Chapter 6 System Rating Factors And Design Criteria

Rating factors form an integral part of the proposed preliminary selection tool. These factors are a means of numerically indicating how well an HVAC system is suited to fulfil the different design criteria. In this chapter, rating factors and the necessary correlation equations are presented for 16 generic HVAC system types. These factors were obtained by using historic and published data as well the expertise from various designers. The methods used can however be applied to rate other systems or incorporate new design criteria.

NOMINCLATURE

A : Area (m^2)
AE : Annual expense (R)
C_p : Initial capital investment (R)
E : Annual energy costs (R)
F : Maximum allowable rating
L : Equipment service life (Number of years)
M_p : Annual maintenance costs (R)
N : Life cycle cost period (Number of years)
NPV : Net present value (R)
R_i : System rating factor for design criteria i
R_p : Present value of replacement costs (R)
O_p : Present value of any other HVAC costs (R)
Q : Cooling load (kW)
Q_Z : Cooling load per zone (kW)
W : System weight (kg)
X : Year in which equipment is to be replaced
i : Escalation rate
e : Average inflation rate

Subscripts

A : Available
C : Calculated

E : Energy
M : Maintenance
P : Present value
Z : Zone

6.1 INTRODUCTION

A simple yet effective preliminary HVAC selection tool can be obtained by combining the positive features of both numerical ranking methods and expert systems. An integral part of this tool is the use of system rating factors. These factors are a means of numerically indicating how well a HVAC system is suited to fulfil the different design criteria.

Design criteria can be divided into quantifiable, e.g. maximum allowable system size, and subjective properties, such as aesthetic limitations. Rating factors for quantifiable system characteristics can be obtained by estimating these properties using published literature such as catalogues, system manuals, textbooks and historical data. Rating factors are taken to be the estimated system characteristics normalised for use in the selection tool.

Subjective design criteria are rated using the method suggested by Scanlon [1]. This consists of assigning the maximum rating to the system that best fulfils the desired design goal. The remaining systems are then rated relative to this system. These factors may differ depending on personal experience and knowledge. It is likely that different people may rate the systems differently. An improved average rating factor is obtained by basing these ratings on input from various experts.

In this chapter, rating factors and the necessary correlation equations are presented for 16 generic HVAC system types. These systems were given a rating between 0 and 5 for different design goals and limitations. A rating of five indicates that the system is well suited for the particular design criterion. It should be noted that the ratings are based on typical system characteristics. It is therefore possible to obtain or manufacture a system that can fulfil the desired task successfully, even though it is given a poor rating.

6.2 PRELIMINARY DESIGN INPUT

Quantifiable system characteristics and certain limitations are influenced by climate, building size and required cooling load. Preliminary design input is therefore required before system performance ratings can be calculated, namely:

1. Proposed building floor area,
2. maximum space available for HVAC system,
3. estimated cooling load requirements,
4. dry or humid climate, and
5. number of zones.

Floor area and cooling load are typically used as independent variables in calculating quantifiable factors. Estimating system cost based on floor area or cooling loads is a typical example of this. Climate and number of zones on the other hand serve as additional limitations in selecting a system.

Most of these factors are already known or established during the initial project meeting. A rough estimate of the cooling load requirements must however be made. This can easily be obtained by using a simplified load calculation tool. Such a tool was proposed and developed in Chapter 2. The calculated cooling load requirement is increased by 25% for full fresh air systems. This is done in order to take the extra outdoor air load into consideration. It will however vary depending on the climate and must be adjusted accordingly.

6.3 DESIGN CRITERIA

Typical design criteria used as basis for choosing a system are given in Table 5.1 in Chapter 5. Sixteen generic system types were evaluated according to how well they suit these requirements. Correlation equations for quantifiable design criteria were obtained, as well as ranking factors for subjective criteria. These rating factors are provided in Table 6.2. These criteria are discussed in more detail in the following paragraphs.

6.4 BUILDING RESTRICTIONS

6.4.1 Available space for the system

HVAC systems require a certain amount of floor space. This is divided into floor area required for the refrigerant plant and air-handling units, as well as the ceiling void and shaft spaces for piping and ducting. In existing buildings this can be a crucial element that restricts the use of certain system types. Although not as critical, these space requirements must also be taken into consideration during the design of new buildings. In some cases a compromise must be made due to other more important design criteria.

Floor area (A1)

Central systems and packaged rooftop units require a certain amount of floor space. Window, console and split units also require space but to a smaller extent. In most cases this is negligible. The outdoor units of larger split units can however be substantial. Window and console units are therefore given a rating of five. The remaining systems are rated accordingly.

Space required is dependent on the load requirements of the system. It stands to reason that the rating factor for this criterion also be dependent on the expected cooling load. Using catalogue data, a relation between floor space and cooling load was obtained for various systems. Figures 6.1 to 6.6 presents the different relations. These relations do not include ducting, piping and additional space needed for maintenance or airflow around equipment.

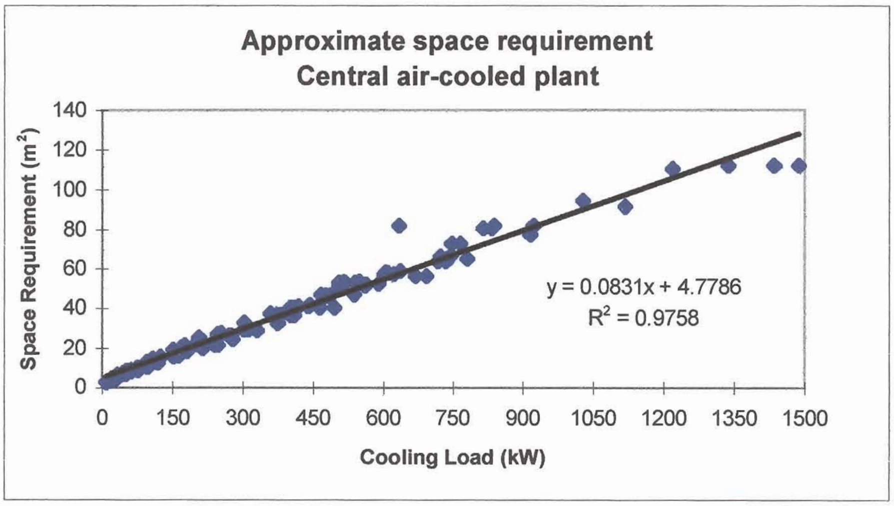

Figure 6.1 - Space requirement correlation for air-cooled all-air systems.

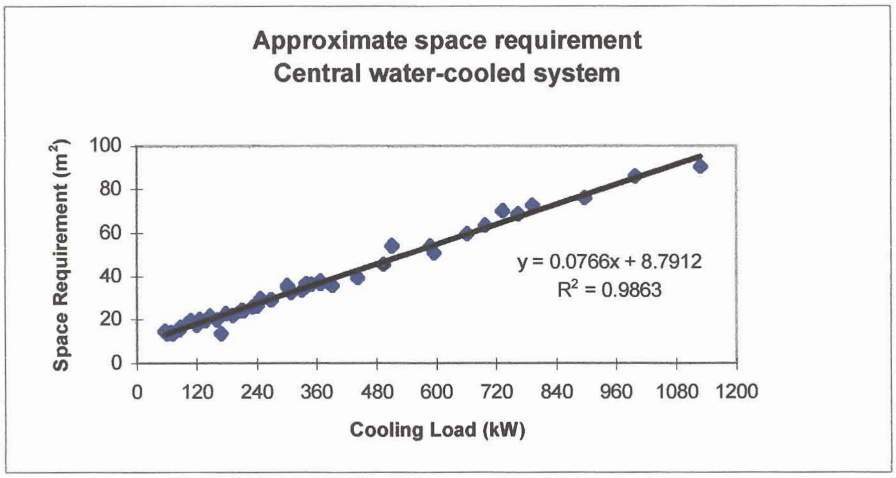

Figure 6.2 - Space requirement correlation for water-cooled all-air systems

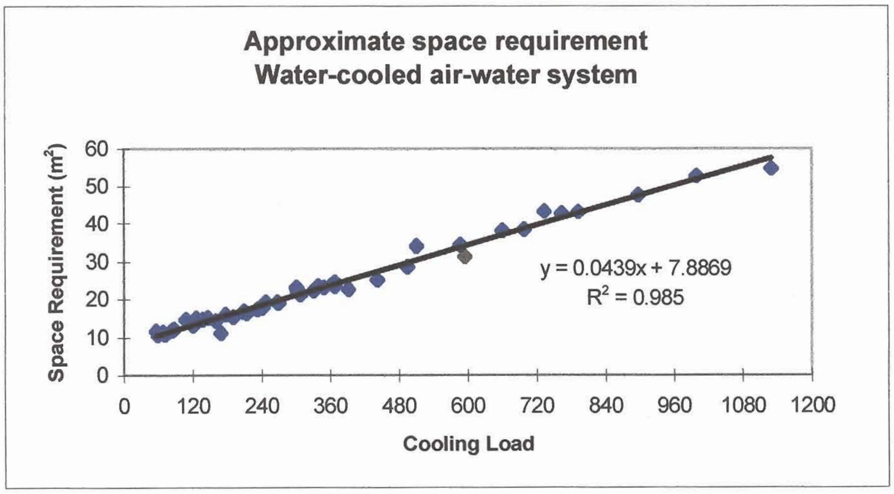

Figure 6.3 - Space requirement correlation for water-cooled air-water systems

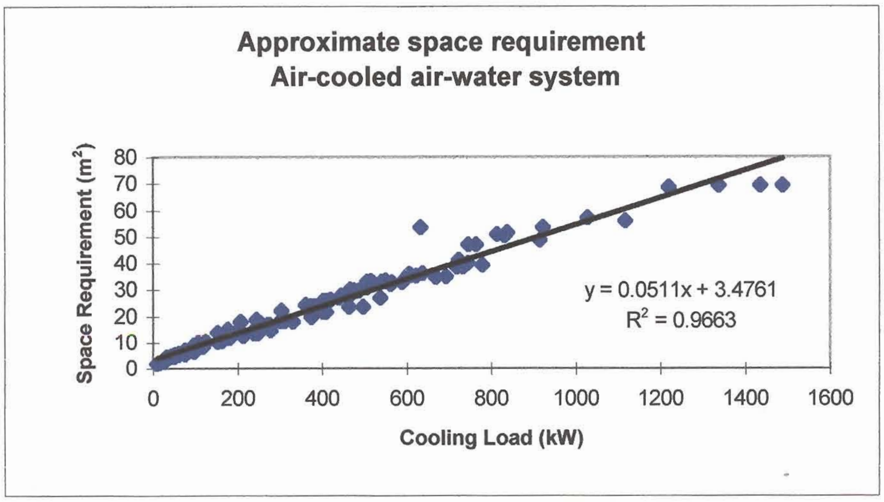

Figure 6.4 - Space requirement correlation for air-cooled air-water systems

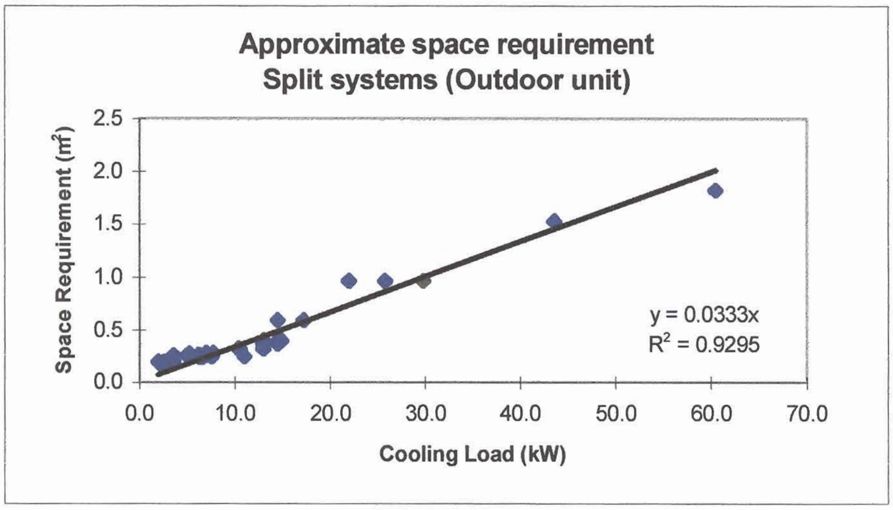

Figure 6.5 - Space requirement correlation for split systems

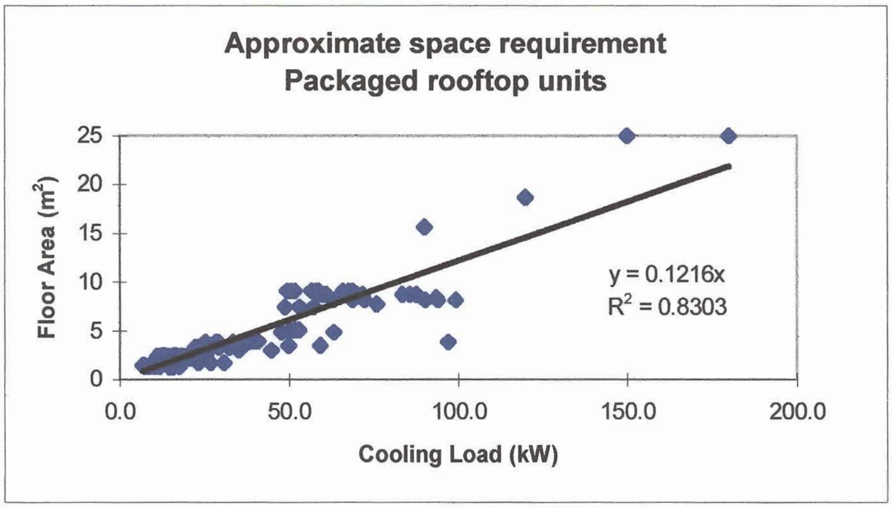

Figure 6.6 - Space requirement correlation for rooftop packaged units

Using these relations, an estimated area requirement for each system can be calculated. If the estimated area is smaller than the desired maximum, the system is given a rating of five. Otherwise it is rated depending on how much it exceeds the desired area. The rating factor is then calculated as follows:

$$R_i = F - \frac{(A_C - A_A)}{(A_C)} \times F \qquad (6.1)$$

Ceiling void and shaft space requirements (A2)

Central systems require ceiling void space and vertical shafts for ducting and piping. The use of all-air and some air-water systems can therefore be eliminated due to lack of sufficient space. Damhuis [2] and Chadderton [3] give a comparison of the relevant space requirements for different systems. The systems were rated using this information as basis. Water is approximately four times more efficient in transferring heating or cooling than air. Water systems therefore require less space to transfer the same amount of energy. Space required by mixed systems will vary depending on the ratio of cooling done by the primary air to that of the secondary water. This ratio was taken to be 1:1 for rating purposes.

Window and console units do not require space for ducting or piping. These systems are therefore given the maximum allowable rating. Rooftop package units usually supply air via a ducting system. Their rating is therefore the same as central all-air systems. Split systems require refrigerant pipes. They are however usually relatively small and not very long. These systems are consequently given a rating of four. Ducted-split systems are not considered here. Ducted-split system ratings must be determined in the same manner as all-air systems.

6.4.2 System mass (A3)

The mass of the system influences the structural requirements of a building. The more a system weighs, the stronger the building structure needs to be. System mass consequently directly influences the construction cost of a new building. In existing buildings, the system choice is furthermore restricted to the maximum carrying strength allowable for the structure. In both cases it is therefore preferable to keep the mass down as low as possible.

Items located on the roof of a building have the highest structural impact. Equipment such as cooling towers, packaged rooftop units, and air-cooled refrigeration machines are frequently located on the roof. Relations for mass to cooling load were obtained for these equipment types. Systems using this equipment were rated accordingly, and the rest are given a rating of five by default.

A rating factor for this criterion is obtained by normalising the estimated system mass relative to the system with the maximum mass.

$$R_i = F - \frac{(Estimated\ System\ \ Mass)}{(Maximum\ \ Mass)} \times F \tag{6.2}$$

These factors are however only taken into consideration if equipment needs to be installed on the roof.

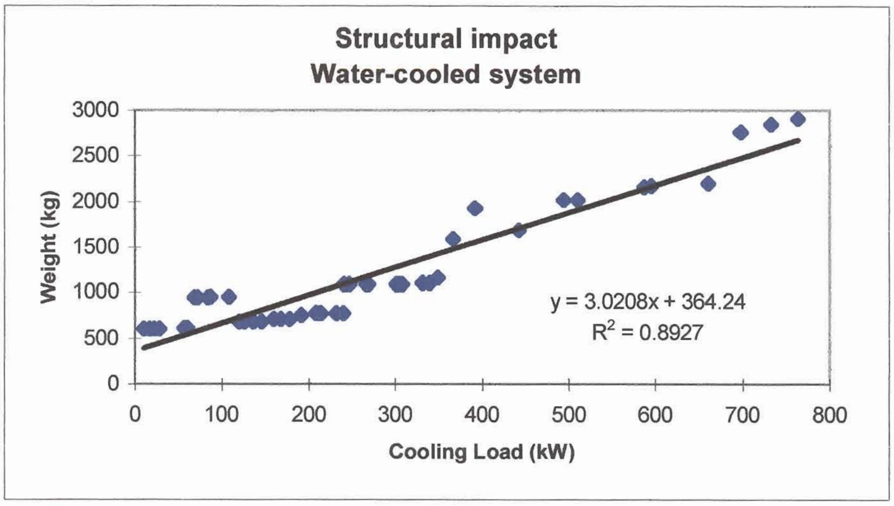

Figure 6.7 - Mass correlation for water-cooled system cooling towers

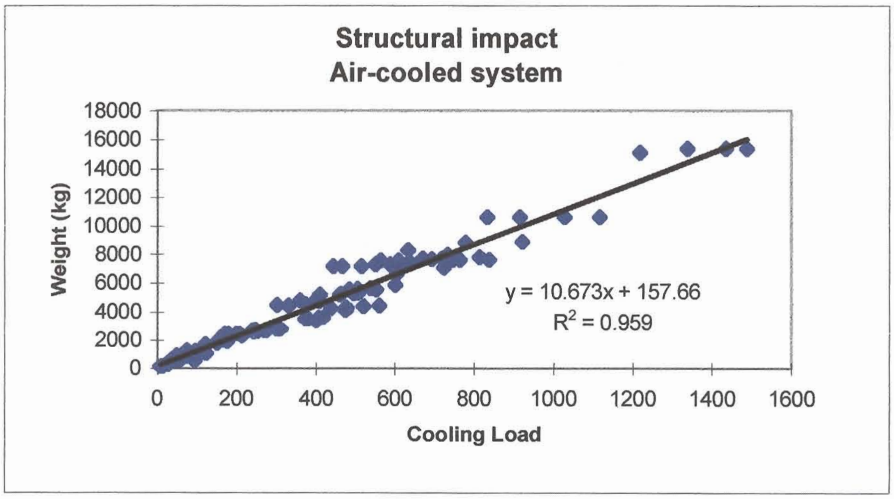

Figure 6.8 – Mass correlation for air-cooled refrigeration machine

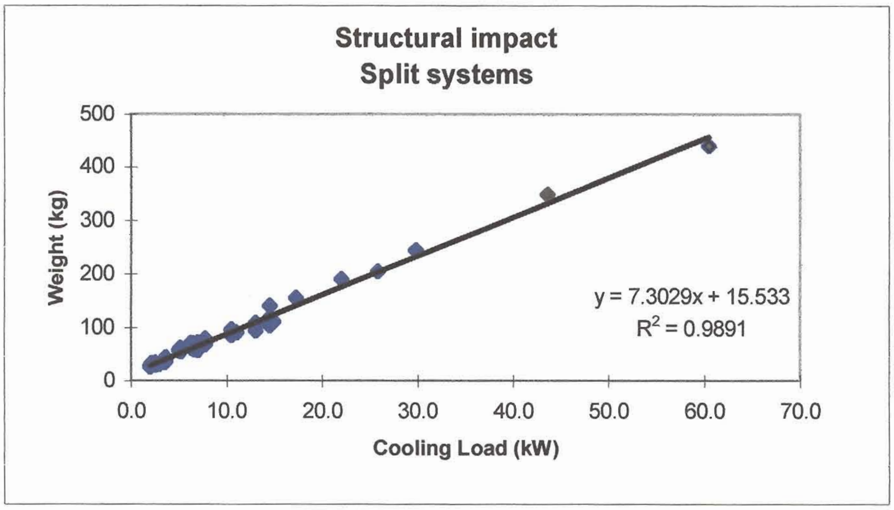

Figure 6.9 - Mass correlation for the outdoor unit of a split system

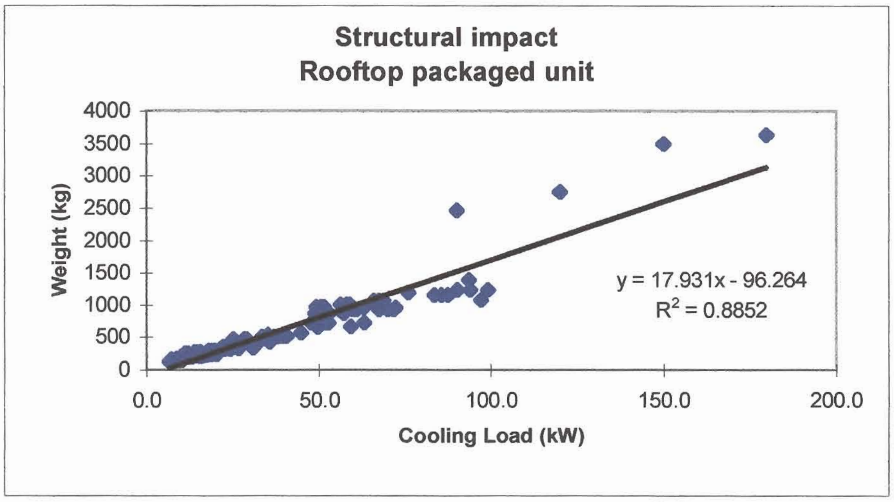

Figure 6.10 – Mass correlation for rooftop packaged units

6.4.3 Zoning (A4)

Some systems can only be used in perimeter zones. Typical examples are window and console units. These systems are given a rating of nought. Most of the other systems can however be adjusted to cope with interior zones. Split systems and air-water systems however will potentially need drainage facilities for condensate. These systems are therefore less suited to interior zones unless located near a drainage point.

6.5 AESTHETIC LIMITATIONS

Air-conditioning systems influence the overall aesthetics of a building. In general it is preferable to hide the system as much as possible. Modern window, console, and split units are colour coded to blend into the surroundings. Larger central systems are usually located in a separate plantroom or enclosure. Inlet and exhaust grilles for ventilation are other features of the HVAC system that must be considered in the building design.

6.5.1 Indoor equipment (B1)

In some cases it is aesthetically undesirable to have equipment located within a zone. Constant volume all-air systems and packaged rooftop units only require supply and return air diffusers within the zone. Variable volume systems further require either a mixing box or additional zone fan. Air-water systems and split systems have a fan and cooling coil combination within the zone. The entire system of window and console units are located within the zone.

6.5.2 Window units (B2)

Window units are probably the most visible system from the outside and inside. These systems are also prone to condensate drip. They are consequently generally, aesthetically speaking, unacceptable in most cases. These systems are however relatively cheap and easy to install. In some cases their usage is further restricted due to the overall building construction. A typical example is a building with a full glass facade.

6.5.3 Grilles and condensers (B3)

Console or through-the-wall units require an outside grille for each installed unit. The outdoor units of split systems require a ledge or they must be wall mounted to the outside of the building. These units can also be located on the roof or ground for low-rise buildings. These features must be incorporated in the design of the building.

6.5.4 Rooftop and exterior enclosures (B4)

Air-cooled refrigerant plants, cooling towers, rooftop-packaged units and the outdoor units of split systems need to be aesthetically concealed. This is usually done by building an enclosure to house the equipment. The volume taken up by these systems largely influences the ease with which the system can be concealed. Ratings for the different systems are obtained in a similar fashion as the structural impact factors.

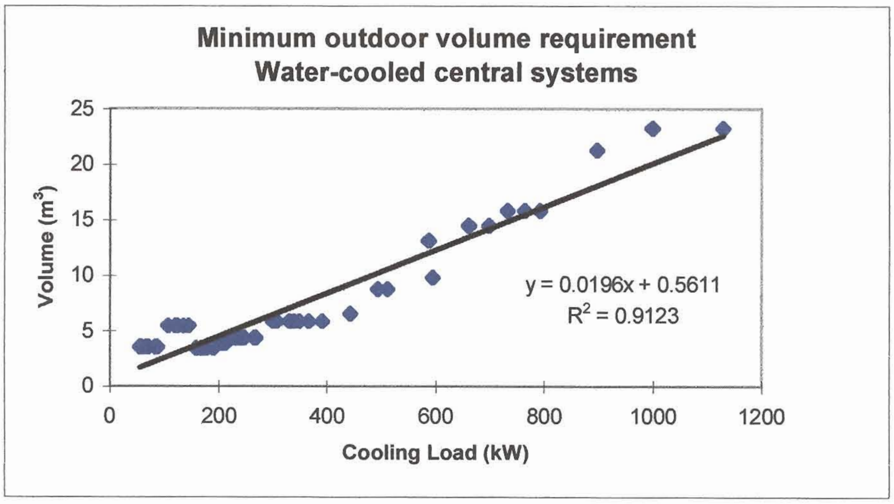

Figure 6.11 - Outdoor volume correlation for water-cooled system cooling towers

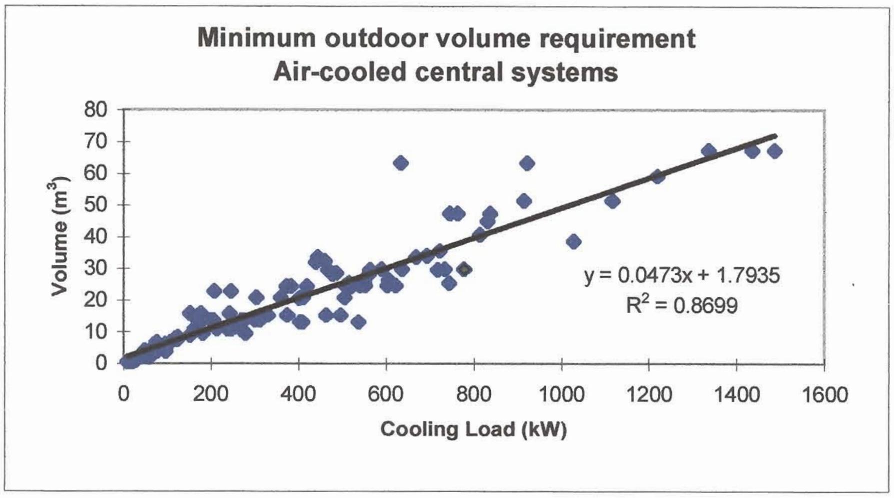

Figure 6.12 - Outdoor volume correlation for air-cooled refrigeration machines

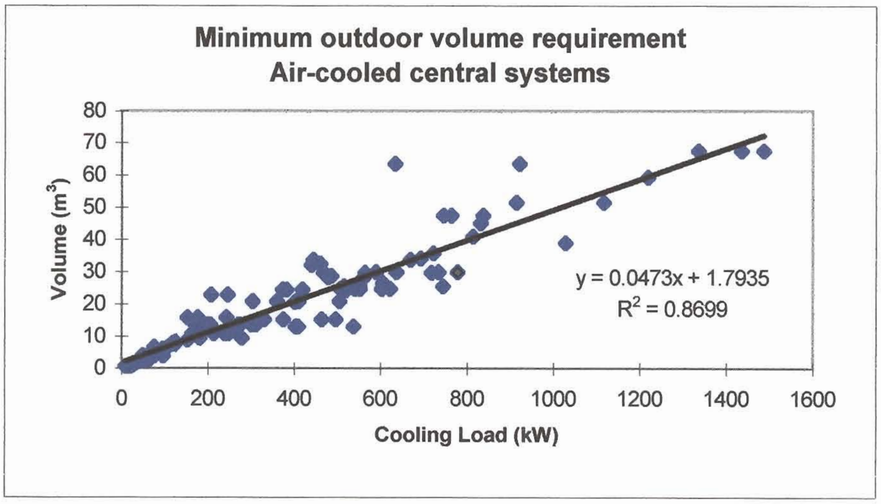

Figure 6.13 - Outdoor volume correlation for rooftop packaged unit

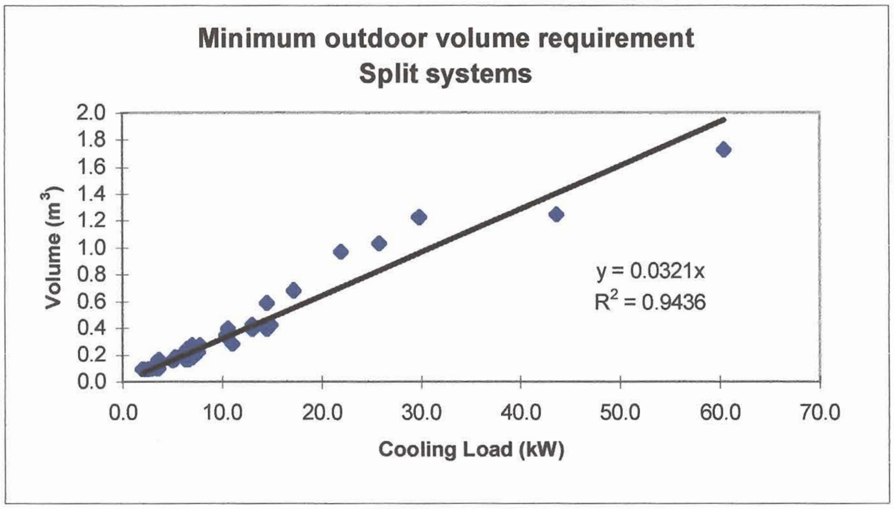

Figure 6.14 - Outdoor volume correlation for split system outdoor unit

6.6 SYSTEM REQUIREMENTS

6.6.1 Indoor noise (C1)

HVAC equipment generates noise. Central systems are however well suited to reduce the noise within the building. The major noise generating equipment such as compressors and fans are far away from the building. These system types also have a wide range of vibration and noise damping equipment available. Equipment located within the zone on the other hand tends to be noisy. Split systems benefits from the fact that the systems compressors are located outside of the building.

6.6.2 Skilled system operators (C2)

Central systems require a skilled systems operator to monitor and run the equipment efficiently. A typical example being two-pipe systems that need to be manually adjusted from summer to winter conditions. Packaged and unitary room equipment on the other hand is simple to operate and maintain as they are built from standard equipment. Most people can operate them. They are frequently referred to as appliances.

6.6.3 In-zone maintenance (C3)

Air-conditioning systems needs maintenance to ensure that they remain operational. This can cause disruptions if the equipment is located in occupied areas. This is especially true for the unitary type systems located completely within the occupied areas. The more prominent equipment of central systems that requires frequent service is located away from occupied areas. Variable volume systems and air-water systems do however have mixing boxes, fans and filters which are located within the building and sometimes occupied spaces.

6.6.4 Individual control (C4)

Different people have different comfort requirements. In order to satisfy everyone the system needs individual control settings for each of the occupants. Unitary window, console and split systems are ideal for this. Central systems on the other hand are usually regulated according to a single design setting. Most air-water systems do allow, to a certain extent, individual adjustment of each fan-coil or induction unit. Some variable volume systems also allow individual control of the VAV mixing boxes.

6.6.5 Load diversity (C5)

Zones on opposite sides of a building can have a huge variance in the load requirements. In some cases it can be that one zone requires cooling while another needs heating. Two pipe systems that requires a manual switch over from refrigerant plant to boiler will thus be unable to cope with this load diversity. It is however possible to cope with this diversity by equipping each zone with a separate heating system. Most systems will be able to cope with load diversity if separate zones have their own air-handling units and heating system. Multi-zoned systems were not taken into consideration.

6.7 AIR QUALITY AND FLOW RESTRICTION

The quality and requirements of airflow play an integral part in selecting an appropriate air-conditioning system. These requirements are often dictated by special processes or equipment located in the building.

6.7.1 Filtration (D1)

In dusty areas or clean-room applications it is essential that the air be filtered sufficiently. Typical applications where filtration is essential are operating theatres and mainframe computer or electronic control rooms. Central all-air systems are particular well suited for this. There is a wide range of high quality and durable filtration equipment available for these systems. Air-water systems can use the same filtration equipment as all-air systems. Only the primary air supply however is filtered. Packaged units are also usually fitted with substantial air filters, but these systems are restricted to standardised equipment. Window, console and split systems on the other hand, are generally only supplied with lint screens to protect their cooling coils from dust build-up.

6.7.2 Air contamination (D2)

Mixing of air from different building zones can sometimes be undesirable. This is especially true if the zones under consideration are full of volatile contaminants. Hospital wards or chemical laboratories are typical examples of such zones. These zones require systems that supply sufficient outdoor air to flush out the contaminants. Window, console and split units usually do not make provision for outdoor air supply. These systems are therefore generally unsuitable for these applications.

6.7.3 Room pressurisation (D3)

Some buildings require specialised make-up air in order to keep zones under positive pressure. This is usually necessary to ensure that surrounding air does not infiltrate the zone. A typical application is to keep smoke out of certain areas in the event of a fire. Systems required for this need to be able to supply more air than is being extracted. These systems consequently need substantial ventilation capabilities.

6.7.4 Outdoor air supply (D4)

One of the main functions of HVAC equipment is to supply adequate amounts of outdoor air. In most cases this is a legal requirement. ASHRAE standard 62-1989 [4] gives the typical minimum requirements for different types of buildings. Window, console and most split units do not make provision for supplying any outdoor air. These systems thus require additional provision for supplying outdoor air to the zone.

6.7.5 Humidity (D5)

Indoor humidity is one of the comfort indices often overlooked. In some cases it is essential to maintain the relative humidity levels within certain margins. Static electricity can cause major damage in electronic control and computer rooms. Humidity control can easily be incorporated in large central systems. These systems are however usually absent in smaller room equipment. Certain split systems designed for computer room applications do however make provision for humidity control.

6.8 BUILDING MANAGEMENT REQUIREMENTS

6.8.1 Central building management system (E1)

From an energy savings and system managing perspective it is ideal to regulate the system from one control station. Building Management Systems (BMS) provides this control. These systems can easily be incorporated into the control of central systems. Window units, console units and spilt systems are usually not suited for this type of control system. Rooftop package units are usually furnished with their own standardised control system. These systems do not always make provision for interfacing with a building management system.

6.8.2 Unused zones (E2)

It is desirable to be able to switch of the air-conditioning in zones not being used. This saves energy and money that would otherwise be wasted. Typical applications are hotels and buildings that are only partially used. Window units, console units and split systems are ideal for this as they can be individually operated. Air-water systems also partially fulfil this requirement by allowing the individual fan-coil or induction units to be switched off. The primary air and cooling plant will however still be operational.

6.8.3 Separate billing (E3)

In multi-tenant buildings it is often necessary to measure the air-conditioning energy consumption of each tenant separately for billing purposes. The ideal would be that each area leased by the tenant has its own air-conditioning system. Unitary window units, console units or split systems are ideal for this. These systems are however impractical for bigger buildings.

Air-water system can also be metered to a certain extent. Conditioned water and fan power consumption can be measured for each fan-coil or induction unit used by the tenant. The primary air usage is generally constant and can be billed according to a flat rate. This can however not be done for all-air systems, as it is difficult to measure how much each patron adds to the total building load.

6.8.4 Flexibility (E4)

Buildings are dynamic commodities. Their requirements and interior layout may change over their life cycle. System flexibility is an indication of how well the system can be adapted to provide the same function with a different configuration. This is typically required in buildings where the interior layout frequently changes. Buildings where office space is often adapted to meet various tenants requirements is an example of this. In America, approximately 25 percent of the people employed in the commercial sector are relocated each year [5].

Systems that do not require major structural change are ideal for buildings with a high turnover. All-air systems designed in close co-operation with the architect can fulfil this need. In most cases the return and supply outlets need only be moved. Window and console units on the other hand are built into the building façade and are consequently costly to move.

6.9 SYSTEM COST

The cost of installing and operating the system is, and probably always will be, one of the most important factors in selecting a system. A project will not be completed without the necessary capital funding. The financial implication of system selection varies depending on the owner's goals. Developers are generally more interested in systems with a low initial cost. Building owners will also take into consideration the operating and maintenance cost of the system over a period of time. Life-cycle cost analysis is therefore required.

Buys [6] gives a short overview of simple life-cycle costing techniques used in the building industry. The net present value method is frequently used since it is simple yet applicable for medium to long term analysis. This method consists of calculating the present value of all the relevant cash flows for a certain period of time.

$$NPV = C_p + E_p + M_p + R_p + O_p \tag{6.3}$$

The time period used to do the financial analysis strongly influences the system choice. Shorter periods will favour systems with a lower initial cost. Longer periods will however favour systems with low operating and maintenance cost. The initial cost is used for the short-term analysis period. Ten and twenty years were respectively used for medium- and long term cost analysis.

Energy (E) and maintenance (M) are annual operating expenses. The cost of energy and maintenance however increases over time as the system deteriorates. Expressing this increase as an annual escalation rate, the net present value of these expenses can be calculated using standard economic cash flow relationships [7].

$$P = AE\left[\frac{(1+i)^N - 1}{i(1+i)^N}\right]. \qquad (6.4)$$

where AE is the constant annual expense if no cost increase occurred.

The value of money furthermore decreases with time due to inflation. By taking inflation into account equation 6.4 becomes

$$P = AE\left(\frac{1+e}{i-e}\right)\left[1-\left(\frac{1+e}{1+i}\right)^N\right]. \qquad (6.5)$$

with e being the average inflation rate for the analysis period.

The service life of HVAC equipment must also be taken into consideration in the economic analysis. Typical service lives for various system components can be found in ASHRAE [8]. Certain equipment may need to be replaced during the analysis period. The replacement cost of this equipment can be calculated using the present cost of equipment corrected for inflation.

$$R_P = C_P(1+e)^L \qquad (6.6)$$

Assuming that there are no other expenses, equation 6.3 becomes:

$$NPV = C_P + E\left(\frac{1+e}{i_E - e}\right)\left[1-\left(\frac{1+e}{1+i_E}\right)^N\right] + M_p\left(\frac{1+e}{i_M - e}\right)\left[1-\left(\frac{1+e}{1+i_M}\right)^N\right] + C_P(1+e)^L \qquad (6.7)$$

The capital cost (C_P) of the systems can be estimated using historical data. Data gathered by Konkel [9] and suppliers were used for this purpose. Some of the data is based on American labour rates. This data can however be applied since it is only used to compare equipment relative to one another. All costs are converted to South African currency with 1993 as cost basis.

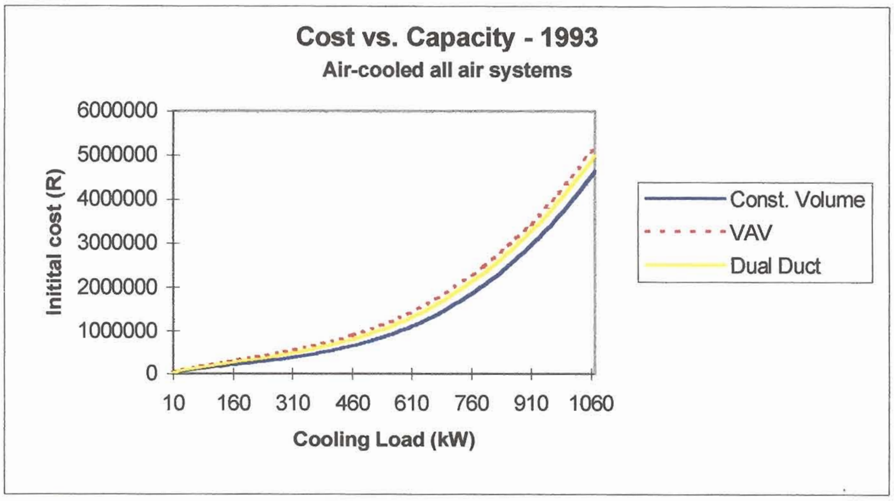

Figure 6.15 - Cost versus capacity relation for air-cooled all-air systems

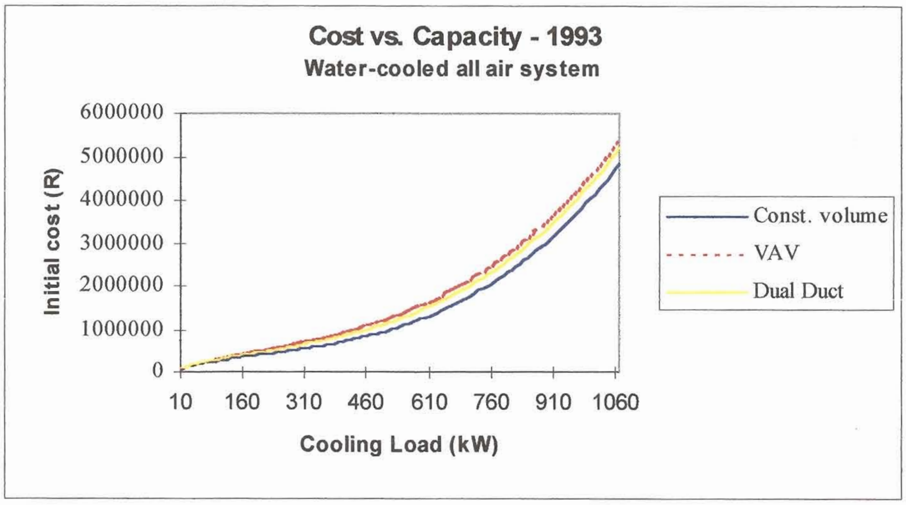

Figure 6.16 - Cost versus capacity relation for water-cooled all-air systems

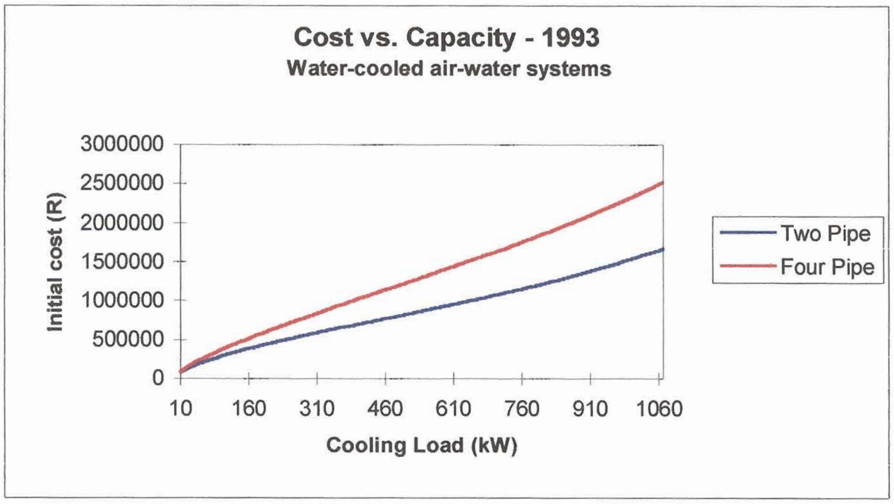

Figure 6.17 - Cost versus capacity relation for water-cooled air-water systems

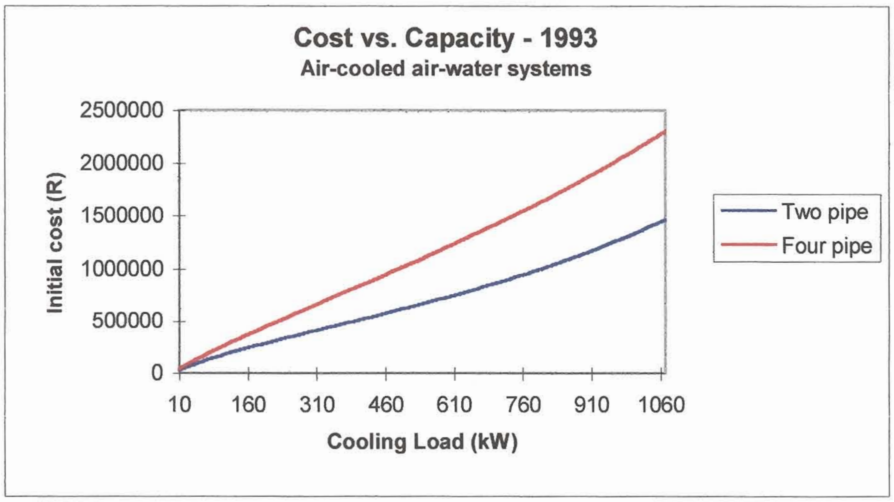

Figure 6.18 - Cost versus capacity relation for air-cooled air-water systems

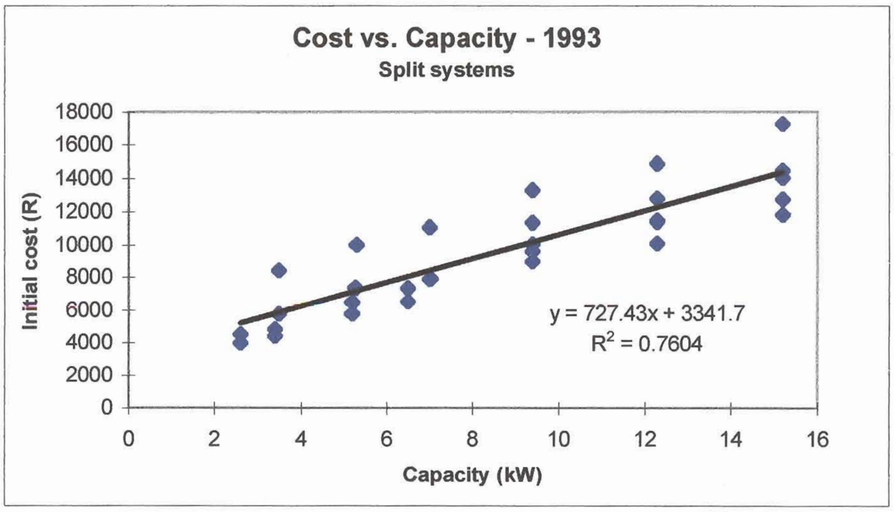

Figure 6.19 - Cost versus capacity relation for split systems

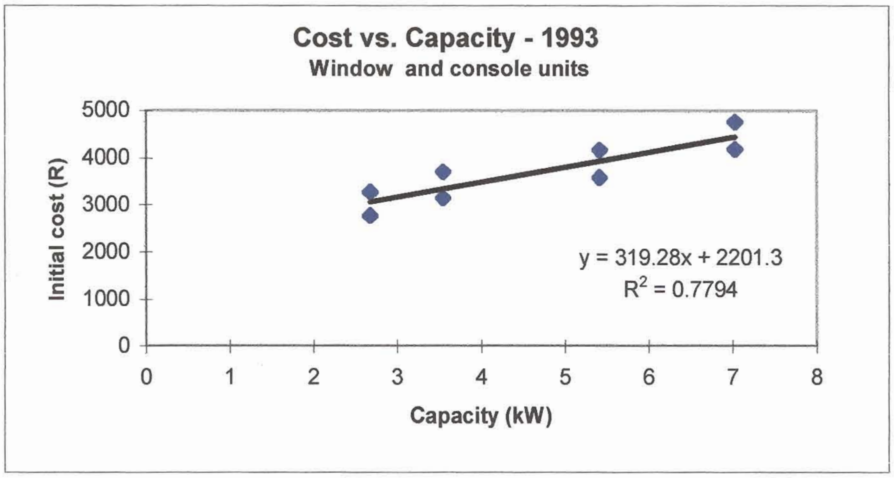

Figure 6.20 - Cost versus capacity relation for window and console units

In general, South African consultants and contractors estimate yearly maintenance cost as a percentage of the replacement value of the system [6]. This percentage varies depending on the installed system. Typical values are given in Table 6.1. Maintenance cost will increase as the system deteriorates. This increase is taken into consideration with a maintenance escalation rate.

Obtaining the energy expense of the various systems is not a simple task. It is a function of the energy tariff structure, building characteristics and climate. A simplified characteristic value can however be obtained using cost data from existing buildings. Alternatively, a cost database can be created using integrated simulation software.

Using a simulation tool, the annual energy consumption of various systems can be calculated for a particular building [10]. By applying an average energy tariff, the annual cost can be estimated for each of the system types. Using this database a simple annual cost per square meter value can be obtained. Illustrative values are given in Table 6.1. Energy consumption will increase as the system ages. This is due to a decrease in the energy efficiency of worn equipment. This is taken into consideration by using an energy escalation rate.

System ratings based on estimated cost are obtained by normalising the system cost relative to the system with the highest cost.

$$R_i = F - \frac{(NPV_i - NPV_{\min})}{(NPV_{\max} - NPV_{\min})} \times F \tag{6.8}$$

It must be stressed that this cost estimation is not very accurate due to the multiple assumptions made. The estimates will however provide reasonable values that can be used to quickly compare the various systems to each other. A sensitivity analysis can be performed in more critical situations by changing the cost ratios and noting what the influence is on the system ranking.

6.10 PRELIMINARY DESIGN RESTRICTIONS

6.10.1 Cooling capacity (G1)

The required cooling capacity also influences the selection of a system. It is impractical to select a system type with a maximum capacity lower than required. The opposite also applies. According to the numerous catalogues and brochures studied, the following typical characteristic capacity ranges were identified:

• Water-cooled central systems	$Q > 30$ kW
• Air-cooled central systems	$Q > 10$ kW
• Split systems	$Q < 60$ kW (per zone)
• DX unitary systems	$Q < 10$ kW (per zone)
• Rooftop packaged units	$7 < Q < 180$ kW

These capacity ranges may however vary in different countries.

Systems are given a rating of one if the cooling capacity falls within the typical capacity range. If not, they are given a rating of zero. Total cooling capacity is used to check central systems. Unitary and split system compliance is checked using the capacity per zone requirements. For the purposes of the preliminary selection tool the capacity per zone is estimated as total cooling capacity divided by the number of zones.

6.10.2 Climate (G2)

Water-cooled systems use mass transfer of water vapour and heat transfer as a means of rejecting heat to the surrounding atmosphere. In a hot dry climate, evaporation takes place easily. In humid climates however this is less effective. Air-cooled systems are given a rating of five, and water-cooled zero. These factors are however only taken into consideration if the user indicates that the system is located in a humid climate.

6.11 SUMMARY

Typical design criteria used for selecting systems were identified and discussed. Rating factors and correlation equations were obtained for these criteria. Correlation equations are summarised in Table 6.1. Using these relations, rating factors can be obtained by normalising each system characteristic relative to the system with the worst characteristic.

The correlation equations for full fresh air and economiser systems are the same. The only difference being that the system load requirements must be increased to cope with the increased outdoor load. In this selection tool it was done by increasing the load by 25%.

Subjective design criteria are rated based on experience and expert knowledge. To reduce prejudice towards certain systems, it is preferable that the expertise from various designers be used in rating the systems. Typical rating factors are given in Table 6.2.

Air-conditioning system	Initial Cost C_P =	Maintenance Cost % of C_P	Energy Cost R/m²/year	Area (m²) A =	Structural Impact (kg) W =	Volume V =
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	$0.0047(1.25Q)^3 - 2.766(1.25Q)^2 + 1876.2(1.25Q) + 88266$	2.5%	12.2	$0.0766(1.25Q) + 8.7912$	$3.0208(1.25Q) + 364.24$	$0.0196(1.25Q) + 0.5611$
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	$0.0044(1.25Q)^3 - 1.9291(1.25Q)^2 + 1319.5(1.25Q) + 24661$	2.5%	14.8	$0.0831(1.25Q) + 4.7786$	$10.673(1.25Q) + 157.66$	$0.0473(1.25Q) + 1.7935$
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	$0.0047Q^3 - 2.766Q^2 + 1876.2Q + 88266$	2.5%	10.4	$0.0766Q + 8.7912$	$3.0208Q + 364.24$	$0.0196Q + 0.5611$
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	$0.0044Q^3 - 1.9291Q^2 + 1319.5Q + 24661$	2.5%	12.2	$0.0831Q + 4.7786$	$10.673Q + 157.66$	$0.0473Q + 1.7935$
5. All-air, dual duct system with water-cooled refrigeration plant.	$0.0046Q^3 - 2.4623Q^2 + 2145.8Q + 90684$	3.0%	9.7	$0.0766Q + 8.7912$	$3.0208Q + 364.24$	$0.0196Q + 0.5611$
6. All-air, dual duct system with air-cooled refrigeration plant.	$0.0043Q^3 - 1.7322Q^2 + 1591Q + 27140$	3.0%	11.8	$0.0831Q + 4.7786$	$10.673Q + 157.66$	$0.0473Q + 1.7935$
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.	$0.0047Q^3 - 2.6828Q^2 + 2433.8Q + 88236$	3.0%	11.8	$0.0766Q + 8.7912$	$3.0208Q + 364.24$	$0.0196Q + 0.5611$
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	$0.0044Q^3 - 1.9553Q^2 + 1880.4Q + 24702$	3.0%	9.5	$0.0831Q + 4.7786$	$10.673Q + 157.66$	$0.0473Q + 1.7935$
9. Four-pipe system with air-cooled refrigeration plant.	$2053.7Q + 19327$	3.0%	10.2	$0.0511Q + 3.4761$	$10.673Q + 157.66$	$0.0473Q + 1.7935$
10. Four-pipe system with water-cooled refrigeration plant.	$2155.2Q + 144616$	3.0%	12.7	$0.0439Q + 7.8869$	$3.0208Q + 364.24$	$0.0196Q + 0.5611$
11. Two-pipe system with air-cooled refrigeration plant.	$0.0007Q^3 - 0.8623Q^2 + 1435.2Q + 30493$	3.0%	9.7	$0.0511Q + 3.4761$	$10.673Q + 157.66$	$0.0473Q + 1.7935$
12. Two-pipe system with water-cooled refrigeration plant.	$0.001Q^3 - 1.5853Q^2 + 1988.6Q + 94133$	3.0%	12.2	$0.0439Q + 7.8869$	$3.0208Q + 364.24$	$0.0196Q + 0.5611$
13. Split systems	$727.43Q + 3341.7$	2.8%	14.4	$0.0333Q$	$7.3029Q + 15.533$	$0.0321Q$
14. Window units	$319.28Q + 2201.3$	3.3%	14.4	Negligible	Negligible	Negligible
15. Through-the-wall console units	$319.28Q + 2201.3$	3.3%	14.4	Negligible	Negligible	Negligible
16. Packaged rooftop units	$603.76Q + 9505.9$	3.3%	11.6	$0.1216Q$	$17.931Q - 96.264$	$0.241Q - 2.9694$

Table 6.1 - Summary of system correlations equations and data.

Air-conditioning system	Building Restrictions				Aesthetic Limitations				System Requirements				
	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	C5
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	Calculate	2	Calculate	5	5	5	5	Calculated	5	0	4	0	1
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	Calculate	2	Calculate	5	5	5	5	Calculated	5	1	5	0	1
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	0	4	0	1
4. All-air, variable air temperature, economiser system and air- cooled refrigeration plant.	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	1	5	0	1
5. All-air, dual duct system with water-cooled refrigeration plant.	Calculate	0	Calculate	5	4	5	5	Calculated	5	0	3	1	2
6. All-air, dual duct system with air-cooled refrigeration plant.	Calculate	0	Calculate	5	4	5	5	Calculated	5	0	4	1	2
7. All-air, variable volume, economiser system and water- cooled refrigeration plant.	Calculate	1	Calculate	5	3	5	5	Calculated	4	0	4	2	2
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	Calculate	1	Calculate	5	3	5	5	Calculated	4	0	4	2	2
9. Four-pipe system with air-cooled refrigeration plant.	Calculate	3	Calculate	4	2	5	5	Calculated	3	0	3	3	3
10. Four-pipe system with water-cooled refrigeration plant.	Calculate	3	Calculate	4	2	5	5	Calculated	3	0	3	3	3
11. Two-pipe system with air-cooled refrigeration plant.	Calculate	4	Calculate	4	2	5	5	Calculated	3	0	3	3	1
12. Two-pipe system with water-cooled refrigeration plant.	Calculate	4	Calculate	4	2	5	5	Calculated	3	0	2	3	1
13. Split systems	Calculate	4	Calculate	3	1	5	2.5	Calculated	3	4	3	4	4
14. Window units	5	5	5	0	0	0	0	Calculated	0	5	0	5	5
15. Through-the-wall console units	5	5	5	0	0	5	0	Calculated	0	5	0	5	5
16. Packaged rooftop units	Calculate	1.5	Calculate	5	5	5	5	Calculated	5	3	5	0	1

Table 6.2 - System ranting values

Air-conditioning system	Air Quality and flow Restrictions					Building Management				Cost	Preliminary Design Restrictions	
	D1	D2	D3	D4	D5	E1	E2	E3	E4	F	G1	G2
1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.	5	5	5	5	5	5	0	0	5	Calculate	Q>30 - 5 ; Else - 0	0
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.	5	5	5	5	5	5	0	0	5	Calculate	Q>10 - 5; Else - 0	5
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.	5	3	5	5	5	5	0	0	5	Calculate	Q>30 - 5 ; Else - 0	0
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.	5	3	5	5	5	5	0	0	5	Calculate	Q>10 - 5 ;Else - 0	5
5. All-air, dual duct system with water-cooled refrigeration plant.	5	3	5	5	5	5	0	0	0	Calculate	Q>30 - 5 ; Else - 0	0
6. All-air, dual duct system with air-cooled refrigeration plant.	5	3	5	5	5	5	0	0	0	Calculate	Q>10 - 5 ; Else - 0	5
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.	5	2	5	4	5	5	0	1	4	Calculate	Q>30 - 5 ; Else - 0	0
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.	5	2	5	4	5	5	0	1	3	Calculate	Q>10 - 5 ; Else - 0	5
9. Four-pipe system with air-cooled refrigeration plant.	3	2	3	3	3	3	3	3	2	Calculate	Q>10 - 5 ; Else - 0	5
10. Four-pipe system with water-cooled refrigeration plant.	3	2	3	3	3	3	3	3	2	Calculate	Q>30 - 5 ; Else - 0	0
11. Two-pipe system with air-cooled refrigeration plant.	3	2	3	3	3	2	3	3	3	Calculate	Q>10 - 5 ; Else - 0	5
12. Two-pipe system with water-cooled refrigeration plant.	3	2	3	3	3	2	3	3	3	Calculate	Q>30 - 5 ; Else - 0	0
13. Split systems	0	0	0	0	3	1	5	5	2	Calculate	$Q_z<60$ -5 ; Else - 0	5
14. Window units	0	0	0	0	0	0	5	5	0	Calculate	$Q_z<60$ -5 ; Else - 0	5
15. Through-the-wall console units	0	0	0	0	0	0	5	5	0	Calculate	$Q_z<10$ -5 ; Else - 0	5
16. Packaged rooftop units	3	3	4	5	4	3	0	0	4	Calculate	7<Q<180 - 5 ; Else - 0	5

Table 6.2 - System ranting values (Continued)

6.12 BIBLIOGRAPHY

1. P.W. Scanlon, "*Economic Impact of HVAC system selection*", Heating/Piping/Air Conditioning, pp. 32-44, September 1992.
2. H. Damhuis, "*An evaluation of air-conditioning systems and rating their suitability for buildings of the future*", Proc. Fridgair, Durban South Africa, 1994
3. D.V. Chadderton, "*Air-conditioning : A Practical introduction*", E & FN Spon, 2-6 Boundry Row, London SE1 8HN, 1993.
4. ASHRAE, "*ASHRAE Standard 62-1989 : Ventilation for acceptable indoor air quality*", American society of heating, refrigerating and air-conditioning engineers, inc., 1791 Tullie Circle, NE, Atlanta, GA 30329, 1989.
5. R.P. Gupta, "*HVAC for commercial office buildings*", Heating/Piping/Airconditioning, pp.53-59, March 1997.
6. J.H. Buys, "*Development of life-cycle cost models for HVAC economic analysis*", Masters dissertation, University of Pretoria, 1994.
7. C.S. Park and G.P. Sharp-Bette, "*Advanced engineering economics*", John Wiley & Sons, 1990.
8. ASHRAE '*ASHRAE HANDBOOK : HVAC Applications*" American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. 1791 Tullie Circle, N.E. Atlanta, GA 30329, 1995.
9. J.H. Konkel, "*Rule-of-thumb cost estimating for building mechanical systems : Accurate estimating and budgeting using unit assembly costs*", McGraw-Hill Book Company, ISBN 0-07-044957-0, 1987.
10. S.C. Sekhar and J.Y. Chung, "*Energy simulation approach to air-conditioning system evaluation*", Building and Environment, Vol. 33, No. 6, pp. 397-408, 1998.