Chapter 5 Development Of A Simplified Preliminary HVAC System Selection Tool

Thermally efficient building design can greatly reduce the need for, and size of air-conditioning systems. Certain buildings will however always require some form of HVAC system. More often than not these systems are selected based solely on initial cost, or the designer's experience. This is however short sighted as the system choice largely influences the socio-economic success of the building. Ideally, the selection process should consist of a detailed performance analysis for various systems as applied to the building under consideration. The system with the best overall performance is the logical choice.

Detailed analysis is very time consuming and impractical, especially during the initial stages of design. A simplified, preliminary analysis can however be carried out by estimating system performance. This estimate is based on data and experience gathered from similar projects as well as general system information. The selection criteria used as basis for comparing the various systems is strongly dependent on the building owner or developers requirements. It is therefore essential that these requirements also be reflected in the selection process. This chapter discusses the development of a simplified comparison method and selection rating system into a preliminary selection tool.

NOMENCLATURE

R_i : System rating factor for design criteria i

F : Maximum allowable rating

W_i : Weighing factor for design criteria i

SR : System ranking factor

S_i : Screening factor for design criteria i

P_i : Allocated percentage point for design criteria i

n : Number of design criteria

5.1 INTRODUCTION

Ever since the energy crisis of the seventies, a lot of research has gone into improving the efficiency of buildings. As a result, various guidelines and thermal design tools have been developed. Using these tools in the design of new buildings can greatly reduce the need for air-conditioning systems or their capacity requirements. However, some buildings will still need an HVAC system in order to maintain acceptable indoor comfort levels.

Selecting the most appropriate system for these buildings is not a simple task. It can be challenging even for the most experienced designer. This is compounded by the fact that there is generally little or no guidance when it comes to choosing the right system for a given building. According to Clark [1], HVAC system selection is often given less thought than that of the carpet selection. He further states that in most cases selection is usually based on the lowest initial cost. In other cases, systems are selected simply because the designers are familiar with them or because they are commonly associated with that type of building.

Using only the above factors as basis for the final system selection is very short-sighted. HVAC systems have the single largest impact on the owning and operating cost of buildings. They are also frequently cited as one of the biggest sources of complaints from occupants. It is thus essential that these systems be selected and designed with great care.

Ideally, the optimum system choice is obtained by means of a detailed analysis [2,3]. This consists of calculating, comparing and contrasting the characteristics of various systems for each building. Such an analysis is time consuming, and it also requires information usually not readily available during the preliminary design phase. Detailed analysis is therefore impractical and uneconomical, especially during the early stages of design.

During the preliminary design phase the requirements of the building owner or developer are identified. These requirements influence the building structure, layout, aesthetics and overall building characteristic, which subsequently affect the system choice. It is thus essential that the selection process also be initiated during this phase. A simplified analysis and selection tool suitable for use during the early stages of design is therefore required

System analysis can be simplified for the preliminary design phase by estimating performance characteristics. These estimates are based on data and experience gathered from similar projects. Simple equations relating system characteristics to floor area and capacity can be obtained through regression analysis. Using these equations, an assessment of the impact of each system can be made without the need for detailed design calculations.

A preliminary selection tool can be obtained by applying these equations into simple numerical ranking and rating method [4]. A prototype of such a simplified selection tool was developed using a spreadsheet during this study. Typical generic air-conditioning systems and selection criteria were identified and incorporated into the selection tool.

5.2 THE NEED FOR AIR-CONDITIONING

It is possible to design buildings that do not require elaborate HVAC systems. Indoor comfort can be obtained passively by means of natural ventilation or by other architectural features built into the building [5,6]. Passive design features are however not always sufficient to maintain indoor comfort. Certain building designs, applications, and buildings located in harsh climatic conditions need air-conditioning.

Buildings that are typical candidates for air-conditioning are as follows [7]:

- High-rise buildings;
- buildings that have extensive glazing areas;
- buildings located in areas where the windows cannot be opened due to dust, noise, etc;
- buildings with high internal loads or occupant density;
- deep plan buildings with internal heat gain.

5.3 AIR-CONDITIONING SYSTEMS

There are a multitude of different system types and configurations available for use by air-conditioning designers. It would consequently be impracticable to define all the systems and their variations. These systems can however be generically classified according to their method of operation. Systems are primarily classified as all-air systems, air-water systems, all-water systems or direct expansion or unitary systems. Each group has distinct advantages and disadvantages [2,8,9,10,11].

5.3.1 All-air Systems

Description

These systems provide the required sensible and latent cooling, heating and humidification via air supplied to the zone. No additional cooling is done in the zone. In some cases however there can be some form of reheat present in the zone. These systems are generally central systems.

Both air treatment and refrigeration plants may be located some distance from the conditioned space. The refrigeration and air treatment plants are connected either through refrigerant or water piping. A system of ductwork and diffusers conveys the conditioned air to the zones.

These systems can further be classified as either:

- *constant or variable volume* - depending on whether the system changes the supply temperature or the amount of air to control load variances;
- *air or water cooled* - indicating how heat is rejected from the refrigeration plant;
- *full fresh or re-circulation* - depending on whether the system supplies only fresh air to the zone or a mixture of recycled and outdoor air.

Advantages

- These systems have little or no equipment within the occupied areas that require maintenance. They therefore also take up little or no space within the tenant's area.
- Noise levels are low since the equipment is located away from the occupied areas. In addition, these systems can also incorporate a wide range of vibration and noise control systems.
- Keeping piping, electrical and mechanical equipment, wiring and filters away from occupied areas reduce the potential risk of injury to occupants or damage to furnishings or processes.
- Equipment is generally durable and of a high quality as the system contains only a few air-handling units.
- These systems lend themselves to good filtration and outdoor air distribution.
- Free cooling or the use of outdoor air can be incorporated relatively easily and at low cost.

- A wide choice of zoning, flexibility and humidity control under all operating conditions is available.
- These systems are well suited for applications that require specialised makeup air quantities such as positive or negative pressurisation.
- All-air systems adapt well to winter humidification.
- Using high-quality controls it is possible for these systems to maintain the strictest operating conditions of ±0.15°C dry-bulb, and ± 0.5% relative humidity.

Disadvantages

- These systems require large additional spaces for ducting. Required ceiling voids increases the height of the building and building cost. Usable floor space is also smaller, as space is required for the duct risers.
- Close co-operation is required between architect and engineers to ensure that terminal devices are accessible.
- Air balancing, particularly on large systems, can be difficult.
- These systems cannot cope with large changes in space load and function.
- Adding capacity is both costly and difficult.
- It is difficult to accurately bill tenants for air-conditioning costs.
- After-hours operation for single occupants can be costly. This is also true if sections of the building are unoccupied but they still contribute to the air-conditioning load.
- Breakage can effect large areas.

5.3.2 Air -water systems

Description

Air-water systems use both water and air to condition the indoor spaces. Air and water are conditioned by means of a central plant and then supplied to the different building zones. The conditioned air serves to balance the normal building load, satisfy the ventilation requirements, and provide humidity control. This air is called the primary air.

The water on the other hand accounts for the zone specific load requirements and fluctuations. The water supplied to each zone is called the secondary water. Electric heating may be present in some cases instead of a hot water coil.

Two basic types of air-water air-conditioning systems exist namely, induction units and fan-coil units. These units can be arranged in a multitude of configurations from ceiling mounted units to floor units. They can basically be classified as either being:

- *air or water cooled* - indicating how heat is rejected from the central refrigeration plant;
- *two-, three- or four pipe systems* - indicating the number of water pipes connecting the zone coils with the central plant.

Advantages

- These systems provide individual room temperature control at a reasonable cost. They also cater for individual preferences by adjusting each thermostat of each zone coil.
- Air-water systems take up less building space. The air distribution system is smaller and therefore requires less ceiling and vertical shaft space for ducting. The size of the central air-handling plant is also smaller as less air needs to be conditioned centrally.
- Dehumidification, filtration and humidification are performed at a central location away from the conditioned spaces.
- Routine maintenance in the zones is generally limited to temperature controls and cleaning of lint screens. Induction units require infrequent cleaning of the induction nozzles, and fan coil units require servicing and lubrication of the fan and motor.
- Minimum cross contamination of air from different areas occurs since each zone uses its own air for re-circulation.

Disadvantages

- These systems require some space in the tenants' area for the induction or fan-coil units. A certain amount of maintenance therefore is also required within the tenants' area.
- These systems are generally limited to perimeter spaces. They are also not applicable for use in spaces with high exhaust requirements unless supplementary ventilation is supplied.
- The controls and electrical reticulation required for these systems are more complex.

- Filtration of the air inside the conditioned space is not very good. This can reduce the efficiency of the induction and fan-coil units. The lint screens of the units must therefore be cleaned regularly. Outdoor air, usually supplied as primary air, can however be filtered efficiently.
- Primary air is usually supplied as a constant volume with no provision for shutoff. Managers can not turn off the air-conditioning in unutilised spaces to save energy.
- Noise levels experienced inside conditioned areas can be higher than that for all-air systems.
- Control tends to be more numerous for many all air systems.
- Initial costs of four-pipe systems are generally higher than those of all-air systems.

5.3.3 All -water systems

Description

All-water systems are basically the same as air-water systems, the only difference being that no conditioned air is supplied to the zones. Outdoor air requirements are either provided for by windows or in some cases by the use of through-the-wall units. One of their main uses is as hot water radiant or panel heaters. These systems can also be further sub-classified in the same manner as the air-water systems.

Advantages

- The biggest advantage of these systems is that they do not require any ducting. Loss in usable floor area and ceiling height is therefore kept to a minimum.
- They provide individual room control while still retaining some of the advantages of a central system.
- In retrofitting existing buildings it is often easier to install piping and wiring rather than ducting.

Disadvantages

- These systems have more units that require maintenance. Most of this work must be done within the occupied spaces.
- Some of the units require costly and difficult drainage systems. This is especially essential for units working at low dew-point temperatures.

- These systems do not make provision for required outdoor ventilation. Ventilation is usually provided by open windows or wall mounted fans. Stack effect and wind can therefore affect ventilation.
- Summer room humidity levels tend to be high

5.3.4 Direct expansion or unitary systems

Description

The main characteristics of these units are that they consist of integrated factory assembled components. The components of these self-contained units are matched and assembled to achieve specific performance objectives. These units are therefore only available in pre-set capacity and performance increments, such as the sensible heat ratio for a given room condition, or litres of air per second per kilowatt of refrigeration [9].

These limitations however are offset by units that are cheap and easy to manufacture with high standards of quality control. There is also a wide variety of types and configuration available. These units can also be sub-classified further according to how they look and function. They are typically one of the following:

- *Split units* - these systems are split into indoor and outdoor units. Refrigerant piping connects the two units;
- *Window or through-the-wall console units* - the systems are self contained air-conditioning systems incorporated into a small package.
- *Rooftop packaged units* - these units consist of larger self-contained units. They are usually installed on the roof of a building. As with all-air systems, these units also supply conditioned air to the zones. The length of ducting is however restricted.

Advantages

- Individual room control by tenants is simple and inexpensive.
- Heating or cooling can be provided independently from other spaces.
- Factory assembly of the units allow for improved quality control, reliability, and certified performance data and ratings.
- Easy installation due to repetitive tasks and manufacturers instructions.

- The systems are generally readily available. This reduces problems in scheduling the ordering and delivery of equipment and less co-ordination is required during the building stage.
- These systems are simple to use and therefore do not require trained operators.
- Breakdown only affects a small area.
- Energy costs can be metered directly to each tenant. Units in unutilised areas can be switched off.
- Less mechanical and electrical space is required than for central systems.
- Initial costs are usually low.

Disadvantages

- Systems are limited in available airflow and distribution as well as cooling coil and condenser sizes.
- These systems are generally not suited for close humidity control. Some units designed especially for computer rooms etc. can however accomplish this.
- They have a higher operating and owning cost than central systems.
- Units have a relatively short life (± 8 years in dry areas and 4 to 5 years in coastal areas [8]).
- Overall appearance of systems can be unappealing.
- Noise levels within the zones can be high and unacceptable.
- Outdoor air supply requirements need to be addressed by other means. Usually by window operation. These systems also have limited filtration options.
- Building depth is severely limited. (Maximum depth of office is 4 to 4,5 metres [8]).
- Condensation leakage from the units can be a problem.
- Maintenance is required in the tenants' areas and can be difficult to perform.

5.4 SELECTION GOALS AND CONSTRAINTS

In theory, it is possible to successfully apply every system to any building. In practice however, design goals and constraints limit system choice. The financial and functional objectives and criteria of the building owner or developer dictate design goals, and constraints normally comprise of geographical and physical building limitations.

Typical design goals and constraints considered are [2,9,12,13]:

- Available space for the system;
- performance requirements;
- indoor air requirements;
- initial costs;
- running costs;
- aesthetics;
- flexibility;
- maintainability.

5.5 SYSTEM SELECTION

Identifying and rating the relative importance of the above design criteria is the first step in selecting a system. These factors are however interdependent and affect not only one another but the other building design disciplines as well. Sometimes it is necessary for a compromise to be reached between the various design goals and other design disciplines. It is therefore crucial to involve the whole design team in the selection process

The rated design goals and constraints are used as basis for comparing and weighing the various system strengths and weaknesses against each other. Suitability of a system depends on how well its' characteristics match those of the rated design criteria [9]. System characteristics may vary depending on building size, climate and load conditions. A detailed system analysis is therefore required for each new building.

New integrated building and system simulation tools can greatly reduce the effort required for detailed system analysis [14,15]. These tools however still require a reasonable amount of time and skill to use. They also do not make provision for explicitly involving the entire design team in the selection process. A simplified selection tool that incorporates the design goals and constraints of the whole design team is required. Such a tool can be used to screen systems, thereby effectively reducing the number of systems to be compared.

5.6 EXISTING SELECTION TOOLS AND METHODS

Expert systems [16,17] for selecting HVAC equipment and numerical ranking methods [4,18,19] have in the past been applied to aid designers in selecting equipment. Expert systems use heuristic rules and if-then statements to make design selections. These rules and statements are based on knowledge and experience gained from several experts in the field. A typical example of such a tool was developed by ASHRAE for research project RP-642 [13,20]. Expert systems however have certain inherent problems.

Obtaining and encoding the knowledge from experts is difficult. The decisions made by these systems are also only as good as the experts that compiled the rules. Furthermore, these systems are restricted to the information originally encoded into the knowledge database. They can consequently become obsolete, as advances are made in technology or if new and different air-conditioning systems need to be added. A certain amount of programming will therefore be required to maintain the program. Expert systems are therefore generally too complex to be maintained and used by the majority of designers.

Numerical ranking methods on the other hand are simple and straightforward design evaluation techniques [4,18,19]. These methods typically use weighted system rating factors to rank systems in order of suitability. Systems are given rating factors according to how well their characteristics match certain design criteria. A weighing factor is assigned to each of the criteria based on its relative importance. The system with the highest overall weighted rating is ranked as the most appropriate system choice.

These methods also have some limitations that need to be addressed. Some of these methods do not account for all the design criteria or include an explicit method for involving the whole design team [4]. These methods may also be biased toward certain systems. This is due to the assigned rating factors being based solely on the experience and judgement of the system designer. Another problem of the numerical ranking methods is that it requires a detailed system analysis to be completed in order to rate varying factors, such as spatial requirements. It is therefore not ideally suited as a preliminary design tool.

5.7 A SIMPLIFIED PRELIMINARY SELECTION TOOL

A simplified preliminary design tool can be obtained by combining the positive features of both expert systems and numerical ranking methods. This is achieved by using a numerical ranking method as an expert shell. Such a tool will retain the simplicity of the numerical ranking method. Rating factors will however not only be based on one designer's judgement, so prejudice towards certain systems can thus be reduced. Expert knowledge can be used to rate varying system characteristics without the need for a detailed system analysis.

Some system characteristics can be estimated from published system information as well as experience gained from completed projects. Using this information and regression analysis it is possible to obtain simple equations that relate various system characteristics to floor areas and cooling loads. Characteristics such as cost, space requirements, and weight can be predicted by applying these equations for each different system type being evaluated. This is illustrated in more detail in Chapter 6.

The rating factors, required by the selection tool, can be obtained from the estimated system design characteristics. This is done by normalising each property by using the system with the worst characteristic as a basis. A rating factor for initial cost, for example, is obtained as follows:

$$R_i = F - \frac{(Estimated\ \ Initial\ \ Cost\ \ of\ \ system)}{(Maximum\ \ Estimated\ \ Initial\ \ Cost)} \times F \qquad (5.1)$$

Non-quantifiable criteria, such as aesthetics, are rated based on feedback from various experts. In the absence of such data, the method as described by Scanlon [4] can be used. 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. Rating factors only indicate how well a specific system is suited towards a particular design goal or constraint. The importance of achieving this criterion however varies for each different building.

Weighing factors are used to adjust the rating factors so that those criteria, which are more important, have a greater influence. Weighing factors must be obtained for each design criteria. These factors are dependent on the requirements identified by the design team and owner or developer. These factors must therefore be obtained through direct communication with the entire design team. This is done by means of simple questions structured to gauge the design preferences, goals and constraints.

For each system being considered, a total system ranking is calculated by adding the product of the weighing and rating factors of each of the design criteria:

$$SR = W_1 R_1 + W_2 R_2 + \ldots + W_n R_n \tag{5.2}$$

Suitability of the systems can be compared once a ranking factor for all the systems has been calculated. The higher the system ranking value, the better the systems fulfils in the design criteria. Using this method it is possible to identify the top two or three systems. Only these systems need to be evaluated in greater detail. In some cases the ranking can indicate that one system has an overwhelming advantage over the others. Detailed calculations are therefore only required for this system.

A preliminary selection tool was developed and implemented in a spreadsheet application to demonstrate the use of this model. Spreadsheet applications are ideal for this type of problem since they are simple and already used by many designers. Changing or updating the knowledge database is a simple task that does not require any programming skills. The rest of this chapter and chapter 6 deals with gaining the domain specific knowledge required for the tool. The potential systems and the design goals and limitations are identified for application in the selection tool prototype.

5.8 SYSTEMS CONSIDERED FOR THE TOOL

The aim of the selection tool is to provide designers with an aid in selecting the appropriate air-conditioning system during the preliminary stages of design. Detail construction and layout of the systems are therefore not required. The generic system types previously identified can thus be used.

The South African climate is mostly hot and dry. Buildings consequently require cooling for most of the year. The selection tool therefore focuses on selecting a cooling system. The methods used to develop this tool can however be applied to incorporate other or new systems.

The following air-conditioning units are defined for this tool:

1. All-air, variable air temperature, full fresh air system with water-cooled refrigeration plant.
2. All-air, variable air temperature, full fresh air system with air-cooled refrigeration plant.
3. All-air, variable air temperature, economiser system and water-cooled refrigeration plant.
4. All-air, variable air temperature, economiser system and air-cooled refrigeration plant.
5. All-air, dual duct system with water-cooled refrigeration plant.
6. All-air, dual duct system with air-cooled refrigeration plant.
7. All-air, variable volume, economiser system and water-cooled refrigeration plant.
8. All-air, variable volume, economiser system and air-cooled refrigeration plant.
9. Four-pipe system with air-cooled refrigeration plant.
10. Four-pipe system with water-cooled refrigeration plant.
11. Two-pipe system with air-cooled refrigeration plant.
12. Two-pipe system with water-cooled refrigeration plant.
13. Split systems.
14. Window units.
15. Through-the-wall console units.
16. Packaged rooftop units.

5.9 DESIGN CRITERIA

The design criteria used for the selection tool prototype are based on the typical goals and constraints previously identified. The relative importance of the different design criteria is obtained by allocating 100 percentage points to be distributed among the criteria. These points are awarded to each criteria based on proportional significance, as determined by the entire design team. This value is expressed as the goal factor.

Constraints placed on the design can limit the use of certain systems. Systems that require space for ducting, for example, can be eliminated if the building design does not allow for this. Suitable questions were identified to gauge these absolute limitations. Table 5.1 lists typical questions with their possible answers and respective screening factors.

Based on these questions, a screening factor between 0 and 1 is allocated to each of the corresponding design goals. A value of 1 indicates extreme importance, while 0, indicates that no absolute requirement is imposed on the design goal. Design criteria not affected by absolute limitations, such as cost and cooling load per zone, are assigned a screening factor of one.

The screening factor of each design criterion is increased relative to its allocated percentage point. The weighing factor for each criterion is the adjusted screening factor, expressed as a percentage of the total of all the adjusted values.

$$W_i = \frac{S_i \times (1 + P_i)}{\sum_{i=1}^{n} S_i \times (1 + P_i)} \times 100 \tag{5.3}$$

5.10 CONCLUSION

Selecting HVAC systems greatly influences the future success of a building. It is however not a trivial task. The designer must select from the myriad of options available, a system that best suits the requirements and limitations imposed on the building. This often requires some form of compromise to be reached between the different design disciplines. To effectively achieve this, it is necessary to get the whole design team involved in the selection process. This is especially important during the preliminary design stage.

A simplified analysis and selection tool suitable for use during the early stages of design can be of great assistance to designers. A prototype of such a tool was developed by combining the simplicity of numerical ranking methods with the proficiency of expert systems. This tool aids the designer in establishing and ranking the design goals and limitations in order of importance. Based on this information, the tool suggests one or two systems that can be analysed in more detail.

The use of such a preliminary tool promotes the concept of integrated building design. It incorporates the whole design team in the selection of the air-conditioning system. This in turn promotes more confidence in the validity of the system choice and it reduces the need for detailed analysis of a multitude of systems. Other building design disciplines will also be better equipped to make provision for the system, the end result being a more effective design effort.

Ref.	Design Criteria	Typical answers and Relative Screening factor
A	**Building Restrictions**	
A1	Is there enough floor space available for equipment. (Including rooftop)?	Yes = 0 /Restricted =0.5 /No = 1
A2	Is there sufficient space for the secondary heat transfer system i.e. ducting and chilled water piping?	Yes = 0 /Restricted =0.5 /No = 1
A3	Impact of system weight on building structure?	No = 0 /Yes = 1
A4	System required for both interior and perimeter zones, or only perimeter zones?	No = 0 /Yes = 1
B	**Aesthetic limitations**	
B1	Is aesthetically allowable to have equipment located in the zone?	Yes =0 /Limited = 0.5 /No = 1
B2	May window mounted units be used?	Yes = 0 /No = 1
B3	May inlet grilles or condensers form a major feature of the facade?	Yes = 0 /No = 1
B4	Can rooftop or external enclosure be aesthetically incorporated in design?	Yes = 0 /No = 1
C	**System requirements**	
C1	Noise level in the zone critical? (i.e. sound stage vs. Workshop area)	No = 0 /Intermediate = 0.5/Yes = 1
C2	Will there be skilled maintenance and system personnel?	Yes =0 /No = 1
C3	Is regular in-zone maintenance allowed?	Yes = 0 /No = 1
C4	Individual control of setpoint and temperature required?	No = 0 /Yes = 1
C5	Do the zone loads differ greatly?	No =0 /Yes = 1
D	**Air quality and flow restrictions**	
D1	Is the filtration of air important? (I.e. clean room environment)	No = 0 /Intermediate = 0.5 /Yes = 1
D2	High amounts of air contaminants present in the zone? (i.e. Laboratories)	Yes = 0 /limited = 0.5 /No =1
D3	Specialised make up air required? (i.e. room pressurisation)	No = 0 /Yes = 1
D4	Does the building have any other means of providing outdoor air?	Yes = 0 /No = 1
D5	Stringent humidity control important?	No = 0 /Intermediate = 0.5/Yes = 1
E	**Building management requirements**	
E1	Must the system be manageable from a central control room?	No = 0 /Yes = 1
E2	Is it important to cut of the supply to unused zones? (i.e. unused hotel rooms)	No =0 /Yes = 1
E3	Is separate zone electrical billing required?	No =0 /Yes = 1
E4	Is the layout of the zones and loads going to vary in the foreseeable future?	No = 0 /Yes = 1
F	**System cost (Initial cost or life-cycle cost)**	**1**
G	**Preliminary design restrictions**	
G1	Required cooling capacity per zone?	1
G2	Is the system located in a dry or humid climate?	Dry = 0 /Humid = 1

Table 5.1 – Design criteria and screening factors

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