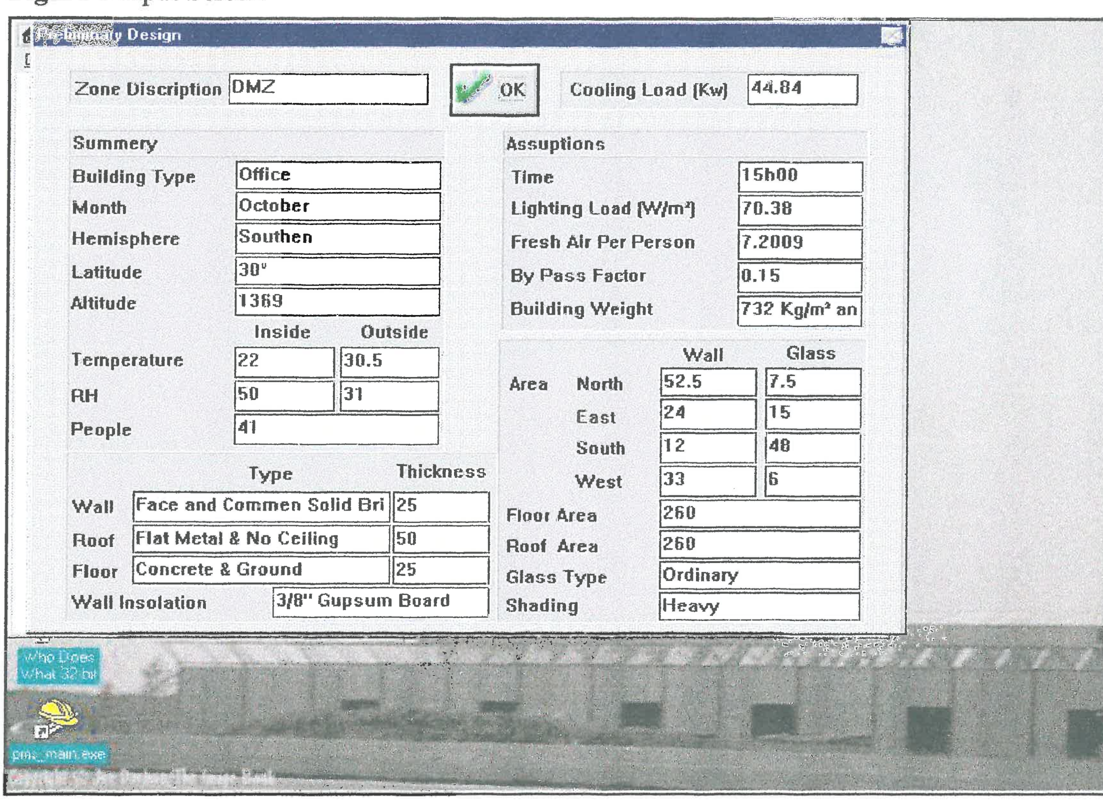

Figure 4 Output Screen

The user's inputs were kept to a minimum by making use of combo boxes of the drop-down list type. A drop-down list combo box is an input box that expands into a list of possible options when clicked on. It is only possible to choose one option in the list of the combo box. This limits the possible inputs and increases the speed of selection. The wall, roof and floor type selection was done by combo boxes. To speed up the selection extra buttons were added which give the option to select the wall, floor and roof graphically. Figures 5-7 show examples of the graphical selection of wall, roof and floor selection.

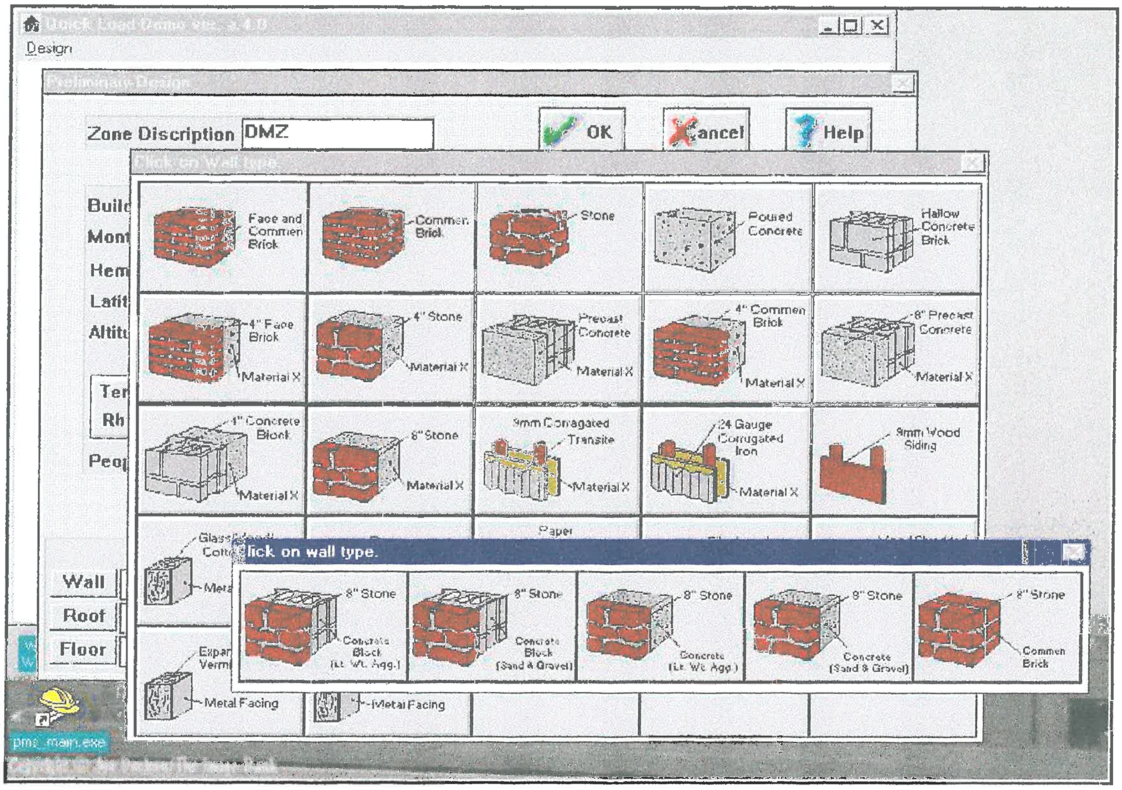

Figure 5 Graphical selection of wall type

This is a lot faster than going through all the possible options in the combo box. The module used the building type to select values for bypass factor, air changes and heat gain from people. The module also calculates the building weight using the selected walls, roof and floor weights. This is then used to calculate the thermal storage. The result of this design process will be discussed in the next section.

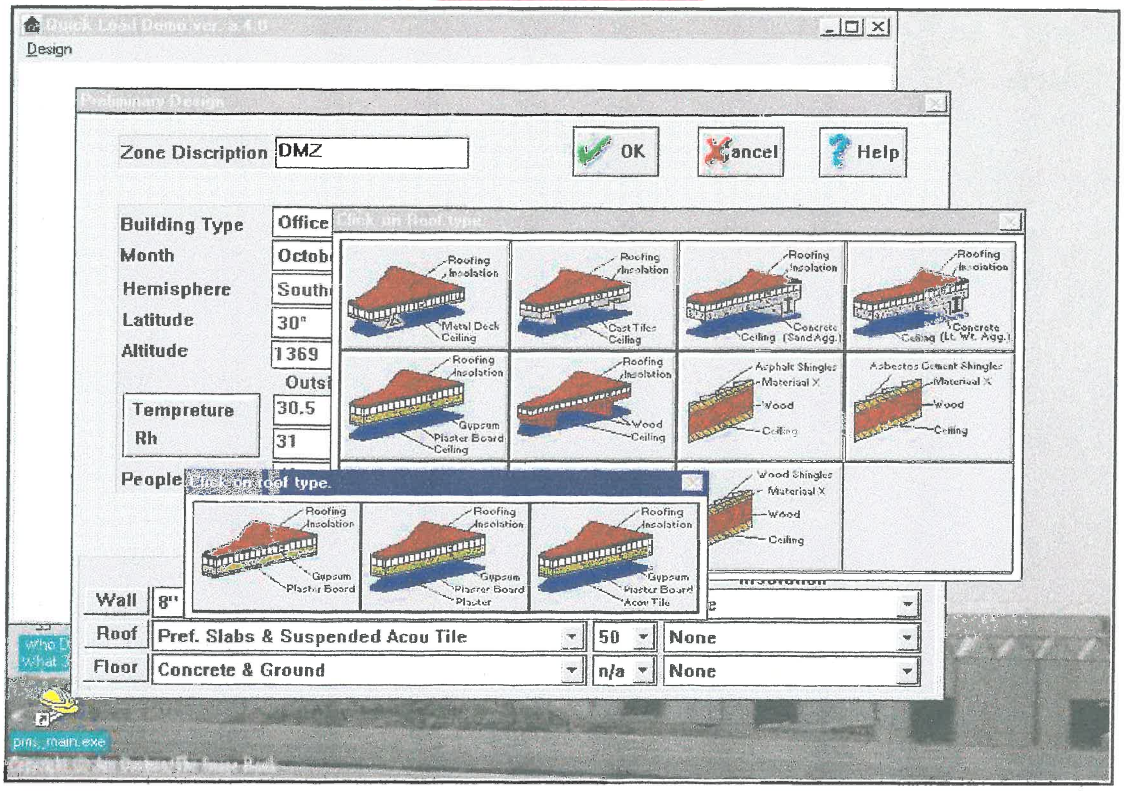

Figure 6 Graphical selection of roof type

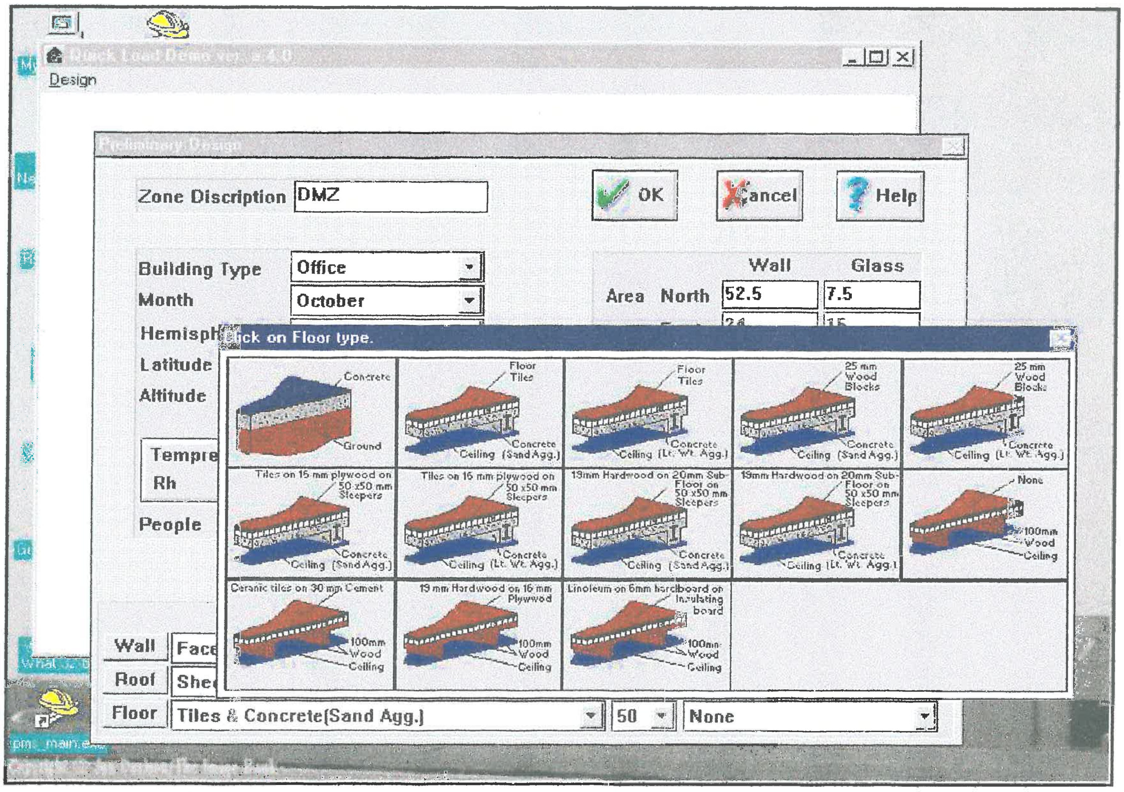

Figure 7 Graphical selection of floor type

4

Stage 4: Testing and Evaluation

4.1 Introduction

The end result of the simplicity/understandability design philosophy was a module that made it easy and fast to enter information and gave a cooling load, assumptions and summary of inputs. The only technical input is relative humidity. All the complex inputs like wall type, roof type and floor type can be selected graphically. The calculation takes less than a second to perform on a Pentium 120 MHz with 64 Meg Ram. The time wise bottle neck in the calculation of the cooling load is the entering of data. The speed of the program makes real-time consulting with the program feasible. The program is not hardware intensive because it works on a 386-SX 40 MHz with 4 Meg RAM and fits on a stiffy.

The evaluation of the cooling load calculation was done in three tests. Test A consisted of ten case studies of a wide variety of fictional buildings. Load calculations were done for each of these case studies using the simplified cooling load calculation program (called Quick load), ASHRAE CLTD method, New Quick (TEMMI), Panasonic method and two thumb rule methods. New Quick was used as the benchmark (Mathews,Van Heerden & Arndt, 1999:429-449). Test A was used to get a feeling of the accuracy of the different methods in real life situations. New Quick is a fourth-generation electrical analogy program. It was used as the bench-mark because it has been extensively verified(Mathews,Van Heerden & Arndt, 1999:429-449). The Panasonic method is given to companies to help them to select the right size of HVAC units. The method is intended to calculate the cooling load in small offices or homes where unitary systems are usually used. The results of the different methods were also compared to the thumb rules because they are widely used for sizing by small companies that sell small unitary systems.Test B tried to identify where the errors seen in Test A originated from. The same case studies were used but with the difference that the same wall type, roof type and floor type were used for each case. The load calculation of each case was done using Quick loads, New Quick and ASHRAE CLTD. Test C tried to pinpoint the difference between the Quick loads and New Quick. This was done by using a single case where one variable at a time is changed.

4.2 Test A: Global View

Introduction

This test was done to get a global view of the accuracies of several different load calculations. The methods included New Quick, a small unit calculation sheet method, ASHRAE CLTD calculation method, Quick load and a general thumb rule type of calculation. The test was intended to see if complexity really improves the accuracy of the answer and by how much. The case studies that were used were chosen for their diversity, from a low-cost house to a high-rise building. Different wall, roof and floor types were used for each case. This made it difficult to identify the origin of the errors. Three sets of calculations were done. The Real (A.1) set used the information as specified in the case studies. In the No-load (A.2) set all internal loads where assumed to be zero. The final Empty (A.3) set of calculation assumed the building has no people or internal loads.

Results Test A.1: Real Set

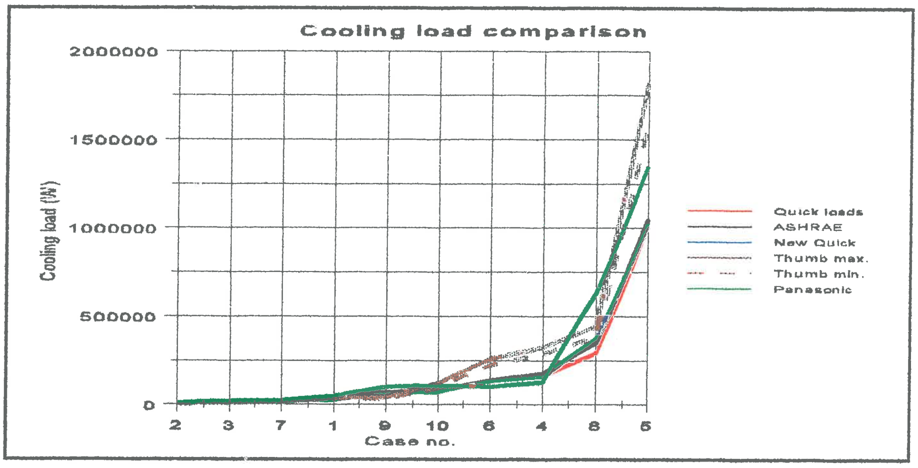

Figure 8 Test A.1: Cooling load comparison

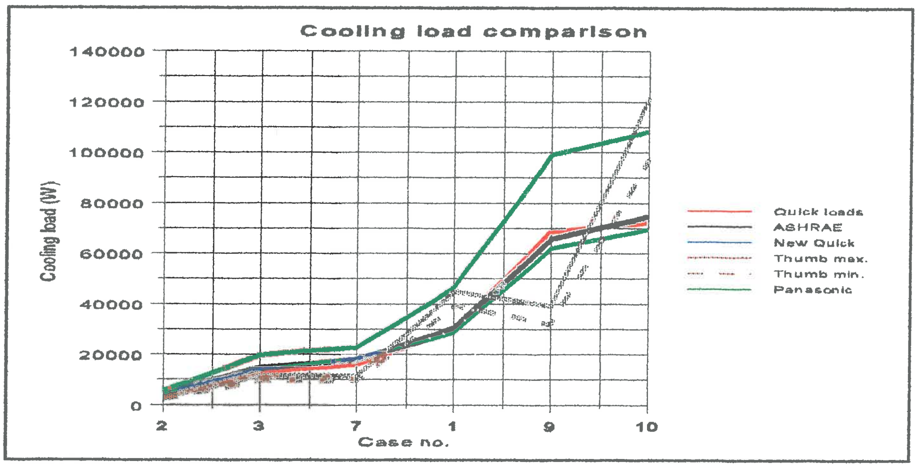

Figure 9 Test A.1: Zoom of cooling load comparison

The previous two figures show that the added complexity does improve the accuracy in relation to New Quick. The thumb rules method and the Panasonic method showed similar trends. They were reasonablely accurate in cases that required small cooling loads. The accuracy of these methods declined drastically as the required cooling load increased. This behavior is predictable because the Panasonic method was created to calculate loads where small unitary systems are used. The Panasonic method is also a lot better than the thumb rules in that it takes a lot more things into account. Thumb rules use only floor area to calculate a maximum and minimum cooling load. This makes this type of method susceptible to mistakes when the internal loads and occupancy vary in two identical buildings. This can clearly be seen in the graph. The Panasonic overestimates the load in all but one of the cases. This is in line with the design philosophy used in the sizing of small unitary and window-mounted systems. Such systems are usually operated by the occupant of the zone. The system may be left off to save energy while the occupant is not in the zone. When the occupant returns, or realises that the zone is hot, the occupant will then switch on the air-conditioning system. The occupant usually wants instant change in the temperature. A slightly oversized system can more easily cope with such demands. The graphs also show that the decision to only consider the Quick load and CLTD methods was correct because they followed New Quick closely. The CLTD line is below the CARRIER line in Figure 8. The thumb rule and the Panasonic method were removed from the next graphs to study the differences of the remaining methods. An error graph is also drawn to show the error associated with each method in relationship with New Quick.

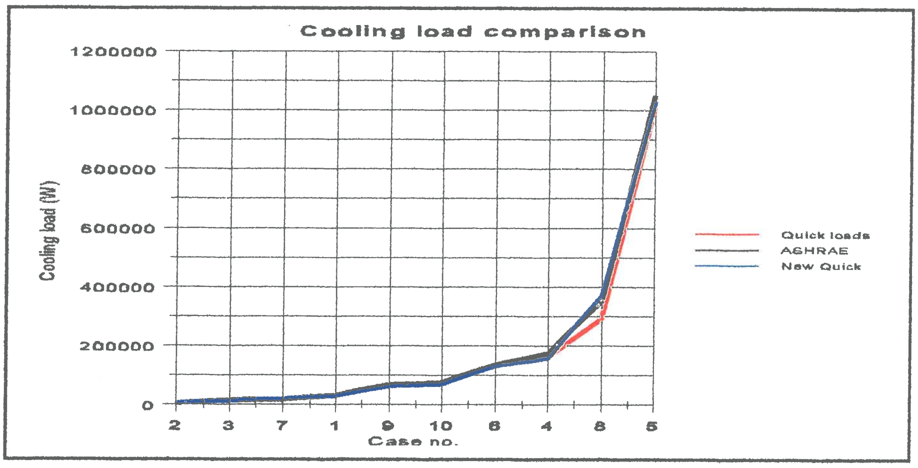

Figure 10 Test A.1: Simplified cooling load comparison

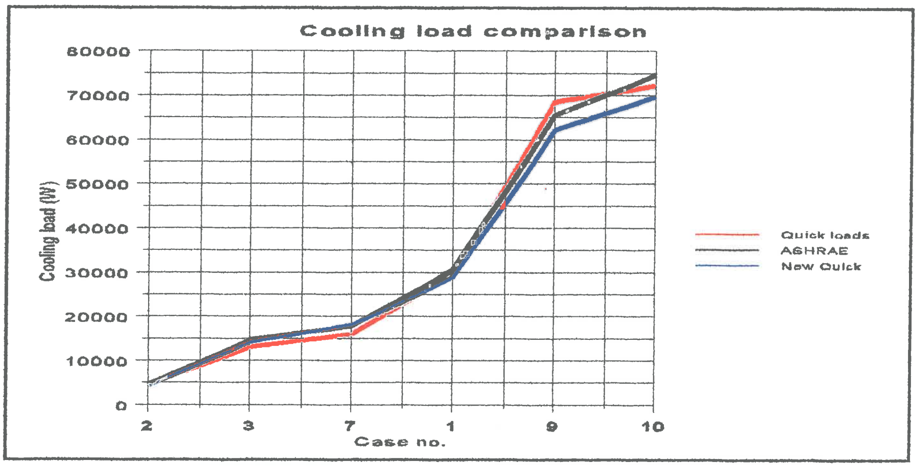

Figure 11 Test A.1: Zoom of simplified cooling load comparison

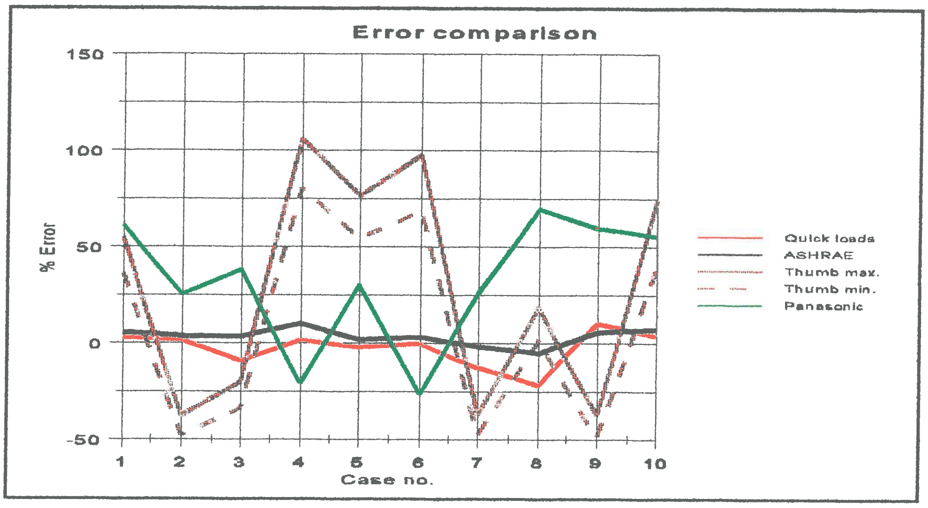

Figure 12 Test A.1: Error comparison

The two textbook-based method results are very close to each other with the ASHRAE CLTD method giving slightly better results. The difference between the module and the CLTD method can be contributed to difference tables that the two methods use to calculate the cooling load. The errors of the two textbook-based systems with respect to New Quick were similar. The methods also gave better results than the thumb rules and the Panasonic method. Unfortunately the two textbook modules gave errors of between -8% and 22% which translate to a possible error of ± 30%. The module therefore failed to achieve the desired accuracy required. In the next two sets of tests, firstly the internal loads and then the occupants were removed to see if the errors of the two textbook systems are related to the internal load or occupancy.

Results Test A.2: No-Loads Set

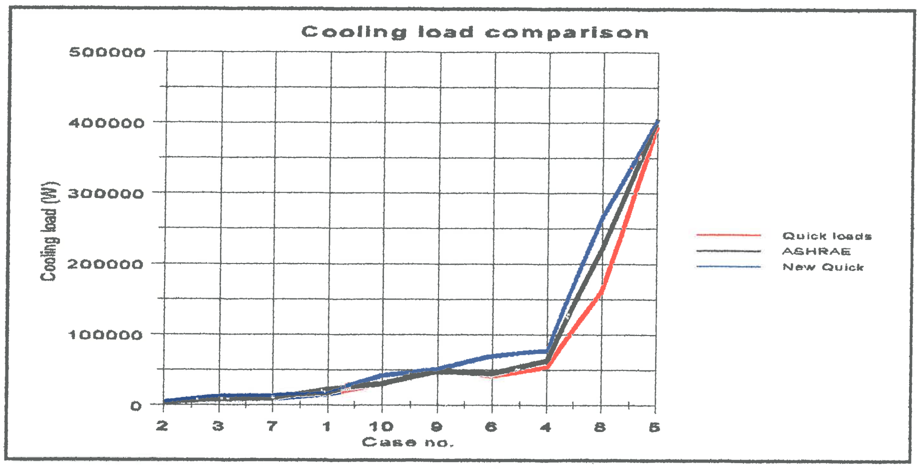

Figure 13 Test A.2: Cooling load comparison

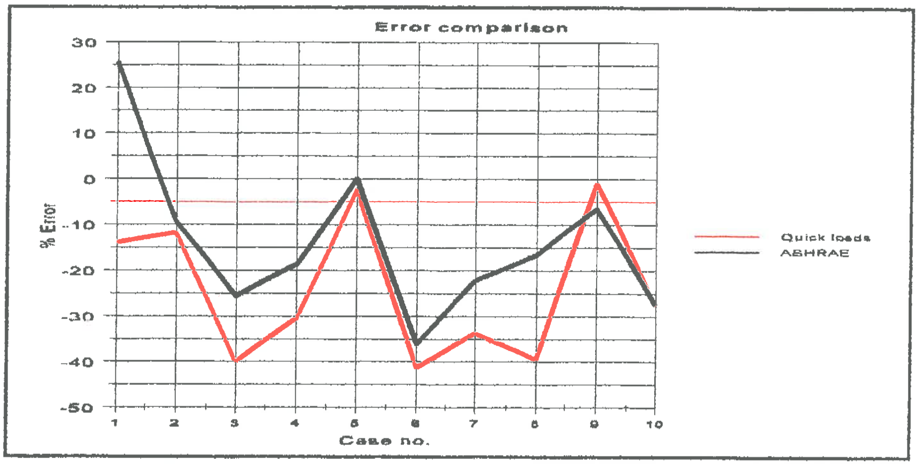

Figure 14 Test A.2: Error comparison

The error of the two textbook methods becomes more pronounced when the internal loads are removed. Both the methods underestimate the load with the CLTD method giving better results. They show maximum errors of up to 42% in comparison with maximum errors of 22% for the Real Test. The error of the methods is therefore bigger than first thought. It seems that the internal loads are correcting some of the error caused by the building and/or the occupant. This in itself is not preferable because it in turn means that the internal load effect on the cooling load is not the same as in New Quick. The occupancy is removed in the next test to leave an empty building.

Results Test A.3: Empty Set

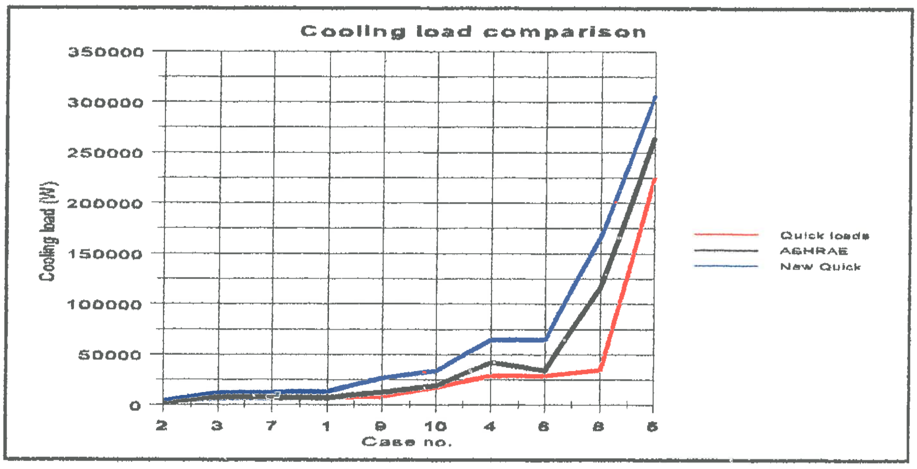

Figure 15 Test A.3: Cooling load comparison

Figure 16 Test A.3: Error comparison

The trend of increased error continues with this set of tests where the occupants are also removed. This leaves only an empty shell of the building to compare. The two methods again underestimate the cooling loads and the ASHRAE CLTD method again gives better results. The maximum error increases to 80% for Quick loads and 52% for the ASHRAE CLTD methods. This means that the two textbook-based methods give unusable results. The occupancy has a similar effect on the internal loads in that it corrects some of the error caused by the shell of the building. This also means that the occupancy has a bigger effect on the cooling load calculated by the two textbook methods than in New Quick. No trend was found when the error was plotted against wall, glass, floor, roof area and glass to wall ratios.

Discussion

The maximum error of the different tests and methods are shown in the following Table.

Test	Quick Load	ASHRAE CLTD	Thumb max.	Thumb min.	Panasonic
A.1	22%	10%	106%	80%	70%
A.2	41%	36%			
A.3	80%	52%			

The ASHRAE CLTD method is the most accurate, followed by Quick load. The Panasonic method gives decent results for the simplicity of the method. The thumb rule is inadequate. The table also shows how the accuracy decreases as the building is emptied. In this set different walls, glass, roof and floor were used. This makes it difficult to identify a trend. A new set of tests, with buildings that have similar type of shell, were therefore needed to see if the source of the error could be identified.

4.3 Test B: Comparable View

Introduction

This test was done to compare accuracies of three different load calculation methods. The methods included a New Quick, ASHRAE CLTD calculation method and Quick load. Several assumptions were made to make it possible to compare results and identify trends. The assumptions are listed below.

Case studies assumptions.

- The buildings are all office buildings.
- The buildings are in the same location:
  - Hemisphere
  - The latitude
  - The altitude
  - Month
- Inside design specifications are the same:
  - Design temperature
  - Design relative humidities
- Outside climate is the same:
  - Temperature
  - Relative humidities
- The walls are the same for each building:
  - Type
  - Thickness
  - Insulation
- The glass used in all the buildings are the same:
  - Type
  - Shading
- Floors are also the same:
  - Type
  - Thickness
  - Insulation
- Roofs are the same for all the buildings:
  - Type
  - Thickness
  - Insulation

These are reasonable assumptions except in the case of the lowcost housing, residential house and the house office. These assumptions should make it possible to identify the origin of the error. New Quick was again used as the benchmark. Three sets of calculations were done. The Real (B.1) set used the information as specified in the case studies. In the No-load (B.2) set all internal loads were assumed to be zero. The final Empty (B.3) set of calculation assumed the building had no occupancy or internal loads.

Results Test B.1: Real Set

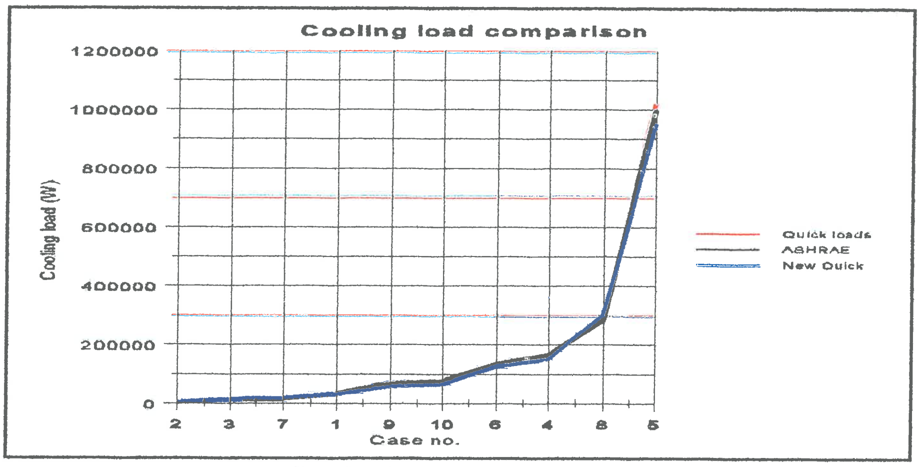

Figure 17 Test B.1: Cooling load comparison

Figure 18 Test B.1: Error comparison

The test shows similar results to the A.1 test with a slightly lower maximum error of 20%. In most of the cases the two textbook methods overestimate the cooling load. The CLTD again achieved a lower error than Quick loads. The fact that the error for this test differs from the A.1 test shows that the building shell material selection influences the maximum error. The next test is similar to Test A.2 in that the internal loads are removed to determine the effect of them on the cooling load.

Results Test B.2: No-Loads Set

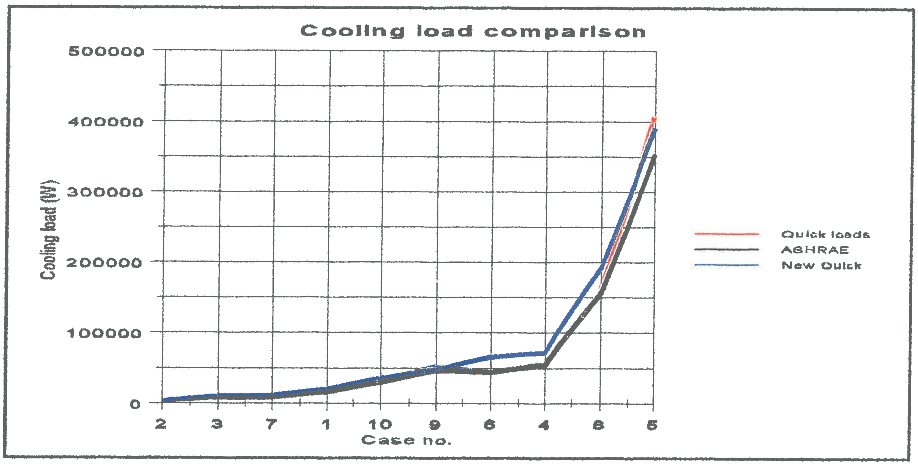

Figure 19 Test B.2: Cooling load comparison

Figure 20 Test B.2: Error comparison

The test shows similar results to the A.2 test with a lower maximum error of 34%. The maximum error also increases as in the A.2 test. In most of the cases the two textbook methods underestimated the cooling load. From the similarity to Test A.2 a conclusion can be reached that the internal loads correct some of the error of the building shell and/or occupancy. This again raises the problem that it means that the effect of the internal loads on the cooling load is also not correct. In the next test the occupants of the buildings are also removed.

Results Test B.3: Empty Set

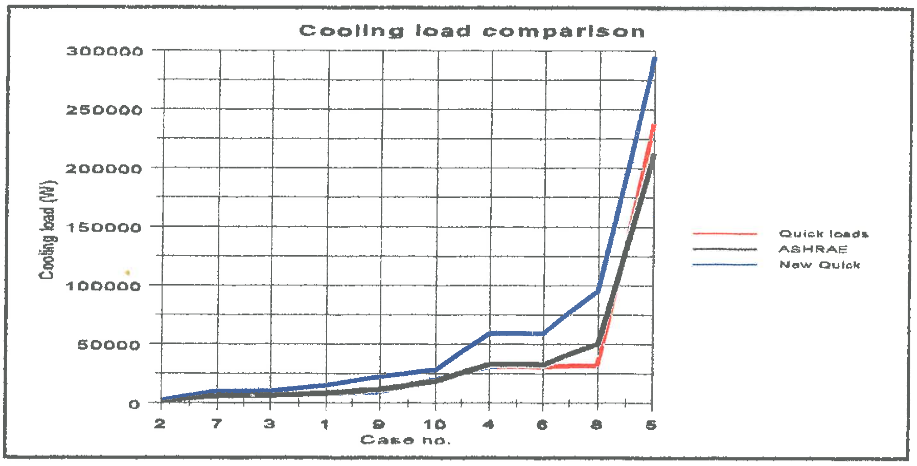

Figure 21 Test B.3: Cooling load comparison

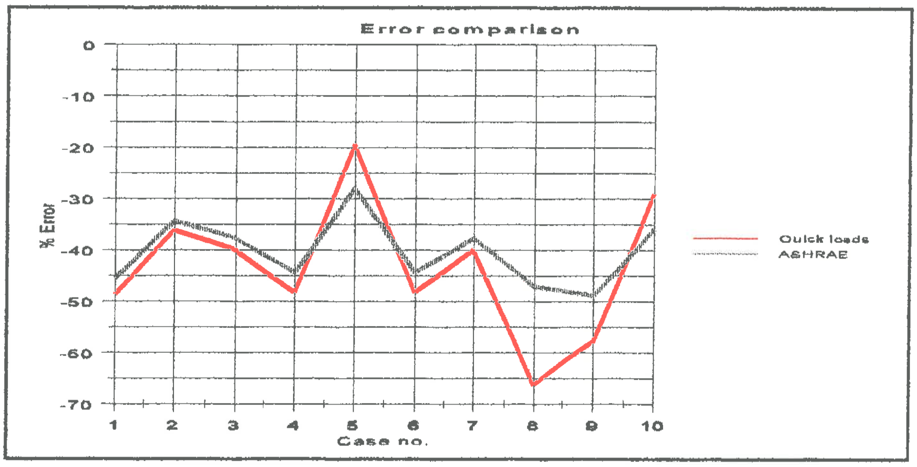

Figure 22 Test B.3: Error comparison

The test shows similar results to the A.3 test with a lower maximum error of 66%. The maximum error also increases over the B.2 test. It can be seen in the cooling load comparison graph that the two textbook methods give similar results that underestimates the cooling load. The CLTD method returns a lower maximum error than Quick load. A similar tendency is seen that the occupancy corrects some of the error that is caused by the building shell. This also means that the effect of the occupancy on the cooling load is not correct. The error is now plotted for a number of physical dimensions of the buildings to try and identify a possible cause for the underestimation of the cooling load by the two textbook methods. These did not show any trend.

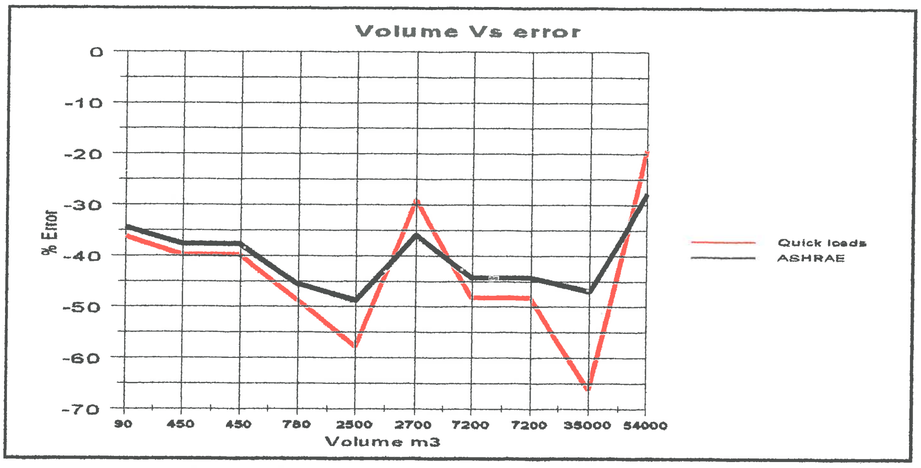

Figure 23 Test B.3: Volume vs % error

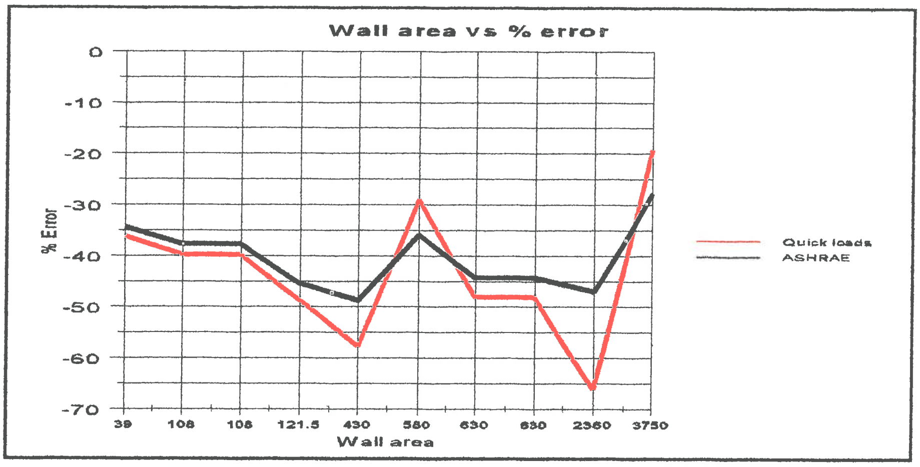

Figure 24 Test B.3: Wall area vs % error

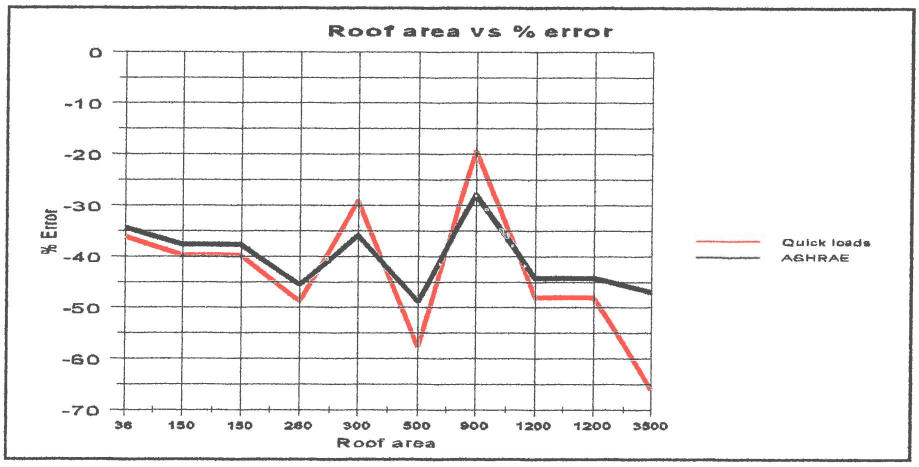

Figure 25 Test B.3: Roof area vs % error

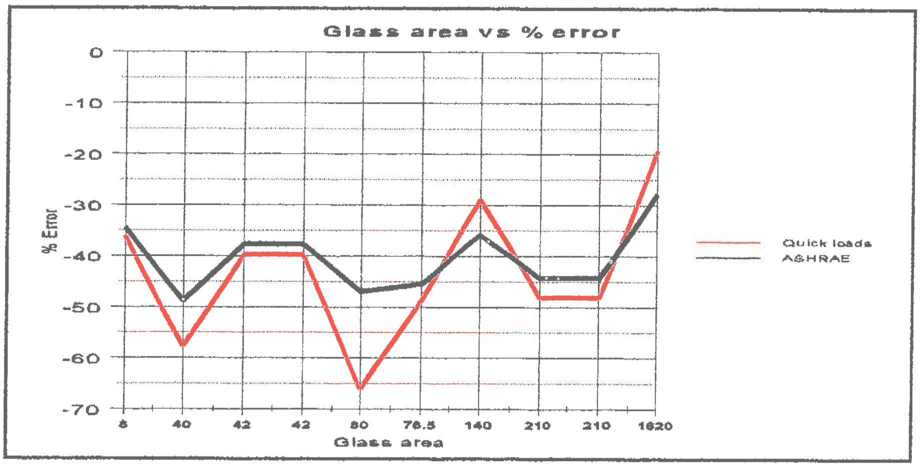

Figure 26 Test B.3: Glass area vs % error

The previous four graphs show that there is no simple answer to the deviation of the two textbook load calculation methods. A number of other graphs were plotted that showed similar results. It is therefore necessary for the new set of tests to see what effect each element of the load calculation formulas has on the end result.

Discussion

The maximum error of the different tests and methods is shown in the following table.

Test	Quick loads	ASHRAE CLTD
B.1	20%	17%
B.2	33%	33%
B.3	66%	47%

The ASHRAE CLTD method is the most accurate, followed by Quick loads. The table also shows how the accuracy decreases as the building is emptied. It also shows that the two methods are not very accurate and that it is preferable not to use any of the two methods. From the A and B tests one can come to the conclusion that the two textbook methods underestimate the cooling load if only the shell building is considered and that this error will vary with different materials used. The second conclusion that is reached is that the two methods overestimates the effect of the people and the internal loads on the cooling load. A new set of tests were therefore needed to see if these two assumptions are true.

4.4 Test C: Pinpoint View

Introduction

This test was done to pinpoint the differences between the New Quick and Quick load. The most simple case was used. This case used the same wall, roofs and floor types throughout the test. Only one variable is chanced and then plotted. The building can be compared to a simple cube. The following graphs show how the Quick load result differs from the result of New Quick.

Results

The result of the test of the four wall areas will be shown first.

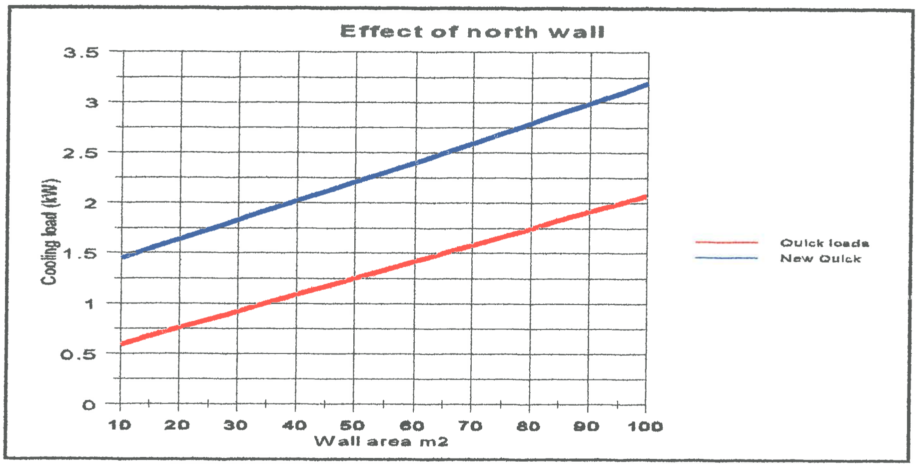

Figure 27 The effect of the north wall on the load

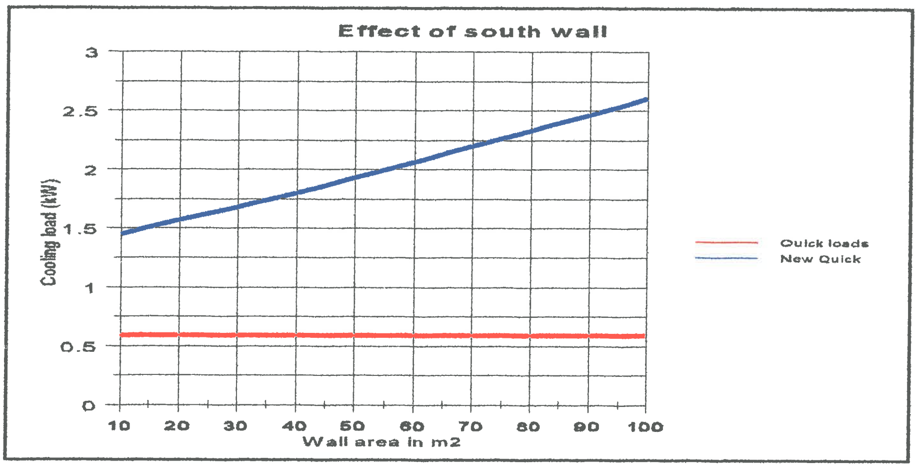

Figure 28 The effect of the south wall on the load

Both the north and south wall will cause the simplified method to underestimate the cooling load. The effect of the south wall is especially worrying because of the negative slope.

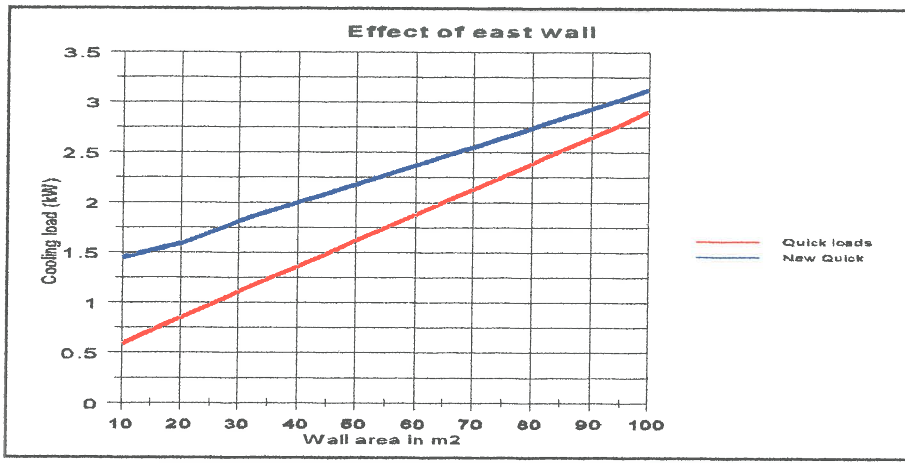

Figure 29 The effect of the east wall on the load

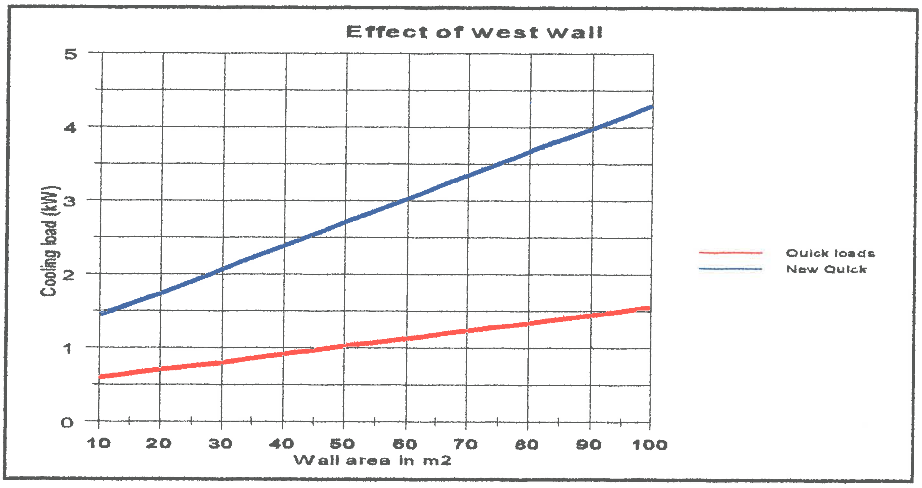

Figure 30 The effect of the west wall on the load

The east wall shows an interesting tendency to underestimate the cooling load if the area is under about 120 m^2 as in this case, and that it will then start to overestimating the required cooling load after that. The west wall shows a tendency of underestimating the cooling load. The shallow slope means that the error will increase with an increase in west wall area. The glass area will be looked at next.

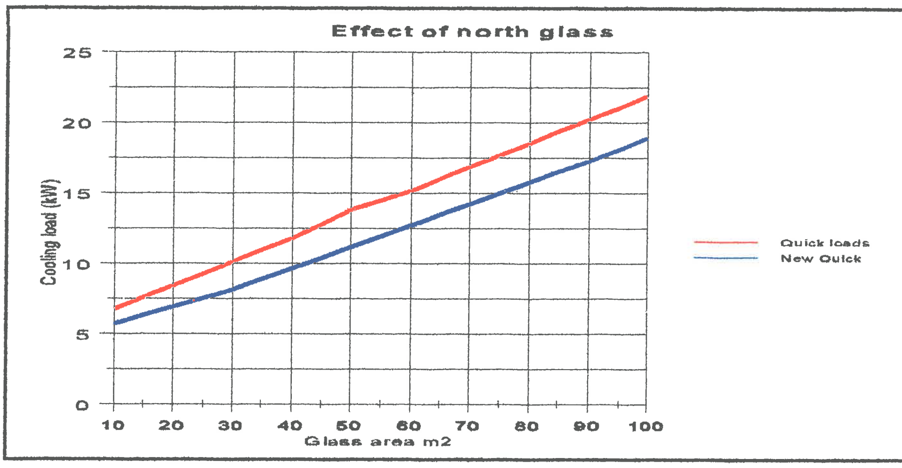

Figure 31 The effect of the north glass area on the load

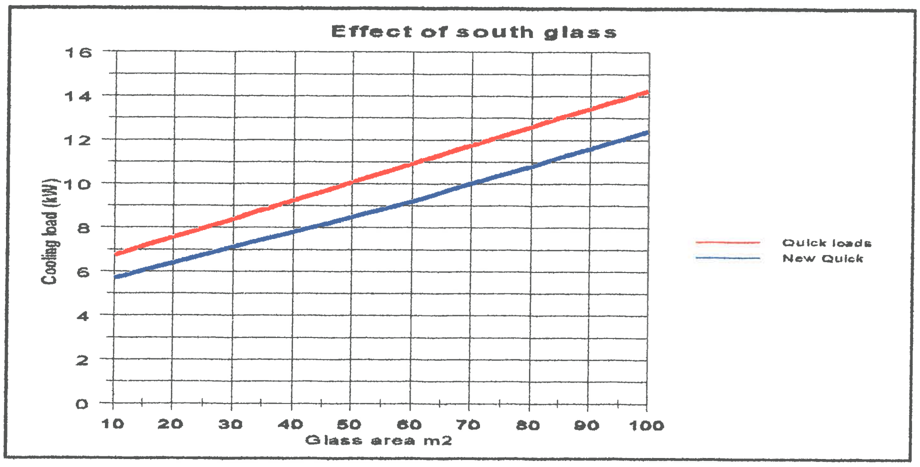

Figure 32 The effect of the south glass area on the load

The north and south areas give results that are close in value and in slopes to New Quick. This translates to almost constant slightly increasing error.

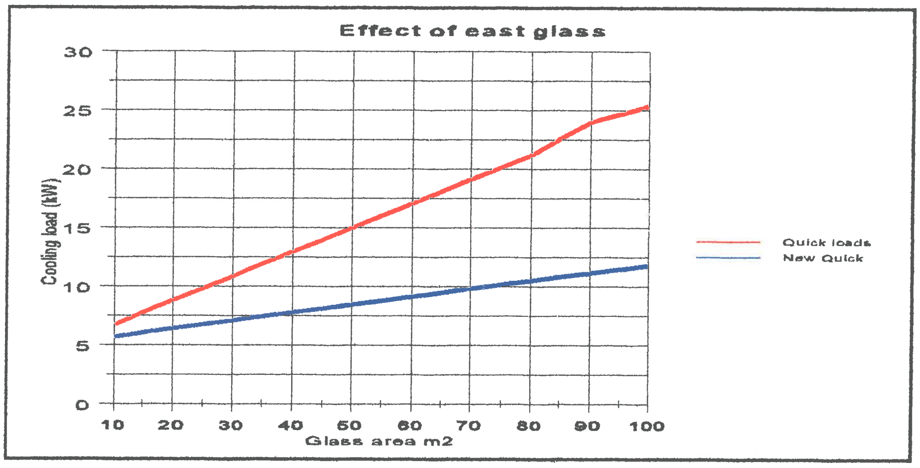

Figure 33 The effect of the east glass area on the load

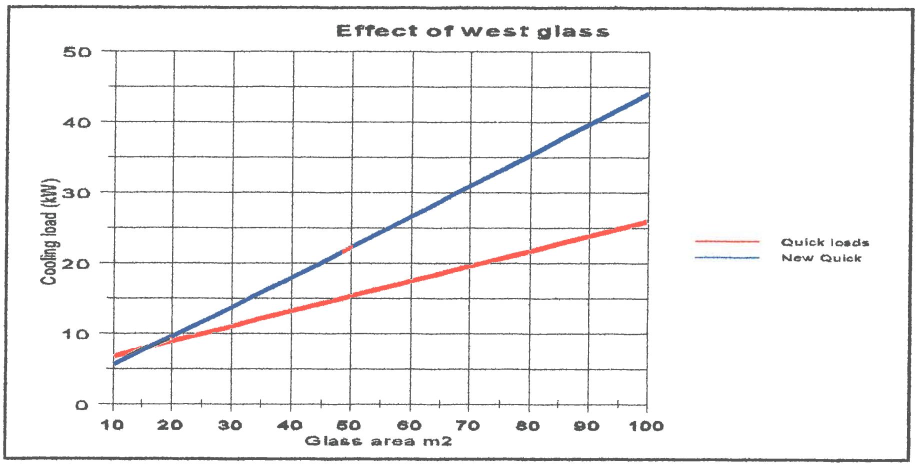

Figure 34 The effect of the west glass area on the load

The west and east glass areas give results that underestimate the cooling load and with a difference in slope to New Quick. An increase in glass area will therefore increase the error significantly. The roof area graphs are shown next.

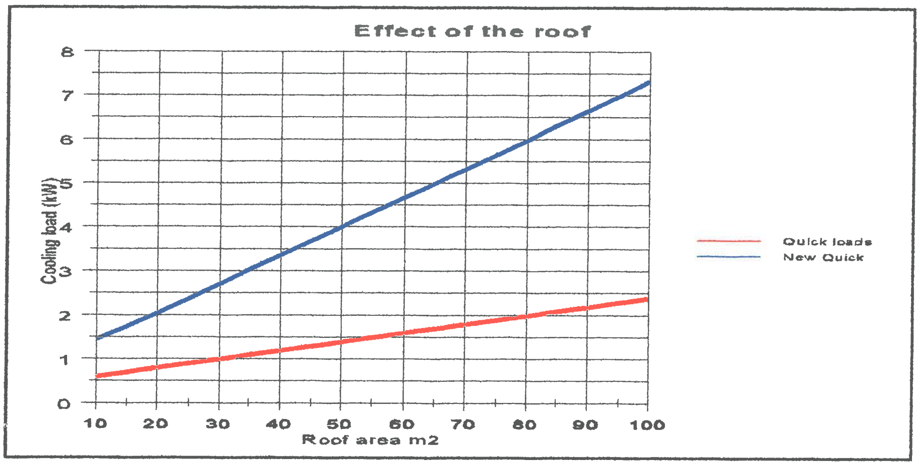

Figure 35 The effect of the roof on the load

The roof area also underestimates the cooling load required. The difference in slope between New Quick and Quick loads will increase the error with an increase in roof area.

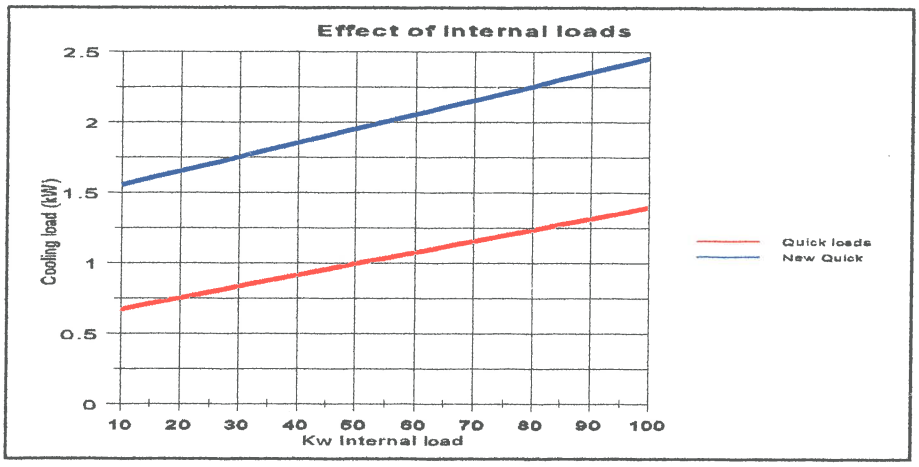

Figure 36 The effect of internal loads on the load

This graph does not confirm our second assumption that the internal loads effect is larger than it should be. From Tests A and B one would expect that the two lines would have been the other way round. The error will increase slightly with an increase of internal loads because the slopes of the two lines are nearly the same. The graph below confirms that one half of the second assumption was correct, the effect of people is much larger than it should be.

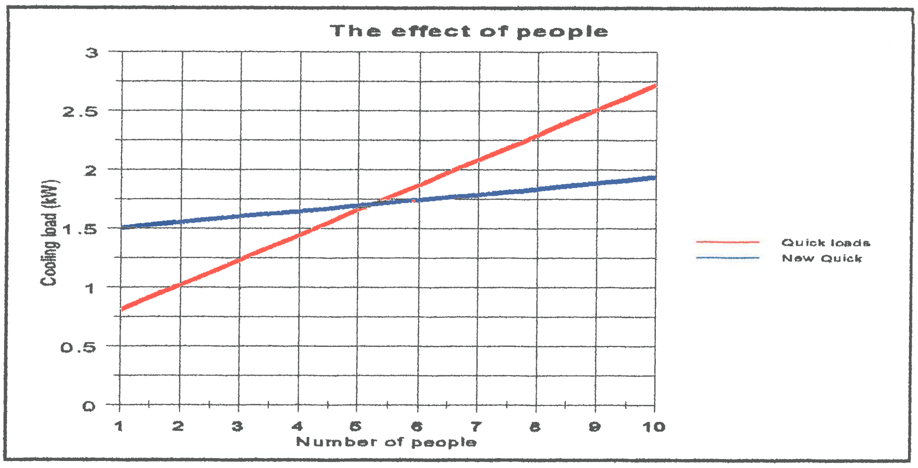

Figure 37 The effect of people on the load

Discussion

The graphs showed how the answers of the different methods differ. One can also see that the simplified Carrier method (Quick load) mostly underestimates the cooling load except in the case of people. This is the reason why the Real test gives reasonable answers and the empty test unusable answers. These results can unfortunately not be used to calculate a factor, by which results can be multiplied to get a closer result. This is because the factor will vary with the type of material used. This means there is not any easy fix to the accuracy problem of the module.

4.5 Conclusion

The cooling load program met most of the design specifications. Unfortunately the module was unable to meet the required accuracy needed. The speed and ease of use made the module ideally suited for real-time consulting work. The module can make a very valuable tool for any consultant engineer and architect if the accuracy of the module can be improved.

It may be possible to do so without losing the simplicity and ease of use of the input interface. This can be done by using the existing interface to enter data into an equivalent resistance calculation method. This will give an error closer to the allowed specification.

Several improvements to the interface can also be recommended. It must be possible to enter internal loads without using floor area. Another problem identified is that the difference between total floor area and foot print floor area must be defined more clearly. It should also be possible for the lighting loads to be incorporated without confusing the floor areas with the footprint floor area.

Several nice to have features were also identified that will improve the input interface. The users must be able to specify the time at which the calculation must be done. The calculation for a 24-hour period to determine the maximum cooling load must be possible. The graph of the cooling load for that 24 hours can then be plotted. It must also be possible to save and load projects. This will make presentations a lot easier. It will also be a good idea to verify the module with the results of existing buildings. The next chapter will deal with the development of the system selection module.

5

Simplified System Selection

Artificial intelligence is better than no intelligence at all.
An unknown author

5.1 Introduction

A key item of the IDA design philosophy, as discussed in the prologue, is the correct selection of an HVAC system (Todesco, 1997:45). An expert system was used to do the selection of an HVAC system. Expert systems are designed to mimic the thought process of the expert in a problem-specific domain. Expert systems use reasoning techniques to manipulate knowledge in a knowledge base to solve a specific problem. Usually the problems are very knowledge intensive with several acceptable answers. The answers that an expert system generates are therefore qualitative rather than quantitative. This means that instead of generating a lot of repetitive calculations, an expert system will analyse a problem and give the most appropriate answer with an explanation of its thought process. The expert system must help the user that does not have the problem-specific knowledge, to select an HVAC system in the absence of an expert. The development of the second module, the system selection, will be discussed in this chapter. The system was developed using the same system as used for the load calculation module.

5.2 Stage 1: Identification and Definition

The problem has been discussed in detail in section 1.3 of the prologue. The aim of the program, as discussed in section 1.4, is to create a simplified system selection program for the brief and preliminary stages of HVAC design. The potential users of the module, as highlighted in section 1.4, are consultants, architects and sales representatives. For the selection of an air-conditioning system for a building one needs a lot of HVAC experience. This type of experience takes time and sometimes several mistakes to acquire.

A system selection program was written to simplify the selection processes and to make it possible for people with limited technical knowledge to select an air-conditioning system. The system selection module had the same design goals as the cooling load module. The interface must be very easy to use. Inputs must be as non-technical as possible, in other words, any question that the user would not understand must not be asked. The program should be fast so that it can be used for real-time consulting. The cooling load module and the selection program make it possible to calculate the cost and space implication of a selected HVAC system. This should make an excellent design tool for the brief and conceptual design phase of HVAC design.

The same criteria, as discussed in section 3.2, were used for the selection of hardware and software.

5.3 Stage 2: Development of a Prototype

The knowledge used for this module again comes mainly from domain-independent sources like textbooks and articles. Some domain-dependent information was also used. The reason for the use of an expert system for selection of an HVAC system is discussed next.

Most texts concerning HVAC system selection are not clear about how exactly one selects a system and only give broad outlines on how to do the selection. They usually give an outline of all the basic systems used. With the advantages and disadvantages known, they start to try to select a system. Most HVAC systems will work in any situation. However, there will usually be several systems that are more appropriate. To give an example, one will not use window-mounted units for the World Trade Centre or use an all-water system for a low-cost house. This is where intelligence comes in. An expert uses problem-specific knowledge, common sense, experience, rules of thumb and short cuts to select an HVAC system.

There are an infinite number of HVAC systems and combinations of systems. The major systems were first identified and then the main subdivision of each of them. The subdivision was kept very basic, therefore no hybrid systems were considered. This basic subsystems were used as the source of the possible answers of this module. The basic systems listed below are not an absolute selection of basic systems, it is merely a selection of the main type of systems. Some would select the systems simpler and other like Shams et al. (1995:165-172) selected a more detailed basic system. The following systems were considered as possible answers:

- Ventilation
  - Mechanical
  - Natural
- Direct expansion
  - Package
    - Water cooled
      - Economiser
      - Full fresh air
    - Air cooled
      - Economiser
      - Full fresh air
  - Window mounted
  - Split units
- Chilled water
  - All air
    - VAV
      - LVD
        - Water cooled
          - Economiser
          - Full fresh air
        - Air cooled
          - Economiser
          - Full fresh air
      - HVD
        - Water cooled
          - Economiser
          - Full fresh air
        - Air cooled
          - Economiser
          - Full fresh air
    - CVVT- LVD
      - Water cooled
        - Economiser
        - Full fresh air
      - Air cooled
        - Economiser
        - Full fresh air

	- HVD	- Water cooled	- Economiser
			- Full fresh air
		- Air cooled	- Economiser
			- Full fresh air
- Air-water		- Water cooled	- Economiser
			- Full fresh air
		- Air cooled	- Economiser
			- Full fresh air
- All water		- Water cooled	- Economiser
			- Full fresh air
		- Air cooled	- Economiser
			- Full fresh air

- Evaporative cooler - Direct
  - Indirect
  - Multi stage

VAV = Variable air volume
CVVT = Constant volume variable temperature
LSD = Low velocity ducts
HSD = High velocity ducts

The standard methodology was used by using textbooks for information about each system. The advantages and disadvantages of each system were listed. This information then had to be converted into a useful form. Knowledge can be represented in several ways. The knowledge base represents the knowledge in an organised and orderly way. The knowledge gained from the information was presented as production rules for this problem. Production rules are conditions that can be written as IF THEN statements. The IF part of the statement is applicable on a condition, state or object. The THEN part is activated if the IF part is true. For example: IF there is no space for ducts THEN select a system that does not use ducts. The advantages and disadvantages of each system were used to write several production rules.

Problem solving strategies are necessary to make it possible to solve a problem. The problem solving strategy contains a search model and a control strategy. The search method is the method used by the expert system to search through the knowledge base. In this case a heuristic search method is used. Heuristic search methods take the organisation of the knowledge base into account when searching. So doing it can prune possible solution paths that must not be searched. This increases the efficiency of the method but it also decreases the completeness of the search. The expert system consists of several heuristic rules. The heuristic rules decide which branch of the search tree to expand next. Forward reasoning was used as the control strategy. Forward reasoning is a data-driven search where the search is started with an initial condition and then searches through the knowledge base to a solution. This is also known as a ground-up control strategy. The search starts in the trunk of the search tree and ends in the tip of a branch. A schematic of such a search is shown in Figure 38.

Asking the right questions that make it possible to select a specific HVAC system is very difficult because most systems are very similar. To make it possible to select a specific system, it is easier to concentrate on the main difference and special features of each system. The design philosophy in the creation of the heuristic rules was pruning. The purpose of each question was to eliminate at least one system. The questions were compiled and linked to systematically reduce the number of possible systems that meet the requirements of the user. The questions were arranged in order of importance. The questions about areas of the design the user has little control over, like space for ducts and space for plant room in a building, are asked first. Questions concerning cost are asked last to prevent the user specifying systems that have low initial cost and low running cost but cannot be installed in the building. This means that question about special cases where only one type of system will work were asked first. As the question session goes on the questions become more general because all special cases have been eliminated. The last question is usually about cost because at this stage almost any system will work. The question will quickly converge to a system if the user selects a system for a special case where only a small number of systems could possibly work. The questioning session could be considerably longer for a more general case.

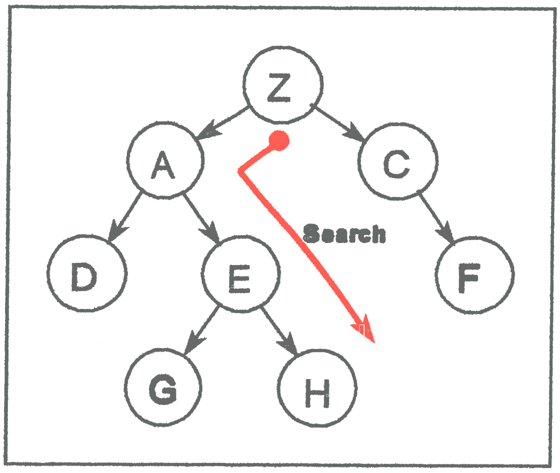

Figure 38 OR search tree representation

An object-orientated design philosophy was followed with the design of the search algorithm. This means that each question that was asked could be seen as a black box. Each of these black boxes can be called and can receive a data string for another black box. The black box can be called and can call any other black box. The black box prompts the user for an answer for its question. The black box then reacts to the answer of the question by calls and passing the modified data string to the next black box. This process continues till the algorithm converges to an answer. The algorithm that consists of several question black boxes has the shape of an inverted tree. The branch of the search tree splits after each question box. Some branches interweave and reconnect with other branches. On the tip of each branch is a selected system.

A number of question black boxes were grouped into a black box to make it easier to understand. The fact that the algorithm was designed using the black boxes method that makes it very easy to insert a new question or to modify and rearrange the existing questions. The detailed construction is discussed next.

5.4 Stage 3: Construction

The program has only one input screen and output screen to meet the design specifications. The user's inputs were kept to a minimum by only giving two to three possible answers from which the user can choose. This has the effect that it limits inputs and increases the speed of selection. The questions and answers are displayed as the questions are answered to show the progress of the session. When a system is finally specified, the program gives a summary of the cooling system. The detailed knowledge structure is shown in figure 39. Each question in this tree is discussed, in Appendix A, using the following format:

Question index : The question ID number as used in the decision tree
Previous question : List of questions calling this question

Question : The question

Purpose of question : The reason behind the question

Result parameters : Gives the possible answers

Result of question : For one of the above result the following is true:

Knowledge gained : Knowledge gained out of this answer to the question
Recommended systems : Systems that can be recommended with the knowledge gained
Not recommended systems : Systems that cannot be recommended with the knowledge gained
Action : Action that must be taken now
Next question : The next question that must be called

Result of question : For the other result the following is true:

Knowledge gained : Knowledge gained out of this answer to the question
Recommended systems : Systems that can be recommended with the knowledge gained
Not recommended systems : Systems that cannot be recommended with the knowledge gained
Action : Action that must be taken now
Next question : The next question that must be called

The testing of the selection program is discussed in detail in Chapter 6, using ten case studies.

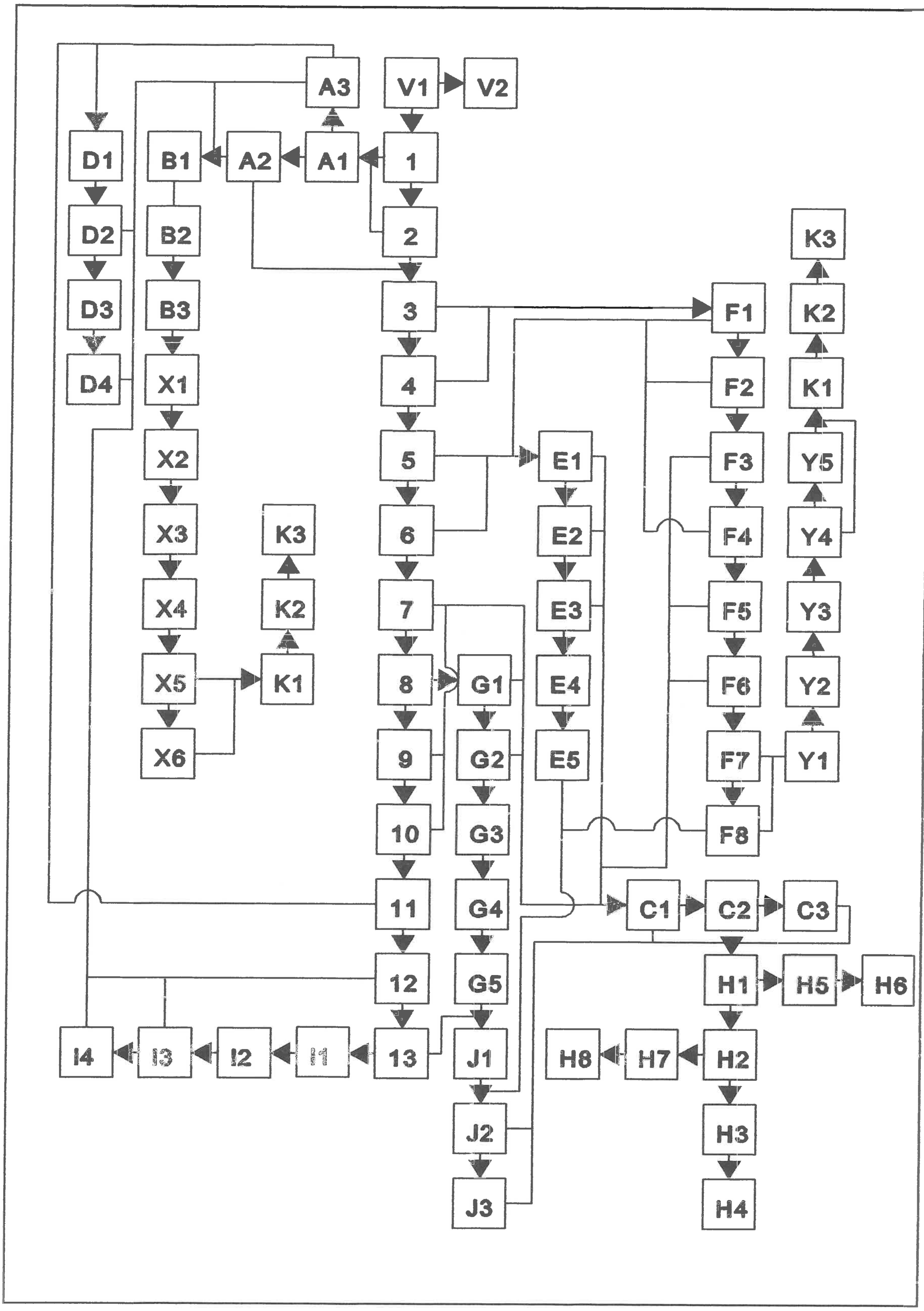

Figure 39 Detailed knowledge structure

6

Stage 4: Testing and Evaluation

6.1 Introduction

The program was verified by selecting cooling systems for ten case studies. The selected system of each of these cases was then compared to the system installed in the building. The system selection process for each case will be discussed here. A short summary of the building is first given, then the selection process. Each question with its corresponding index number and answer are shown in a table. The selected system and installed system are then shown at the bottom of the questions table. The selected system is then discussed and evaluated. The path of questioning is shown on the detailed knowledge tree after each case study.

The following case studies were used:

1. University of Pretoria Engineering Tower Building, Pretoria
2. First National Bank Gezina, Pretoria
3. MMA Office, Vanderbijlpark
4. Cold Mills South Change House, ISCOR, Vanderbijlpark
5. Cold Mills South Administration Building, ISCOR, Vanderbijlpark
6. Main Administration Building, ISCOR, Vanderbijlpark
7. Paint Line Painting section, ISCOR, Vanderbijlpark
8. Data Centre, Computer Room, ISCOR, Vanderbijlpark
9. Direct Reduction Control Room, ISCOR, Vanderbijlpark
10. Neonatal Unit, Medivaal Hospital, Vanderbijlpark

6.2 Case Study

University of Pretoria Engineering Tower Building, Pretoria

Introduction

The following information was used to select the system:

- The system was installed when the building was erected.
- There is limited space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a high-rise building.
- The building is an office building.
- All the offices are on the perimeter of the building.
- Dust is not a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment is allowable in occupied zones.
- It isn't necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically not allowed on the outside of the building.
- A large cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.
- The system should be selected for the lowest 20-year life-cycle cost.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	New building
2	Is there space for the installation of ducts or an equipment room?	No
A1	Is there space for the installation of ducting?	No
A3	Is there room for cooling equipment in the building, on the roof or on the outside of the building?	Yes
D1	Is the building a large medium to high-rise building?	Yes
P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	Yes
P5	Should the system be selected for the lowest initial cost or on the lowest 20-year life-cycle cost?	Lowest life-cycle cost

Selected	Chilled water system - All water system with water cooling
Installed	Chilled water system - All water system with water cooling

Discussion

The selected and installed systems are the same. The selection can be explained on the following grounds:

1. The following systems are not recommended because there is no space for ducting:
   - All air systems.
   - Air-water systems.
2. It is unpractical to use WMU, split units and evaporative coolers in a high-rise building.
3. WMU, split units and evaporative coolers are not aesthetically pleasing on the outside of the building.
4. The following systems are recommended for this application.
   - Small vertical package units.
   - All water systems.
5. A vertical package unit and an all water system are ideally suited for a large number of small perimeter zones.
6. It is sensible to use all water systems in a high-rise building where a large cooling load is needed.
7. An all water system has a better life-cycle cost than a vertical package unit.
8. Water cooling should be used because it is more effective than air cooling. This is important to ensure that the lowest 20-year life-cycle cost is achieved.

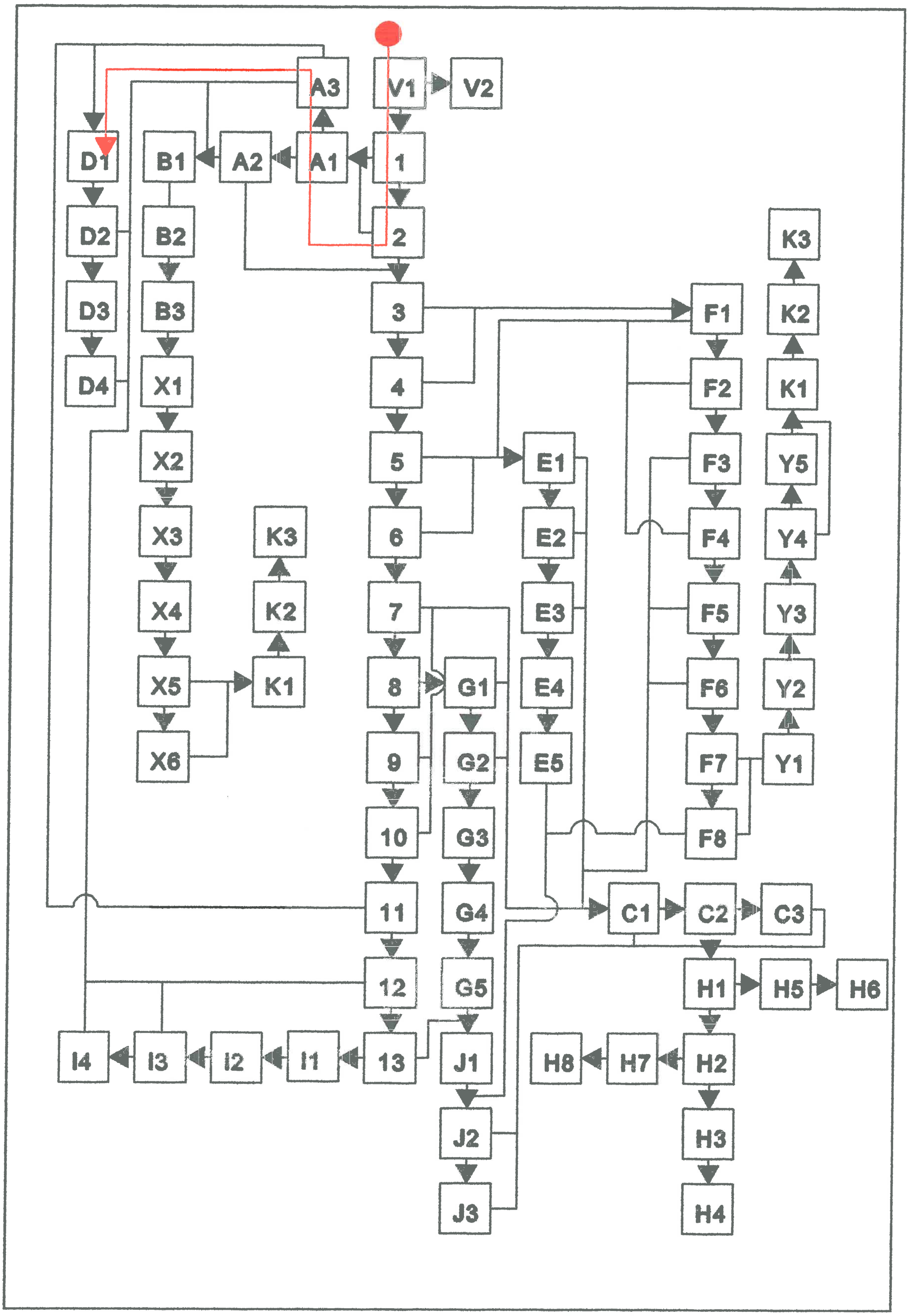

Figure 40 Engineering tower selection path

First National Bank Gezina, Pretoria

Introduction

The following information was used to select the system:

- The system was installed when the building was erected.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building is an office building.
- Most of the bank is one large zone.
- Dust is not a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in the occupied zones is not preferable.
- It is necessary to supply large volumes of fresh air because of the large number of people that can be in the bank at one time.
- Cooling equipment is aesthetically not allowed on the outside of the building except the roof.
- A medium cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	New building
2	Is there space for the installation of ducts or an equipment room?	Yes
3	Are large volumes of fresh air required in the zone?	Yes
F1	Is dust a problem in the area?	No
F2	Is noise control very important?	No
F3	Is there stringent RH requirements in the zone?	No
F4	Is cooling equipment allowed on the outside of the building (walls, windows or roof).	Yes
F5	Is cooling equipment acceptable in occupied zones?	Yes
F6	Is maintenance acceptable in occupied zones?	No
C1	Is a large cooling load necessary?	No
C2	Is the building a small low-rise building?	Yes
P1	Are large volumes of fresh air required in the zone?	Yes

P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	No
P5	Must the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life cycle cost

Selected	Direct expansion cooling - Package unit with full fresh air and water cooling
Installed	Direct expansion cooling - Package unit with economiser and air cooling

Discussion

The selected and installed systems are not totally the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because large volumes of air are required:
   - All water systems.
   - Window-mounted units.
   - Through-the-wall units.
   - Split units.
2. The following systems are not recommended because maintenance is not allowed in occupied zones:
   - Small evaporative coolers.
   - Air-water systems.
3. An all air system may be a slight overkill if a large cooling load is not required.
4. The following systems are recommended for this application.
   - Large evaporative cooler with ducted air supply.
   - Package units.
5. The knowledge base cannot distinguish between small through-the-wall evaporative coolers and large evaporative coolers with ducted air supply.
6. This can be rectified by redirecting the questioning to the Y group of questions and modifying this group to make it possible to discern between these types of evaporative coolers.
7. A package unit is therefore selected because of this problem.
8. Full fresh air supply is selected because of the large fresh air demand.
9. Water cooling is selected because it is more effective than air cooling. This is important to ensure the lowest 20-year life-cycle cost is achieved.

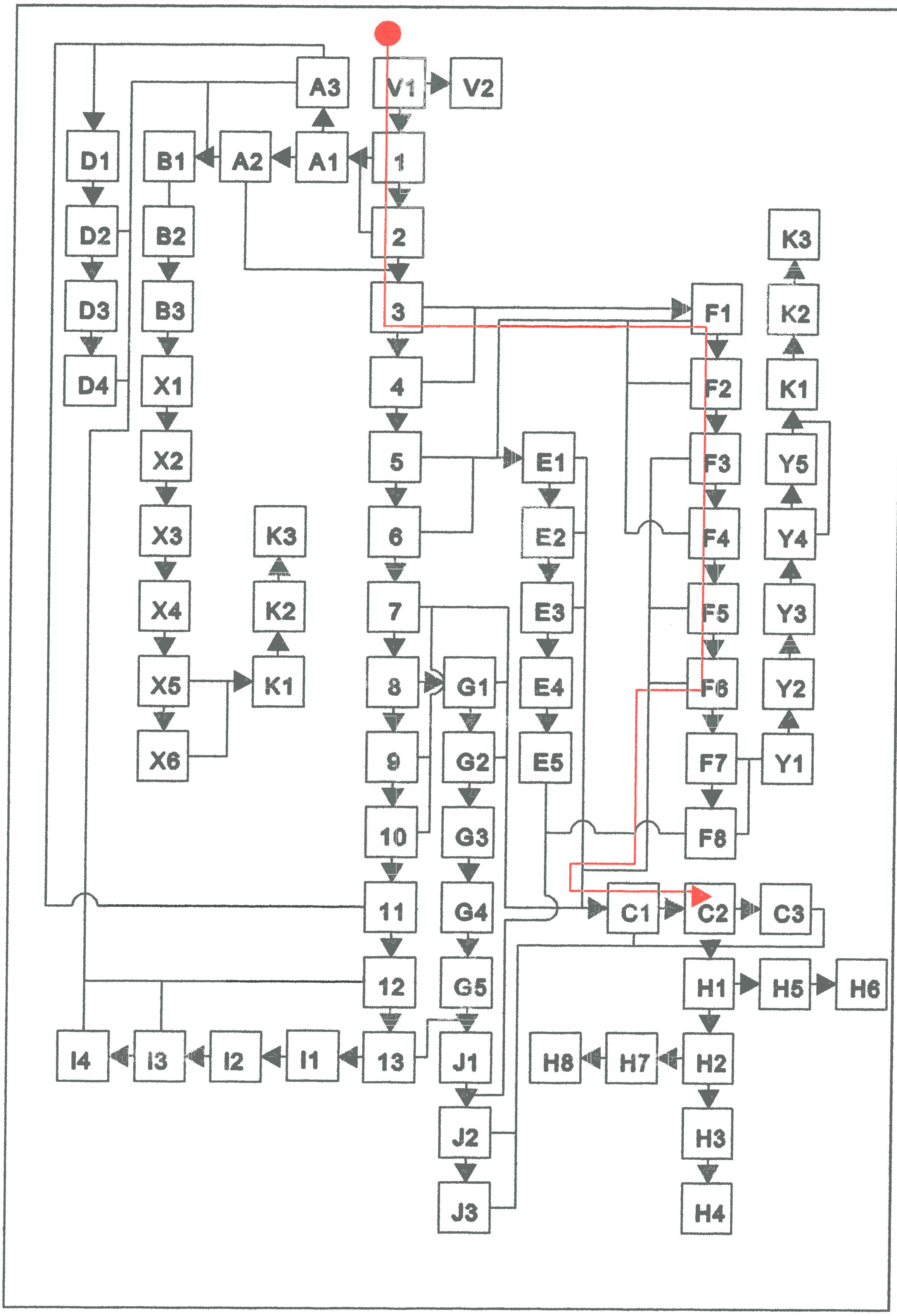

Figure 41 First National Bank selection path

MMA Office, Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed as a retrofit.
- There is no space to install ducts.
- There is no space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building is an office building.
- The building consists of several small zones.
- Dust is not a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is not necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A small cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest initial costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	Retrofit
A1	Is there space for the installation of ducting?	No
A3	Is there room for cooling equipment in the building, on the roof or on the out side of the building?	No
B1	Are there non-perimeter zones in the building that have to be cooled?	No
B2	Can and may cooling equipment be installed in the windows or through a wall?	No

Selected	Direct expansion cooling - Split unit
Installed	Direct expansion cooling - Split unit

Discussion

The selected and installed systems are the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because there is not space for ducts or an equipment room:
   - All water systems.
   - All air systems.
   - Air-water systems.
   - Large evaporative cooler with ducted air supply.
   - Large package units.
2. The following systems are not recommended because the windows are too small to install cooling equipment.
   - Window-mounted units.
   - Small evaporative coolers.
3. The following systems are recommended in this application.
   - Split units.
   - Small vertical package units.
   - Through-the-wall unit.
4. The knowledge base cannot distinguish between small vertical package units and large package units with ducted air supply.
5. This can be rectified by modifying the B group of questions to make it possible to distinguish between these types of package units.
6. A split unit is therefore selected because of this problem.
7. This is not a problem because the cooling load is so small that a vertical package unit would have been inappropriate.

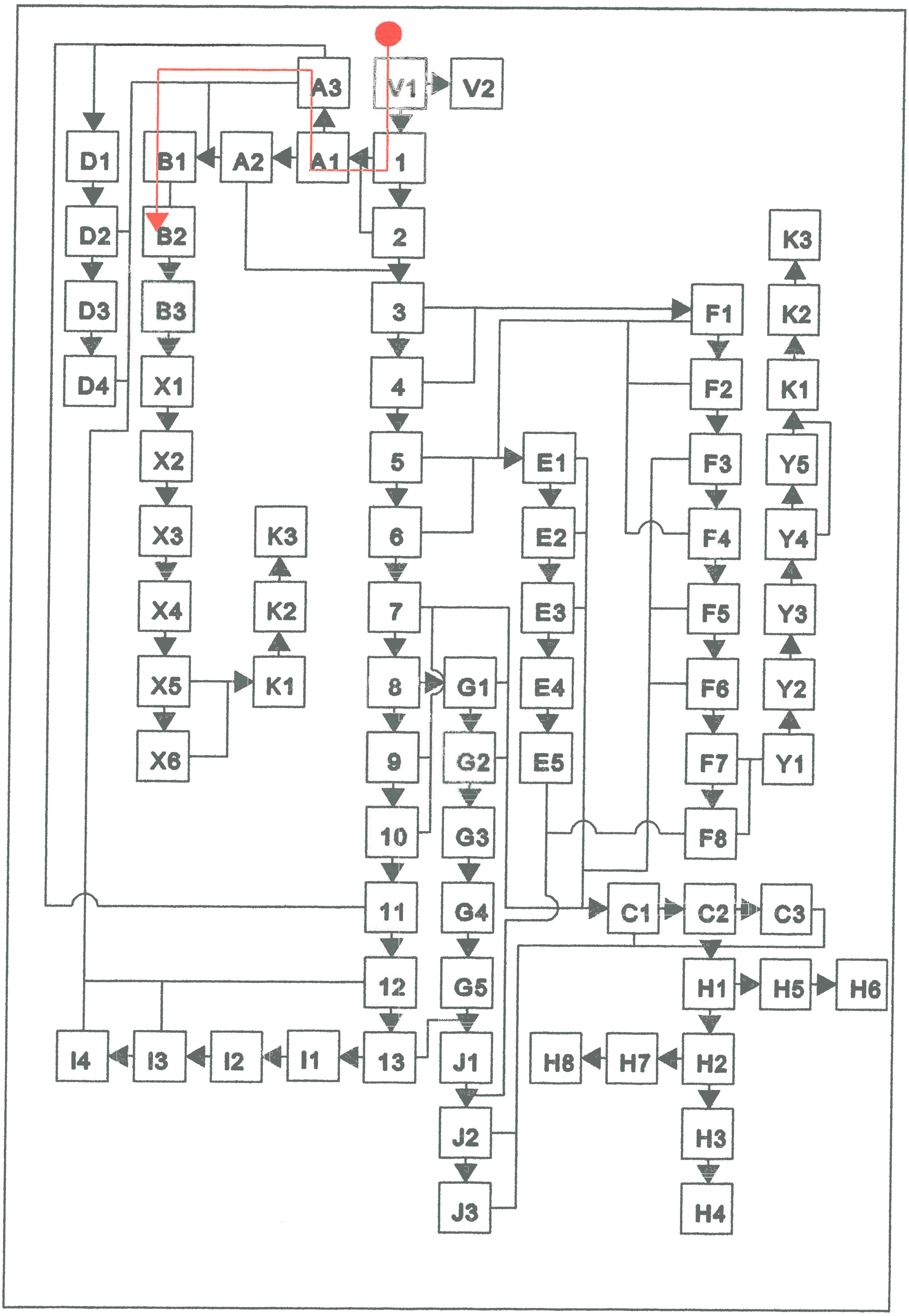

Figure 42 MMA selection path

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Cold Mills South Change House, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed as a retrofit.
- There is no space to install ducts.
- There is no space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building is a change house.
- The building consists of one zone.
- Dust is a bit of a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- No cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- There is a humidity problem when the people shower.
- There is an odour problem.
- The building is inside a factory.
- The design emphasis is on lowest initial costs.

Selection

V1	Is only ventilation needed?	Yes
V2	Is it possible to use natural ventilation?	No

Selected	Mechanical ventilation
Installed	Mechanical ventilation - Extractor fan

Discussion

The selected and installed systems are the same. This decision can be defended on the following grounds:

1. Only large volumes of fresh are required in the zone.
2. It is not possible to use natural ventilation.

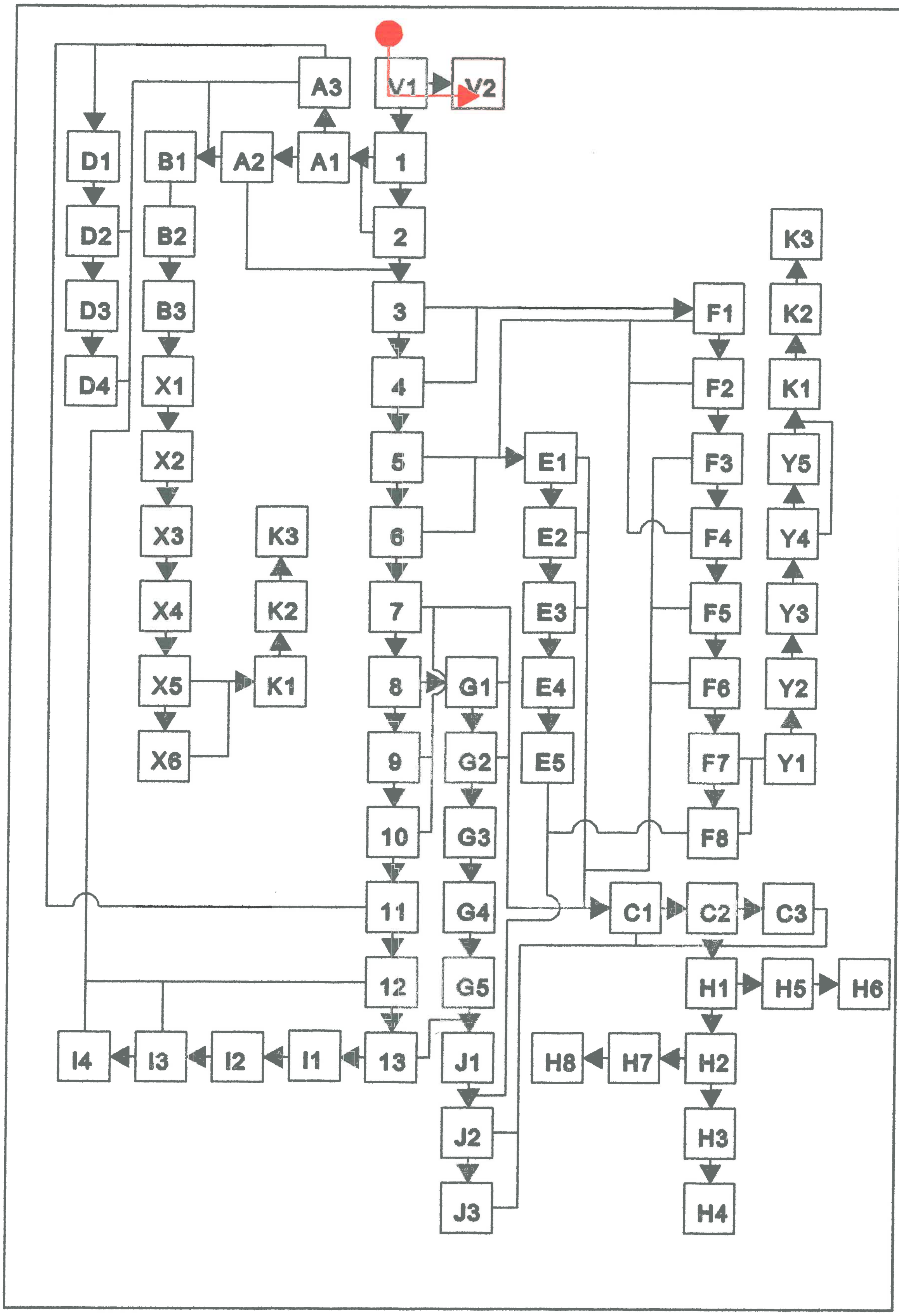

Figure 43 Cold Mills South Change House selection path

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Cold Mills South Administration Building, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed as a retrofit.
- There is no space to install ducts.
- There is no space for cooling equipment in the building.
- The building is a low-rise building.
- The building is an office building.
- Dust is a small problem.
- The building consists of a large number of small perimeter zones.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is not necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A small cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest initial costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	Retrofit
A1	Is there space for the installation of ducting?	No
A3	Is there room for cooling equipment in the building, on the roof or on the outside of the building?	No
B1	Are there non-perimeter zones in the building that have to be cooled?	No
B2	Can and may cooling equipment be installed in the windows or through the walls?	Yes
B3	Must the cooling equipment be aesthetically pleasing?	No
X1	Is the outdoor RH high?	No
X2	Is there water for an evaporative cooler?	Yes
X3	Is the Rh in the zone high?	No
X4	Is dust a problem in the area?	Yes

Selected	Direct expansion cooling - Split unit system or window-mounted units
Installed	Direct expansion cooling - Split unit system and window-mounted units

Discussion

The selected and installed systems are the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because there is no space for ducts or an equipment room:
   - All water systems.
   - All air systems.
   - Air-water systems.
   - Large evaporative coolers with ducted air supply.
   - Large package units.
2. The following systems are not recommended because dust is a problem.
   - Small evaporative coolers.
3. The following systems are recommended in this application.
   - Split units.
   - Window-mounted units
   - Through-the-wall units.
   - Small vertical package units.
4. The knowledge base cannot distinguish between a small vertical package unit and a large package with ducted air supply.
5. This can be rectified by modifying the B group of questions to make it possible to distinguish between these types of package units.
6. A split unit or WMU is therefore selected because of this problem.

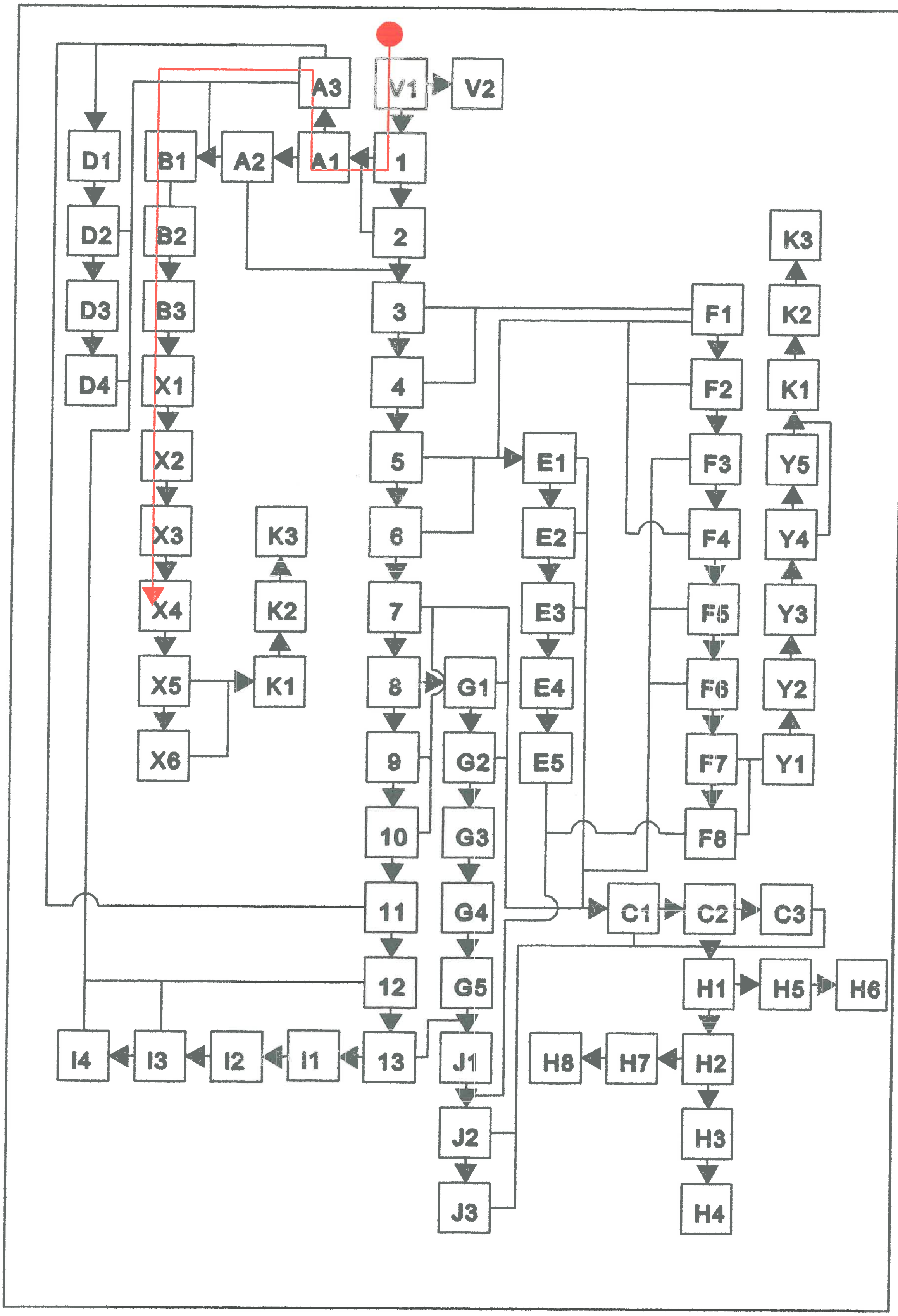

Figure 44 Cold Mills South administration building selection path.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Main Administration Building, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed as a retrofit.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a medium-rise building.
- The building is an office building.
- The building consists of a large number of small zones. Most of them are on the perimeter.
- Dust is a bit of a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in occupied zones is not allowed.
- It is not necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A large cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	Retrofit
A1	Is there space for the installation of ducting?	Yes
A2	Is there room for cooling equipment in the building, on the roof or on the outside of the building?	Yes
3	Are large volumes of fresh air required in the zone?	No
4	Should the system provide + or - pressure in the zone	No
5	Is dust a problem in the area?	Yes
E1	Is there stringent RH requirements in the zone?	No
E2	Is cooling equipment acceptable in occupied zones?	Yes
E3	Is maintenance allowed in occupied zones?	Yes
E4	Is the building a small low-rise building?	No
E5	Should the system be selected for the lowest initial cost or the lowest 20-year life cycle cost?	Lowest life-cycle cost

J2	Are there a small number of large open plan zones?	No
J3	Are most of the zones perimeter zones?	Yes
H1	Is there limited space to install ducts?	No
H2	Is there big differences between temperature in different zones?	Yes
H7	Is noise control very important?	Yes
P1	Are large volumes of fresh air required in the zone?	No
P2	Should the system be selected for the lowest initial cost or the lowest 20-year life cycle cost?	Lowest life-cycle cost
P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	Yes

Selected	Chilled water system - Air-water constant volume variable temperature system with economiser, low velocity ducts and water cooling.
Installed	Direct expansion - Split unit system plus a fresh air ventilation system.

Discussion

The selected and installed systems are not the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because dust is a problem.
   - Split units.
   - Window-mounted units.
   - Through-the-wall units.
   - Small vertical package units.
   - Small evaporative coolers.
   - All water systems.
2. The following systems are recommended for this application.
   - All air systems.
   - Air-water systems
3. The Air-water system is selected because it is ideally suited for perimeter zones.
4. The lowest 20-year life-cycle cost selection choice has several effects. The following selections are accordingly made:
   - Water cooling of condenser equipment.
   - Low velocity ducts.
   - The use of an economiser.
   - The use of a constant volume variable temperature system.
5. The knowledge base does not take hybrid system into account.

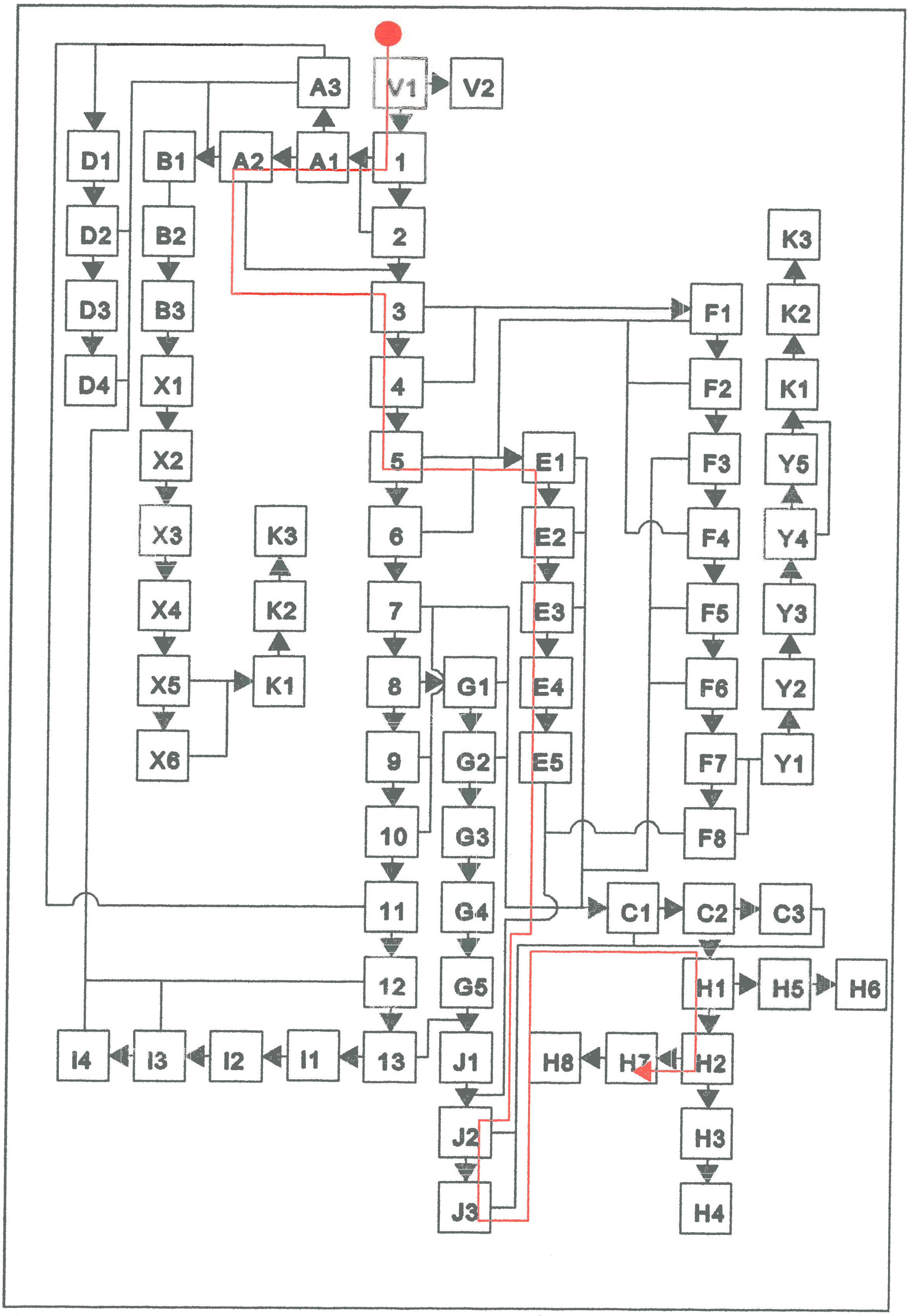

Figure 45 Main administration building selection path

Paint Line Painting Section, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed as a retrofit.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building is a factory.
- The building consists of a large zone.
- Dust is a bit of a problem.
- It is not necessary to keep the building under a positive or negative pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A large cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	Retrofit
A1	Is there space for the installation of ducting?	Yes
A2	Is there room for cooling equipment in the building, on the roof or on the outside of the building?	Yes
3	Are large volumes of fresh air required in the zone?	Yes
F1	Is dust a problem in the area?	Yes
E1	Is there stringent RH requirements in the zone?	Yes
C1	Is a large cooling load necessary?	Yes
H1	Is there limited space to install ducts?	No
H2	Is there big differences between temperature in different zones?	No
H3	Is noise control very important?	No
H4	Must the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
P1	Are large volumes of fresh air required in the zone?	Yes

P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	No
P5	Must the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost

Selected	Chilled water system - All air variable air volume system with full fresh air, low velocity ducts and water cooling.
Installed	Chilled water system - All air constant volume variable temperature system with full fresh air, low velocity ducts and air cooling.

Discussion

The selected and installed systems are not totally the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because large volumes of air are required:
   - All water systems.
   - Window-mounted units.
   - Through-the-wall units.
   - Split units.
2. The following systems are not recommended because stringent Rh control is needed.
   - Small evaporative coolers.
   - Large evaporative coolers with ducted air supply.
   - Air-water systems.
3. The following systems are recommended for this application.
   - All air systems.
   - Package units.
4. An all air system is selected because a large cooling load is required.
5. Full fresh air supply is selected because of the large fresh air demand.
6. Water cooling, low velocity ducts and the variable air volume are selected to ensure the lowest 20-year life-cycle cost is achieved.

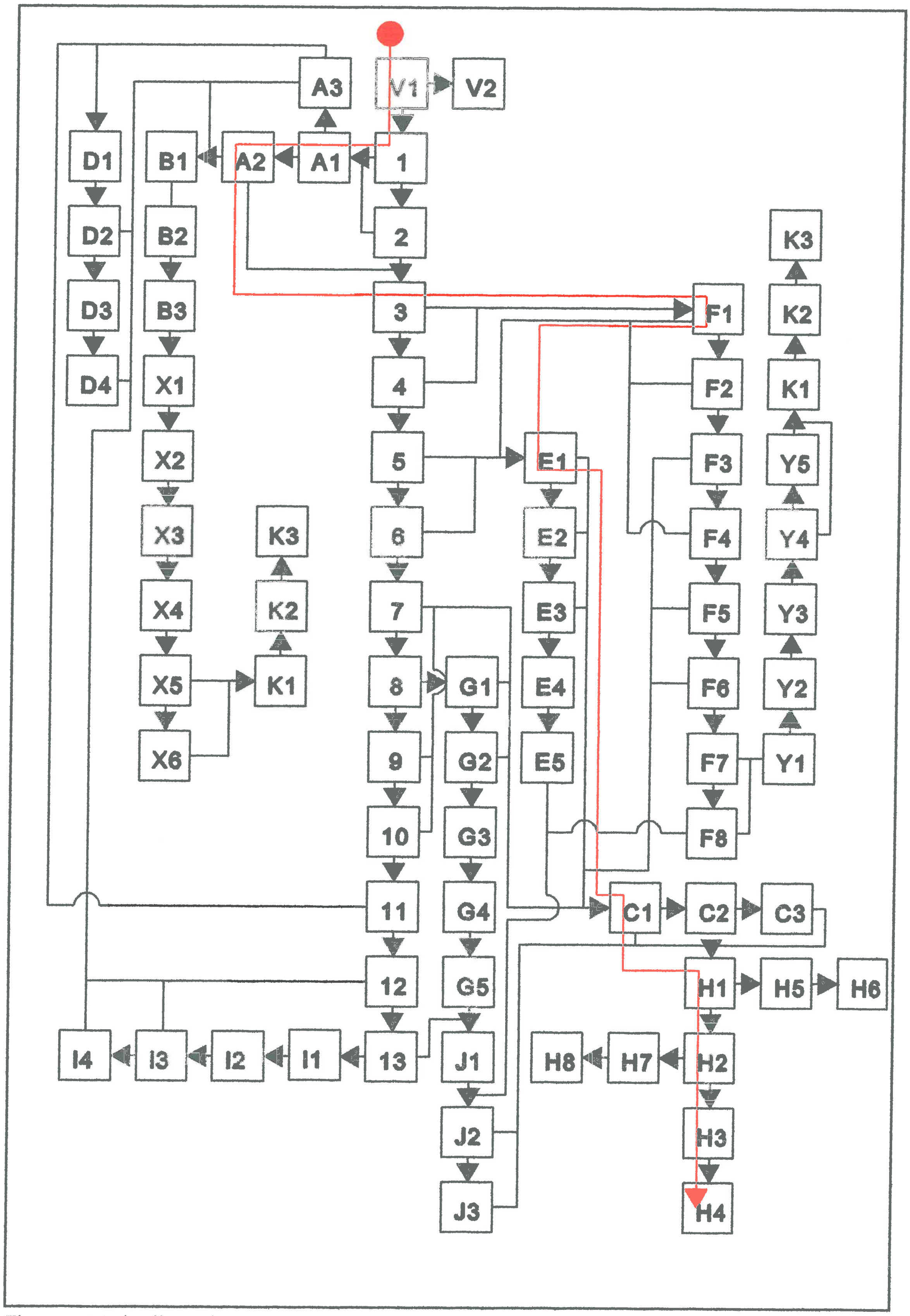

Figure 46 Paint line selection path

Data Centre, Computer Room, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed when the building was erected.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building houses a computer room.
- The computer room consists of a large zone.
- Dust is a bit of a problem.
- It is necessary to keep the building under a positive pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is not necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A large cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	New building
2	Is there space for the installation of ducts or an equipment room?	Yes
3	Are large volumes of fresh air required in the zone?	No
4	Should the system provide + or - pressure in the zone	Yes
F1	Is dust a problem in the area?	Yes
E1	Is there stringent RH requirements in the zone?	Yes
C1	Is a large cooling load necessary?	Yes
H1	Is there limited space to install ducts?	No
H2	Is there big differences between temperature in different zones?	No
H3	Is noise control very important?	No
H4	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
P1	Are large volumes of fresh air required in the zone?	No

P2	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	No
P5	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost

Selected	Chilled water system - All air variable air volume system with economiser, low velocity ducts and water cooling.
Installed	Chilled water system - All air constant volume variable temperature system with economiser, low velocity ducts and water cooling plus all water system with water cooling

Discussion

The selected and installed systems are not totally the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because they cannot provide the zone with positive pressure.
   - Split units.
   - Window-mounted units.
   - Through-the-wall units.
   - Small evaporative coolers.
   - All water systems.
2. The following system is not recommended because stringent Rh control is necessary.
   - Air-water systems.
3. The following systems are recommended for this application.
   - All air systems.
   - Package units.
4. The all air system is selected because a large cooling load is required.
5. The lowest 20-year life-cycle cost selection choice has several effects. The following selections are accordingly made:
   - Water cooling of condenser equipment.
   - Low velocity ducts.
   - The use of an economiser.
   - The use of a variable air volume system.
6. The knowledge base does not take hybrid system into account.

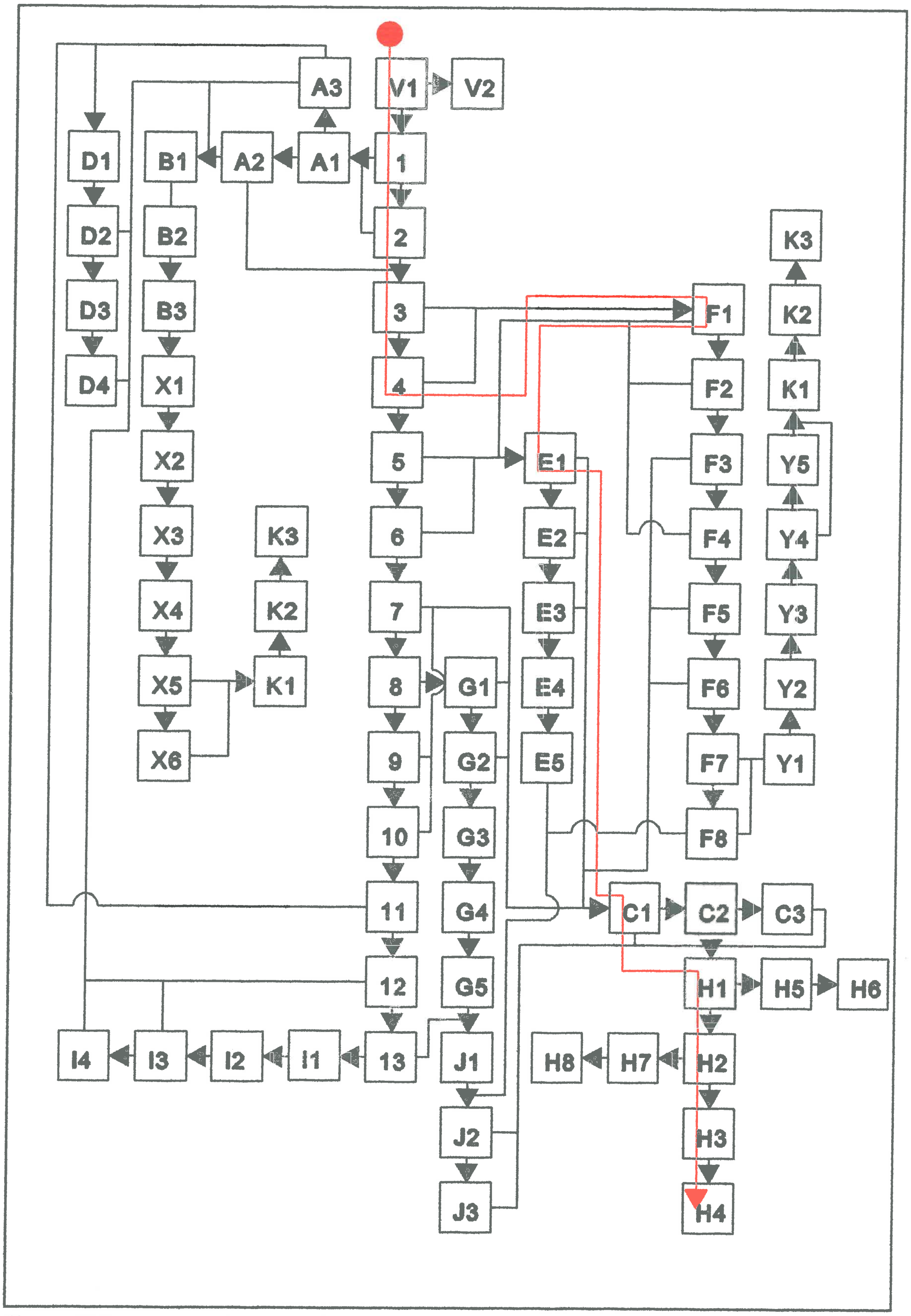

Figure 47 Data centre selection path

Direct Reduction Control Room, ISCOR Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed when the building was erected.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a high-rise building.
- The building houses a control room.
- The control room consists of a large zone.
- Dust is a bit of a problem.
- It is necessary to keep the building under a positive pressure.
- Maintenance and cooling equipment in occupied zones is allowed.
- It is not necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A medium cooling load is required.
- Noise control is not very important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	New building
2	Is there space for the installation of ducts or an equipment room?	Yes
3	Are large volumes of fresh air required in the zone?	No
4	Must the system provide + or - pressure in the zone	Yes
F1	Is dust a problem in the area?	Yes
E1	Is there stringent RH requirements in the zone?	Yes
C1	Is a large cooling load necessary?	No
C2	Is the building a small low-rise building?	No
C3	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
H1	Is there limited space to install ducts?	No
H2	Is there big differences between temperature in different zones?	No
H3	Is noise control very important?	No

H4	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
P1	Are large volumes of fresh air required in the zone?	No
P2	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost
P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	No
P5	Should the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost

Selected	Chilled water system - All air variable air volume system with economiser, low velocity ducts and water cooling.
Installed	Chilled water system - All air constant volume variable temperature system with economiser, low velocity ducts and water cooling.

Discussion

The selected and installed systems are not exactly the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because they cannot provide the zone with positive pressure.
   - Split units.
   - Window-mounted units.
   - Through-the-wall units.
   - Small evaporative coolers.
   - All water systems.
2. The following system is not recommended because stringent Rh control is necessary.
   - Air-water systems.
3. The following systems are recommended for this application.
   - All air systems.
   - Package units.
4. The all air system is selected because the lowest life-cycle cost is required.
5. The lowest 20-year life-cycle cost selection choice has several effects. The following selections are accordingly made:
   - Water cooling of condenser equipment.
   - Low velocity ducts.
   - The use of an economiser.
   - The use of a variable air volume system.

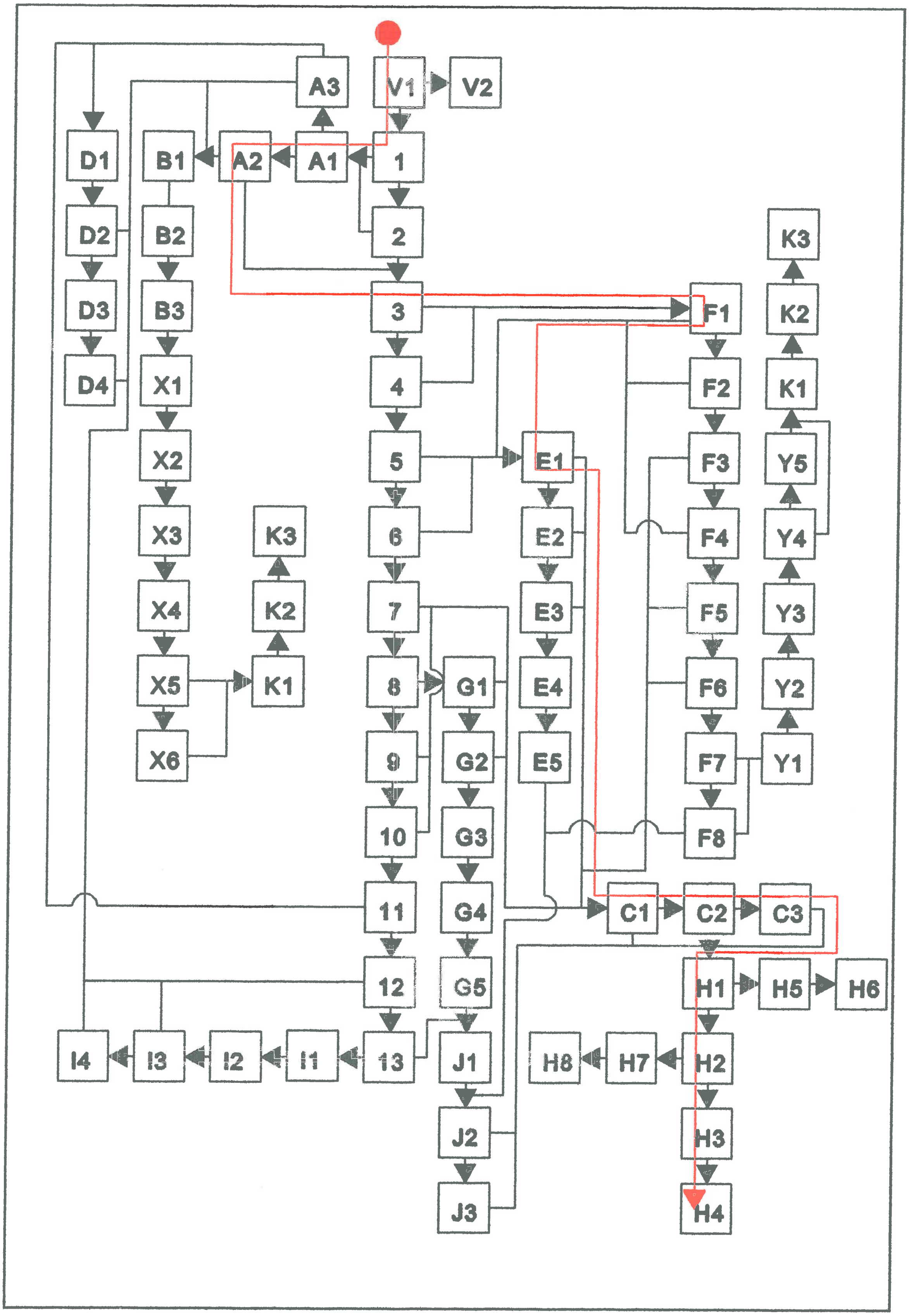

Figure 48 Direct reduction control room selection path

Neonatal Unit, Medivaal Hospital Vanderbijlpark

Introduction

The following information was used to select the system:

- The system was installed when the building was erected.
- There is space to install ducts.
- There is space for an equipment room to install cooling equipment.
- The building is a low-rise building.
- The building houses a neonatal unit.
- The neonatal unit is an intensive care unit for babies.
- The unit consists of a small zone.
- It is necessary to keep the unit under a positive pressure.
- Maintenance and cooling equipment in occupied zones is not allowed.
- It is necessary to supply large volumes of fresh air.
- Cooling equipment is aesthetically allowed on the outside of the building.
- A small cooling load is required.
- Noise control is important.
- There is water for a cooling tower.
- The space for the condenser cooling equipment is close to the cooling equipment.
- The design emphasis is on lowest life-cycle costs.

Selection

V1	Is only ventilation needed?	No
1	Is the system for a new building or for a retrofit?	New building
2	Is there space for the installation of ducts or an equipment room?	Yes
3	Are large volumes of fresh air required in the zone?	Yes
F1	Is dust a problem in the area?	No
F2	Is noise control very important	Yes
E1	Is there stringent RH requirements in the zone?	Yes
C1	Is a large cooling load necessary?	No
C2	Is the building a small low-rise building?	Yes
P1	Are large volumes of fresh air required in the zone?	Yes
P3	Is there water for a cooling tower?	Yes
P4	Is there a distance between the equipment room and space for the installation of condenser cooling equipment?	No
P5	Must the system be selected for the lowest initial cost or the lowest 20-year life-cycle cost?	Lowest life-cycle cost

Selected	Direct expansion - Package unit system with full fresh air and water cooled.
Installed	Direct expansion - Split unit system plus a fresh air ventilation system.

Discussion

The selected and installed systems are not the same. This decision can be defended on the following grounds:

1. The following systems are not recommended because they cannot provide the zone with large volumes of fresh air and positive pressure.
    - Split units.
    - Window-mounted units.
    - Through-the-wall units.
    - All water systems.
2. The following system is not recommended because stringent RH control is necessary.
    - Air-water systems.
    - Evaporative coolers.
3. The following systems are recommended for this application.
    - All air systems.
    - Package units.
4. The package unit is selected because of the small load required.
5. Water cooling is selected to insure that the lowest 20-year life-cycle cost is achieved.

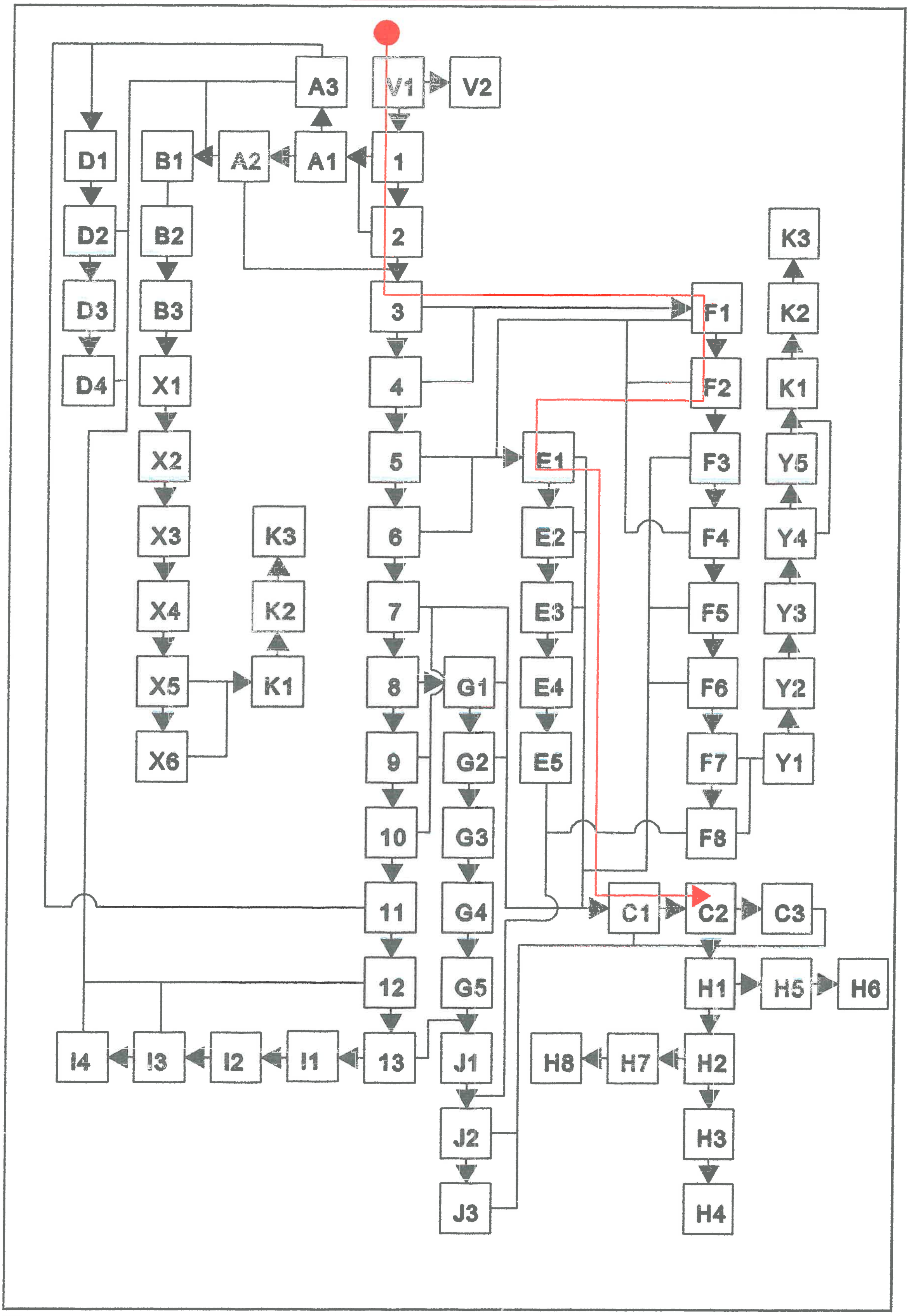

Figure 49 Medivaal neonatal unit selection path

6.3 Conclusion

The module gives realistic answers in each of the ten case studies. Differences between the program and the systems installed in the existing buildings can in some cases be contributed to personal preferences of the person who selected the system. Some of the smaller differences can be attributed to a different design emphasis. An example is the use of air cooling instead of water cooling. This is because the designer selected a system for lowest initial cost instead of lowest life-cycle cost. Differences may also result from different interpretations of a question. A number of problems were identified in the case studies. The selection module does not take hybrid system into account and cannot distinguish between small vertical package units, large package units with ducted air supply and large evaporative coolers with ducted air supply.

The output interface was very successful in that it is very easy to understand. The output gives the user a summary of all the questions asked and the answer. It also gives the characteristics, advantages and disadvantages of the system selected. The program can be used in real-time consulting work. It should make a very valuable tool for any consulting engineer, architect and air-conditioning sales representatives. The selection module program met most of the design goals specified.

After the verification of the program some small improvements to the interface can be recommended. It will be convenient to be able to go back to a question if one wants to correct a wrong answer. The summary of the selected system with all its characteristics, advantages and disadvantages should be displayed in an extra window. The program must furthermore also be incorporated into the whole design program.

7

Epilogue

In the prologue environmental reasons were given why HVAC simulation programs must be used while designing air-conditioning systems. It is an unfortunate fact that most developers, designers and people usually do not care about the environment and the effect that every decision has on the future of the only habitat that they and their children have. This fact can be exploited for the good of the environment because a well designed air-conditioning system costs less and uses less energy than a poorly and overdesigned system.

One of the first questions an engineer will ask is why do I need another HVAC simulation program if there are already so many other design programs on the market. This program doesn't and cannot compete with most of the other design and simulation programs in that it cannot equal these programs' accuracy, the detail of their simulations or their nice special features and graphs.

This program only comes to its full potential in the brief and design stages of a project. At this stage of a project there is very little technical data and engineers usually use their experience to quote loads and to select a system. The program is designed to make this process more reliable and easier. One of the most important design criteria of the program was that it could be used real-time while the engineer is consulting the client. This means that it must be fast and very easy to use.

One starts with a fictional ideal package. This ideal package has several characteristics that define its uses and gives a general feeling of how the interface will look. In the design of the program and its modules one strived to achieve this ideal package. Some characteristics are unfortunately unobtainable and in other cases certain trade-offs have been made between them. This made it important to set priorities between characteristics. At the end of the project one can compare the real program with the ideal, as summarised on page 5 of the prologue. The program meets most of the criteria except that the modules do not interact with each other and the cooling load calculation does not meet the required accuracy necessary.

As can be seen there is still work to be done to achieve this ideal design package. The following is recommended to improve the design package. The cost module must be completed and then all the modules must be integrated into one design package. The linking must be done in an object-orientated manner to ensure that it is possible to start at any of the modules with a design. A Load/Save function must be incorporated into the program. The two modules that have already been written are a foundation to build on and can already be used as separate programs. There is however still some work necessary.