Chapter 7 Application Of The Simplified Design Tools

The simplified design tools developed in the preceding chapters can greatly aid designers. They were applied to design a typical office building in order to demonstrate their use. Ninety-six different building configurations were analysed with the new thermal design tool. A cooling system was selected for the building with the best performance using the preliminary system selection tool.

7.1 INTRODUCTION

The simplified design tools developed in the preceding chapters can greatly aid designers. In order to demonstrate their use, they were applied to design a typical building. For the purpose of this demonstration it was assumed that the client requires an office building of approximately 2500m^2. The building is to be located in Pretoria. The thermal design tool was used to determine the effect that various architectural decisions have on the thermal efficiency of the building.

The analysis indicates that the difference in the cooling and heating system size requirements for the best and worst building configurations respectively are a 54% and 66%. An HVAC system was selected for one of the more efficient building designs. This selection was performed using the system rating factors and preliminary selection tool. The selection is based on typical criteria of a building developer that leases out office space. The building is further taken to be a medium term investment.

7.2 THERMAL ANALYSIS OF AN OFFICE BUILDING

The building used for this demonstration is to have a floor area of approximately 2500m^2. Building form, glazing area, orientation, and construction is however varied in order to determine its effect on the thermal characteristics of the building. A simulation matrix was set up similar to that of Batty [1] and Todesco [2]. Figure 7.1 gives a graphic representation of all the variables. The analysis consists of evaluating all ninety-six combinations of these variables.

The building requiring the smallest HVAC system is taken to be the best solution from a thermal efficiency perspective.

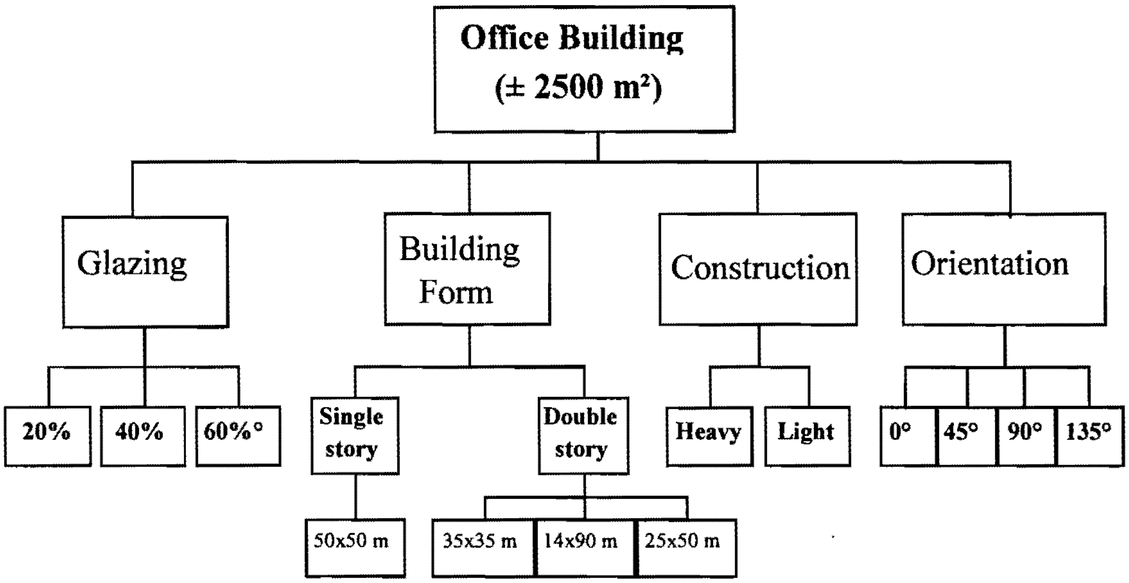


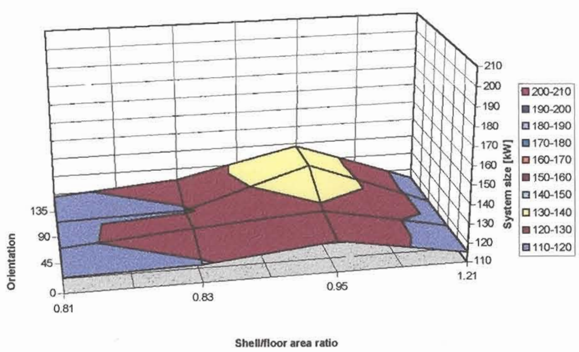
Figure 7.1 – Simulation variables used for the thermal analysis

7.3 ANALYSIS RESULTS

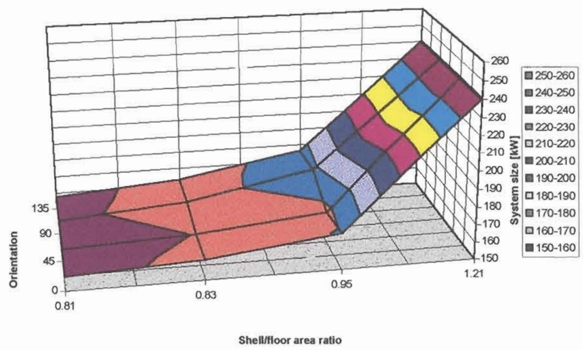
The analysis results are depicted in a series of surface graphs in Figures 7.2 and 7.3. The required cooling and heating system sizes are plotted as a function of building form and orientation. Building form is expressed by the building area exposed to the sun, as a proportion of the floor area.

Building orientation is the angle between true north and the perpendicular of a reference wall surface. For this analysis the reference wall was taken to be the wall with the dominant surface area. The angle is measured clockwise from north.

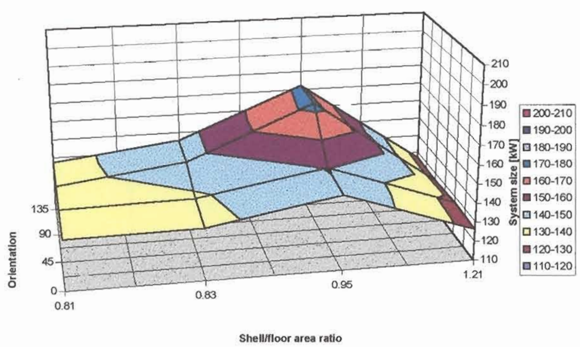
Heavy Construction | **Light Construction**



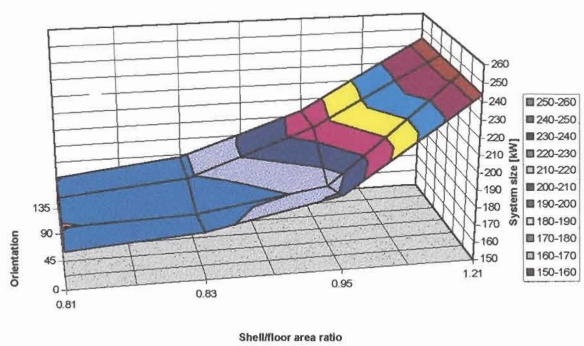
20 % Glazing area



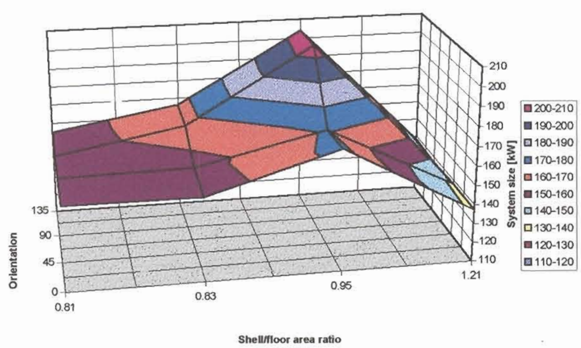
20 % Glazing area



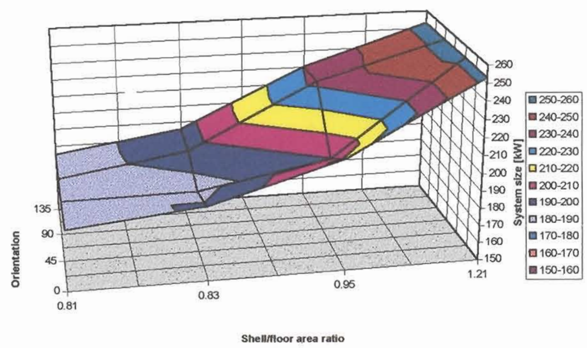
40 % Glazing area



40 % Glazing area



60 % Glazing area



60 % Glazing area

Figure 7.2 - Cooling system requirements for different configurations of a 2500m² office building located in Pretoria.

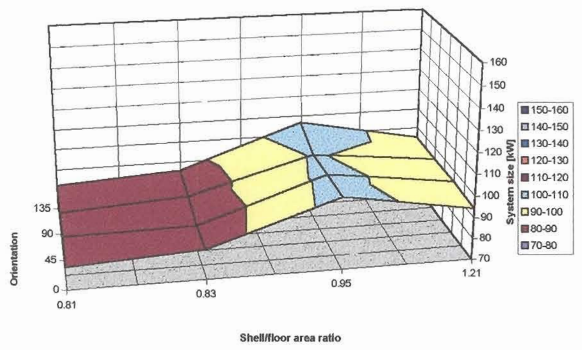
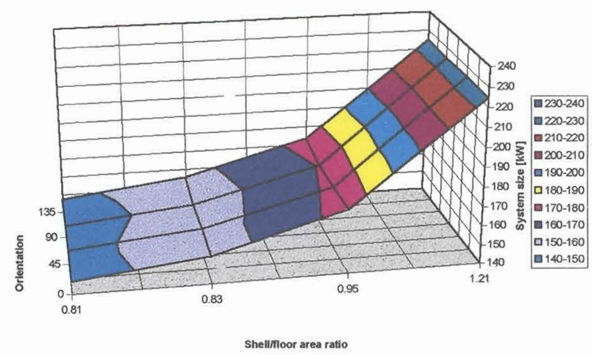
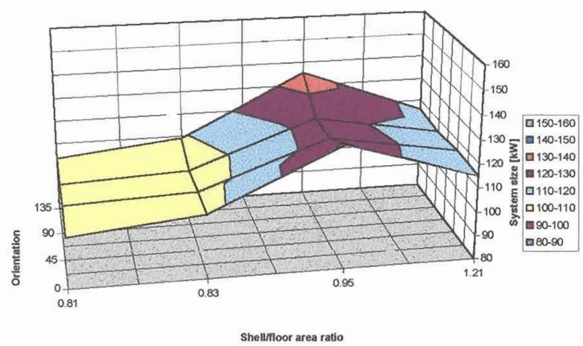
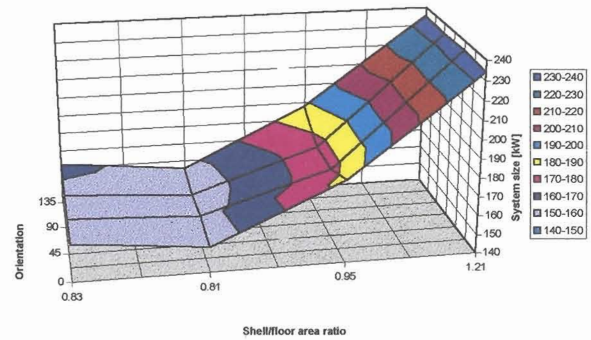
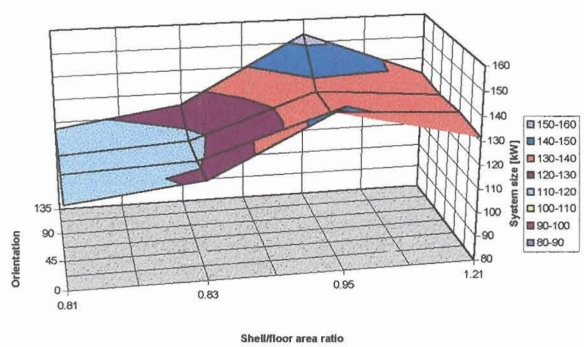
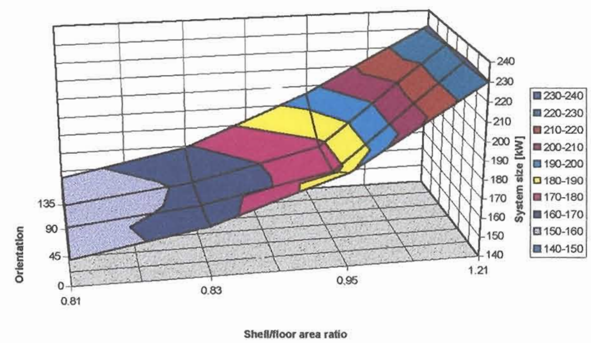
Heavy Construction	Light Construction
 20 % Glazing area	 20 % Glazing area
 40 % Glazing area	 40 % Glazing area
 60 % Glazing area	 60 % Glazing area

Figure 7.3 - Heating system requirements for different configurations of a 2500m² office building located in Pretoria.

The graphs clearly indicate that the abovementioned design variables greatly influence the HVAC system size. The required cooling capacity varies from 253 kW to 115 kW depending on their properties. Similarly, the heating system size can be decreased from 235 kW to 80 kW. The effect that the different design variables had on this reduction is addressed in more detail in the following paragraphs.

7.3.1 Building construction

Thermal resistance and mass of the building construction influence the characteristics of the building. The resistance is an indication of how easy heat is transferred through the building shell. It is expressed in terms of an overall heat transfer coefficient U (W/m^2 K). The lower the coefficient, the smaller the heat gain or loss.

Thermal mass, product of mass and specific heat, determines the heat storage characteristic of the building. This in turn determines the thermal lag and therefore the relationship between heat gain and HVAC load [3]. Figure 7.4 indicates this relation between instantaneous load and the actual cooling load for different thermal mass configurations.

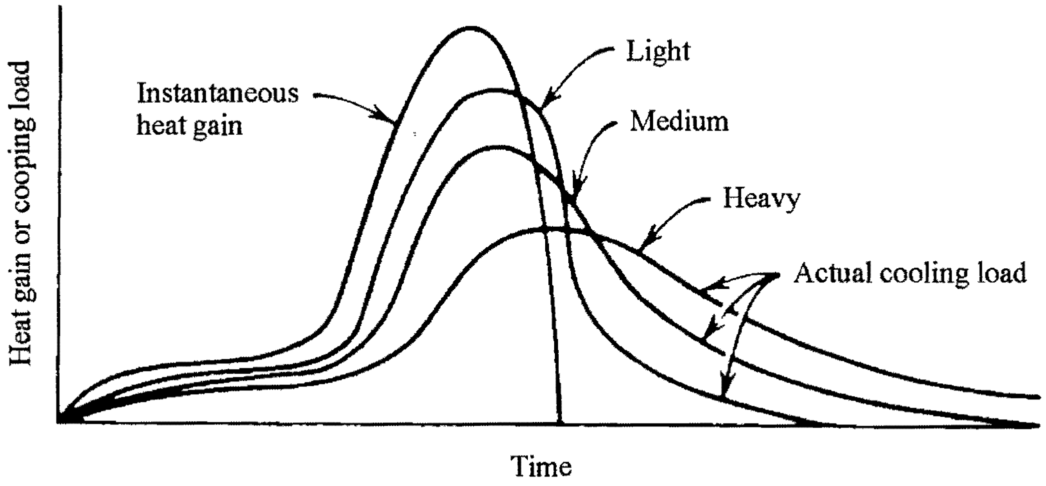


Figure 7.4 - Effect of thermal mass on HVAC system size [3].

Two construction configurations were tested. The first configuration consisted of a face brick and concrete combination for the walls with a cast concrete roof. The second consisted of a face brick and common brick combination with clay tile roofing. The second, lighter construction required a 40 % larger system on average.

7.3.2 Building form

Thermally efficient buildings usually enclose the largest volume for the least surface area. The heat exchange area of the building is thus effectively minimised. The benefit of a small surface to floor ratio (SF) can clearly be seen in the light construction building. There is an average reduction of 32% in system size between 50x50m single story building[1] and the double story 35x35m building[2].

The advantage of having a small SF ratio is less apparent for the heavy construction building. Glazing area and its orientation are the dominant factors for this building. Glazing area is expressed as a percentage of the wall area for the purpose of this study. The actual window area for the different building forms consequently varies. The influence of building form can be noted in the marginal increase in system size with a 28% increase in widow area, when comparing the performance of the 35x35m building to that of the 50x50m building.

7.3.3 Glazing area

Glazing area affects the amount of solar radiation that enters the building. The larger the area, the more solar energy is introduced into the building. This additional heat gain directly influences the cooling system size. Cooling requirements for the office building were increased by as much as 18% by changing the window to wall ratio from 20% to 40%. The effect of natural lighting has however not been taken into consideration.

Window size also adversely affects the heating system size. This is due to radiation heat loss from the warm interior to the cold exterior. The result further indicates that a slight improvement can be obtained by increasing the area of the windows facing east. This is due to the simplification of regarding the whole building as a single zone. The heat gain is thus

[1] Surface to floor ratio = 1.22

[2] Surface to floor ratio = 0.81

dispersed evenly throughout the building. In reality this would most likely result in the eastern side of the building being uncomfortable for the occupants.

7.3.4 Orientation

Solar radiation is a function of intensity and incident angle. The eastern and western façade of the building therefore receive a higher level of energy early in the morning and late in the afternoon. It is a well-known fact that buildings should be orientated with the longest axis running in an east-west direction. A 3% to 10% reduction can be obtained by properly orientating the buildings with a rectangular shape.

7.4 SYSTEM SELECTION

The analysis indicates that the heavyweight double story 35m by 35m building with 20% glazing has the best overall thermal performance. This building is thus chosen for the purposes of this demonstration. The cooling system required for this building is dominant due to the climate of Pretoria being mostly hot with a low humidity. A preliminary cooling system selection can be made using the HVAC selection tool. The assumptions concerning the system requirements and limitations are given in the following paragraphs.

It is assumed that the building is being developed as a multi-tenant office space. The interior architecture of the building is mostly open plan. Partition walls divide the space into eight areas for different tenants. These areas consist of perimeter, as well as interior zones. Space required by the ducting and chilled water piping is the only other building restriction imposed on the system. Ceiling-void height is limited so that building regulation concerning floor to ceiling elevation can be met without increasing the building size [4].

Aesthetic limitations imposed are that, window mounted units may not be used, and equipment within the zones should be kept to a minimum. Ventilation grilles and roof-mounted equipment may however be incorporated into the design. Fresh air and make-up air requirements must be supplied by the system. Only intermediate filtration, noise and humidity control is needed for a general office building. There is also no abnormal source of indoor contaminants. Cross-contamination between tenant areas must however be limited.

Zone loads will vary, since different tenants occupy the building. Separate metering of system use is thus needed for billing purposes. Individual control of the setpoint will further be required to accommodate their different preferences. It is also highly likely that the interior layout of the building will change as tenants come and go. In this process, some of the zones may become empty for short periods of time. The building manager must be able to switch off the supply to these zones.

Other administrative requirements are that the system be managed from a central point. It must thus be compatible with a suitable Building Management System (BMS). The building will also not have maintenance personnel. A suitable contract will be made with a building maintenance contractor. Maintenance within occupied areas must be kept to a minimum so as not to inconvenience the tenants.

It is assumed that the developer requires the building to be a medium term investment. System cost is therefore evaluated for a 10 year life-cycle. The above-mentioned assumptions are used to determine the relevant screening factors (Refer to Table 5.1 in Chapter 5). The relative importance of obtaining the imposed restrictions and limitations were taken to be:

- building restrictions - 5%,
- aesthetic restrictions - 5%,
- indoor air quality - 10%,
- building management - 10%,
- maintenance - 10%,
- flexibility - 20%, and
- cost - 40%.

By applying the screening factors and design goals, the preliminary selection tool is used to rank the suitability of the sixteen generic system types. Table 7.1 indicates their ranking. The detailed evaluation matrix is provided in Appendix D. The tool suggests the all-air, air-cooled system types, systems 1,2 and 3, be evaluated in more detail. Detailed analysis is thus reduced from sixteen potential candidates to only three.

System description	Value	Ranking
All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	320	1
Packaged rooftop units	316	2
All-air, variable volume, economiser system and air-cooled refrigeration plant.	314	3
All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	311	4
All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	306	5
All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	300	6
Four-pipe system with air-cooled refrigeration plant.	295	7
Two-pipe system with air-cooled refrigeration plant.	291	8
All-air, variable volume, economiser system and water-cooled refrigeration plant.	285	9
All-air, dual duct system with air-cooled refrigeration plant.	284	10
Split systems	279	11
All-air, dual duct system with water-cooled refrigeration plant.	277	12
Four-pipe system with water-cooled refrigeration plant.	263	13
Two-pipe system with water-cooled refrigeration plant.	261	14
Through the wall console units	234	15
Window units	207	16

Table 7.1 - System ranking for the hypothetical building

The choice of an air-cooled refrigeration system for this type and size of building corresponds to an analysis performed by Wilson and Nugent [5]. In general, the results of the tool can be considered as a good choice. It is however not always the best. The choice depends heavily upon the criteria evaluated and available systems. In this case a, combination of the rooftop packaged units and VAV system will probably be the best.

7.5 POTENTIAL IMPACT OF THE DESIGN TOOLS

The impact of the thermal analysis can clearly be seen in the large difference in HVAC system size for different building configurations. The results are even more impressive considering that not all the possible configuration were tested. Insulation and shading of the windows are typical examples of other building characteristics that affects building thermal efficiency.

The analysis indicated that a reduction in HVAC size of around 55% can be obtained. It is however highly unlikely that an architect will perform more than five simulations. Restrictions due to property size and aesthetics also play a role. A more realistic value will typically be in the order of 10% reduction in energy usage [2].

Using the selection tool also impacts the future success of the building. An experienced designer will be able to make an appropriate system choice without using the tool but the tool is a great communication aid. Communication or the lack thereof, between the different design team members is one of the major reasons why building system designs fail [6]. The tool can be used to obtain critical input and requirements from all the role players. Second-guessing as to system choice is thus reduced. The other design disciplines will also be better equipped to make provision for the HVAC system requirements.

7.6 CONCLUSION

Using the simplified preliminary design tools, an extensive building and system analysis was performed without the need for detailed information. This type of analysis can typically be done during the initial project meeting. This will improve communication between the different role players. The end result being a more energy efficient and comfortable building design.

7.7 BIBLIOGRAPHY

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