Chapter 2 Developing A New Simplified Thermal Design Tool For Architects

Architects form an integral link in the design of efficient buildings. Energy efficient design strategies therefore require architects and engineers to work closely together in optimising the building shell. However, this is not always practical. Architects must therefore be able to perform a preliminary thermal analysis if energy efficient design strategies are to succeed. Existing tools do not cater for this or fit their design methodology. A need therefore exists for a simplified thermal design tool for architects. This chapter discusses the development of such a tool.

2.1 INTRODUCTION

It has long been known that the building envelope has a considerable impact on thermal comfort and HVAC system size [1,2,3,4]. Hens [5] in fact states that the HVAC system and building shell are inseparable, like Siamese twins. In most cases, architects design the building shell. These designs are then passed on to HVAC engineers. They perform a thermal analysis and design the necessary systems to achieve the required comfort level [6].

According to Holm [7], the thermal analysis is done at a stage when major design decisions have already been made. It is then difficult for the architect to change his design based on the thermal analysis results. This sequential design can potentially lead to buildings that are energy inefficient and require large HVAC systems. It is therefore essential that architects can evaluate their designs before important building characteristics are frozen.

Building thermal simulation tools have a tremendous potential for aiding designers in evaluating and optimising the building envelope design. Unfortunately, existing tools do not accommodate architects nor fit into the current design process. These tools tend to be complicated and time consuming to use. Furthermore, they often require detailed information of the building construction. Existing tools have thus so far failed to be incorporated into the general design practice [8]. A need for a simplified thermal design tool for architects therefore still exists.

A new thermal design tool was developed to fulfil the above requirements by addressing the needs identified by the design community in Lausanne [9]. The tool was simplified by reducing the number of input parameters and defining them in terms that architects can relate to. The output of the program further enables designers to quickly evaluate their design without the need for detailed processing of the analysis results. These properties make the design tool ideal for use early in the design.

2.2 INTEGRATED BUILDING AND HVAC DESIGN

Buildings serve a dual function. They provide a comfortable working and living environment that protects the occupants from harsh climatic conditions, and they serve as an expression of the owners' style, status and individualism. Buildings must therefore be aesthetically pleasing yet functional. Before the advent of electricity and mechanical HVAC equipment this was achieved by incorporating passive comfort design features into the building structure [6,10].

The once integrated design process evolved into a sequential process with the development of fluorescent lights and mechanical HVAC equipment [6]. This equipment made it possible to obtain indoor comfort anywhere in a building. Freed from the comfort constraints, architects could design buildings based purely on aesthetics. These designs were then passed on to HVAC designers. They devised the necessary systems needed to achieve comfort. Close co-operation between the various design disciplines consequently ceased to exist.

Lack of communication and close co-operation between the various design disciplines is seen as one of the major causes of energy inefficient and uncomfortable buildings [11,12,13,14]. Blaine [13] believes that poor design integration is mostly responsible for buildings diagnosed with Sick Building Syndrome (SBS). Some building owners and developers are thus requiring architects and engineers to work closely together [15]. Regaining the lost art of integrated building and HVAC design is therefore receiving a lot of attention [1,6,12,16].

2.3 IMPORTANCE OF INITIAL DESIGN STAGES

Building designers typically follow a top-down design procedure when designing new buildings [7,17,18]. It consists of initially starting with the building as a whole and then working down to smaller detail, such as colour and wall finishes. This process is divided into several design stages [19,20]. The definition and detail of the various design stages may vary for different designers, but the basic idea remains the same.

Typical stages of building design are as follows:

- *Design briefing stage*- the initial specifications of the building are fixed with respect to function and size;
- *Preliminary design stage*- during this stage the building orientation, general construction, and window areas are defined and set;
- *Detailed design stage* - final decisions on building interior layout, construction and colour are made;
- *Construction documentation stage* - specifications and detailed working drawings are drawn up. This documentation is put out for tender;
- *Contract administration stage* - a contractor is selected and the building is constructed. During this stage the architect oversees the works and performs general administration.

The initial design stages form the foundation of all new building designs. During these stages the general size, orientation and construction of the building are defined. All subsequent decisions and design calculations are based on these characteristics. It therefore becomes more difficult and costly to alter the design as it progresses. Decisions made early on, without careful consideration or knowledge of their consequences can have a dire effect. It is therefore essential that thermal analysis and feedback start early in the design process.

This top-down design practice has evolved over a long period of time. It is therefore unlikely that this approach will change radically in the foreseeable future. Energy efficient design strategies need to take this into consideration. If a strategy alters the design process too much, it will most likely not be used extensively [21].

2.4 THE ARCHITECT AND THERMAL DESIGN

The Integrated Design Approach (IDA) is suggested as a simple inexpensive means of achieving energy efficient and comfortable buildings [16]. Figure 2.1 shows a simple flow chart of this approach. Minimising the building load is the first step in designing new energy efficient buildings. This load is mainly affected by the building shape, form and thermal characteristics [3,4]. Architects consequently have a significant effect on the building load.

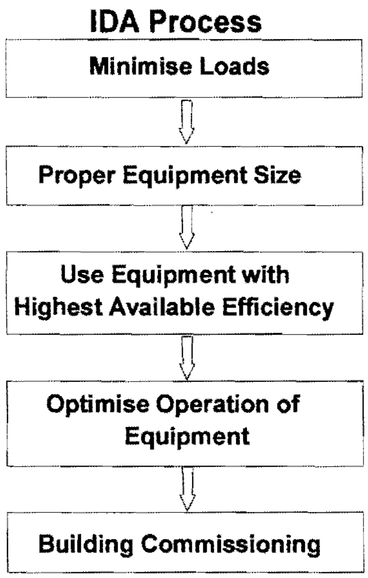

Figure 2.1 – Integrated building design approach [16]

Building thermal efficiency is only one of many items to be considered by the architect. According to Holm [7], it is often given little or no thought at all during the design of the building. He further states that this can be attributed to the fact that many architects and building owners have not been exposed to the realities of life-cycle energy cost, nor its social and environmental impact. Initial cost of the building and its aesthetic value are therefore frequently still used as basis for evaluating the design.

Thermal design requires the architect to allocate more of his time and resources to considering the thermal impact of his design decisions. Holm [7] states that "the architect doing thermal design does so at considerable additional cost to himself, putting himself at risk while the building owner enjoys the long-term benefit, often without paying for it." There is thus little incentive for architects to perform thermal load analyses.

Currently, HVAC designers usually perform building thermal load analyses in order to determine the size of the HVAC system. It is thus only done after most of the building design has been finalised. The critical initial design stages have thus already been completed making it difficult and expensive to change the design based on its results.

Building thermal characteristics must be analysed and modified if needed before significant design decisions are fixed. This can typically help to avoid buildings with large glazing areas, without due consideration to solar heat gains. If the IDA is to succeed, it is essential that architects become involved in minimising the building load when designing the building shell.

2.5 THE NEED FOR A THERMAL DESIGN TOOL FOR ARCHITECTS

Most new energy efficient design strategies require the architect and HVAC engineer to work closely together in minimising the building load. Ideally, these two design professionals need to be appointed at the same time. This however does not always fit into current design practice. In many cases, the building design is near completion when the HVAC engineer is first appointed [11]. The critical, initial design stages have by then already been completed. Architects must therefore be able to perform some preliminary thermal analyses on their own.

Building simulation is seen as an ideal tool to aid designers with thermal analysis [1]. Using a simulation tool it is possible to determine the effect various design decisions will have on the building load. Changes can thus be made before major design decisions are fixed. There are a host of simulation tools available for use by designers. To date these tools have however largely failed to be applied into the building design process.

Various speakers discussed this lack of use during the 1997 International Building Performance Simulation Association (IBPSA) conference held in Prague. Complexity and the time required to use these tools are frequently cited as reasons for this. The users further require knowledge of thermal and numerical analysis [22]. Architects, in general, are not well versed in these areas.

Detail required to generate a thermal model of the building is also a major limitation. Most of the information needed for simulation is not yet available during the preliminary design stages when analysis is most needed [7,23]. According to Holm [7], the thermal simulation process is diametrically in the opposite direction of the architectural design approach.

Another trend in new software development is towards total building energy estimation. These tools therefore incorporate elementary lighting and HVAC system simulation. Although beneficial during subsequent design stages, these features tend to cloud the impact of architectural design decisions by a host of other data. Existing simulation tools consequently do not cater for architects or aid them in designing the building thermal shell. These obstacles must be addressed if architects are to be encouraged to perform preliminary thermal analysis. There consequently exists a need for a simplified thermal design tool for architects.

2.6 DESIGN TOOL REQUIREMENTS FOR ARCHITECTS

The first step in developing a new thermal design tool for architects is to determine their requirements. The basic needs identified during the third International Congress on Building Management (ICBEM) in Lausanne [9] are still applicable today. They are as follows (adapted from Holm [7]):

1. The design tool should be user friendly and easy to use.
2. Input formats must be user orientated and in terms of building materials rather than thermal properties.
3. Solutions must be obtained quickly, in minutes rather than hours. This is more important than the accuracy of the tool.
4. It should be able to handle 'what if' alternatives readily.

The social component of design tools is another often-overlooked factor [24]. The fears and reservations that designers have in the use of these tools should also be addressed. It is consequently important that designers are aware of the merits and limitations of using the design tool [14]. The tool must thus be extensively verified. A tool that can be used for marketing or has financial benefits is furthermore also more likely to succeed according to

Stevens [24]. This will give architects an incentive for using the tool. These requirements must be reflected in the input, simulation and output of the new design tool.

2.7 SIMPLIFYING THE INPUT REQUIREMENTS

The user interface and data required by the tool forms an important link between the designer and the design tool. Tools that overwhelm architects with the amount of input data or knowledge required will not be used. This is especially true in countries where architects are not legally bound to perform building thermal analyses. One of the main areas of development is consequently in making existing tools accessible to designers.

Improvements in computing power and graphic capabilities have resulted in more "user-friendly" interfaces than the old ASCII based text files. A survey conducted on users of thermal simulation programs however still indicate that this area requires attention [25]. Complexity of the input structure is believed to be one of the main contributing factors.

Irving [26] states that "the probability of pure user-injected mistakes usually increases with the complexity of the input structure. Much of this complexity arises from geometrical specification of the building and in level of the building detail described." Transferring data from building drawings directly into the simulation program has been suggested as a solution to this problem. Geometrical and construction information is stored in computer generated architectural drawings. The simulation tool accesses the drawing database for the necessary information.

Connecting CAD[1] software with building simulation programs seems to be a clever solution. It is however not suitable for preliminary architectural design. During this stage, the building is defined in a very coarse manner. The requirements of the building developer are normally expressed as sentences, rather than sketches. These tools will thus require the architect to complete his design before performing the thermal analysis. Morel [21] lists various other drawbacks and problems that this approach has.

[1] Computer-aided drafting

The use of default values and automatic generation of complex building models is an alternative means of simplifying the use of simulation tools. Default values can greatly aid designers in obtaining useable design values for parameters that are still unknown. However, they do not necessarily reduce the input structure complexity. To solve this problem, the number of input parameters must be restricted to a minimum.

A Danish study indicates that by using as few as six user-specified parameters, it is possible to auto-generate complex building models with reasonable accuracy [27]. This tool is based on statistical information of existing buildings to determine their construction. The Finnish WINETANA program follows a similar approach [28]. These applications are restricted to the building types used to generate the statistical knowledge database. It is however believed that a similar reduction in input parameters can be obtained using Pareto's law of distribution.

Vilfredo Pareto (1848-1923), an Italian economist and engineer developed a curve known as Pareto's law of distribution. This curve has a general application in areas where a significant number of elements are involved. It indicates that 20% of the elements are generally responsible for 80% of their total effect [29]. In building design terms, twenty percent of the design parameters are largely responsible for the building thermal performance.

A logical deduction is that this also applies to the input data required by building simulation tools. A good indication of a building's performance can thus be obtained by specifying a few critical elements and defining the remaining from typical values for the specific building type. The added advantage of this is that architects need only consider and analyse design parameters that have a huge effect on thermal efficiency.

2.8 CRITICAL INPUT PARAMETERS

There are two elements that need to be considered when establishing the critical input parameters for the architectural design tool. The first consists of determining whether the parameter has a significant effect on the thermal response of the building. The second involves focusing on parameters that are directly influenced by architectural design decisions.

During the preliminary design stages, architectural design decisions consist mainly of defining the building size, form, glazing and general construction. Identifying the important parameters however, is not that simple, since they influence each other. A study done by Shaviv [30] on typical Israeli residential buildings however revealed that design parameters can be divided into three categories.

The first category consists of parameters with a weak effect on the building thermal performance, and thus insensitive to other design parameters. Parameters that have a strong influence but are not affected by other design parameters form the second category. The third category consists of parameters that have a strong effect on building performance and also sensitive to other parameters.

Using the above categories as basis it is possible to reduce the input requirements for the architectural design tool. Parameters of the first and second category, such as internal loads, ventilation, temperature setpoints and operating hours can be modified during the final design stage without compromising other design features. They thus require little attention and can be specified using default values. The third group forms the critical input parameters for thermal simulation.

In order to establish the critical input parameters for the design tool, a sensitivity analysis was performed. It consisted of changing the design parameter of interest and noting the effect that the change has on the building load. This is repeating for various building configurations and climatic conditions in order to obtain a sufficient set of data from which the typical influence of the parameter on building load can be obtained.

The average value of the data indicates the mean influence that the parameter has on the building load. The standard deviation of the data from the mean value shows how much the parameter is influenced by other design criteria. Critical parameters would on average cause a large change in the building load relative to a small change in the design parameter. This relationship is referred to as the sensitivity ratio.

Except for construction material, the sensitivity ratio of the analysed parameters was calculated as the percentage change in load divided by the percentage change in the design parameter. Construction material choice affects thermal mass and conductivity. It is thus difficult to express it in terms of a change in one parameter. Its ratio is consequently defined as the percentage change in load due to a change in material.

By defining the ratios in the above manner it is possible to compare parameters with small value changes, such as the number of zones, with parameters with large numerical changes such as the window area. Table 2.1 indicates the sensitivity analysis results for over 2000 base building configurations. The results indicate a strong sensitivity towards window area, roof colour and internal loads.

A small change in the above parameters would have a large influence on the building load. A substantial reduction in the load can thus be obtained by changing these parameters. There is also a huge difference in choosing building materials with a high thermal mass and high conductivity, compared to a heavy construction with low thermal conductivity. Using these results as basis it is possible to simplify the architectural design tool input requirements.

Parameter	**Summer**		**Winter**	
	Avg. sensitivity ratio	**Std. Deviation**	**Avg. sensitivity ratio**	**Std. Deviation**
Number of zones	5.1	4.5	10.1	7.5
Window area	42	34	34	23
Wall ratios	1.3	1.5	1.2	1.5
Shading – Windows	7.8	9.7	3.5	3.1
Shading – Walls	2.1	1.7	1.2	0.3
Wall colour	3	2.5	1.3	0.5
Roof colour	84.7	7.3	9.0	2.0
Internal loads	60.5	8.7	59.7	7.8
Construction material	83.1	-	60.5	-

Table 2.1 – The influence of various design criteria on the building load

2.9 PROGRAM INPUT

One of the main input requirements of thermal analysis tools is the geometric specification of the building. It is believed that most buildings can be approximated as a square or as the sum of multiple squares. The equivalent projected areas can be used to approximate buildings that are not exactly rectangular. It is hence only necessary to specify floor area, building height and the length of one wall to sufficiently describe the building geometry for the purpose of a preliminary thermal analysis.

The above simplification is possible as the sensitivity analysis showed that the number of zones and the wall ratio's, i.e. North/South wall length relative East/West wall length has small effect on the total building thermal load. In practice these items however influence the load diversity of the required air-conditioning system and must be taken into consideration during later design stages. For the purposes of the design tool the North/South wall length is used as input since this façade is usually exposed to the most solar radiation.

Window area and its orientation are other input parameters required by the design tool. During the preliminary stages of design, the exact window size and their position has not yet been determined. Window area is thus rather specified as a percentage of the wall area, making it easier for the architect to estimate. Generally the window type will not vary and therefore only needs to be specified once.

Shading on the windows and walls further effects the total building load. However, calculating the shaded area is a complex process. It requires the dimensions and positions of the shading devices. These dimensions are only finalised later in the design process. Fortunately the analysis indicates that these items can be simplified. The design tool takes shading on windows into consideration by requiring the user to specify the percentage of shaded window area. The influence of shading on the walls is assumed to be insignificant and thus disregarded.

The colour of exterior surfaces influences the short-wave absorptance characteristics of the building. Darker coloured materials absorb more solar radiation than lighter coloured material. Wall colour has a small effect, as it generally does not receive all the solar radiation. The roof on the other hand is directly exposed to solar radiation and is therefore more sensitive towards colour.

The effect of colour is taken into consideration by allowing the architect to indicate if the walls and roof are light, medium or dark coloured. Solar absorptance characteristics of the exterior surfaces are then adjusted accordingly. The effect of roof colour reduces for high-rise buildings. This ties in with the fact that energy efficient buildings enclose the largest volume for the least surface area [6].

The thermal mass and overall heat transfer coefficient of the surface area plays a major role in defining the thermal characteristics of the building. These items depend on the materials used to construct the building. There is theoretically an infinite number of potential combinations. In practice it can however be restricted to a few representative construction types. ASHRAE [31] and CIBSE [32] provide typical American and British construction types.

A similar set was identified for South Africa and is provided in Appendix A. Construction of the building can be defined by simply selecting the wall, roof and floor assembly that closely matches the qualities of the proposed construction. This process can further be simplified by providing architects with a graphic interface for selecting the appropriate assembly. Figure 2.2 provides an example of such a graphic interface for selecting wall construction.

Internal heat generation is generally a parameter of the second category. It can however influence decisions regarding the building construction. Insulated buildings with high internal loads can cause unwanted heat to become trapped inside the building. In such cases it may be more beneficial to use building material with a higher conductance. This is taken into consideration by allowing the architect to either use a typical Watt per square meter default value or specify the load if it is known.

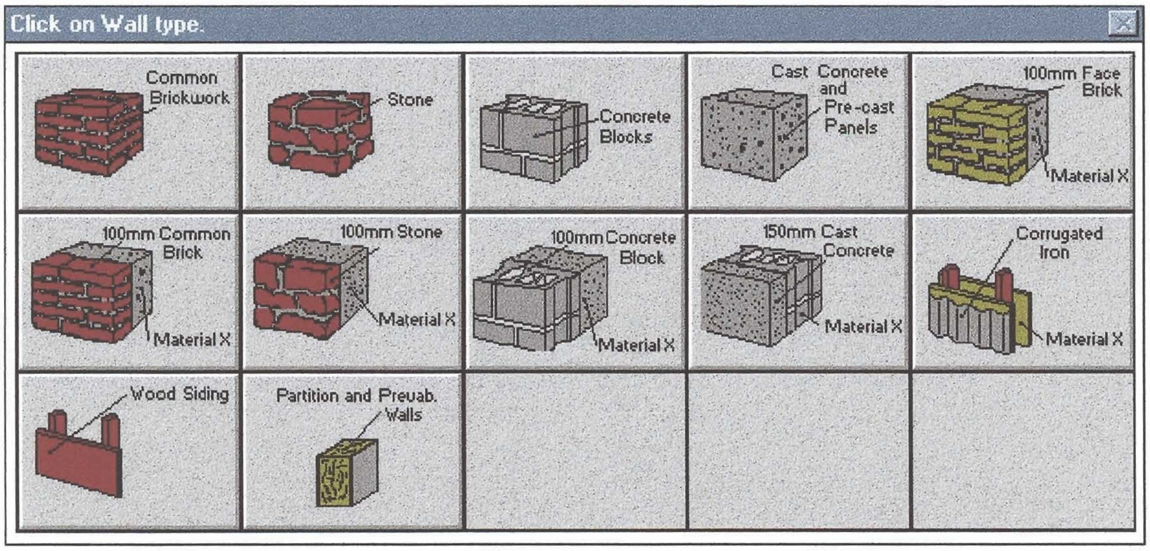

Figure 2.2 – Typical graphic interface for selecting building construction assemblies.

Other input parameters required for thermal simulations are the climate, building type, and orientation. The building type is required for determining default values such as load and ventilation. Climate is selected according to the climatic region in which the building is located. This is facilitated using a graphic interface consisting of a map indicating the regions. Building orientation is a reference angle relative to North with which the designer can specify the orientation of the building in cases were the walls do not face North/South or East/West.

The results of the above research findings made it possible to considerably reduce the input complexity required by thermal simulation tools. A validation study was performed using measured data to further ensure that all the critical design parameters are taken into consideration. The results of this validation study are presented in Chapter 3.

A new simplified design tool for architects was developed and commercialised in conjunction with TEMMI/MCI[2] using the above as basis. Figure 2.3 indicates the user-input interface of the tool. Graphic interfaces for choosing climate, orientation and building construction are all activated from this screen. From the input information the geometry of the building is defined automatically and thermal characteristics of the building material set. Default values are set according to the chosen building type as indicated in Appendix A.

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[2] TEMMI/MCI (Pty) Ltd. P.O. Box 13516 Hatfield 0028, South Africa

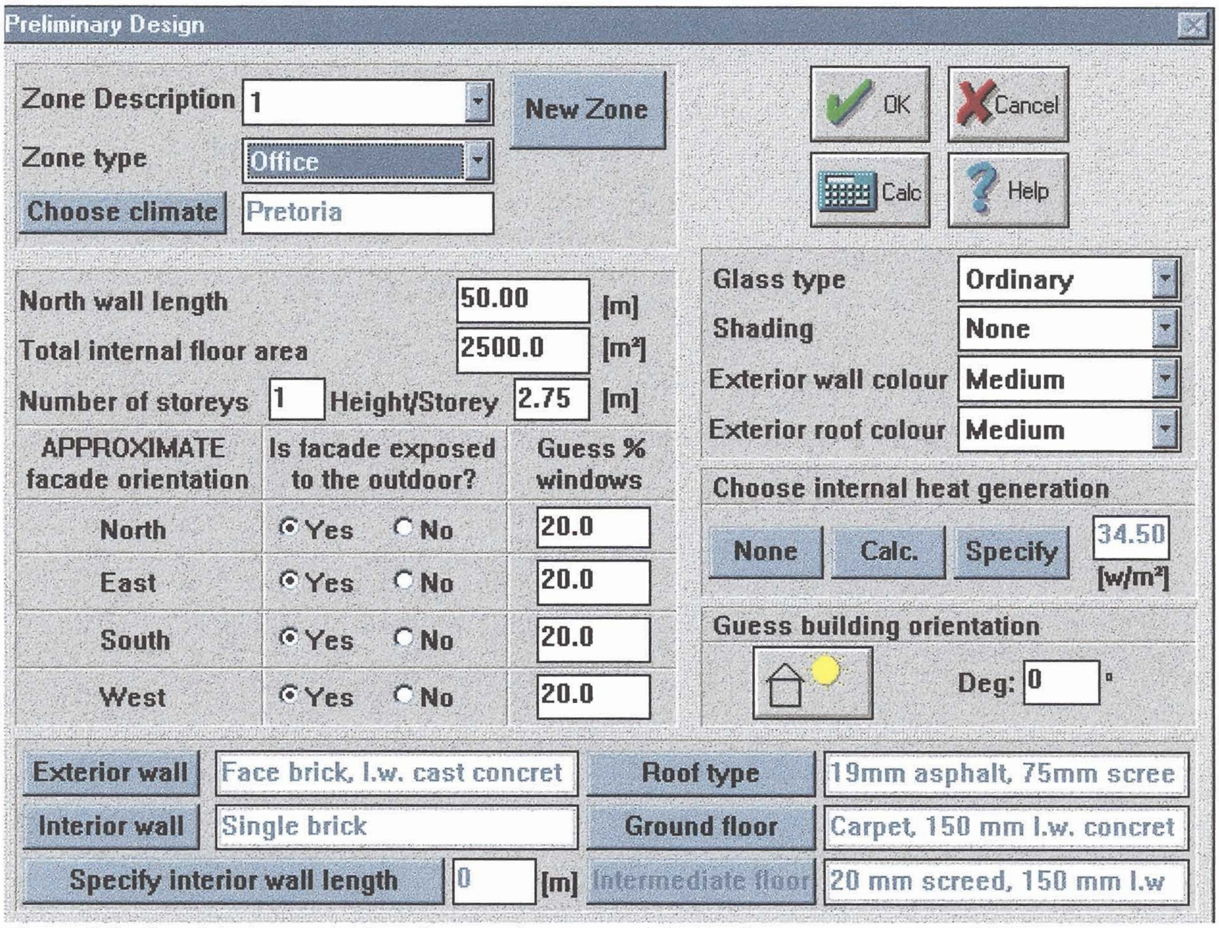

Figure 2.3 - Simplified user interface for specifying critical design data

2.10 SIMULATION MODEL

The simplified design tool uses the simulation model developed by Van Heerden and Mathews [33,34]. It consists of a triple node electrical analogy for solving the building thermal network. This model has been extensively verified and used in practice. The model therefore has an established track record and credibility. These are important factors if the new tool is to be accepted by the design community.

Simulation time is approximately 5 seconds using a PII-266 personal computer. The simulation consists of performing a hot and cold day simulation for a single zone. The model can be used to calculate both HVAC loads and as a passive design tool for estimating indoor temperatures. It has been applied in a more detailed integrated building and HVAC simulation tool, namely QUICKcontrol [35].

An additional benefit of using this model is that the preliminary design data can easily be transferred to the detailed simulation tool. The preliminary design information only needs to be slightly modified for use during the detail design stage. This typically consists of changing the default design characteristics, such as ventilation, occupancy or internal load profiles so that it reflects the actual design conditions. It consequently saves the engineer time and enhances communication between the architect and HVAC engineer.

2.11 OUTPUT CONSIDERATIONS

The output of existing design tools is another area that needs attention. Output from sophisticated tools tend to be too detailed, making it difficult for the architect to interpret [11,28]. These tools typically provide a breakdown of monthly energy loads, utility bill predictions, peak load analyses, demand charge evaluations, etc. of the building, HVAC system and lighting combination. The effect that architectural design decisions have on the building shell performance is thus diminished by other data.

Graphic representation of the results allows the user to quickly get a qualitative evaluation of the building. Post processing of data is however still required for comparing the performance of different designs. Furthermore, such a detailed output is impractical for a simplified design tool due to the numerous assumptions and simplifications made. A comparative analysis between design alternatives subjected to the same assumptions will be more credible.

In order to handle 'what if' alternatives readily, the tool must have an automatic means of comparing and ranking the various design alternatives. Energy-10 [36], distributed by the PSIC council, is a good example of a tool that applies such a ranking scheme. It ranks various energy savings schemes such as energy efficient lighting and the use of optimised HVAC controls against each other. The ranking is based on estimated building energy consumption.

A similar rating scheme for comparing the thermal efficiency of building shells can be obtained using the building load as basis. The design is given a rating out of five depending on how it compares to a reference building of minimum acceptable thermal efficiency. The smaller the load, the higher the rating and thus the more thermally efficient the design. Using this method architect's can quickly assess whether their design satisfies building regulations.

Improvements in design alternatives are also expressed in terms of a percentage reduction in heating and cooling load. This is necessary to reflect small changes that do not effect the design ranking. Comparison between design alternatives can thus also easily and quickly be accomplished.

An added advantage of such a rating scheme is that design firms can use it as a means of marketing themselves [37]. The downside of the rating scheme is that it is dependent on climate and building type. It was consequently necessary that such a rating scheme be developed for the tool. In chapter 4 the rating scheme for South African residential and office are developed in detail.

2.12 FEEDBACK FROM DESIGNERS

The new simplified design tool addresses all the static requirements identified in a previous section. A tool that fulfils these requirements is however not necessarily guaranteed to succeed. Holm [7] states that design tool development must be done in close co-operation with the people it is intended for. The reason being that it is impossible to determine in advance exactly what design professionals need and expect from design tools. The new tool was consequently developed in close co-operation with design professionals.

During the initial development, architects were asked to use the program. They were observed to identify problem areas and see how they interact with the program. The user interface was then modified based on these observations. The final product was re-evaluated by providing it to a group of 26 consisting of practising engineers and architects. They were required to complete a questioner on the use of the design tool.

All 26 indicated that they find the tool useful and easy to use. Twenty-three of the twenty-six indicated that they would use the program of which twenty further stated that the program would aid them in improving their designs. Feedback from these designers was thus very positive. It is thus believed that the tool successfully addresses the need of the design community.

2.13 POTENTIAL IMPACT AND IMPLEMENTATION

Researchers believe that energy savings of around 30% can be obtained by using improved design and management practices, and through retrofit projects of existing commercial buildings [38]. A study performed by Todesco indicates that on an individual level, architectural optimisation can result in energy savings of roughly 10% [6]. These savings however also affect the initial capital cost of the HVAC system and the environment.

A smaller and thus cheaper HVAC system will be required for buildings with an optimised thermal shell. In some cases, the use of air-conditioning systems can be avoided completely. Environmental benefits are a decreased depletion rate of non-renewable energy sources and a reduction in atmospheric pollution. Using the new tool, these savings can potentially be obtained by spending between 30 to 60 minutes more on the design of the building shell.

It is believed that architects will be hesitant to purchase and apply the new thermal design tool before it has been proven to be beneficial to them. One of the more difficult tasks is thus to initially get architects interested in using the new tool. It is suggested that manufacturers of insulation and glazing material as well as electrical utility companies sponsor the development and distribution of the tool.

The manufacturers would provide the tool to their customers as a means of marketing their products. Architects will then be able to see what the advantages of using the manufacturer's insulation and special glazing types are. As architects become more familiar with the tool, they will also start to experiment with the other design parameters. In the long run this will save energy, thus benefiting the client, the utility company and the environment.

2.14 CONCLUSION

The thermal characteristics of a building are largely influenced by design decisions made by the architect during the preliminary design phase. They consequently have a major role to play in the design of energy efficient and comfortable buildings. Unfortunately, architects hardly ever consider the building thermal efficiency at this stage of the design process. Often, thermal analysis of the building is only done after most of the design has been completed. At this stage it is too late to make changes based on the analysis results.

To be effective, thermal analysis must be performed during the preliminary design stages, before critical decisions are fixed. Existing thermal design tools do not cater for architects or fit their design methodology. A new simplified thermal design tool was developed to address these problems. Innovative features of the new tool are that the input complexity is reduced considerably without having to simplify the thermal building model, and a new ranking evaluation method that enables an architect to quickly compare different design variations.

The tool enables architects to reduce building energy consumption, save on the initial HVAC system cost, and benefit the environment by spending as little as 30 to 60 minutes more on the design of the building shell. An additional advantage of the new tool is that it uses the same simulation model as an existing integrated building and HVAC design tool. Project data is easily transferred from the preliminary design stage to the detailed design stage. The tool thus improves communication between the architect and engineer.

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