ECONOMIC EVALUATION OF A DISTRICT COOLING SYSTEM INCORPORATING THERMAL STORAGE

by

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ABSTRACT

The following report investigates district cooling systems. This form of technology provides an alternative means of providing cooling. In a traditional cooling system each building would include cooling equipment to serve only that building. District cooling differs in that water is chilled at one location and pumped to two or more buildings. District cooling has many benefits over traditional cooling systems. This report, however, aims to determine the economic benefits (if any) of district cooling systems.

The location chosen as a model for this study was the University of Natal (Durban) campus. This campus currently operates a district cooling system serving six buildings. This study is hypothetical in nature, as the cooling system is already finalized and operational. Te aim of this dissertation is to answer the question of which would be the more attractive alternative if the University were in a position of having to install a completely cooling system.

One of the most important steps in this process is the calculation of cooling loads. The cooling load was estimated for each of the buildings associated with the district cooling system. The LOADEST software package was used to derive these cooling loads. The accuracy of LOADEST software was also validated in this study.

The bulk of this report is composed of the preliminary work required to obtain capital and operating costs for cooling systems, including validation of cooling load calculation software. It was felt that this preliminary work justified inclusion in the final report to provide accurate representation of the steps taken before any economic evaluation could be reached.

The capital and operating costs of the district cooling system and a more traditional system were compared. It was found that the district cooling system reduces operating costs significantly, although it's capital cost is higher than the traditional system against which it was compared.

PREFACE

The author hereby states that this entire dissertation, unless specifically indicated to the contrary in the text, is his own original work, and has not been submitted in part or whole to any other University. This dissertation records the work carried out by the author in the School of Mechanical Engineering at the University of Natal from January 2001 to December 2002. This project was supervised by Professor S. Govender.

"Light travels faster than sound. This is why some people appear bright until you hear them speak"

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CHAPTER 1

INTRODUCTION

Energy is traditionally defined as the ability to do work. In our modern society we require energy in large quantities to perform a multitude of everyday tasks. Some of the major consumers of energy include industry, the transport sector, individual and commercial users and agriculture.

In order to perform work there needs to be some sort of fuel source. In theory there are many sources of energy, such as fossil fuels (coal, gas, oil), biomass (forests), wind, solar radiation, hydro, nuclear, geothermal and tidal power. In practice, however, society has become reliant on only one group of fuels, the fossil fuels. There are, of course, exceptions to this rule but our reliance on fossil fuels (especially oil) cannot be disputed. It is estimated that the world consumes the equivalent of 200 million barrels of oil per day, McCabe [1]. The United States and Canada have the highest per capita consumption of energy in the world.

There are two main concerns regarding our current (and extrapolated) energy usage pattern. Firstly, our main source of fuel is fossil fuels. These are non-renewable energy sources. The process through which coal, oil and natural gas is formed takes millions of years. Once we use these reserves we can never replace them. In addition, the bulk of these resources are in the control of only a few countries. This inequitable control of resources is the source of much conflict, and allows certain sectors the potential for manipulation of the others. The oil crisis of the early seventies is an illustration of this point. Following the laws of supply and demand, a reduction in the supply (or perceived supply) can cause sharp increases in the price of oil. At the time of writing the world is facing a potential war in the Middle East, and strikes by oil workers (amongst others) in Venezuela are in their second month.

The second major issue is the effect energy usage is having on the environment. The manner in which we live our lives is very detrimental to our surroundings. The manifestations of global climate change are apparent. Global warming can no longer be argued or ignored. One of the reasons for this is the increase in greenhouse gas emissions. These gases trap the heat from the sun more effectively than our natural atmosphere, and hence warm the planet. One of the major contributors to this effect is the increased level of Carbon Dioxide (a by-product of the burning of fossil fuels). The current level of CO_2 in the atmosphere is 25% higher than levels prior to man's influence, McCabe [1].

This report is concerned primarily with the energy use (and economic cost thereof) associated with comfort air-conditioning. It investigates the suitability of providing cooling to many buildings from a central energy source (district energy), rather than each area's cooling being self-contained. The idea of grouping areas together for the provision of cooling (or heating) is not innovative in itself. The Romans of Pompeii used geothermally heated water running through open trenches to serve community baths. The first district heating system in the United States was established in 1877.

The novelty, however, is in the manner in which each project is able to respond to influencing factors. These factors vary from country to country, but the main concern used to be the provision of comfortable internal environments at the lowest cost. Nowadays, equal concern must also be paid to the effect which our energy usage will have on the environment. It must be remembered that any cost saving associated with a reduction in energy is likely to have two added benefits. A reduction in energy usage means that fewer natural resources are being used. In addition less harmful by-products are being introduced to the environment.

The economic benefits of district energy will be illustrated in this report. These benefits include the potential for lower capital cost, lower energy cost, an allowance for more revenue generating space, the provision of a reliable heating and cooling service and a cleaner environment.

A buzzword in the field of district energy is "core activities". What this means is that the provision of a comfortable internal environment should not detract focus from an institution's main activity. The University of Natal was chosen as the model for this report. The University's core activity is the teaching of students and the pursuit of knowledge through research. The more emphasis which is placed on the air-conditioning/heating system the less time (and money) there is available to further the activities of teaching and research.

This report will summarise the benefits to the University, through the optimal use of resources available.

CHAPTER 2

LITERATURE SURVEY

2.1 District energy – a definition

McCabe [1] provides the following concise definition of district energy systems, "A district heating or cooling system provides thermal energy in the form of steam, hot water, or chilled water from a central plant and distributes the energy through pipes to two or more buildings"

There are two types of district energy systems, district heating and district cooling systems. District energy systems are further described by Pierce [2].

2.2 District heating & cooling

2.2.1 District heating

District heating systems distribute steam or hot water to multiple buildings. The heat can be provided from a variety of sources, including geothermal, cogeneration plants, waste heat from industry, and purpose built heating plants.

2.2.2 District cooling

District cooling systems distribute chilled water or other media to multiple buildings for air-conditioning or other uses. The cooling (actually heat rejection) is usually provided from a dedicated cooling plant.

There are two broad categories of district energy systems. Those that are owned by, and serve the buildings of, a single entity are categorized as institutional systems. All other systems are classified as commercial.

2.3 Refrigeration

The topic of refrigeration is the starting point for any discussion involving air-conditioning and, hence, district cooling. It is best described by Gosney [3], "The science and art of refrigeration is concerned with the cooling of bodies or fluids to temperatures lower than those available in the surroundings at a given time."

The two most common refrigerating cycles are the vapour compression cycle and the vapour absorption cycle.

2.3.1 The vapour compression cycle

McQuiston and Parker [4] describe the single-stage vapour compression cycle in a very concise manner. The vapour compression is by far the most common refrigeration cycle in use today. The cycle consists of four processes, expansion, evaporation, compression and condensation, as shown in Figure 2.1.

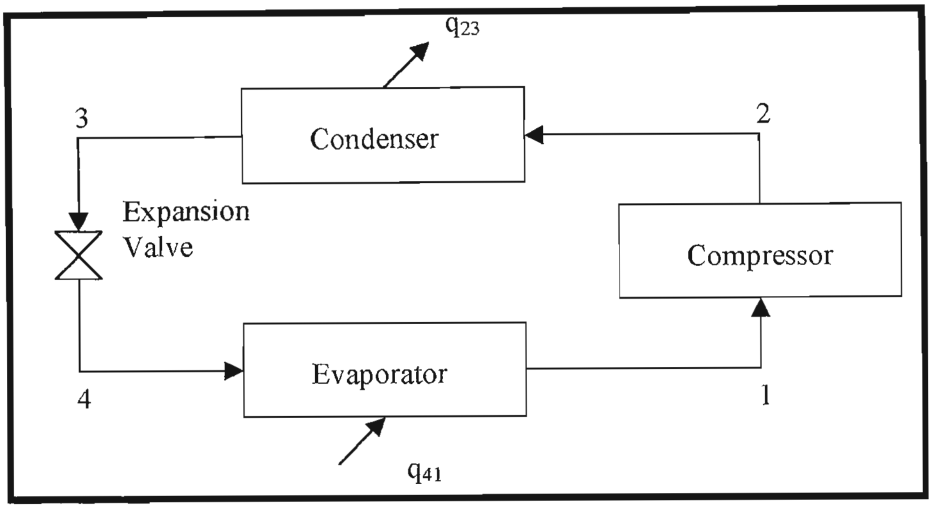


Figure 2.1: The single-stage vapour compression cycle

The refrigeration cycle may be plotted on pressure-enthalpy axes, as shown in Figure 2.2.

Process 1-2 is a compression process. The ideal compression process is isentropic, and hence follows the constant entropy lines drawn on the refrigerant chart. The actual process deviates from this ideal cycle. The deviation from the lines of constant entropy is based on the efficiency of the compressor.

Process 2-3 is a condensing process. The refrigerant leaving the compressor is superheated vapour. The condensing process represents the rejection of heat to the outside atmosphere, where it will have little or no effect on the area being cooled. The condensing process occurs in two parts. Firstly, the refrigerant is cooled to the saturated vapour line. This heat transfer is referred to a de-superheating, and is sensible in nature. Secondly the refrigerant changes from a saturated vapour to a saturated liquid. This is a transfer of latent heat. The heat rejected in the condenser is the heat removed from the cooled space or liquid, and the heat added to the refrigerant by the compressor.

Process 3-4 is an expansion process. The temperature and pressure of the refrigerant is reduced from condensing conditions to evaporating conditions. The best analogy is that of steam expanding over a turbine blade. In the case of an expansion valve, however, there is no work output, and hence no change in the enthalpy of the refrigerant.

Process 4-1 is an evaporation process. The liquid/vapour refrigerant mixture evaporates at constant pressure. This evaporation requires heat transfer from the surroundings. This removal of heat from the surroundings is responsible for the cooling effect associated with refrigeration.

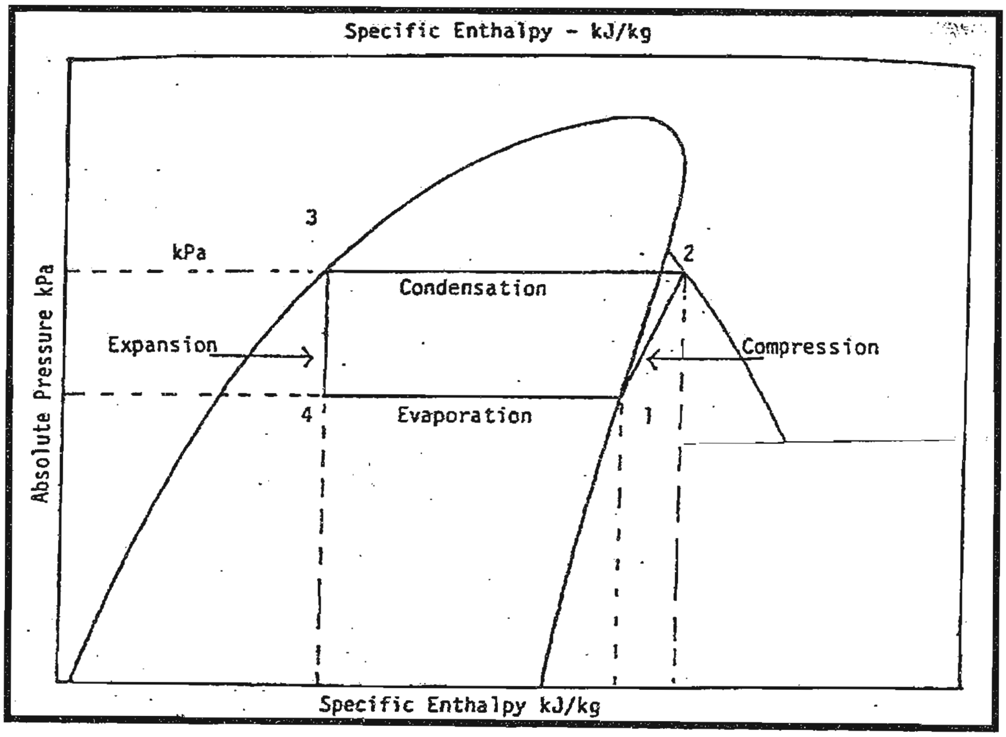


Figure 2.2: The theoretical single-stage vapour compression cycle, courtesy of Parsons [20]

The following quantities may be evaluated;

Specific Heat of Compression $= h_2 - h_1$

Specific Heat Rejection $= h_2 - h_3$

Specific Refrigerating Effect $= h_1 - h_4$

The expansion process occurs at constant enthalpy, hence $h_3 = h_4$

This means that;

Specific Refrigerating Effect $= h_1 - h_3$

Hence

Specific Refrigerating Effect + Specific Heat of Compression $= (h_1 - h_3) + (h_2 - h_1)$

$= h_2 - h_3$

which is the same quantity as the Specific Heat Rejection.

This confirms what was mentioned earlier that both the heat removed from the cooled space, and the heat added during the compression process must be rejected to the surroundings.

Specific Refrigerating Effect $= h_1 - h_4$

This quantity has units of kJ/kg (or an equivalent unit).

In order to get the capacity of the machine in terms of energy units such as kW (kJ/s), the Specific Refrigerating Effect must be multiplied by the mass-flow of refrigerant through the evaporator. In the simple vapour compression cycle shown in Figures 2.1 and 2.2 the mass-flow is constant throughout the cycle. The more accurate and realistic cycle, in which mass-flow of refrigerant differs throughout the cycle, is explained in Gosney [3].

Capacity $= (\dot{m}_{evap})(h_1 - h_4)$

Capacity Unit	Equivalent value in Watts
kCal/hr	1.163
Btu/hr	0.293
Ton of Refrigeration	3516.850

Table 2.1: Some common refrigeration units, and their equivalent value in watts

The Units in which capacity is expressed may be either Metric or British. A common unit used is Tons of Refrigeration. This is the cooling capacity required to make 1 short ton (2000 lb) of ice from water at 0^0 C in the time of one day. Cengel and Boles [10] explain the history of this unit in more detail

The choice of refrigeration equipment must include consideration of the type of refrigerant which will be used. Many refrigerants (especially CFC's and HCFC's) have a detrimental effect on the environment. Not only is their continued use unethical but restrictions on CFC and HCFC production may make these refrigerants expensive and difficult to source.

The legality of production and usage of environmentally damaging refrigerants is dictated by the Montreal Protocol. This agreement, signed more than a decade ago, established the rate at which production of these harmful refrigerants should be reduced.

This agreement is significant as it influences the choice of cooling plant. It is now far less attractive to buy equipment utilising CFC's or HCFC's. New equipment may be chosen to be more environmentally friendly. In some instances old equipment may be retrofitted to use more acceptable refrigerants. The Trane website [13] provides the applicable facts and figures for the phase-out of CFC's and HCFC's.

2.3.2 The vapour absoption cycle

A different refrigeration cycle is the absorption cycle. This cycle makes use of the fact that some gases will be absorbed by other substances. The vapour compression elements, described in 2.3.1 are replaced by an absorber, generator, condenser and evaporator. There are also several pumps involved in the cycle.

The main difference is that the bulk of the work input is not in the form of shaft work, but rather heat energy. This heat may be provided by steam or hot water, and the cycle becomes particularly economically attractive where large amounts of waste heat are available at temperatures between 100 and 200^{0}C.

Absorption refrigeration is considered only briefly in this study, and therefore is not described in much detail. Further explanation of this cycle is available in Pita [11], McQuiston and Parker [4] and Cengel and Boles [10].

2.4 The chilled water air-conditioning cycle

The refrigeration cycle thus far has considered only air as the cooled medium. This is, however, not a particularly common practice in large buildings. A more representative arrangement is the chilled water air-conditioning cycle, shown in Figure 2.3.

McQuiston and Parker [4] explain the chilled water cycle in a very concise manner.

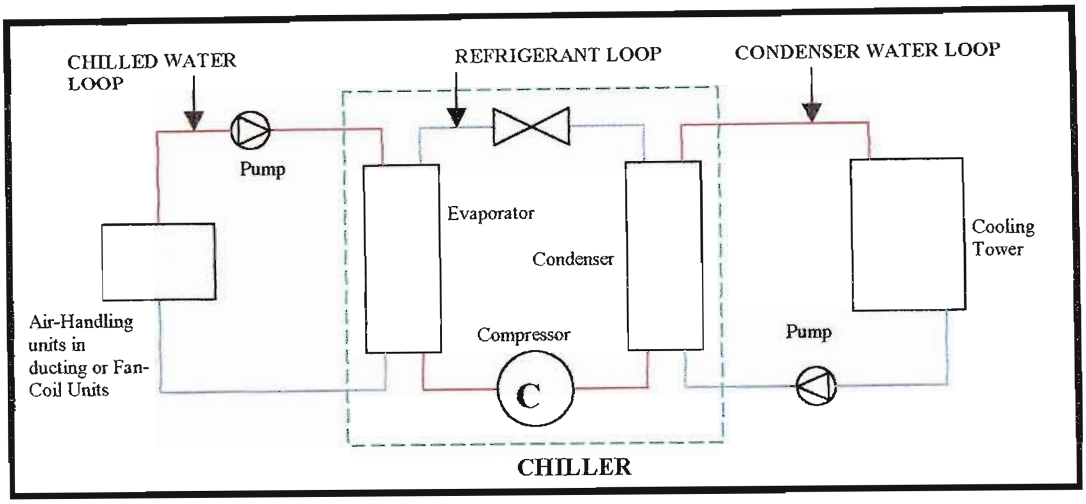


Figure 2.3: The chilled water air-conditioning cycle

This cycle utilises a chiller, which incorporates a refrigeration cycle. The chiller consists of an evaporator, a condenser, a compressor and other miscellaneous components. The fluid cooled by the chiller is, however, water and not air.

The evaporator and condenser are used for cooling and for heat rejection respectively, as in the vapour compression cycle. The difference is that the evaporator and condenser are heat exchangers, inside which there are refrigerant and water flows.

In addition to the refrigerant circuit there are two water circuits in the diagram above, a chilled water circuit and a condenser water circuit.

The chilled water circuit comprises the evaporator, the air-handling units and a chilled water pump. The condenser water circuit comprises the condenser, the cooling tower and a condenser water pump. The refrigerant circuit passes through both the evaporator and condenser, and is driven by the compressor.

Water is driven through the evaporator by the chilled water pump and loses heat to the refrigerant. This heat loss results in a temperature decrease of water leaving the evaporator. The chilled water leaving the evaporator is pumped to air-handling units. The air-handling units are simply heat exchangers over which air is blown. The chilled water gains heat from the air and, hence, increases in temperature. After passing through the air-handling units the water is returned to the evaporator. It returns at a higher temperature and must once again be cooled.

The refrigerant absorbs heat from the chilled water. This absorption of heat causes the refrigerant to evaporate (as in the simple vapour compression cycle). The refrigerant then passes through the compressor, where it is compressed to a superheated vapour. As in the simple vapour compression cycle, the refrigerant must lose the heat gained both from the chilled water, and from the compressor. This is done in the condenser.

Water is driven through the condenser by the condenser water pump. The refrigerant loses heat to this water, resulting in an increase in temperature of the water. This water is then pumped to a cooling tower, where the heat gained in the condenser is transferred to the atmosphere. This is done through evaporation. The airflow over this water may occur naturally, or the heat transfer may be aided by means of a fan. Cooling towers are classed according to whether air flow is natural or forced.

2.5 The efficiency and performance of refrigeration systems

The capacity of a refrigeration system is a measure of the system's ability to meet a given cooling load. This is, however, not the only measure of the suitability of a refrigeration plant to a given situation.

The cooling capacity is provided largely by energy input to the compressor. This energy may be electrical, engine-driven, or may even be supplied by a turbine. This energy is, however, not free. It needs to be supplied, at some cost to the user.

Refrigeration equipment may be compared on the basis of the amount of energy required to obtain a certain amount of cooling.

There are two common measures of system suitability.

The efficiency of a refrigeration plant measures the amount of energy input required to obtain a given amount of cooling. A common unit used is kilowatts of energy required to obtain 1 Ton of refrigeration effect [kW/ton].

The reciprocal quantity is the coefficient of performance. This is the amount of cooling obtained from a given amount of energy input. The units used for both the cooling and energy input are usually the same. This means that the units cancel, leaving the Coefficient of Performance as a dimensionless number

2.6 Coefficient of Performance of chillers (C.O.P.)

The efficiency of a chiller is a function of the load at which it is operating. The performance of a chiller is usually specified only for the fully loaded (maximum cooling capacity) condition.

EPRI [6] discusses several issues relating to the performance and operation of electrical chillers. The efficiency of centrifugal and screw chillers, at various loading conditions, were shown graphically by EPRI [6]. The efficiency was described in units of kilowatts per ton of refrigeration. These values were interpolated and the efficiency values converted to C.O.P. values. As a final adjustment, the C.O.P. at each degree of loading was divided by the full-load C.O.P. The result is that a graphical estimate is obtained of the performance of each of chiller type at various loading conditions.

This information is shown in Figure 2.4.

The C.O.P. of a chiller is a measure of the amount of cooling output for every unit of energy input. The question arises as to what exactly constitutes the energy input. The chillers considered in this study are mostly electrically driven, meaning that the compressor is powered by an electric motor. This is usually a three-phase alternating-current motor.

The power factor of an electrical machine or circuit (alternating–current) is defined by Wildi [12] as follows. "It is the ratio of the active power P to the apparent power S, and is given by the equation". In this study it is useful to think of the active power as the power, in units of Watts, which a refrigeration compressor must supply to meet a given cooling load. The apparent power, in units of kilovolt-Amperes, is the power delivered from the electrical supply in order to do this.

$$\text{Power Factor} = \frac{P}{S} \qquad (2\text{-}1)$$

Where;

P = Active Power delivered to the device [W]

S = Apparent Power of the device [VA]

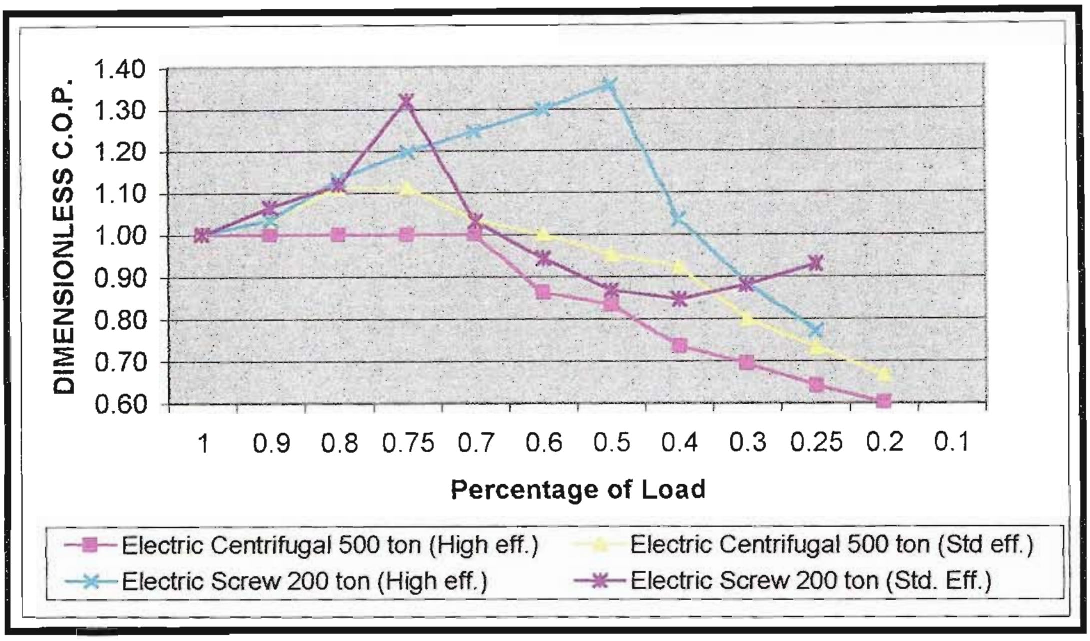


Figure 2.4: C.O.P. as a percentage of full load C.O.P. for various chiller types, derived from EPRI [6]

2.7 Electricity generation in South Africa

Eskom has the responsibility of generating and supplying electricity to consumers in South Africa. There are many different ways of generating electricity. These include coal fired power stations, hydroelectric and/or pumped storage schemes, gas turbine stations and nuclear power stations. The total electrical generating capacity in South Africa is 39154 MW, which is spread across 20 power stations. Two thirds of that capacity is concentrated in just ten base load coal-fired power stations. This information obtained from the Eskom website [7]. The plant variety is as follows.

Type of Generation	Capacity [MW]	Percentage of Total
Coal-Fired	34882	89.0
Hydroelectric	600	1.5
Nuclear	1930	5.0
Pumped Storage	1400	3.6
Gas Turbine (oil-fired)	342	0.9

Table 2.3: Summary of South Africa's electrical generating capacity

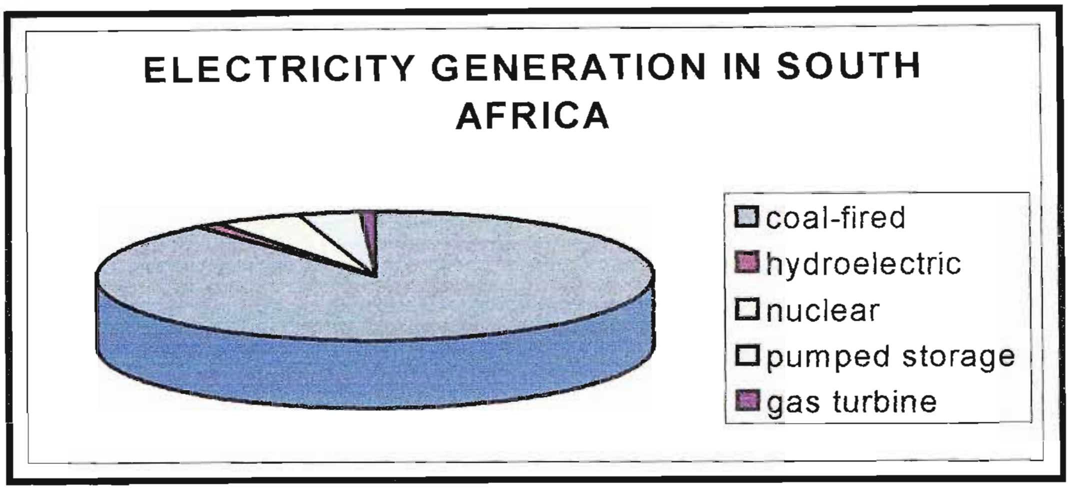


Figure 2.5: Graphical representation of South Africa's electrical generation capacity.

Figure 2.5 clearly illustrates South Africa's heavy reliance on coal as a fuel for the generation of electricity. This is in contrast to a country such as France, which meets three-quarters of it's electrical requirements through nuclear power.

A concerning fact is the comparatively minor use of renewable energy sources. The only large-scale generating capacity in South Africa utilising renewable energy sources is the 600 MW of hydroelectric generating capacity. All other generating capacity uses non-renewable energy sources. Methods of electricity generation such as wind farms, geothermal energy and tidal power, which are environmentally friendly are, unfortunately, largely unsuitable for South African conditions. Akinbode [14] discusses the issue of renewable energy resources further.

The reason why coal-fired, centrally located power stations are so wasteful is that combustion gases are allowed to escape through the boiler chamber and the cooling tower. They constitute a large source of under-utilised energy. Despite devices such as economisers and water pre-heaters the maximum efficiency of such a plant is only about 40%. This is because most power stations are situated close to coalfields, and are often too remote from any operation which could make use of the rejected heat.

The topic of electricity generation cycles is covered by Cengel and Boles [10].

2.8 Pricing structure of electricity in Durban

Any electrical use, by a company or individual, is charged for by the utility according to an applicable tariff structure. This tariff structure is agreed by both parties.

The local electrical supplier in the Durban Area is Durban Metro. The tariff structure used by the University is the Durban Metro "time-of-use" tariff. This tariff charges more for electricity at times of high demand, and less at times of low demand. These high demand and low demand periods are based on the time of year and the time of day during which electricity is used. This is because the cost of generating electricity is a function of the overall demand for electricity. For example, in winter a large amount of electricity is used to heat homes. Typically this demand is at a maximum when people reach home after a day's work.

There are two components to the cost of electricity under this tariff structure.

- Demand charge
- Active energy cost

The demand charge is a charge imposed for the maximum power drawn for a certain period of time. This is the power passing through the transformer, and is measured in kiloVolt-Amperes (kVA). KVA is similar to kilowatts, differing only by the power factor (2-1) of a machine, which is a percentage .

The active energy charge is a charge imposed for the amount of energy drawn over the billing period (usually a month). This is the energy passing through the transformer, and is usually measured in kiloWatt-hours.

The total cost to the user is made up of the demand cost (demand charge multiplied by maximum demand for the month), and the active energy cost (active energy charge multiplied by the energy usage for the month).

The low demand months are October to March, with the high demand period from April to September.

Hour of Day	Cost (c/kWh)	Hour of Day	Cost (c/kWh)
00h00	8.6019	12h00	14.0854
01h00	8.6019	13h00	14.0854
02h00	8.6019	14h00	14.0854
03h00	8.6019	15h00	14.0854
04h00	8.6019	16h00	14.0854
05h00	8.6019	17h00	14.0854
06h00	14.0854	18h00	14.0854
07h00	25.1671	19h00	14.0854
08h00	25.1671	20h00	14.0854
09h00	25.1671	21h00	14.0854
10h00	25.1671	22h00	8.6019
11h00	25.1671	23h00	8.6019

Table 2.3: Active Energy costs for low demand months

Hour of Day	Cost (c/kWh)	Hour of Day	Cost (c/kWh)
00h00	8.9920	12h00	15.6682
01h00	8.9920	13h00	15.6682
02h00	8.9920	14h00	15.6682
03h00	8.9920	15h00	15.6682
04h00	8.9920	16h00	15.6682
05h00	8.9920	17h00	15.6682
06h00	15.6682	18h00	37.5062
07h00	37.5062	19h00	37.5062
08h00	37.5062	20h00	15.6682
09h00	37.5062	21h00	15.6682
10h00	15.6682	22h00	8.9920
11h00	15.6682	23h00	8.9920

Table 2.4: Active Energy costs for high demand months

Period of Year	Demand Charge [R/kVA]
Low demand	13.6337
High demand	15.1317

Table 2.5: Demand charges for high and low demand periods

The tariff structure reproduced in Tables 2.3 to 2.5 was obtained from the Durban Metro website [8].

2.9 Thermal storage

Thermal energy is a form of energy, and hence thermal storage obeys the same basic principles applicable to other energy storage methods. Thermal storage is simply the method and equipment used to store thermal energy. This energy is produced during one time period and used during another. These operations are designed to be cyclical, with charging/discharging periods ranging from hours to complete seasons.

Thermal energy may be stored as cool thermal storage. Pierce [2] issues the following warning, "The fundamental basic never-to-be-forgotten rule of energy storage is to remember that it is part of a system, and whatever storage mechanism is used has to be properly engineered into that system."

The different mechanisms for cool thermal storage are:

- Chilled water storage
- Ice harvesting

- External melt ice-on-coil storage
- Internal melt ice-on-coil storage
- Encapsulated ice
- Eutectic salt phase change storage

This project will consider only chilled water storage. This is because it is the simplest and most common form of thermal storage. It is also the form of thermal storage currently used on the University of Natal campus.

2.10 Chilled water thermal storage

Chilled water systems store cooling capacity by utilising the sensible heat capacity of water. No use is made of the latent heat of fusion.

Water is chilled during one time period, and stored in a tank for later use. The chilled water is then pumped to the cooling load as required. This results in the water gaining heat, and therefore increasing in temperature, before being pumped back to the storage plant. The amount of cooling energy stored in a tank is given by the equation 2-2.

$$E = (m)(c_p)(T_{return} - T_{storage}) \qquad (2\text{-}2)$$

Where:

E	= Stored cooling capacity	[kJ]
m	= Mass of water in tank	[kg]
c_p	= Specific heat capacity of water	[4.2kJ/kgK]
T_{return}	= Temperature at which water returns to storage plant	[deg C]
$T_{storage}$	= Temperature at which water storage is charged	[deg C]

It can be seen that in order to increase the amount of cool storage, either the storage mass of water, or the temperature differential must be increased. The storage temperature is the temperature at which the water leaves the chiller during a charging cycle, and is typically between 4 deg C and 7 deg C. The return temperature is typically 6 deg C to 11 deg C higher than the storage temperature. These temperatures require approximately 48 to 91 litres of water (and corresponding tank volume) for every kiloWatt-hour of cool storage.

An important consideration is the method used to maintain separation between the warm and chilled water. Four methods are commonly applied.

2.10.1 Multiple tank systems

The chilled water is stored in one tank, and warm water is returned to a second separate storage tank.

2.10.2 Membranes

A flexible membrane is mounted inside the storage tank, above the upper level of chilled water. The membrane is designed to move up and down as the level of chilled water changes. When water returns at a higher temperature, it enters the same tank, but above the membrane. The membrane thus forms a boundary between the chilled and the warm water.

2.10.3 Labyrinth and baffle systems

These tanks use an arrangement of partial walls (baffles) to divide the storage tank into multiple compartments. They rely on the concept of plug flow through these compartments to maintain separation of the chilled and warm water.

2.10.4 Thermal stratification

There is a far simpler, more efficient and common way to separate warm and chilled water. It relies on thermal stratification to divide the tank into layers of separate temperature water.

A common layout of stratified chilled water thermal storage system is illustrated in Figure 2.6. This method returns the warm water to the chilled water tank through a diffuser. If excessive turbulence and mixing is avoided, then the water will settle into a number of layers. The success of this method lies in the variation of water density as a function of temperature. Water has a maximum density at a temperature of 4 deg C, with density decreasing as temperature increases. This is illustrated in Figure 2.7. The maximum density at 4^0C is a good reason why water used in this storage mechanism should not be chilled below this temperature.

The water returning to the tank is less dense than the chilled water. If turbulence and mixing is prevented, the tank will be stratified, and warmer water will settle above cooler water. The diffusers at the top and bottom of the tank must be correctly designed to reduce turbulence. The shape, Reynold's number and Froude number are the primary considerations in diffuser design. A transition layer (thermocline) forms between the chilled water and the warmer water, maintaining separation. The thickness of the thermocline is approximately 30 cm to 1 m. An example of the temperature profile in a typical storage tank is shown in Figure 2.8.

All information pertaining to thermal storage was sourced from Dorgan and Elleson [9].

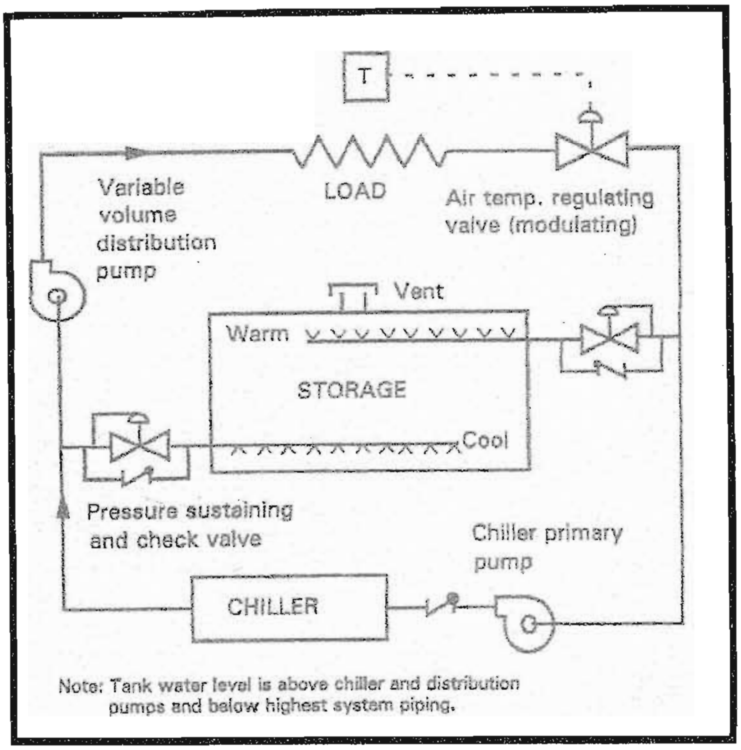


Figure 2.6: Basic stratified chilled water configuration, courtesy of Dorgan & Elleson [9]

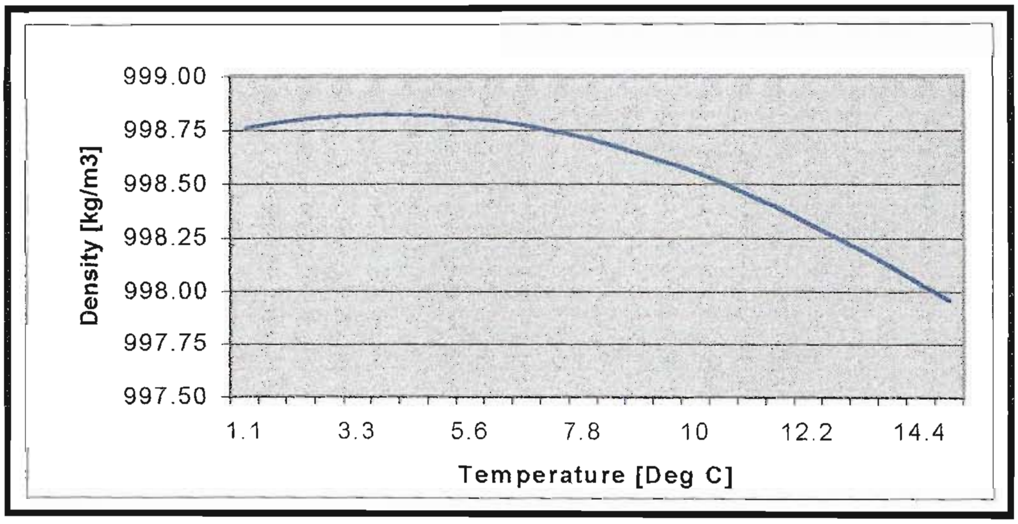


Figure 2.7: Density of water as a function of temperature

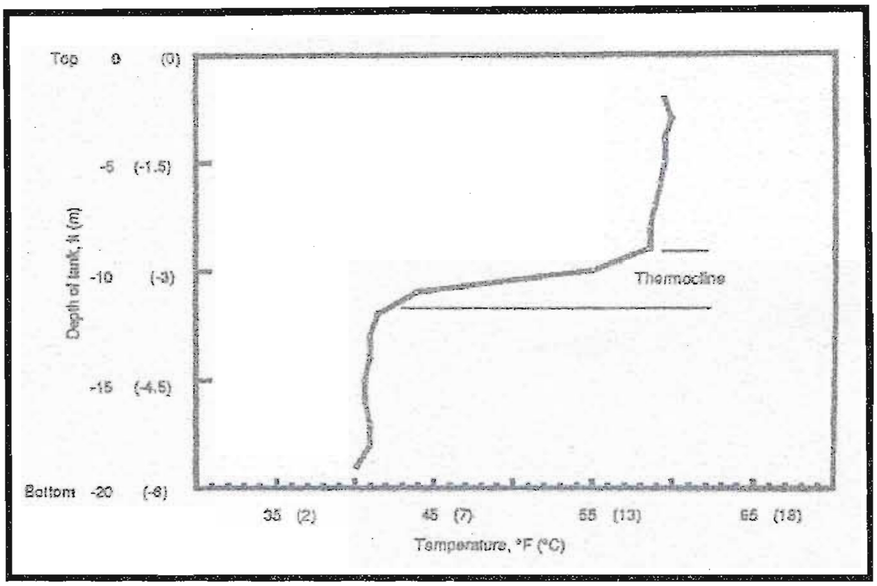


Figure 2.8: Typical temperature distribution in a stratified thermal storage tank, courtesy of Dorgan & Elleson [9]

CHAPTER 3

COOLING LOAD CALCULATIONS

3.1 Introduction

Comfort air-conditioning is defined as the simultaneous "control of the following five parameters in any occupied space in order to render this space comfortable to the occupants".

- Air temperature
- Air humidity
- Ventilation and air movement
- Cleanliness and odour
- Noise due to air-conditioning equipment and air flow

The space to be air-conditioned must be kept at a certain indoor design condition, which is usually of lower temperature and relative humidity than ambient outdoor conditions. Heat enters the conditioned space from various sources. As explained by Devasahayam [16], if internal conditions are to be maintained, then this heat must be removed at a rate equal to that at which it enters.

Mcquiston and Parker [4] summarise the theory concerning the calculation of this heat entry. The following definitions are provided.

3.2 Heat gain

Heat gain is the rate at which energy is transferred to or generated within a space. There are two components to heat gain, sensible heat and latent heat.

3.2.1 Sensible heat

Sensible heat transfer to a room results in a change in temperature of the air in that room. A sensible heat gain results in an increase in temperature, whilst a sensible heat loss causes a reduction in temperature.

3.2.2 Latent heat

Latent heat is associated with the moisture content of the air in the room. The humidity ratio is the number of grams of water vapour per kilogram of dry air. A latent heat gain implies an increase in the moisture content of the air in the room. A latent heat loss refers to a decrease in moisture content.

3.3 Cooling load

Cooling load is the rate at which energy must be removed from a space to maintain the temperature and humidity at design values.

3.4 Heat extraction rate

Heat extraction rate is the rate at which energy is removed from the space by the cooling and/or dehumidifying equipment.

3.5 Sources of heat gain

Jones [17] distinguishes between heat gains arising from outside the conditioned space and those originating within it.

3.5.1 External sources of sensible heat gain

Sensible heat gain arises from the following sources outside the conditioned space;

- Direct and scattered solar radiation through windows
- Heat transmitted through the glass and also through the non-glass fabric of the room enclosure by virtue of the air-to-air temperature difference (Transmission gains)
- Solar radiation eventually causing a heat gain to the room through the non-glass fabric of the room
- Sensible heat gain arising from the infiltration of warm air from the outside

3.5.2 Internal sources of sensible heat gain

Sensible heat gain arises from the following sources inside the conditioned space;

- Electric lighting
- Occupancy
- Power dissipation
- Process work

3.5.3 Sources of latent heat

Latent heat gain originates from the following sources, both inside and outside the conditioned space

- Infiltration of outside air (External)
- Occupancy (Internal)
- Process work (Internal)

3.6 The heat storage effect

The instantaneous heat gain to the room is variable with time, due largely to the transient effect caused by the hourly variation is solar radiation. At any given time there may be an appreciable difference between the heat gained by the structure and the cooling load. This difference is due to the storage, and subsequent transfer of energy, from the structure (and contents) to the air circulated within the room. Failure to take this phenomenon into account will usually result in selection of excessively large cooling equipment.

The illustration in Figure 3.1 shows how the instantaneous heat gain is related to cooling load for three different types of construction. The terms light, medium and heavy refer to the mass of the building, and the contents of the conditioned space, per unit area of floor space. For example, the contents of a workshop such as lathes have appreciable mass, even in comparison to the mass of the walls and roof.

The instantaneous heat gain is flattened by the storage of energy in the building fabric. The building acts almost like a sponge. The heavier the construction of the building, the larger is this ability to store energy.

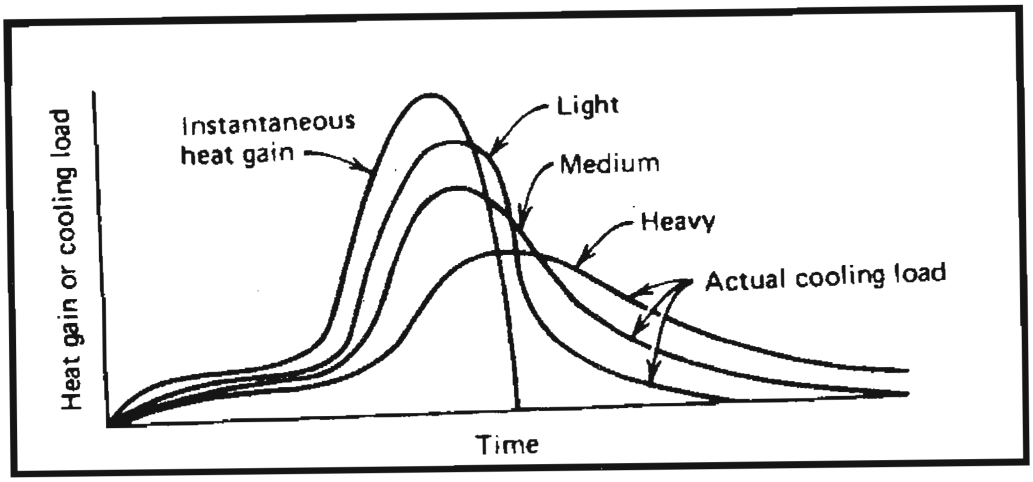


Figure 3.1: Illustration of the heat storage phenomenon for light, medium and heavy construction, courtesy of McQuiston and Parker [4]

In addition, the peak cooling load is smaller in magnitude than the maximum instantaneous heat gain. The peak is also shifted to a later point in time. The heavier the construction, the larger is this lag time.

3.7 Methods to determine cooling load

McQuiston and Parker [4] describe two methods for the calculation of cooling load, the transfer function method (TFM) and cooling load temperature difference, solar cooling load, cooling load factor method (CLTD/SCL/CLF).

3.7.1 The transfer function method (TFM)

The TFM is based on two important concepts; the conduction transfer function (CTF) and the room transfer function (RTF). Both transfer functions are time series that relate a current variable to past values of itself and other variables, at discrete time intervals.

3.7.2 The CLTD/SCL/CLF method

The TFM is thought of as preferable, but is not always practical. The CLTD/SCL/CLF method is a hand calculation method, derived from the TFM procedure. This method involves the use of tables and charts to express the transient nature of the problem. The CLTD is used for external walls and roofs, the SCL for solar gain through windows, and the CLF for internal heat sources. Each of these parameters is a function of time, environmental conditions and building characteristics. The result is the cooling load for each hour considered.

This is the theoretical method used in this study.

3.8 Heat gain through walls

The equation governing cooling load due to heat gain through walls and roofs is;

$$\dot{q} = (U)(A)(CLTD) \tag{3-1}$$

where	$\dot{q}$	= Cooling Load	[W]
	U	= Overall Heat Transfer Coefficient	[W/m^{20}K]
	A	= Area	[m^2]
	$CLTD$	= Temperature Difference which gives the Cooling Load at this time	[^{0}C]

Please note that in some texts CLTD is known as ETD (Equivalent Temperature Difference).

In the case of heat transfer through an internal wall there is steady state conduction. The CLTD is very simply the difference in dry bulb temperatures.

For external walls and roofs the CLTD must be obtained from applicable data tables. For any given latitude, the CLTD depends on the time of day (and year), the orientation of the wall (or roof), and the mass of the wall (or roof) per unit area.

A further correction to the CLTD is based on the difference between the ambient outside dry bulb temperature at 3pm and the internal design dry temperature, as well as the daily range of the surroundings.

The daily range of a location is the difference between the average maximum and average minimum dry bulb temperatures, for the warmest month.

The CLTD for external walls and roofs accounts for the thermal response (lag) in heat transfer through the wall or roof. It also accounts for the response (lag) due to radiation of part of the energy from the interior surface to objects in the space.

3.9 Solar heat gain through glass

The equation governing cooling load due to solar gain is;

$$\dot{q} = (SC)(SCL)(A) \tag{3-2}$$

where	$\dot{q}$	= Cooling Load	[W]
	SC	= Shading Coefficient	
	SCl	= Solar Cooling Load	[W/m^2]
	A	= Area	[m^2]

The SCL accounts for the time variation of solar gain, the massiveness of the structure and geographical location. It is important to remember that the SCL will be different for different latitudes. The SCL also accounts for the thermal response (lag) of the radiant part of heat transfer.

The shading coefficient is a dimensionless variable used to accommodate certain parameters of the conditioned space. These parameters include internal and external shading devices, reflective coatings and different types of glass.

3.10 Internal heat gains

Cooling load due to internal heat sources is defined by;

$$\dot{q} = (CLF)\left(\dot{q}_i\right) \tag{3-3}$$

where	$\dot{q}$	= Cooling Load	[W]
	CLF	= Cooling Load Factor at that time	
	$\dot{q}_i$	= Instantaneous Heat Gain from internal sources	[W]

A value of 1 is assumed for CLF, unless otherwise stated.

CHAPTER 4

COMPUTER SIMULATION OF COOLING LOADS

4.1 Introduction to computer simulation

Cooling load calculation was discussed in Chapter 3. Two methods were introduced for the calculation of these cooling loads. It must be appreciated that these calculations are very time consuming when undertaken manually. In addition, using the CLTD/SCL/CLF method, it is possible to find the cooling load for only one specific hour. This is because reference data (from tables) is usually applicable to a particular hour of the day, and specific month(s) of the year. Similarly, the results obtained using the TFM are valid for only one hour of the day.

There are two reasons why the manual approach is not satisfactory;
Firstly the cooling equipment must be sized to be able to meet the peak cooling load. Failure to meet this cooling load will result in internal conditions straying from the design values. The question arises as to the timing of this peak load. With experience, it may be possible to estimate fairly accurately the overall trend of the cooling load profile. To produce a comprehensive profile by hand would necessitate many calculations. Secondly, the cooling equipment is unlikely to operate at full capacity all the time. The performance of equipment at partial load is arguably even more important than the full-load performance.

The above problems relating to time consumption and accuracy may be resolved through the use of computer software to calculate the cooling load. The choice of software is at the discretion of the user. Several of the large equipment manufacturers now market software aimed at design engineers. This software allows for quick and simple calculation of cooling load profiles. Examples of the software may be found at the Trane website [13], the Carrier website [18] and the York website [19].

The software used for the cooling load analysis is LOADEST Software [25]. LOADEST is produced locally, copyrighted to Bruce Meeker and marketed by Sideline Software. It is a popular choice in South Africa for design professionals. A student edition is marketed at very competitive rates, and is useful for instruction purposes.

4.2 Operation of the cooling load software, LOADEST

LOADEST is a cooling load calculation program. It consists of 3 inter-locking applications, namely LOADEST, ZONEST and the WEATHER UTILITY. An algorithm for the use of LOADEST is shown in Figure 4.1.

4.2.1 LOADEST

LOADEST is used to specify the "geometry" of a particular situation. The building under scrutiny is split into a number of smaller, more manageable, areas (zones). The properties of each zone are entered within a series of 6 windows. Some of the properties required include floor area, wall and window areas, internal heat sources such as lighting and equipment, as well as details of human occupation. In addition, the outside design conditions, and the internal conditions to be maintained, must be specified.

Each zone is saved under a separate own filename, and with an "**.inp**" file extension. At this stage it is possible to show the cooling load profile for each zone, but it is usually of more interest to view the simultaneous heat load profile for many zones (all served by a single air-handling unit). In order to do this, each file in LOADEST must also be saved as a "file for zone peak", which has it's own filename, and a "**.zpa**" file extension.

4.2.2 ZONEST

ZONEST is the utility in which the simultaneous cooling load profile for many combined zones is calculated. Each "**.zpa**" file is selected, one by one, and placed in a selection set. A useful trick at this stage, is the ability to save this selection set as a separate file, with a "**.zst**" file extension. This negates the need to re-select each "**.zpa**" file manually to perform the same calculation again, at a later stage.

There are two outputs from the cooling load calculation. The first is a tabular summary of the cooling load for the design day of each month. The second page is a graphical display of the cooling load for the design day of the year, that is the day in which instantaneous cooling load reaches the maximum value.

An important factor to note is that the heat load profile may be shown for an operating schedule of 12, 16 or 24 hours. This means that the cooling load graph will have a corresponding domain.

4.2.3 The WEATHER UTILITY

The WEATHER UTILITY is used to specify the outdoor design conditions for the region in which the building is located. A weather file consists of a two page summary. The first page gives details such as town name, altitude, dry and wet bulb temperatures for the design day, the daily range, as well as the latitude of the town.

The second page gives values of temperature and humidity ratio corrections to be used for different times of day, and different months of the year. This allows the user to construct a temperature and humidity ratio profile for each month of the year. The WEATHER UTILITY includes existing files for almost 40 towns and cities in South Africa. It is also possible for the user to create new weather files for towns. Weather files are saved with a "**.twn**" file extension.

4.3 Weather data used in LOADEST

As was mentioned in 4.2.3, the weather data in LOADEST is represented by a series of dry-bulb temperature and humidity ratio pairs. These are obtained by means of a peak design value, with corrections applied for each month, and hour of the day. These allow the state point for each hour of the year to be plotted on a pychrometric chart.

At the moment all that will be discussed is the method of obtaining each of these state points. The accuracy of this means of representing weather data will be shown later.

4.3.1 Dry bulb temperature data for Durban

The outdoor design peak for Durban is 29.5^{0}C dry-bulb temperature. The hourly and monthly corrections are shown below. The corrections have units of ^{0}C. The corrections used by Loadest are shown in Tables 4.1 and 4.2.

The monthly and hourly dry bulb temperature corrections were applied to the peak design value of 29.5^{0}C. The hourly dry bulb temperatures for the year are shown in Appendix 1

Time	Correction [^{0}C]	Time	Correction [^{0}C]	Time	Correction [^{0}C]	Time	Correction [^{0}C]
01h00	-6.3	07h00	-5.3	13h00	0.0	19h00	-3.7
02h00	-6.7	08h00	-3.6	14h00	-0.1	20h00	-4.2
03h00	-7.0	09h00	-1.7	15h00	-0.7	21h00	-4.6
04h00	-7.2	10h00	-0.9	16h00	-1.5	22h00	-4.9
05h00	-7.4	11h00	-0.5	17h00	-2.3	23h00	-5.4
06h00	-6.8	12h00	0.0	18h00	-3.0	24h00	-5.7

Table 4.1: Hourly dry bulb temperature corrections used in LOADEST

Month	Correction [^{0}C]	Month	Correction [^{0}C]	Month	Correction [^{0}C]
January	0.0	May	-3.0	September	-2.5
February	0.0	June	-5.5	October	-1.0
March	0.0	July	-6.1	November	0.0
April	-1.0	August	-5.0	December	0.0

Table 4.2: Monthly dry bulb temperature corrections used in LOADEST

4.3.2 Humidity ratio data for Durban

No peak design humidity ratio is given in the weather files. Rather, the peak design wet bulb temperature is given. For Durban this value is 25.5^{0}C. By plotting this value of wet bulb temperature, together with the peak design dry bulb temperature on a psychrometric chart, the peak humidity ratio was obtained. This value is 19g/kg. There are no hourly corrections for humidity ratio, only monthly corrections. The validity of this method will be discussed later. The humidity ratio corrections are shown in table 4.3 for each month, in units of g/kg. The corrected values of humidity ratio are shown in Table 4.4 for each month, in units of g/kg.

Month	Correction	Month	Correction	Month	Correction	Month	Correction
January	0.0	April	0.0	July	-11.0	October	-1.0
February	0.0	May	-4.0	August	-7.0	November	0.0
March	0.0	June	-8.0	September	-3.0	December	0.0

Table 4.3: Monthly humidity ratio corrections used in LOADEST

Month	Humidity ratio	Month	Humidity ratio	Month	Humidity ratio	Month	Humidity ratio
January	19.0	April	19.0	July	8.0	October	18.0
February	19.0	May	15.0	August	12.0	November	19.0
March	19.0	June	11.0	September	16.0	December	19.0

Table 4.4: Monthly humidity ratio data used in LOADEST

4.3.3 Internal design conditions

The conditions to be maintained inside the conditioned space are just as important as the external conditions. The internal design conditions are usually fairly standard for comfort applications, but may be more varied in applications where certain conditions must be maintained for industrial processes.

The standard internal design conditions for Durban in LOADEST are 22.5^{0}C dry bulb temperature and 50% relative humidity. These values are suitable for all the areas considered in this study, and will therefore not be altered.

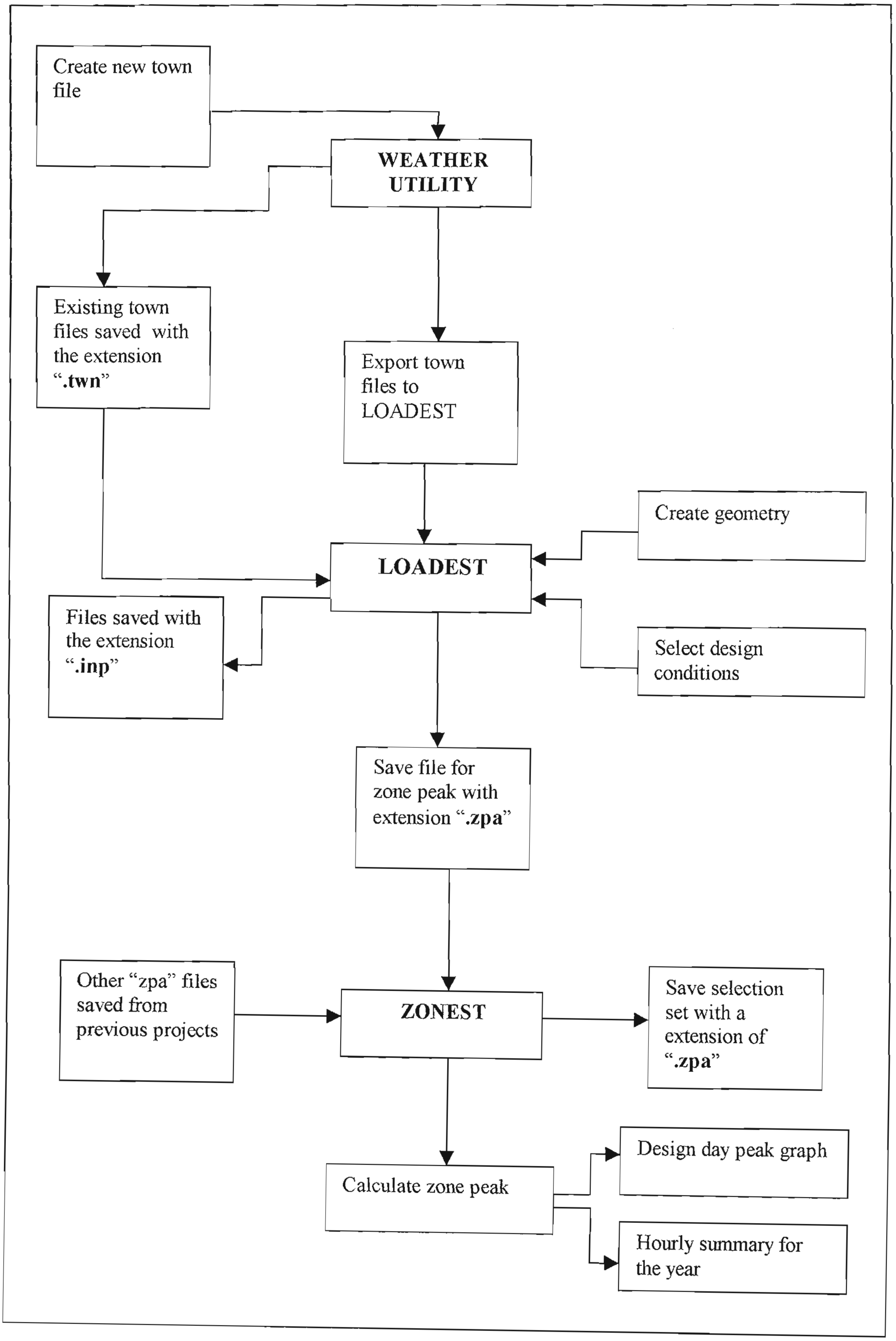
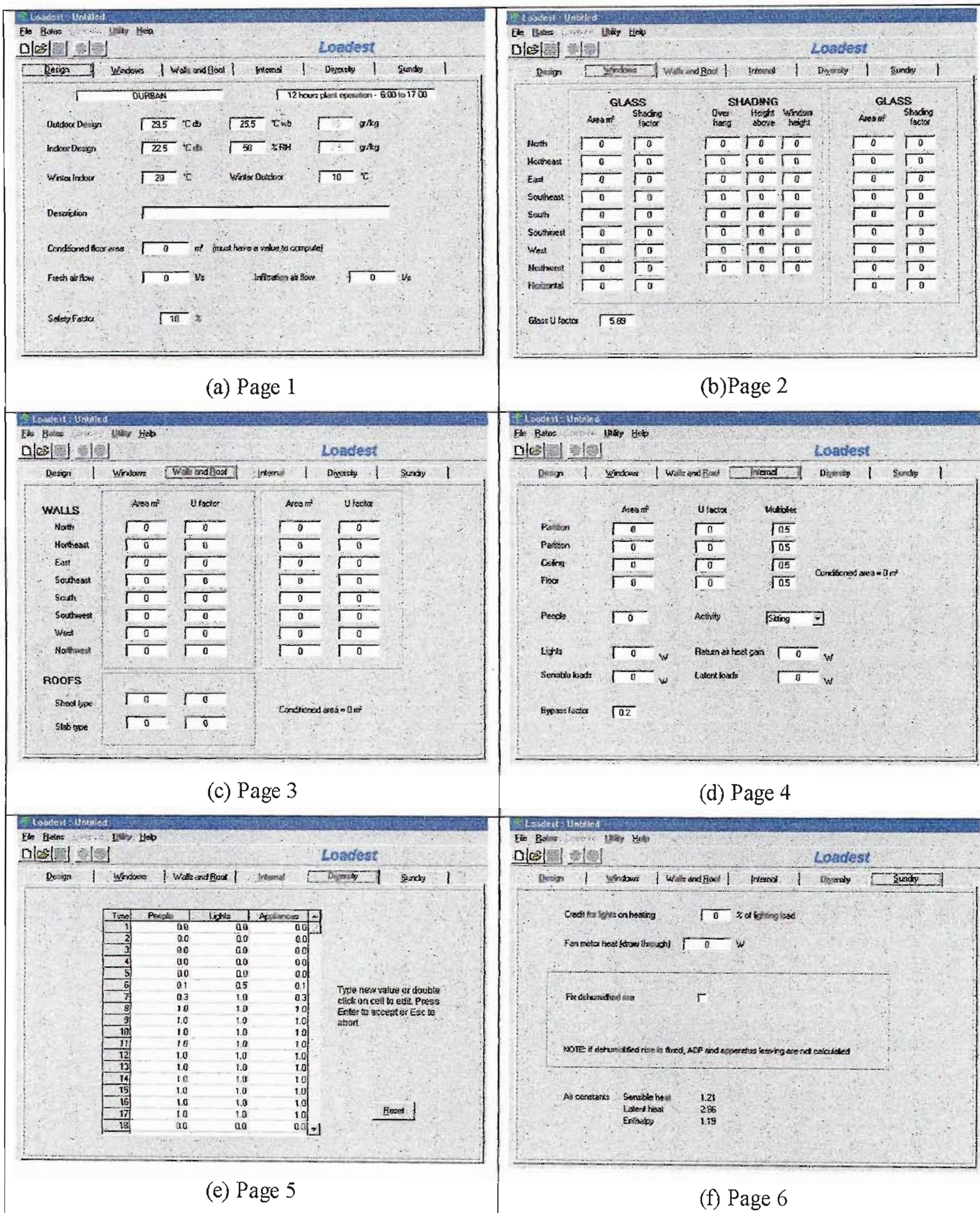


Figure 4.1: Algorithm for the use of LOADEST

4.4 The user interface of LOADEST

The user interfaces of each component of LOADEST are shown below.

4.4.1 LOADEST



(a) Page 1

(b)Page 2

(c) Page 3

(d) Page 4

(e) Page 5

(f) Page 6

Figure 4.2 (a) – (f): The LOADEST interface, pages 1 to 6

4.4.2 ZONEST

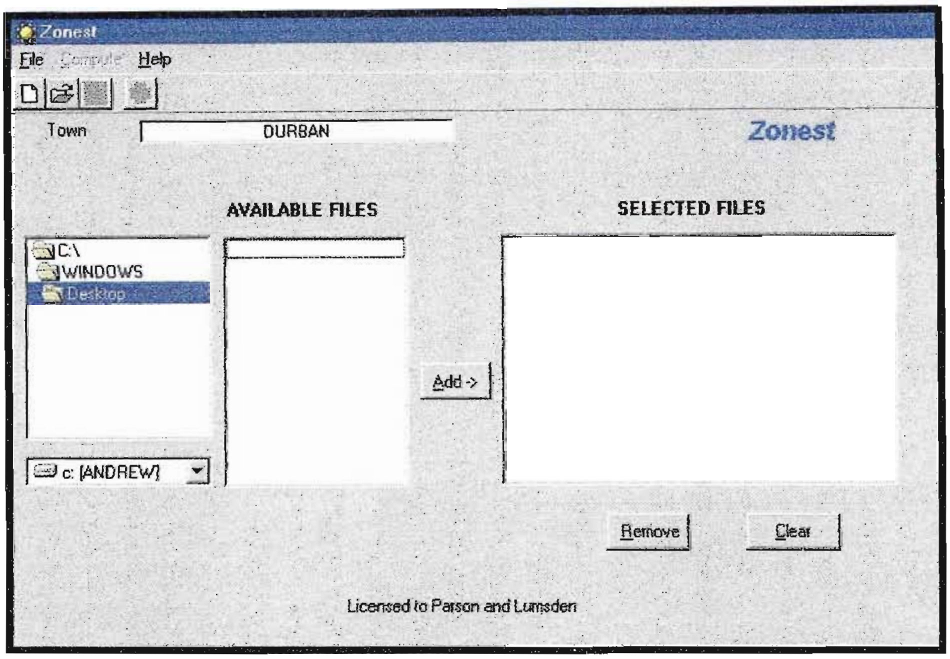
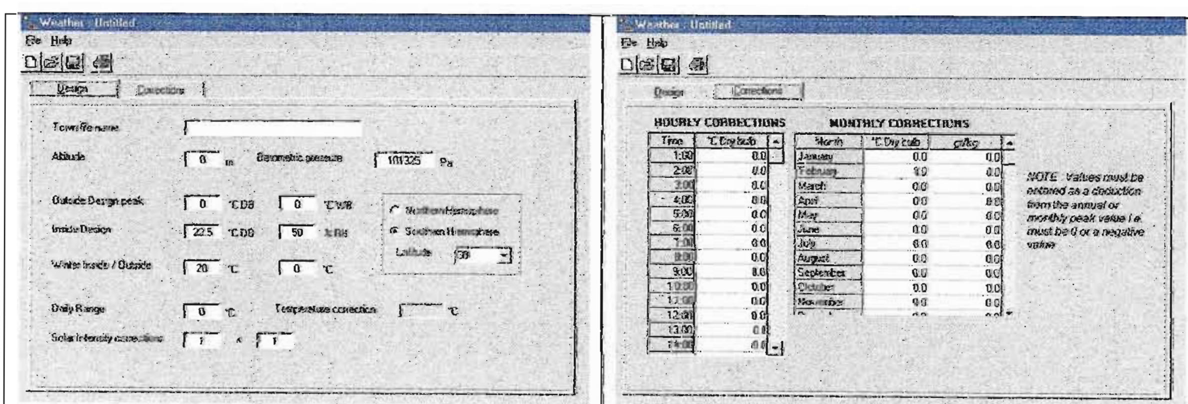


Figure 4.3: The ZONEST interface

4.4.3 The WEATHER UTILITY



(a) Page 1

(b) Page 2

Figure 4.4 (a), (b): The User interface of the WEATHER UTILITY, pages 1 and 2

4.5 Validation of LOADEST cooling loads against theoretical results

The fundamentals of LOADEST have been discussed in the preceding sections. There must, however, be good correlation between the cooling load results obtained from LOADEST, and those obtained from theory, to be able to endorse LOADEST as a suitable design tool.

There are two different procedures through which this validation could be undertaken. Firstly, one could consider a fairly complex problem such as, for example, a computer laboratory. The cooling load for this laboratory could be calculated using both LOADEST and the theoretical method.

Another procedure would be to consider some of the more common heat sources, and evaluate the cooling load due to each of these sources separately. The sources considered would, in each case be fairly simple, such as heat transfer through a single wall or window.

The latter approach was chosen as the method for validating LOADEST. The reason for this choice is simple. If the former method were used, and good agreement were not obtained, then the reason for the discrepancy would be very difficult to pinpoint. All that could be said is that the theoretical and LOADEST results differ.

In the second method, however, the accuracy of cooling load due to each source may be validated one by one. Any differences between LOADEST may be easily identified and the reasons discussed.

The theoretical approach used is the CLTD/SCL/CLF method, which was described in 3.7.2. The values of CLTD, SCL and CLF are obtained from Parsons [20]. There are Tables of data available in references such McQuiston and Parker [4] and Devasahayam [16], but these are primarily for locations in the Northern Hemisphere, whereas Durban lies on the line of 30^0 South Latitude.

4.5.1 Cooling load due to heat gain through partitions

A partition is simply another word for a wall (or other material) separating two enclosed areas. Should the area bordering the conditioned space be warmer than the conditioned space, heat will be conducted through the partition. The equation governing the cooling load due to this type of heat source is 3-1.

Both spaces are enclosed, which means that the partition is not exposed to the sun. The result is that the CLTD is simple to calculate. It is simply the difference in dry bulb temperatures between the two rooms.

Heat gain through internal walls in allowed for in page 4 of LOADEST. The method of expressing the CLTD is called the multiplier. It is simply the ratio of temperature difference between the two rooms to the temperature difference between the conditioned space and the outdoor dry bulb temperature.For example, assuming an internal dry bulb temperature of 22.5^{0}C, if the outdoor dry bulb temperature were 28.5^{0}C and the room bordering the conditioned space were maintained at 26.5^{0}C then the multiplier would be 0.66. If the room bordering the conditioned space were a constant 25.5^{0}C then the multiplier would change to 0.5.

Four different models were used to test the accuracy of LOADEST simulations for this type of heat source. The input values are shown below.

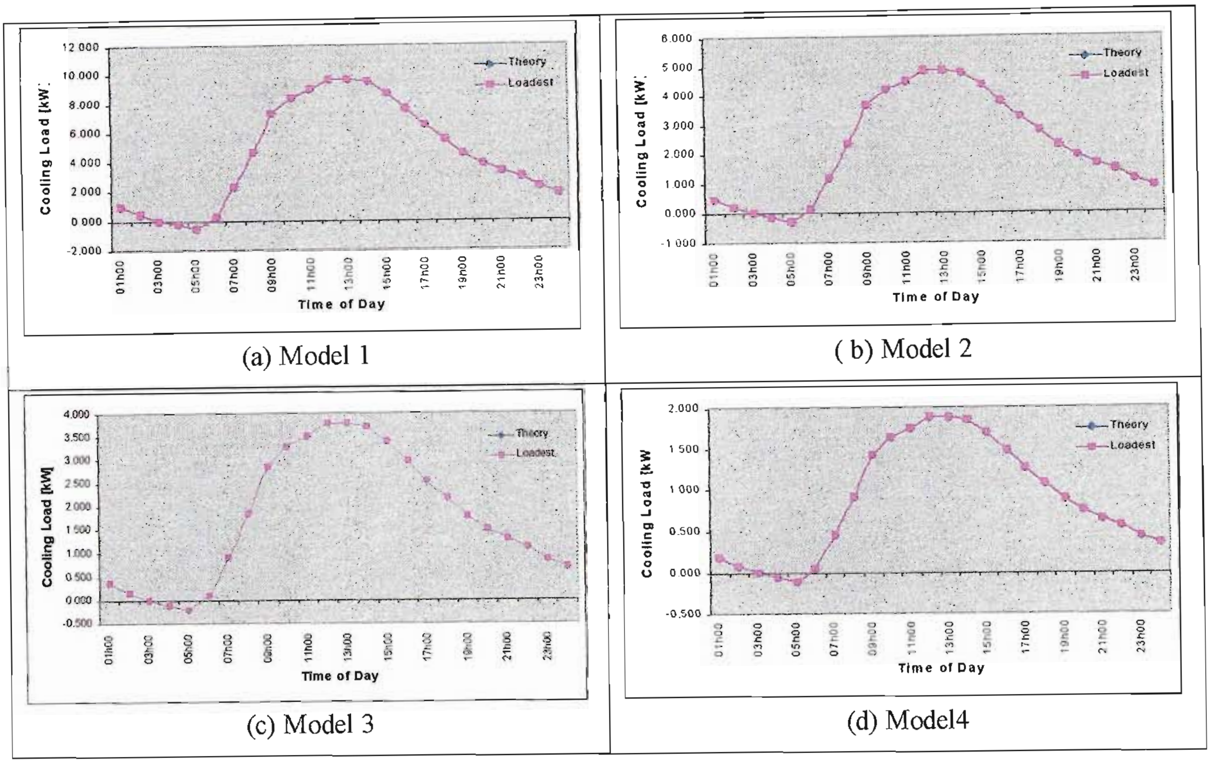
Model Number	Floor Area [m^2]	Partition Area [m^2]	U Factor [W/m^2 ^{0}C]	Temp. Multiplier
1	100	1000	1.377	1.0
2	100	1000	1.377	0.5
3	100	1000	0.538	1.0
4	100	1000	0.538	0.5

Table 4.5: Models used to verify cooling load due to partition heat transfer in LOADEST

Although theoretically the floor area of the conditioned space has no bearing on the cooling load due to partition heat transfer, it is always necessary to enter a floor area value in LOADEST. The floor area has no influence on the cooling load, but one of the outputs from LOADEST is a value of cooling load per square metre. This allows one to compare the amount of cooling load for every square metre of conditioned space in different locations. This comparison could be thought of as a measure building energy efficiency.

In the validation models an arbitrary value of 100m^2 was chosen. The partition area was selected as 1000m^2. This is too large to be realistic, but was chosen simply to get large values of cooling load. The cooling load output from LOADEST is in units of kilowatts, rounded to one decimal place. Should conditions be chosen which give very low cooling loads, an accurate comparison might not be possible, due to the effect of only one decimal point of accuracy.

The results of these simulations for the month of February are shown below.



(a) Model 1 (b) Model 2 (c) Model 3 (d) Model4

Figure 4.5 (a) – (d): Results of the validation of cooling load due to heat gain through partitions

It is easy to see from Figure 4.5 (a) – (d) that the LOADEST cooling loads agree almost exactly with the theoretical values. The same can be said of the results of the other eleven months, which are not shown simply for brevity. The only discrepancy between them is the fact that LOADEST outputs have only one decimal point of accuracy. In applications with very small cooling loads this factor could be significant.

4.5.2 Cooling load due to heat conduction through glass

There are two forms of heat gain through glass. One is a solar gain, due to solar radiation, and will be discussed later. A second form of heat gain is heat conduction through the glass, driven by the temperature differential across the glass (between the conditioned space and the external surroundings). Again, the cooling load due to this form of heat gain is governed by 3-1.

No temperature multiplier (used in partition heat transfer) is used in LOADEST, as it is assumed that windows are externally situated. Should glass form a partition between two rooms as described in 4.5.1 then the glass must be allowed for on page 4 of LOADEST. In order to neglect the effect of solar gain, and calculate only the conduction component of cooling load, the shading factor must be set to a value of zero. This means it is assumed that solar gain does not alter the room cooling load.

A single model was considered sufficient to validate the accuracy of LOADEST for this source of heat gain. The input values used are shown below.

Model Number	Floor Area [m^2]	Glass Area [m^2]	U Factor [$W/m^2\ ^0C$]
5	100	1000	5.89

Table 4.6: Model used to verify cooling Load due to heat conduction through glass

The U Factor for reference (standard) glass in 5.89 $W/m^2\ ^0C$. Again a heat transfer area of $1000m^2$ was chosen to obtain large enough values of cooling load that the 1 decimal point limitation of LOADEST would not cause large discrepancies. It may be seen from Figure 4.6 that there is near perfect agreement between the results obtained from theory and those from LOADEST.

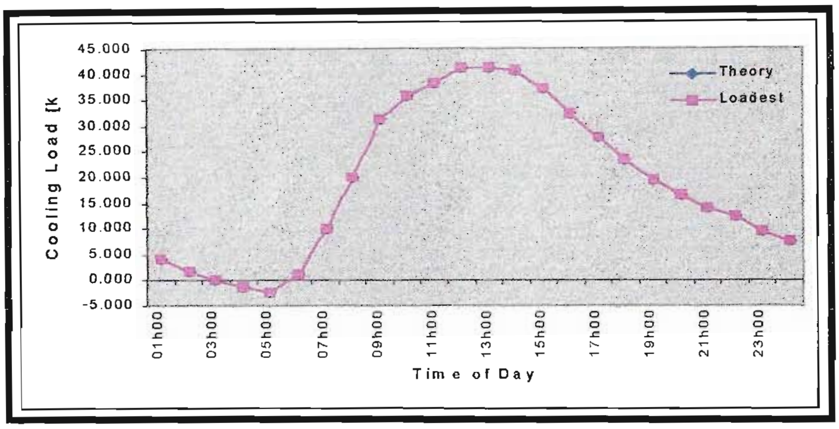


Figure 4.6: Results of the validation of cooling load due to heat conduction through glass

4.5.3 Cooling load due to ventilation and/or infiltration

Ventilation is the term used to describe outside air purposely introduced into the conditioned space, to meet the fresh air requirements of occupants. Infiltration is an unintentional (and sometimes unavoidable) inflow of outdoor air into the conditioned space, through openings such as doors, open windows and cracks in the building.

Ventilation and infiltration are usually both sources of cooling load, because the enthalpy of outdoor air is usually higher than that of the internal environment.

Three models were used to validate the accuracy of LOADEST in determining cooling load due to these heat sources. The input values used are shown below.

Model Number	Floor Area [m^2]	Ventilation Rate [l/s]	Infiltration Rate [l/s]
6	100	750	0
7	100	0	330
8	100	750	330

Table 4.7: Models used to verify cooling load due to ventilation and/or infiltration

A ventilation value of 750 l/s is equivalent to the fresh air requirements of 150 people in a non-smoking environment. The infiltration rate of 330 l/s is roughly equivalent to inflow through a single open door with no vestibule. These values were obtained from Parsons [20].

The method employed was slightly different in this case. The values were input into LOADEST and the hourly cooling load values obtained. Due to time considerations only the peak cooling load was evalauated theoretically. Equation 4-1 governs cooling load due to ventilation and infiltration.

$$\dot{q} = \left(\dot{m}\right)\left(h_{out} - h_{in}\right) \tag{4-1}$$

Where $\dot{q}$ = Cooling load [W]

$\dot{m}$ = Mass flow rate [kg/s]

h = Enthalpy (outside and internal) [kJ/kg]

Model Number	Peak Month	Peak Time	LOADEST Cooling Load [kW]	Theoretical Cooling Load [kW]
6	January	12h00	29.7	30.13
7	January	12h00	13.1	13.2
8	January	12h00	42.7	43.33

Table 4.8: Results of the validation of cooling load due to ventilation and infiltration

4.5.4 Cooling load due to lighting and operation of equipment.

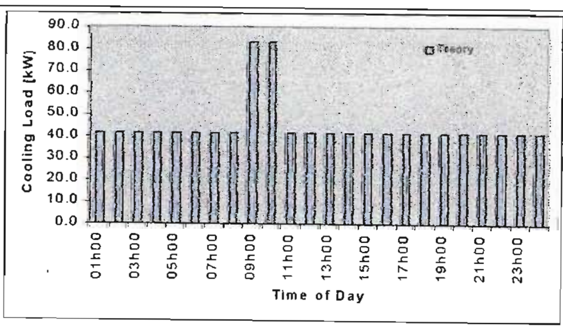
Lighting and equipment both give off heat during operation. Lighting is a source only of sensible heat, while equipment may give off sensible and/or latent heat. Lighting is usually specified as a value per square metre. A value of 25kW would therefore correspond to a rate of 250W/m^2, which is acceptable. Lighting patterns may be fairly easy to predict, but the operation of equipment might be more random. A value of 70kW Sensible load and 13kW latent load would be applicable to equipment like a boiler, Parsons [20].

Diversity factors are included (Page 5 of LOADEST) which are used to calculate the lighting (or equipment) load for any particular time, as a percentage of the maximum cooling load.

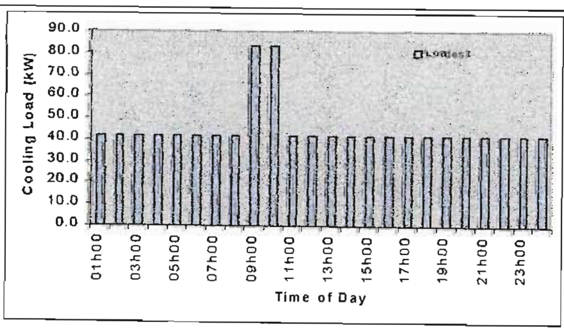
	Model 9	Model 10	Model 11
Floor Area [m^2]	100	100	100
Max. Lighting [kW]	0	2.5	2.5
Lighting Diversity	Not Applicable	0.2 from 6am – 6pm 1 from 6pm – 6am	1 from 6am – 6pm 0.2 from 6pm – 6am
Max. Equipment (Sensible) [kW]	70	0	70
Max. Equipment (Latent) [kW]	13	0	13
Equipment Diversity	1 for 8am, 9am. 0.5 for all other times	Not Applicable	1 for 6am, 7am. 0.5 for all other times

Table 4.9: Models used to validate cooling load due to lighting and equipment

The results of these simulations are shown below.

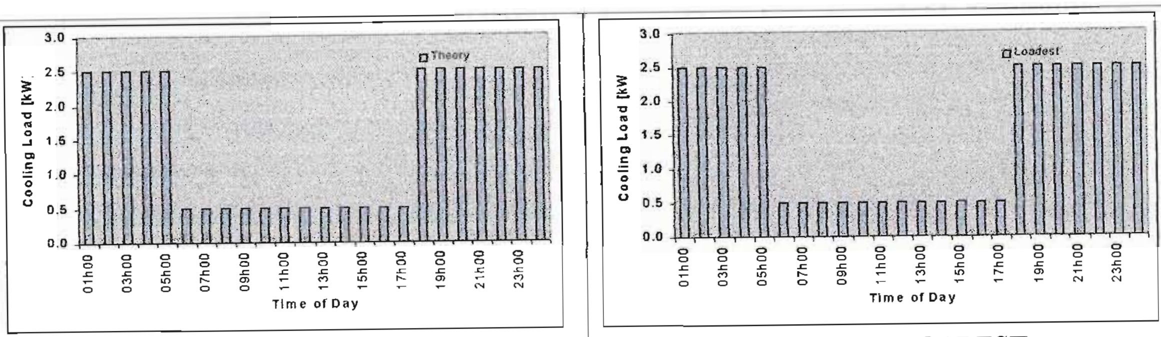


(a) Model 9 (Theory)



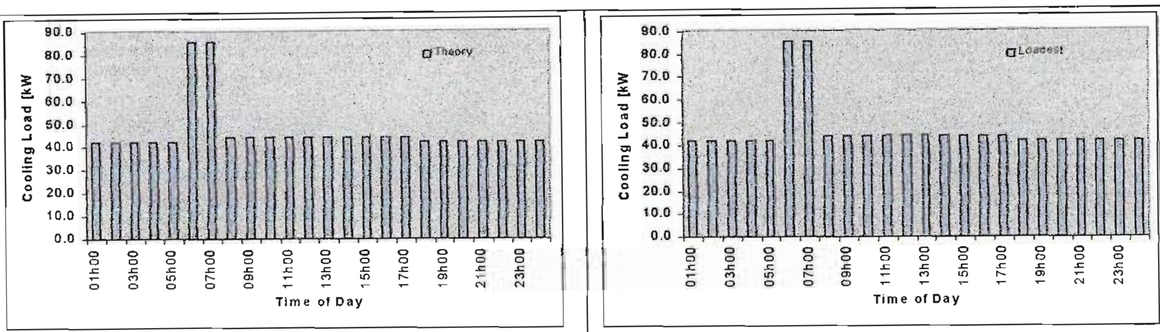
(b) Model 9 (LOADEST)

Figure 4.7 (a) – (b): Results of the validation of Model 9



(a) Model 10 (Theory) | (b) Model 10 (LOADEST)

Figure 4.8 (a) - (b): Results of the validation of Model 10



(a) Model 11 (Theory) | (b) Model 11 (LOADEST)

Figure 4.9 (a) – (b): Results of the validation of Model 11

It is seen that the cooling load values which LOADEST outputs for models 9,10 and 11 agree exactly with theory. In addition it was found that both the latent and sensible heat loads agreed individually.

4.5.5 Cooling load due to human occupation

Humans, and indeed all mammals are a source of heat gain to their surroundings. This is due to metabolic processes occurring within the body. Both sensible and latent heat are products of metabolism. The total amount of heat given off, as well as the composition (sensible and latent percentages) of this heat, is directly related to the activity of the individual concerned, their dress code and also the ambient internal conditions.

Four different levels of activity were considered, sitting, standing, walking and light work. The models used for validation are shown in Table 4.10.

Model Number	Floor Area [m2]	Number of Occupants	Activity
12	100	10	Sitting
13	100	10	Standing
14	100	10	Walking
15	100	10	Light work

Table 4.10: Models used for the validation of cooling load due to human occupation

The cooling load due to occupants is a function only of the internal dry bulb temperature and the degree of activity. The result is that the cooling load will be a single finite, **time independent** value, as long as internal design conditions are maintained. The theoretical values were obtained from Parsons [20]. Models 12 – 15 were simulated in LOADEST, and the results shown below.

Model Number	Theoretical Cooling Load [kW]			LOADEST Cooling Load [kW]		
	Sensible	Latent	Total	Sensible	Latent	Total
12	0.760	0.440	1.200	0.800	0.400	1.200
13	0.760	0.540	1.300	0.800	0.500	1.300
14	0.820	0.680	1.500	0.800	0.700	1.500
15	0.875	0.725	1.600	0.900	0.700	1.600

Table 4.11: Results of the validation of cooling load due to human occupation

Table 4.11 illustrates that good agreement between the theoretical calculations and the LOADEST output exists. The total value of cooling load agrees perfectly, although there appears to be a slight discrepancy in the composition of each cooling load. This is due to the one decimal place limitation on LOADEST in the output of results.

It may be seen that the agreement between LOADEST and theory is, thus far, very good. This is because the heat transfer mechanisms of the cooling loads considered from 4.5.1 to 4.5.5 are very simple. It was stated in 4.3 that the heat gain to a room is transient in nature due mainly to the hourly variation of solar radiation. The effect of this phenomenon will be illustrated in sections 4.5.6 and 4.5.7.

4.5.6 Cooling load due to heat transfer through external walls

Cooling load due to heat gain through external walls is expressed by equation 3-1. This is the same equation governing heat gain through internal walls (partitions) as described in 4.5.1. The difference occurs in the calculation of the value of CLTD. In the case of internal walls the CLTD was simply the difference in dry bulb temperatures. For external walls, however, the CLTD is not as easy to calculate.

The CLTD for external walls must be obtained from tables, with an appropriate correction added. It was decided not to validate the accuracy of LOADEST by calculation of the cooling load alone, but rather to compare the values of CLTD used. The CLTD was made the subject of the formula from equation 3-1, as follows;

$$CLTD = \frac{q}{(A)(U)}$$

Where each term has the same meaning as in equation 3-1.

The U Factor and wall area are constants, and therefore time independent. Cooling load is a time dependent variable dictated by the value of CLTD. Should the theoretical and LOADEST values of CLTD be found to be similar, one can say that LOADEST has been validated for this source of cooling load.

The models used are shown in Table 4.12.

Model Number	Wall Area [m2]	Exposure	U Factor [W/m$^{2 0}$C]	Month of Year
16	100	North	1.178	January
17	100	Northeast	1.178	January
18	100	East	1.178	January
19	100	Southeast	1.178	January
20	100	South	1.178	January
21	100	Southwest	1.178	January
22	100	West	1.178	January
23	100	Northwest	1.178	January

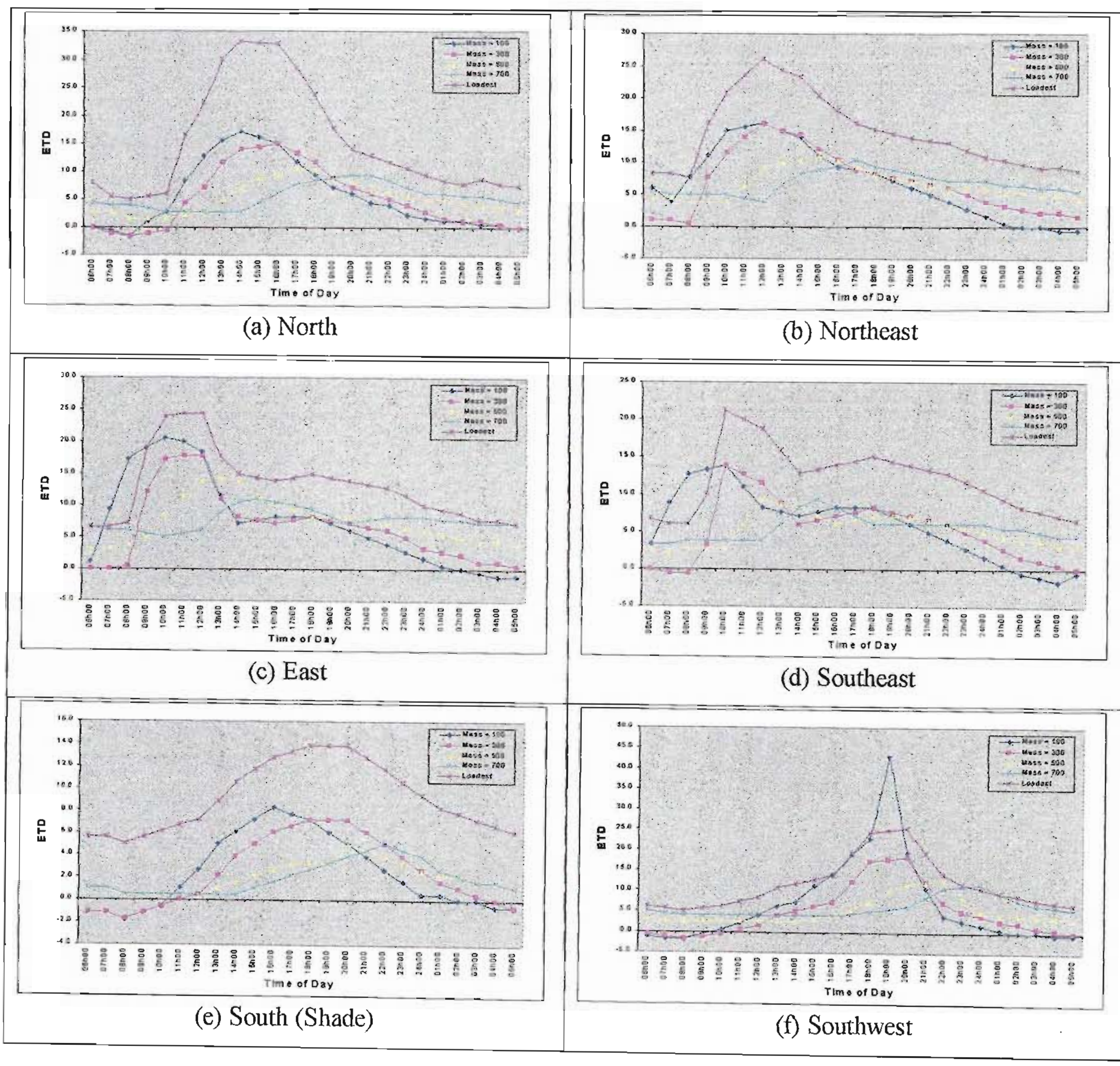
Table 4.12: Models used in the validation of cooling load due to heat transfer through external walls

The results of this exercise are summarised in Figure 4.10 (a) – (h).

Please note that ETD in Figure 4.10 (a) – (h) is an acronym of Equivalent Temperature Difference (with units of ^{0}C), and is analogous to CLTD.

The sequence of operations was repeated for two other values of U Factor, namely 1.453 $W/m^{2}\,^{0}C$ and 2.288 $W/m^{2}\,^{0}C$. These values (together with 1.178 $W/m^{2}\,^{0}C$) correspond to common external wall constructions. It was found that the choice of U Factor has no influence on the value of CLTD. In addition, LOADEST has no allowance for a choice of light, medium or heavy wall construction.

It may be seen that the theoretical family of curves in Figure 4.10 (a) –(h) is in agreement with the heat storage effect described in 3.6. In other words, the heavier the construction the flatter the CLTD curve. There is no way of accounting for this effect in LOADEST, which must be considered a shortcoming.



(a) North

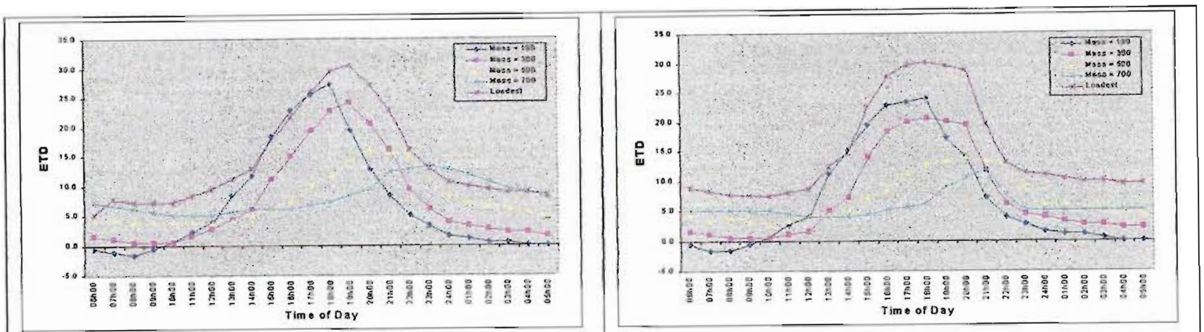
(b) Northeast

(c) East

(d) Southeast

(e) South (Shade)

(f) Southwest



(g) West

(h) Northwest

Figure 4.10 (a) – (h): Results of the validation of cooling load due to heat transfer through external walls

The shape of the LOADEST curve appears to most closely follow that of the 300kg/m^2 curve. There are two notable aspects of the results in Figure 4.10 (a) –(h).

Firstly, the peak cooling load occurs at approximately the same time of day as that of 300kg/m^2 wall. Secondly, the LOADEST cooling load value is almost always higher than that of any of the theoretical curves. An attempt was made to quantify the difference between the LOADEST values and those of any of the curves, to see if there were some correction factor which could be applied to the LOADEST values to increase accuracy. It was found that there is no constant factor relating the LOADEST curve to any one of the theoretical curves.

The fact that the LOADEST value is higher than the theoretical values is, arguably, not a bad thing for design work. It means that cooling equipment may be slightly oversized, which is definitely preferable to a lack of cooling capacity. One should, however, bear in mind the curves in Figure 4.10 (a) – (h) . In some cases it may be possible to select cooling equipment of slightly lower capacity than suggested by LOADEST, if heat gain through external walls is considered to constitute a large portion of the cooling load.

4.5.7 Cooling load due to solar gains

As was explained in 4.5.2 there are two methods of heat transfer associated with glass, conduction and solar gain. Conduction of heat through glass has already been validated. Solar gain through glass is governed by equation 3-2.

As was the case in 4.5.6 it is not the theoretical and LOADEST cooling loads which will be compared. Rather, the solar cooling load (SCL) which has units of W/m^2 which will be made the subject of the formula, as follows;

$$SCL = \frac{q}{(A)(SC)}$$

Where each term has the same meaning as in equation 3-2.

The models used to validate cooling load due to this form of heat transfer are summarised in Table 4.13.

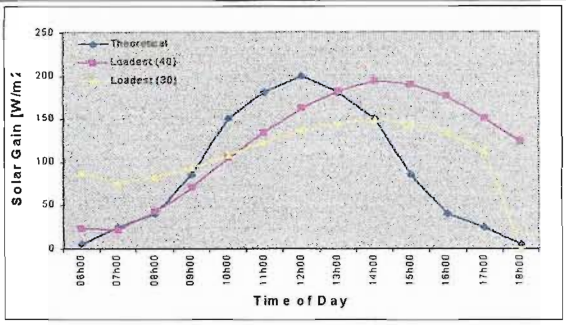
Model Number	Glass Area [m^2]	Exposure	U Factor [$W/m^{2}{}^{0}C$]	Shading Coefficient
24	100	North	0	1
25	100	Northeast	0	1
26	100	East	0	1
27	100	Southeast	0	1
28	100	South	0	1
29	100	Southwest	0	1
30	100	West	0	1
31	100	Northwest	0	1
32	100	Horizontal	0	1

Table 4.13: Models used to validate cooling load due to solar gain

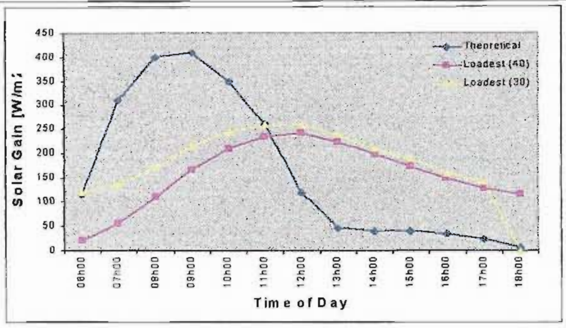
In section 4.2.2, some finite value of U Factor ($5.89W/m^{2}{}^{0}C$) was used together with a shading coefficient of zero. In this instance a U Factor of $0W/m^{2}{}^{0}C$ is used with a shading coefficient of one. The combined effect was that cooling load due to conduction through glass was neglected, and only solar gain considered.

Once the cooling load due to this form of heat transfer had been obtained, corresponding values of SCL were calculated. These values are then compared to the theoretical values of SCL, obtained from Parsons [20].

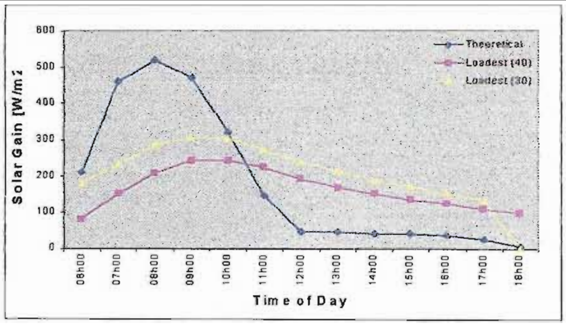
The results of this comparison are summarised overleaf for the month of February. February was chosen as the month in which overall cooling load (due to all possible heat sources) is likely to peak. It was found that the trends shown for the month of February are applicable for the other eleven months as well. Due to space constraints, graphs of these months are not included.



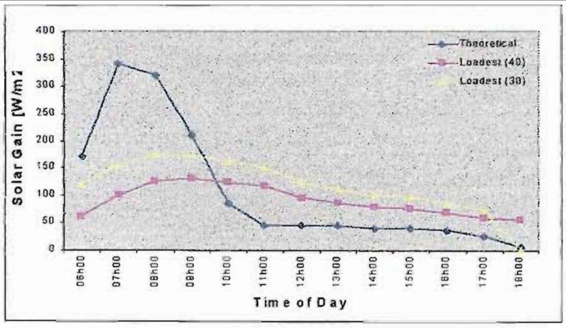
(a) North



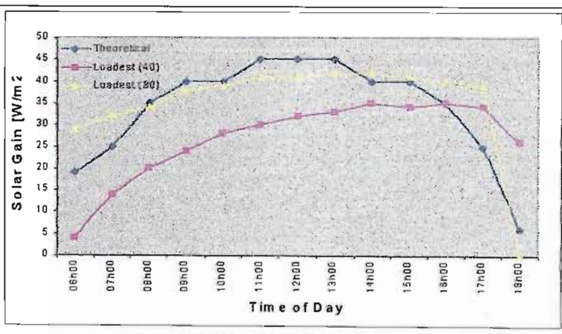
(b) Northeast



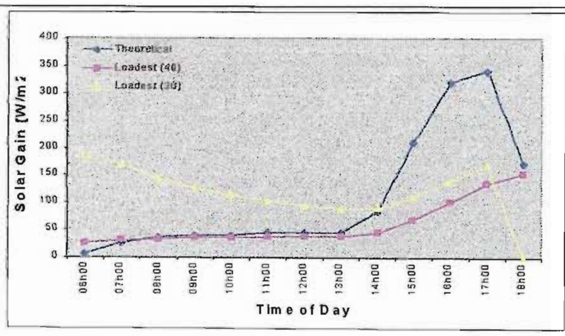
(c) East



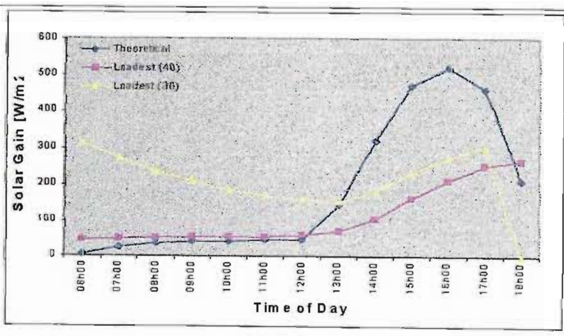
(d) Southeast



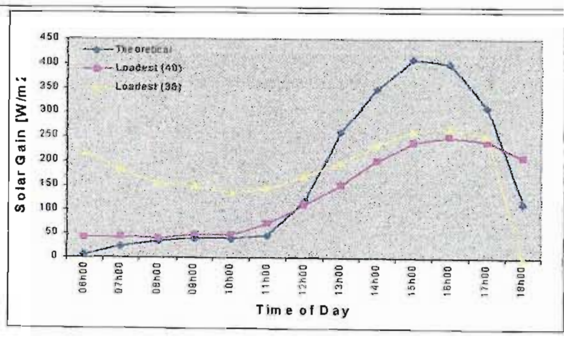
(e) South (Shade)



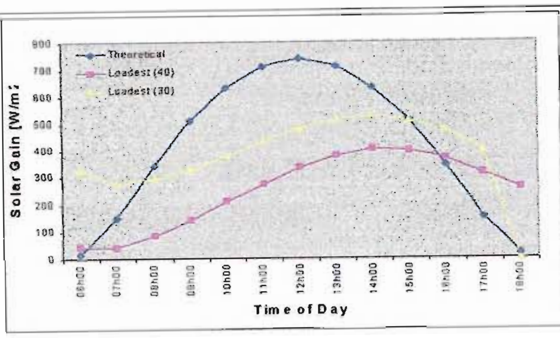
(f) Southwest



(g) West



(h) Northwest



(i) Horizontal

Figure 4.11 (a) – (i): Results of the validation of cooling load due to solar gain, [W/m^2]

In Figure 4.11 (a) – (i) there are two different comparisons shown for LOADEST, one is for a latitude of 30^0 South and the other is for 40^0 South. The change of latitude is effected in the WEATHER UTILITY. No other weather data was changed, and remained the same as the standard Durban data. The theoretical curve is calculated for 30^0 South latitude. The curves shown in Figure 4.11 (a) – (i) are typical of results for the entire year. There are a number of trends visible.

The LOADEST curves are almost always "flattened" in comparison to the theoretical curves, especially for the 40^0 South curves.

The LOADEST curves almost always start and finish at some finite value greater than zero, whereas the theoretical curves often tend towards zero at their endpoints. The area under the curves has not been calculated, but an integral of each of the curves would appear to yield approximately the same value in many instances. What is very important to note is that the peak solar gain calculated by LOADEST is always lower than the theoretical peak. This could be detrimental in design work, as undersized equipment may be supplied should cooling load due to solar gain comprise a large percentage of the overall cooling load.

It was expected that cooling load due to solar gain would not be of major significance in this study. This is because the percentage of glass area in each of the buildings studied is considered relatively small. In addition, most of the buildings are fitted with internal and/or external shading devices, which further reduce the effect of solar gain. Also, it was shown in 4.5.6 that LOADEST tended to slightly exaggerate the cooling load due to heat gain through external walls. The lower than theoretical prediction of cooling load due to solar gain may, in fact, make the overall cooling load more accurate by compensating for the higher than theoretical cooling load due to heat transfer through external walls.

4.6 Effect of Weather data used in LOADEST

The weather data used in LOADEST was discussed in 4.4. Section 4.5 was dedicated to validation of cooling loads due to various heat sources. The accuracy of these was based on the use of the LOADEST weather data.

One of the main contributing factors to loading of air-conditioning plant is the introduction of outside air into the conditioned space. This introduction may be either intentional or unintentional. Air is introduced as ventilation to meet the fresh air requirements of occupants. Air may also be introduced unintentionally as infiltration, through openings such as doors and windows.

Regardless of the method of introduction, outside air is usually warmer and/or more humid (and therefore of higher enthalpy) than the internal conditions. As a result outside air must usually be cooled and/or dehumidified. In some instances the outside air may be of lower enthalpy than the internal conditions. In such cases outside air can be used to cool the conditioned space, with no need for air-conditioning operation. This is, however, unusual, especially in Durban.

4.6.1 LOADEST weather data – South African cities

The ventilation load placed on the plant depends on both the outside conditions, and the rate of ventilation. LOADEST stores approximations of weather conditions for most South African towns and cities as weather files. These consist of ordered pairs of dry-bulb temperature (^{0}C) and humidity ratio ($g_{water\ vapour}/kg_{dry\ air}$) for each hour of every month.

The intention of this exercise was to determine how accurately this data simulates the actual weather conditions. It is the enthalpy difference between internal and external air that determines the cooling load for every kilogram of outside air introduced.

The enthalpy values for each hour of February, May, August and November were calculated. These months roughly correspond to summer, autumn, winter and spring respectively. This was done using Psychrometric software downloaded from the "TECHNISOLVE" website [22]. The software is merely an electronic version of standard psychrometric charts. A psychrometric chart simply shows the properties of moist air, based on input values of two properties (and a selected altitude).

The input values were therefore the dry bulb temperatures and corresponding humidity ratios for each of the months. The LOADEST approximation of humidity ratio being a constant for an entire month led to an immediate problem. In the month of February the humidity ratio is 19 g/kg. At sea level, the corresponding dew-point temperature is 23.99 ^{0}C. The minimum expected dry-bulb temperature (according to LOADEST) is, however, 22.10 ^{0}C. It is impossible to locate any point on the psychrometric chart with a dry-bulb temperature less that 23.99 ^{0}C, and a humidity ratio of 19 g/kg.

This was the main problem associated with plotting the enthalpy values from LOADEST. For all entries where the dry-bulb temperature is above the dew point temperature of the given humidity ratio, the result is simply a horizontal line on the psychrometric chart. The benefit of the electronic chart is the ease with which changes may be made and the chart reprinted.

4.6.2 Weather data for actual Durban conditions

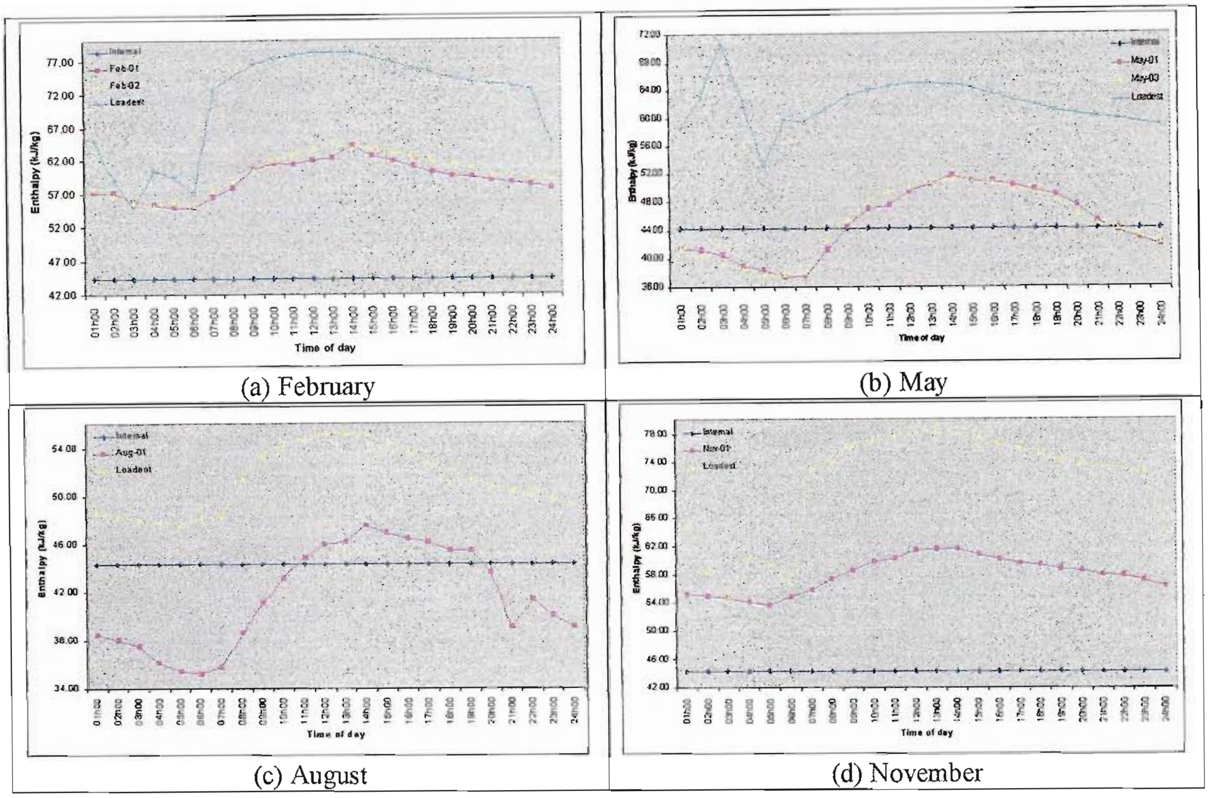
In order to measure the accuracy of the LOADEST approximation, Durban weather data, for the period from January 2001 to May 2002, were obtained. These data were requested from the South African Weather Service [21] via their website. A table of the average dry bulb temperatures for each month from January 2001 to May 2002 is shown in Appendix 1.

The data obtained from the weather service consist of ordered pairs of dry-bulb temperature (^{0}C) and relative humidity (%) values. The data are available for each particular day. In addition, the average values for each month were given. These average values were plotted on the afore-mentioned psychrometric chart, and the corresponding enthalpy profiles obtained. When plotted on the psychrometric chart, the points form a loop.

4.6.3 Comparison between LOADEST weather data and actual conditions

The results of this exercise are summarized in Figure 4.12 (a) –(d). Each of the four graphs shows the LOADEST approximation and the actual conditions for one month. In addition there is a horizontal line at an enthalpy value of 44.28 kJ/kg. This is the enthalpy value of air inside the conditioned space (maintained at a constant 22.5 ^{0}C dry-bulb and 50% relative humidity) and therefore does not change.

External air of an enthalpy above this horizontal line will generate a cooling load when introduced to the conditioned space. Should the enthalpy of the outside air be lower than 44.28 kJ/kg then the introduction of outside air would itself provide cooling.



(a) February (b) May

(c) August (d) November

Figure 4.12 (a) – (d): Comparison between LOADEST weather data and actual conditions for Durban

It may be seen that, in almost all cases, the LOADEST approximation lies above the actual enthalpy profiles for Durban. In the periods from midnight to 6 am there is a region with several sharp turning points. This is a result of dry-bulb temperature being below dew-point temperature, and it being impossible to determine the enthalpy for that point. The general shape of the LOADEST approximation is similar to that of the actual conditions, with an enthalpy peak occurring just after midday. The fact that the measured conditions for 2002 match those of 2001 suggests that any discrepancy between reality and LOADEST is not simply due to one particularly cold season or year.

There are two possible means of improving the accuracy of cooling load simulations. Firstly, the heat load calculations could be manually altered to better reflect actual operating conditions. This would be feasible, as the load due purely to ventilation has been calculated. Multiplication by some appropriate scaling factor would then give a more accurate load. An alternative is to repeat the calculations using different software.

4.7 Summary of the performance of LOADEST Software

The results obtained through the use of LOADEST software agree relatively well with those obtained using the theoretical approach.

There is almost exact agreement between LOADEST and theory for many of the sources of cooling load. It was found that cooling load due to heat conduction through external walls tended to be exaggerated by LOADEST. Conversely, the cooling load due to solar gain tended to be under-estimated by LOADEST.

The exaggeration of cooling load may be justified as being a safety factor, to ensure that cooling equipment is of adequate capacity. The lower than theoretical results obtained for cooling load due to solar gain were not expected to be a major problem, as this cooling load was not expected to form a large percentage of total cooling load.

The biggest discrepancy between LOADEST and reality appeared to lie in the method of representing outdoor weather conditions. Bearing in mind that cooling load calculations are only estimates, and are influenced by a multitude of factors, the author felt that the use LOADEST software would produce results of satisfactory accuracy.

CHAPTER 5

A BRIEF DESCRIPTION OF THE UND DISTRICT COOLING SYSTEM

5.1 Magnitude of the campus district cooling system

The University of Natal (Durban) campus utilises a district cooling system (incorporating thermal storage) as a means of providing cooling to a number of buildings on the campus.

Buildings served by this system are Howard College, the E. G. Malherbe Library and Denis Shepstone Building. The new Chemistry Laboratory, most of the Business Concourse, and some offices in the Chemical Engineering Building are also served by this same storage tank. The areas included in this system are summarised in Table 5.1.

Building	Floor Area [m^2]
Denis Shepstone Building	11055
Howard College	2328
E. G. Malherbe Library	8317
Business Concourse	866
Chemistry	263
Chemical Engineering	154

Table 5.1: UND buildings served by the district cooling system

The heart of the current system is a chilled water storage tank located in front of Howard College. The tank uses thermal stratification as a means of separating warm and chilled water. The chilled water is pumped to each building to supply cooling. The cooling capacity required to chill this water is provided by means of 3 chillers housed on Level 4 of Denis Shepstone Building.

McCabe [1] defines a district cooling system as a system that provides cooling, in the form of chilled water, from a central plant, and distributes this chilled water to two or more buildings. In terms of this definition, the cooling arrangement of the UND campus constitutes a district cooling system.

5.2 History of the campus district cooling system

The history of the district cooling system may be traced back to the early 1980's. Prior to that time each campus building had a self contained cooling plant, responsible for only that building. A problem of insufficient cooling capacity eventually arose. With no storage device, the maximum cooling capacity must be sufficient to meet the maximum instantaneous cooling demand, or else internal conditions cannot be maintained.

The solution to this problem was the construction of a storage tank, with cooling provided by three chillers in Denis Shepstone Building. The storage tank allowed for central distribution of chilled water to the areas mentioned in Table 5.1.

The tank is situated in front of Howard College, and is subterranean. The method of warm and chilled water separation was originally by means of a diaphragm. Approximately the same cooling capacity may be stored as with a stratified tank. The drawbacks are the cost associated with membrane purchase and installation, as well as tearing. Dorgan and Elleson [9] conclude that there is no obvious cost benefit of a membrane tank over a well-designed stratified tank utilising diffusers. There was another problem encountered though. Efficient operation of a diaphragm tank relies on the diaphragm remaining horizontal. There should be no "creasing" of the membrane. This was not the case, however, a problem exacerbated by the presence of support columns in the tank.

The tank was converted to a stratified chilled water tank in the early '90's. This necessitated the design of suitable and efficient inlet and outlet diffusers, as water flow must be carefully controlled. Poor diffuser design results in flow patterns which are detrimental to the thermocline, resulting in loss of stored cooling capacity. The primary considerations involved in diffuser design are the Froude and Reynold's numbers.

At this stage the chiller arrangement in Denis Shepstone was essentially the same as it had been without storage. There were three chillers, two of which operated in series. Chilled water from the tank was fed to buildings via two and three-way control valves. It was felt that the chiller arrangement was not optimal as there was an insufficient temperature difference created between chilled water and warm water, returning from buildings. It must be remembered that the establishment of a larger temperature differential has two benefits. Firstly, the thermocline is better maintained and secondly, cooling capacity is increased.

The piping route at this stage (early '90's) served Denis Shepstone Building, Howard College and the E. G. Malherbe Library. Additional piping was added to serve the Business Concourse, the New Chemistry laboratory and an almost negligible portion of the Chemical Engineering Building. There was a proposal to merge the Memorial Tower Building/T. B. Davis Lecture theatre system with the storage system, but this has never materialised.

5.3 The current district cooling system

The current system is detailed in Parsons and Lumsden [23]. The biggest change is three new chillers, still based in a plant-room on Level 4 of Dennis Shepstone Building. These three chillers are run in a parallel configuration. Each chiller has a capacity of 1345 kW, and is capable of handling 32,1 l/s of water. Each of these chillers is connected to two cooling towers.

The storage tank has remained fairly unchanged. The tank dimensions are 27,3 m X 21,7 m X 4,63m. The volume of the tank is 2743 cubic metres. Dorgan and Elleson [9] estimate that a well designed stratified tank may deliver 85 – 95% of the stored energy as useful cooling. The chilled water design temperature is 5^0C, with a return temperature of 15^0C. The maximum allowable flow rate in the tank is 136,8 l/s, a larger flow rate would disturb the thermocline. It is estimated that the current flow rate is approximately 110 l/s.

The pump room is situated next to the storage tank. There are two primary chilled water pumps, which pump water between the chillers and the storage tank. Four secondary chilled water pumps serve the buildings, one each for Howard College and Denis Shepstone Building. The two remaining pumps serve the E. G. Malherbe Library, the Business Concourse, Chemical Engineering and the new Chemistry Laboratory, and act as back up in the case of shutdown or failure. Each of the secondary chilled water pumps is equipped with a variable speed drive. A variable speed drive is used to maintain high efficiency even when the motor speed (and hence flow rate) is changed.

5.4 Operation of the cooling system

During the charging cycle warm water is pumped, via primary chilled water pumps 1 and 2, from the top of the tank to the chillers. After passing through the chillers the (now chilled) water returns to the bottom of the tank. The charging process is illustrated in Figure 5.1.

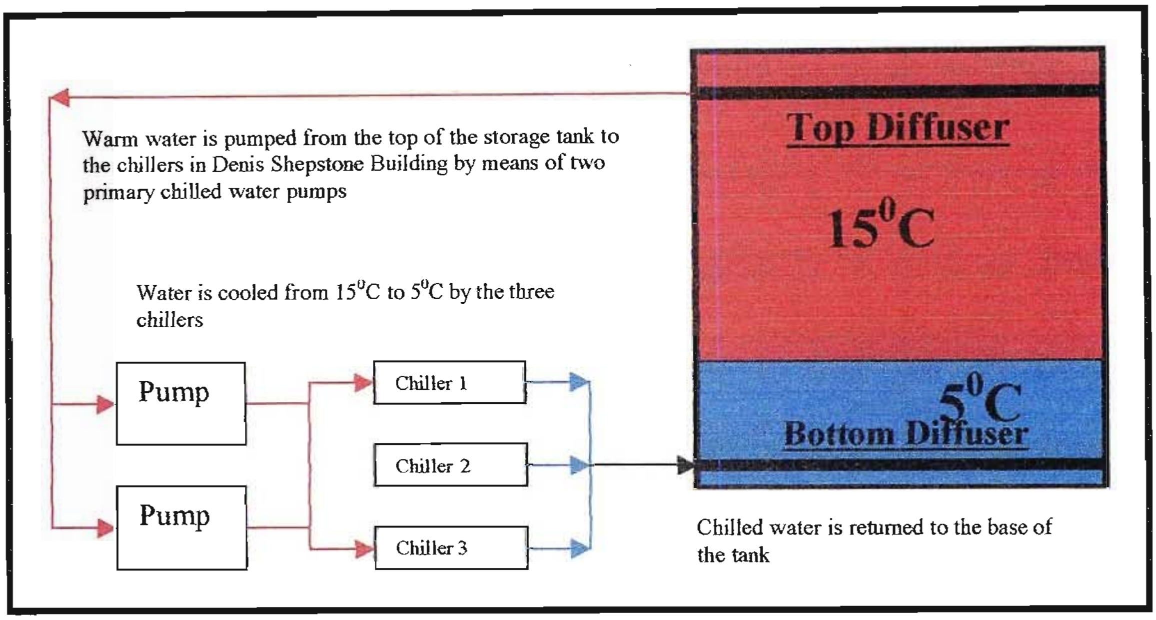


Figure 5.1: Charging of the UND district cooling system

The three buildings (and the miscellaneous areas) are served during the discharging cycle. Chilled water is pumped to air handling units/ fan-coil units in each location. After cooling the buildings, and hence increasing in temperature, the warm water returns to the top of the tank. The discharging process is illustrated in Figure 5.2.

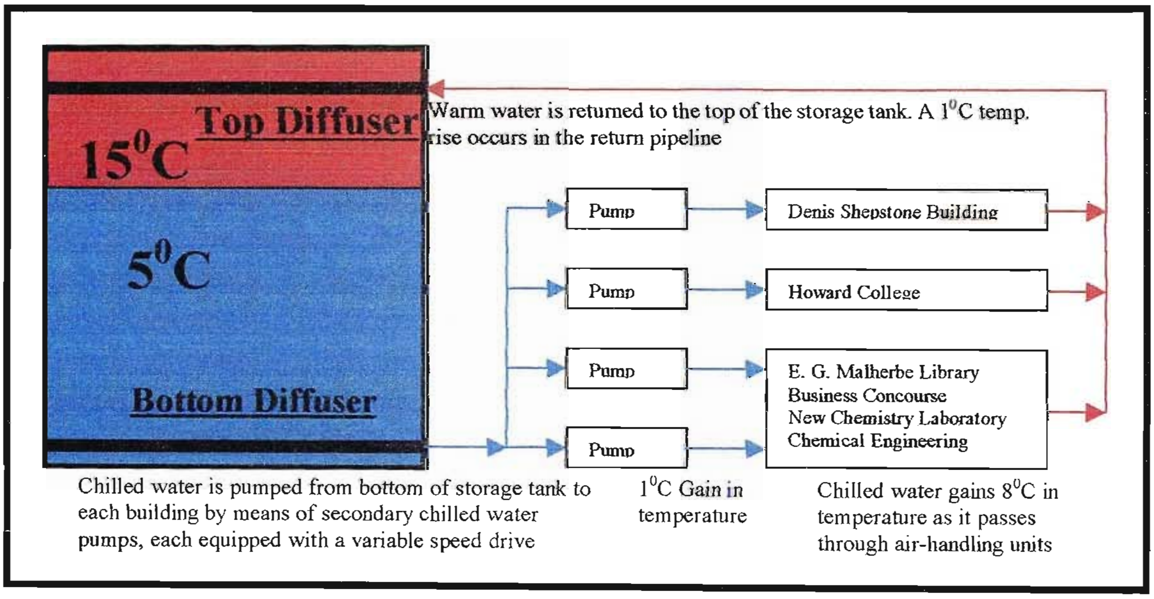


Figure 5.2: Discharging of the UND district cooling system

5.5 Stored cooling capacity

Equation 5-1 gives an estimate of the amount of available cooling.

$$E = (C)(V)(\rho)(c_p)(\Delta T) \qquad (5\text{-}1)$$

where: E = Stored Cooling [J]

C = Percentage of stored cooling available

V = Volume [m^3]

ρ = Density [kg/m^3]

c_p = Specific heat capacity of storage medium [J/kg^0C]

ΔT = Temperature differential in tank [^0C]

The estimated stored cooling for the tank on the UND campus is 97000 MJ (7661.2 ton-hours).

5.6 Comparison with other district cooling systems

The following list of district cooling systems in the United States was obtained from Pierce [2].

Owner	Location	Capacity (ton-hours)	Start-up year
Brazosport College	Lake Jackson, Texas	4000	1991
California State University	Bakersfield, California	10000	1994
California State University	Fullerton, California	37000	1993
California State University	Sacramento, California	12300	1991
California State University	San Bernadino, California	15000	1994
Del Mar College	Corpus Christi, Texas	6000	1993
Florida State University	Tallahassee, Florida	16000	1992
San Jacinto Junior College	Channelview, Texas	5500	1994
University of Akron	Akron, Ohio	28400	1995
Washington State University	Pullman, Washington	17750	1993

Table 5.2: Examples of College/University District Energy Systems

Owner	Location	Capacity (ton-hours)	Start-up year
District Energy St. Paul	St. Paul Minnesota	28000	1994
Energy Networks	Hartford, Connecticut	20000	1985
Trigen-Peoples District Energy	Chicago, Illinois	123000	1994
Trigen-Trenton District Energy	Trenton, New Jersey	36000	1988

Table 5.3: Examples of Commercial District Energy Systems

Owner	Location	Capacity (ton-hours)	Start-up year
City of Hope National Medical Centre	Duarte, California	18200	1996
Milton S. Hershey Medical Centre	Hershey, Pennsylvania	12500	1992
Northam Regional Hospital	Northam, Western Australia	365	1995
St. Joseph's Medical Centre	Stockton California	5400	1992

Table 5.4: Examples of Hospital/Medical Centre District Energy Systems

Owner	Location	Capacity (ton-hours)	Start-up year
Du Page County	Wheaton, Illinois	10700	1995
General Services Administration	Laguna Niguel, California	12000	1996
L. A. Dept. Of Water & Power	Sun Valley, California	13000	1992
Los Angeles County	Lancaster, California	12000	1989
Sonoma County	Santa Rosa, California	9600	1988
U. S. Air Force	Edwards AFB, California	62000	1986
U. S. Air Force	Tullahoma, Tennessee	38000	1993

Table 5.5: Examples of Government District Energy Systems

It may be seen that, in general, the district cooling system on the UND campus is relatively small compared to those mentioned in Tables 5.2 – 5.5. The UND system is, however, not excessively small relative to the other college/university schemes. An encouraging factor is that the UND scheme was initiated earlier than many of the schemes listed.

CHAPTER 6

COOLING LOAD ESTIMATES FOR THE UND CAMPUS (USING LOADEST SOFTWARE)

Chapters 3 and 4 introduced the concepts of heat gain and cooling load. It was stated that estimation of cooling load by means of manual methods is very time consuming. Chapter 4 verified that LOADEST software provides sufficiently accurate results that it may be used to calculate cooling load.

Chapter 5 gave an outline of the history, components and operation of the district cooling system on the UND campus. This chapter is dedicated to the calculation of cooling load on the campus. The cooling load estimates derived in this chapter will provide the raw data for comparison between different cooling strategies.

6.1 Scope of the cooling load calculations

Cooling load calculations were undertaken for each of the buildings associated with the district cooling system on the UND campus. These buildings are;

- Denis Shepstone Building
- Howard College
- E. G. Malherbe Library
- Business Concourse
- New Chemistry Laboratory
- Small portion of the Chemical Engineering Building

6.2 Method for performing cooling load calculations

The sources of cooling loads were presented in Chapter 3, and the validity of using LOADEST software proven in Chapter 4. There is still, however, the task of actually performing these cooling load calculations.

6.2.1 Sourcing the information required

The cooling load for Denis Shepstone Building and the E. G. Malherbe Library had previously been estimated by members of a research group from the School of Electrical Engineering. These calculations were validated, adjusted and eventually used.

The cooling load estimates for the other buildings were initiated and completed during this research project. The process involved calculating all relevant heat transfer areas, as well as predicting human occupation, equipment loading and ventilation/infiltration rates.

Plans were supplied by WSP FMG (facilities managers for the University) [24]. The plans did not include projections of any of the buildings, which meant that areas such as windows had to be estimated, rather than accurately measured. This must be considered a potential source of error.

6.2.2 Instantaneous and pull-down cooling loads

The output from LOADEST is a list of the cooling loads for each hour of cooling plant operation. It must be remembered that the cooling load is the rate at which heat must be removed from the conditioned space to avoid internal conditions deviating from design values. There are 3 choices of plant operation hours, as described in Meaker [25]

- 12 hours (06h00 – 17h00), the normal operating time for most plants.
- 16 hours (06h00 – 21h00), the extended operating time for shops etc.
- 24 hours per day operation for continuously occupied areas such as hotels.

In this study the time of cooling operation was dictated not by the time at which chillers switch on and off, but rather by the secondary chilled water pump scheduling. Cooling may take place only while chilled water is being pumped to and from the buildings concerned. Without any chilled water flow only ventilation may take place, but no cooling. The hours of operation of the cooling plant (chillers) do not need to coincide with the hours of cooling load. This is an inherent benefit of a thermal storage system, that cooling may occur even while chillers are not operational.

A decision was made to quantify the cooling loads in a slightly different, more laborious manner in order to obtain more realistic cooling load data. The 24 hours per day plant operation was selected, which meant that the output was a value of instantaneous cooling load for each hour of the day.

Pump Number	Buildings Served	On-Time	Off-Time
SCHWP - 1	Denis Shepstone	06h30	20h30
SCHWP – 2	Howard College	07h00	22h00
SCHWP - 3	E. G. Malherbe Library Business Concourse Chemistry laboratory Chemical Engineering	00h00	24h00
SCHWP - 4	Reserve/Back-up		

Table 6.1: Schedule of secondary chilled water pumps serving district cooling system

The operating hours of each secondary chilled water pump are shown in Table 6.1. Cooling may occur only during these periods of operation. E. G. Malherbe library is cooled 24 hours a day because close control of the internal conditions is required to prevent damage to the literature inside. This means that as cooling load is generated it may be removed. The output from LOADEST is therefore a good indication of what the overall cooling load profile will look like for the library. Consider the case of Denis Shepstone Building. Chilled water is supplied only from 06h30 to 20h30. This means that cooling load may be removed only during these hours. Cooling load which is removed as soon as it manifests itself is termed instantaneous load in this study. From 20h30 the cooling load will build up, as there is no means of removing it. This load must, however, be removed the following day. The result is that the cooling load which must be removed to maintain comfortable internal conditions early the next day is greater than the instantaneous value given by LOADEST. The method employed was to sum all cooling loads occurring outside cooling periods, and carry this load over till the next morning. This increase in cooling load during the first few hours of cooling is known as pull-down load. An assumption was made that this pull-down load be removed during the first three hours of operation the following morning, so as to put some restriction on the level of discomfort tolerable within the air-conditioned space.

6.2.3 Ventilation/Infiltration diversity

There is a no allowance for changes in ventilation and/or infiltration rates in LOADEST. Over a 24 hour plant operation period, LOADEST assumes that the volumetric flow rate of ventilation and infiltration remains constant. This is, however, not the case.

It has already been discussed how cooling may take place only during hours when the relevant secondary chilled water pump is operational. The same may be said of ventilation and/or

infiltration. Ventilation is usually associated with cooling. Return air from the cooled space is mixed with the necessary fresh outdoor air, before being passed over a cooling coil. Cooling usually occurs only during (or close to) periods of human occupation. The same may be said of ventilation. Ventilation imposes a cost penalty, one has to pay for fresh air to be cooled to room conditions to meet the (legal) requirements of the occupants. If there are no occupants why should the building owner pay for fresh air to be introduced? It is therefore reasonable to assume that during periods of no occupation there will be no cooling and/or ventilation.
A similar argument may be used for infiltration. Infiltration occurs largely as a result of human occupation, through activities such as the opening and closing of doors or windows. During periods of low or zero occupation there is less likelihood of events to promote infiltration. This argument neglects infiltration through the building shell such as cracks, assumed almost negligible.

The author could find only one way to take into account the change in rates of ventilation. Two sets of cooling load data were produced for each building, one set assuming the maximum infiltration and required ventilation. The second set assumed no ventilation or infiltration. A comparison of these two sets of data meant that the cooling load due only to ventilation and infiltration could be calculated.

Using the cooling load data due only to the ventilation (and infiltration), and the cooling load data assuming no ventilation (or infiltration), a composite cooling load profile was produced which the author felt most accurately represented the overall cooling load over the 24-hour period.

6.3 Cooling estimates for each building and the entire district cooling system

The cooling loads for each building are shown on the following pages.
There are 5 tables of cooling load data shown for each building

- Cooling load assuming full ventilation (Appendix 2)
- Cooling load assuming no ventilation (Appendix 3)
- Ventilation load data
- Instantaneous cooling load data (Appendix 5)
- Pull-down cooling load data (Appendix 6)
- Overall University cooling load data (Appendix 7)

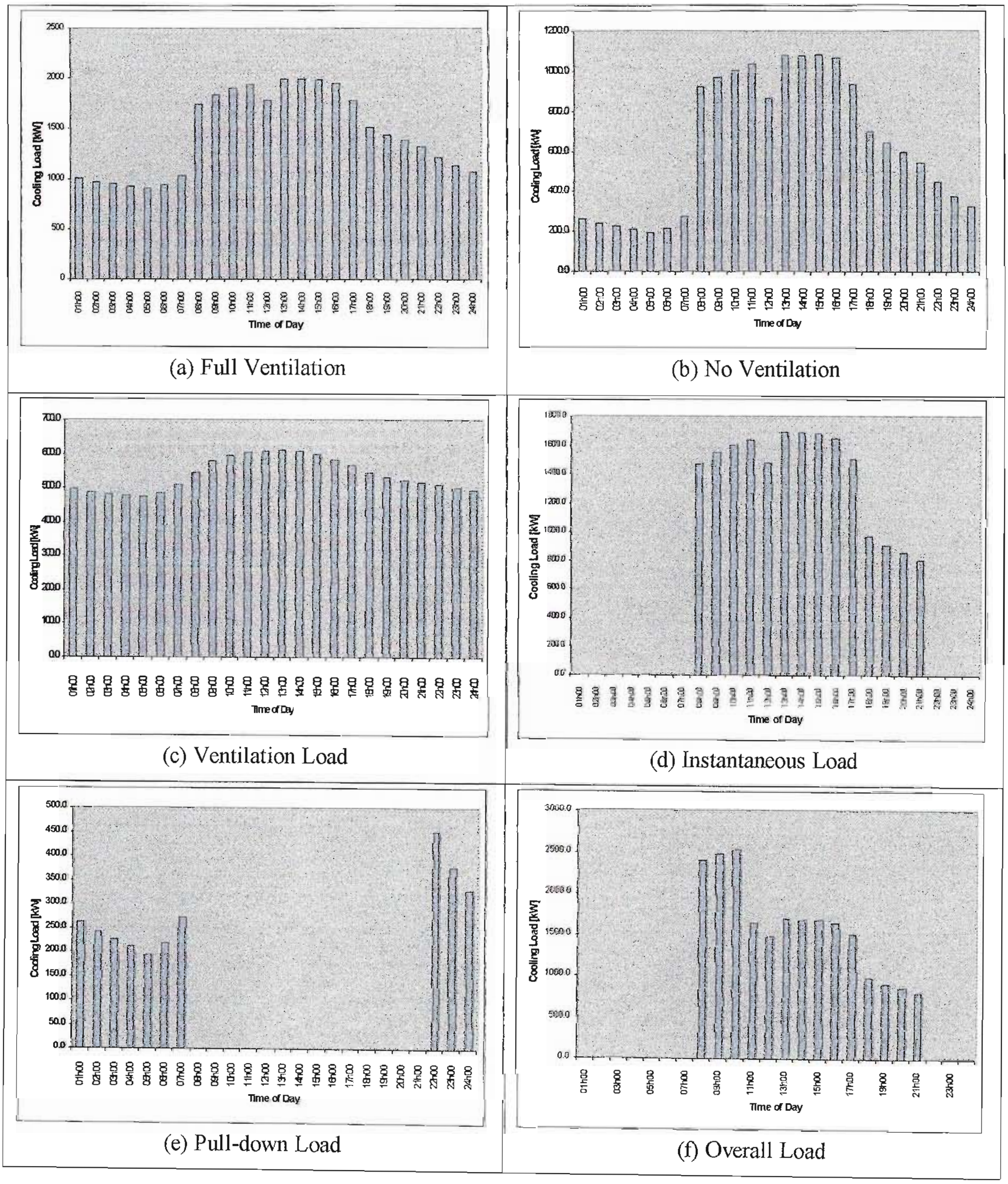
Appendix 4 shows the values of cooling load for each building, once assumptions had been made regarding the percentage of ventilation/infiltration at each hour of the day. These assumptions were based largely on the expected occupational diversity for each hour of the day.

The month of February was selected, as the peak cooling load is likely to occur during this month. Peak cooling load may theoretically occur during the month of January, but practically this is unlikely because of lower occupancies due to university vacation.

The overall cooling load is a composition of cooling loads. It was assumed that the pull-down load, which accumulates during the evening, must be met during the first three hours of cooling the following morning. The total pull down load was therefore divided by three and added to the instantaneous load for each of the first three hours of cooling for each building.

The cooling load estimates for each of the buildings (summarised in Figure 6.1 to Figure 6.6) were summed to obtain the cooling load of all 6 buildings together. This is the cooling load which must be met by the district cooling system on the UND campus. Figure 6.7 shows the cooling load for the month of February.

6.3.1 Cooling load estimates for Denis Shepstone Building



(a) Full Ventilation

(b) No Ventilation

(c) Ventilation Load

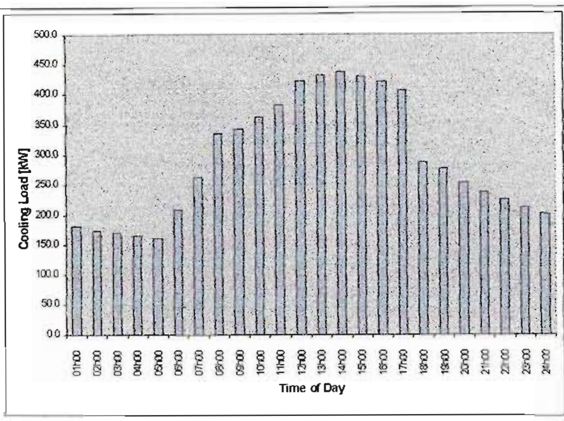
(d) Instantaneous Load

(e) Pull-down Load

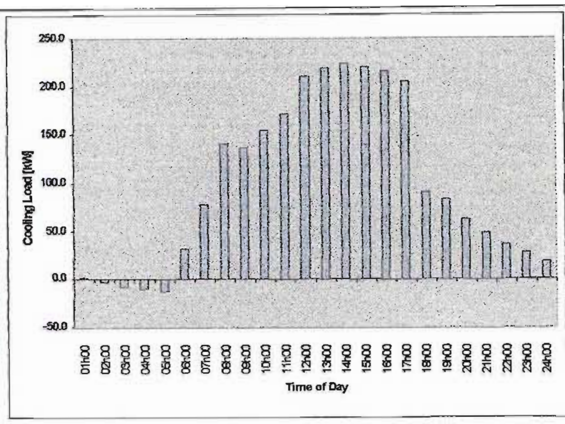
(f) Overall Load

Figure 6.1 (a) – (f): Cooling load results for Denis Shepstone Building

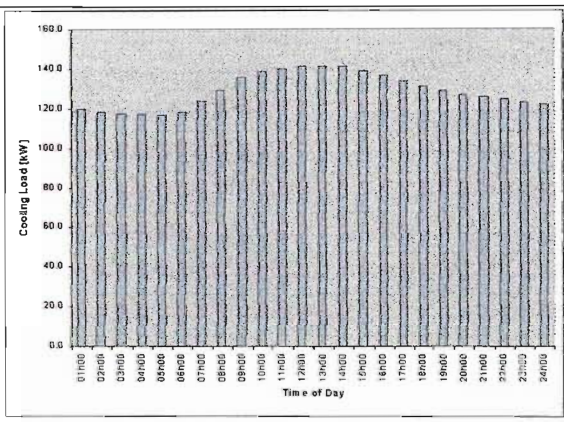
6.3.2 Cooling load estimates for Howard College



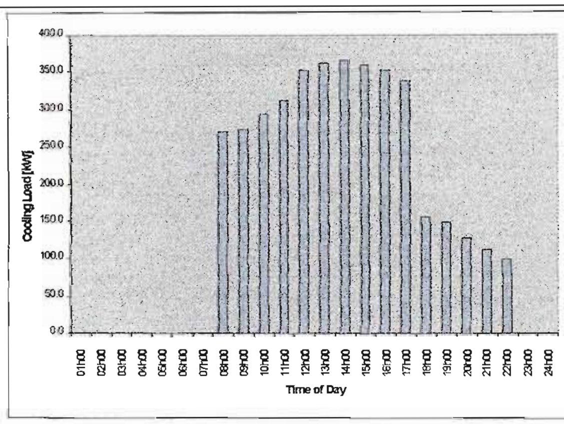
(a) Full Ventilation



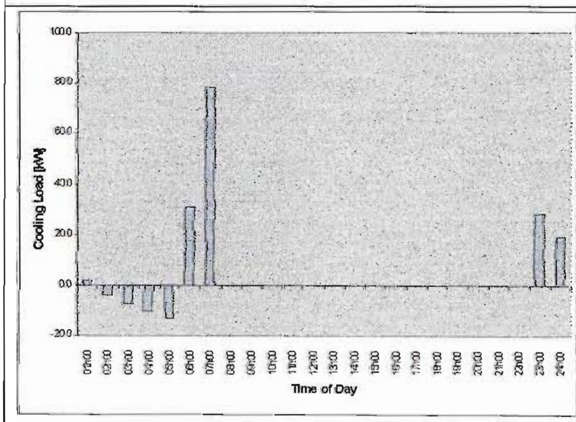
(b) No Ventilation



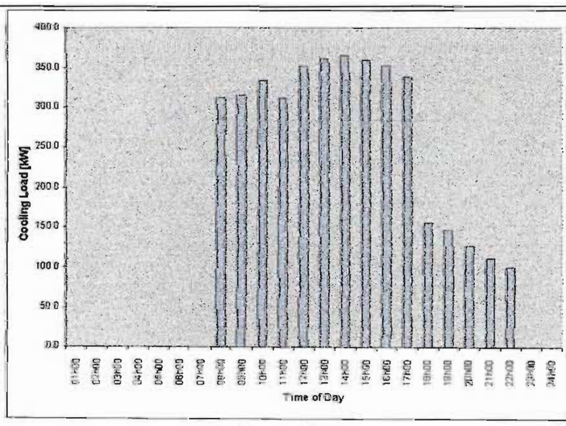
(c) Ventilation Load



(d) Instantaneous Load



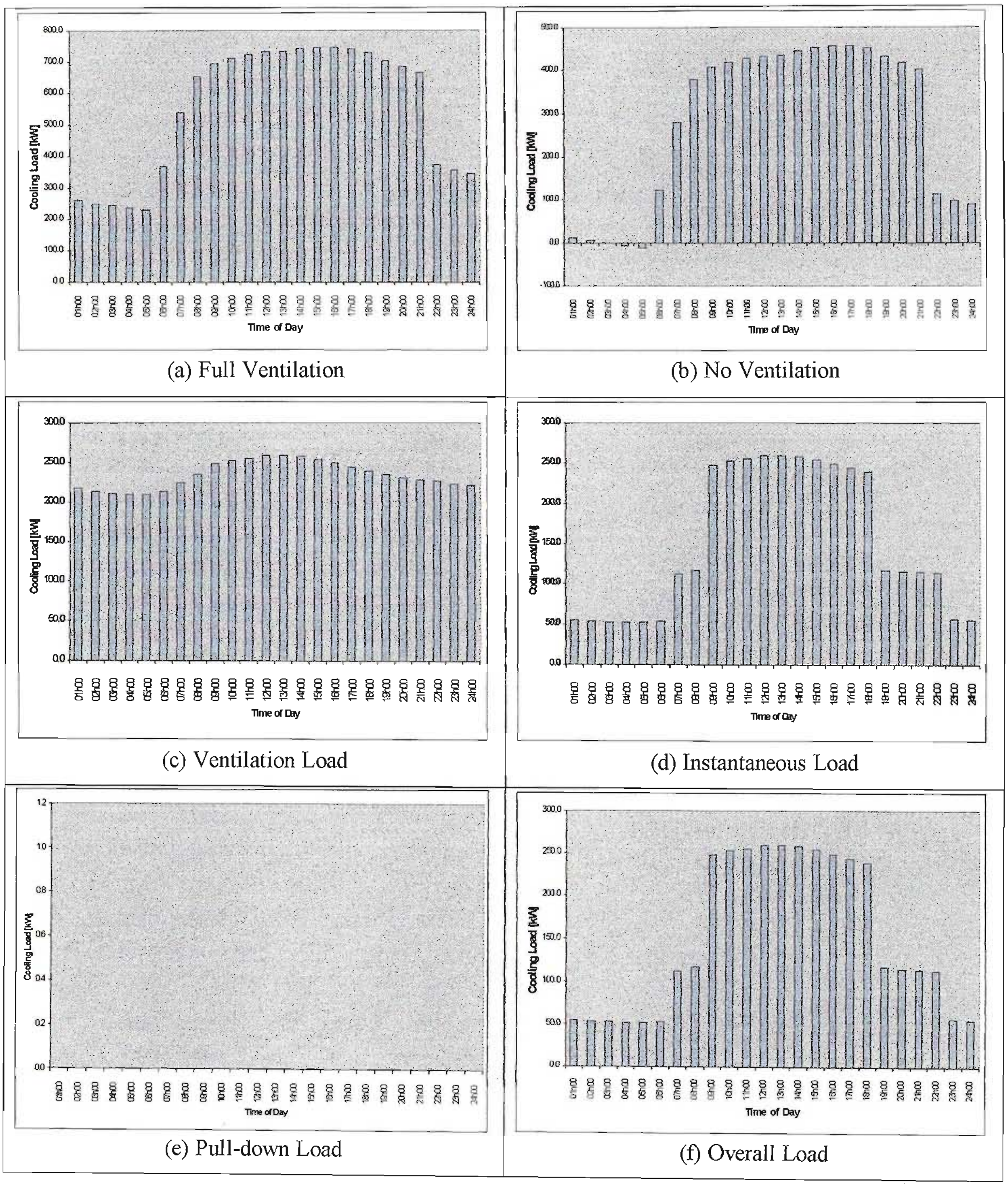
(e) Pull-down Load



(f) Overall Load

Figure 6.2 (a) – (f): Cooling load results for Howard College

6.3.3 Cooling load estimates for the E. G. Malherbe Library



(a) Full Ventilation

(b) No Ventilation

(c) Ventilation Load

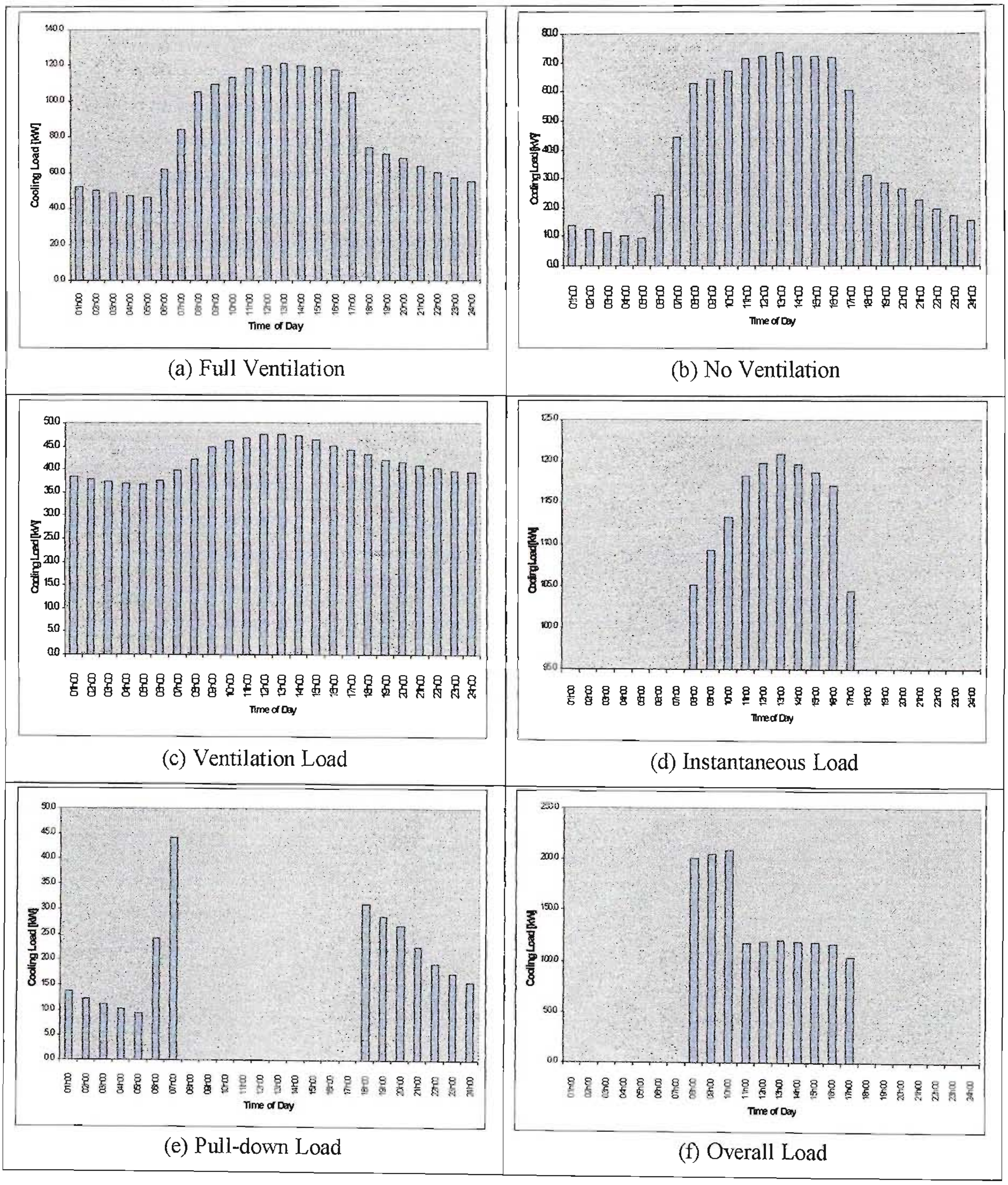
(d) Instantaneous Load

(e) Pull-down Load

(f) Overall Load

Figure 6.3 (a) – (f): Cooling load results for the E. G. Malherbe Library

6.3.4 Cooling load estimates for the Business Concourse



(a) Full Ventilation

(b) No Ventilation

(c) Ventilation Load

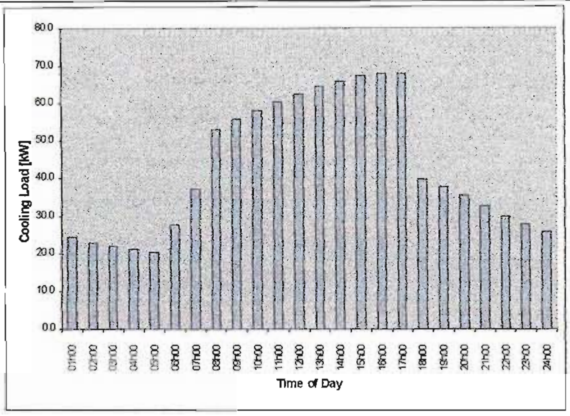
(d) Instantaneous Load

(e) Pull-down Load

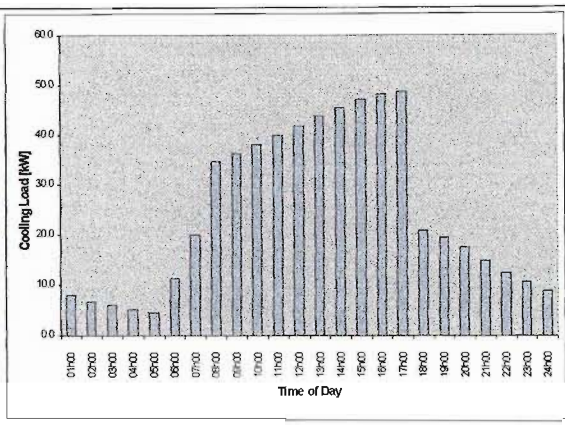
(f) Overall Load

Figure 6.4 (a) – (f): Cooling load results for the Business Concourse

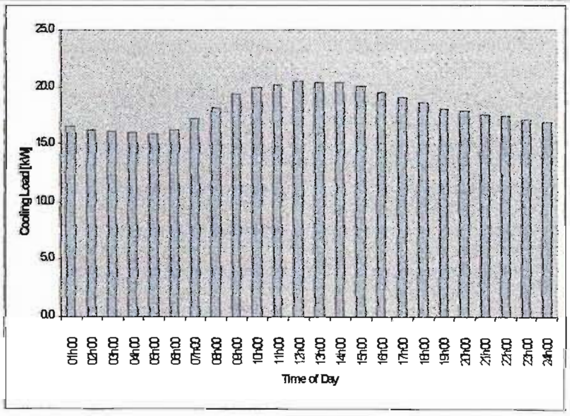
6.3.5 Cooling load estimates for the New Chemistry Laboratory



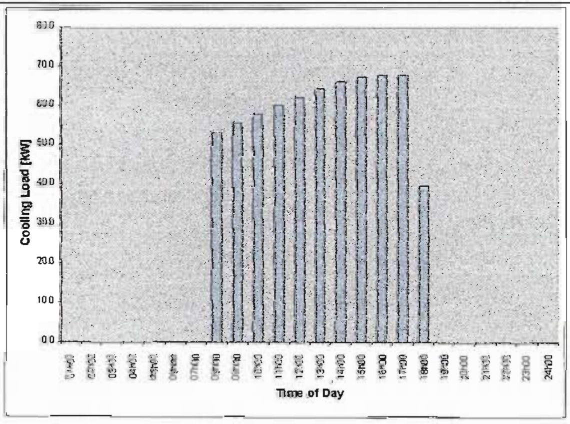
(a) Full Ventilation



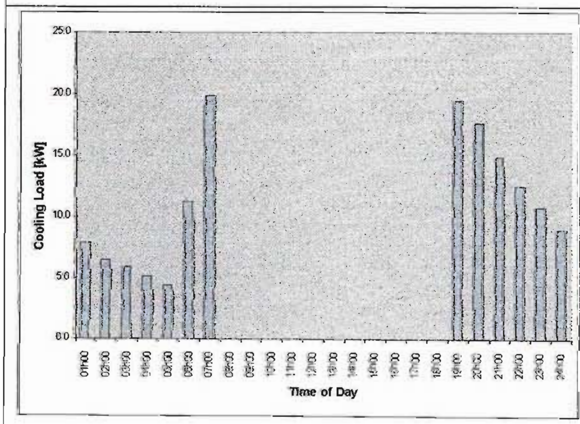
(b) No Ventilation



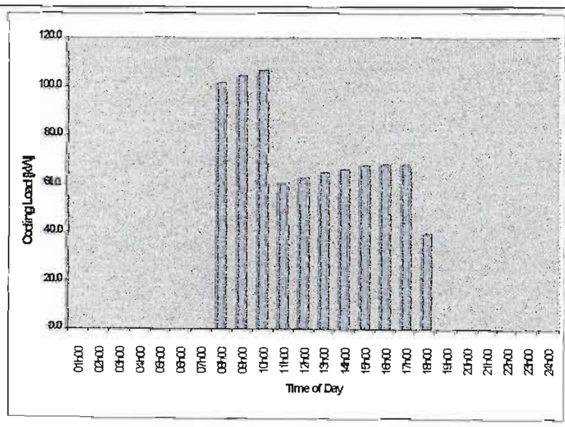
(c) Ventilation Load



(d) Instantaneous Load



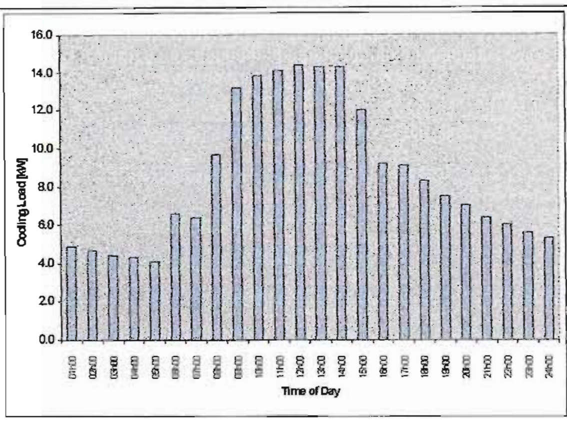
(e) Pull-down Load



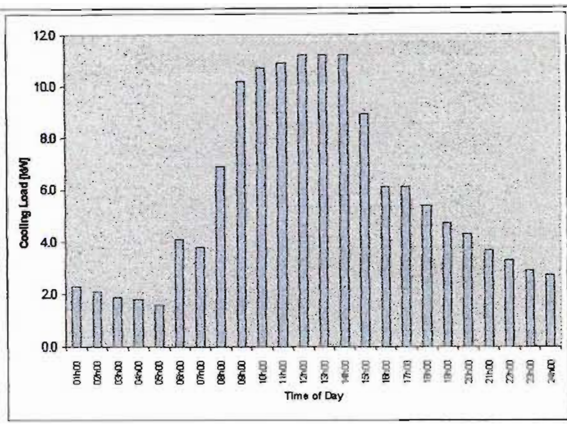
(f) Overall Load

Figure 6.5 (a) – (f): Cooling load results for the New Chemistry Laboratory

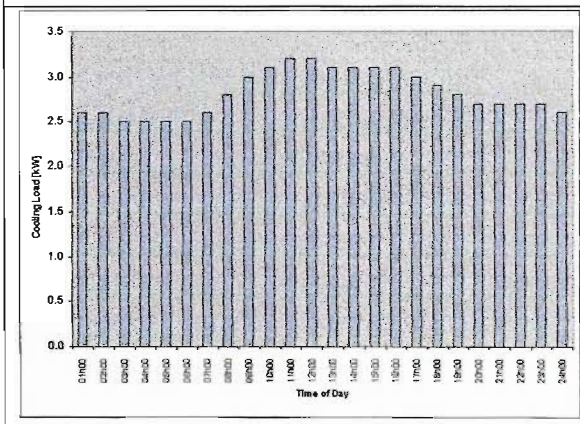
6.3.6 Cooling load estimates for the Chemical Engineering Building



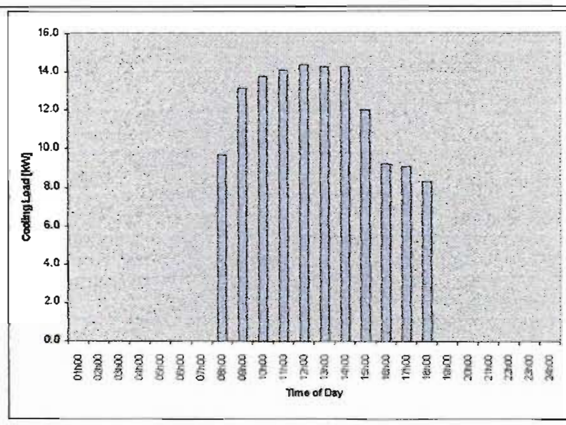
(a) Full Ventilation



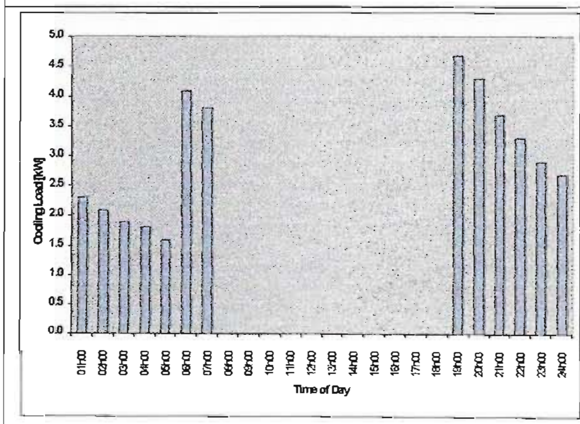
(b) No Ventilation



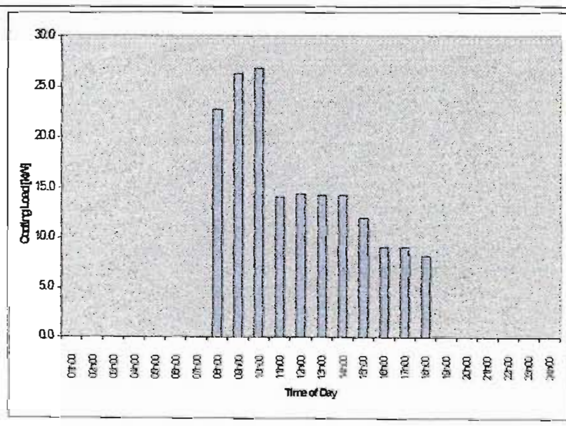
(c) Ventilation Load



(d) Instantaneous Load



(e) Pull-down Load



(f) Overall Load

Figure 6.6 (a) – (f): Cooling load results for the Chemical Engineering Building

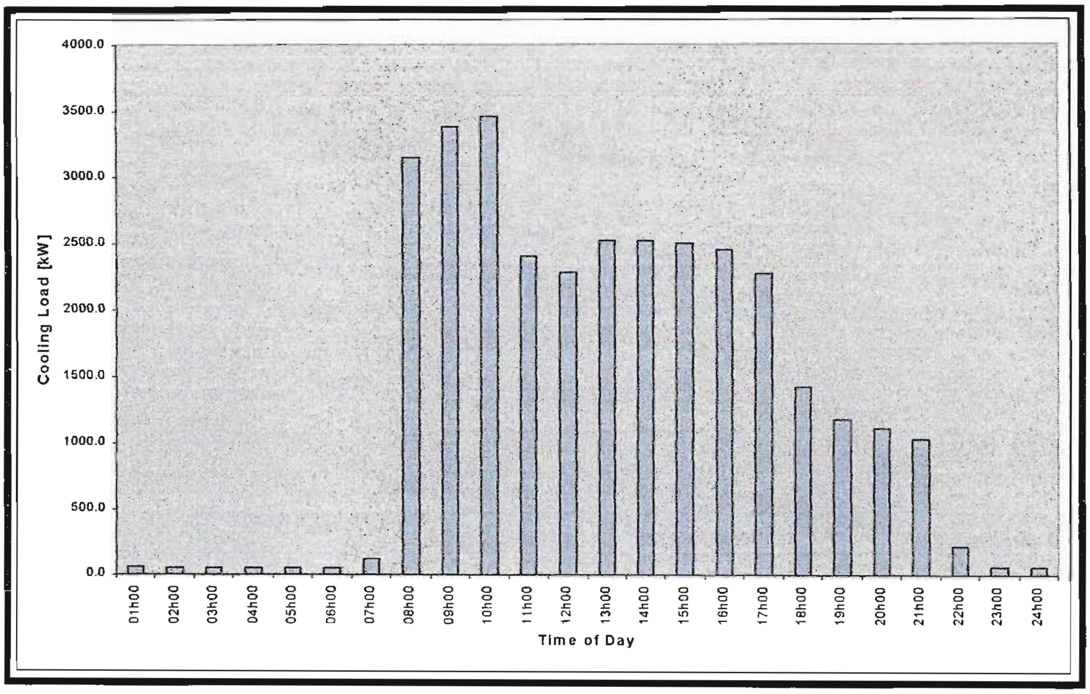


Figure 6.7: Cooling load for the district cooling system

CHAPTER 7

OPERATION, PERFORMANCE AND COST ANALYSIS OF THE UND DISTRICT COOLING SYSTEM

7.1 Limitations of the district cooling system

The thermal storage tank on the UND Campus measures 27,3m X 21,7m X 4,6m, and is supplied with water from the three chillers (each of capacity 1345kW) at a maximum rate of 32 l/s per chiller. This means that the maximum inflow rate to the tank is 96 l/s. The outflow rate is a function of the cooling load to be met.

Outflow occurs through 3 secondary chilled water pumps. There is an upper limit on the maximum allowable flow rate into or out of the tank. This value is 136.8 l/s. A flow rate exceeding this value results in degradation of the thermocline. This disruption causes mixing of cool and warm water, and hence a loss of stored cooling capacity.

Thermocline thickness, in a typical stratified chilled water tank, is estimated by Dorgan and Elleson [9] at between 0.3 and 1.0m. The thickness depends on diffuser design and the age of the thermocline. A thermocline will eventually decline to such an extent that the warm and chilled water mix to such an extent that the tank contains no useful stored cooling. The period for degradation of this degree to occur varies from a few days to a week or more.

7.2 The ideal situation

The system is designed such that the chillers supply water at a temperature of 5^0C, with a return temperature to the chillers of 15^0C. The temperature differential is thus 10^0C, with a flow rate through each chiller of 32 l/s.

A simple method was employed to estimate the chiller scheduling required for adequate cooling to be available throughout the day The cooling load estimates were performed for each of the buildings coupled to the district cooling system. The flow rate through each building was then calculated for specific temperature differentials. It was assumed that the chilled water gains 1^0C in moving from the tank to each building, and that water temperature is increased a further 1^0C along the return path to the tank. The result is that 2^0C of the available cooling is lost, as was explained in Chapter 5.

There now exists only 8^0C of the original 10^0C available to cool each building. This assumption is reflected in Figure 5.2. Once this temperature differential across each building was assumed, it was possible to calculate the chilled water volumetric flow rate required (for each of the buildings) during each hour of operation. The volumetric flow rate for each of the secondary chilled water pumps was then derived. Secondary chilled water pumps 1 and 2 serve only 1 building each (Denis Shepstone Building and Howard College respectively) and hence the volumetric flow rates for each them was easy to determine. Secondary chilled water pump 3 serves E. G. Malherbe Library and three other areas, and hence the volumetric flow rate was more laborious to estimate. It must be remembered that the total flow rates through these three pumps may not exceed the upper limit of 136.8 l/s.

The flow rates allow for calculation of the total volume of chilled water available at each hour in the tank. The available volume must never be allowed to drop below zero. It must also be remembered that an excessive storage of chilled water will increase the amount of heat gained (stored cooling lost) from the surroundings.

The charging/discharging cycle was chosen to extend over the 24-hour period starting at 10pm each night. The reason for this is that off-peak electricity is available for an 8-hour period, from 10pm onwards. It was desired to co-ordinate the inflow rates in such a way that the stored cooling volume approached zero at the end of the cooling cycle. The inflow rates were also always co-ordinated to achieve the lowest cost of cooling the water.

The overall cooling load estimate for each building is reflected in Appendix 7. The total flow rate required through the air-handling units of each building was calculated. The flow rate depends on the increase in water temperature as it passes through the air-handling units of each building. Chilled water flow rate estimates are shown in Appendix 8 for temperature gains of 7, 8 and 9^0 C. The values in these tables show the necessary flow rates to maintain the internal design conditions in each of these buildings.

The flow rates are in units of l/min. The maximum allowable flow rate is thus 8208 l/min (136.8

l/s). It is obvious that the volumetric flow rates for each of these temperature differentials do not exceed this limiting value. The flow rate must, however, increase as the temperature differential across the building load decreases. This is one reason to maximize the temperature differential across the air-handling units in each building. In reality, a problem is encountered in that certain minimum chilled water flowrates must be maintained to ensure water flow to all air-handling units. During conditions of low cooling load the temperature differential may drop below desirable values.

The first aim of this chapter was to determine how the chillers should be scheduled to continually meet the cooling demand of the buildings at the lowest cost. The first step was to evaluate how the cost of electricity varies over the 24-hour cycle. The high demand and low demand periods both have;

- 8 hours of electricity @ off-peak rates (Cheapest)
- 11 hours of electricity @ standard rates (Intermediate)
- 5 hours of electricity @ peak rates (Most expensive)

For both the high and low demand periods, off-peak rates extend from 10pm to 6am. It thus makes sense to choose 10pm as the starting point for the analysis of each charging/discharging cycle. The chillers supply water at a rate of 1920 l/min (32 l/s). A summation of the cumulative required flow rates is shown in Appendix 8. In the case of February, this value was found, for a temperature differential of 8^0C, to be 57803.4 l/min.

The number of hours for which chillers should run during a day to provide sufficient chilled water is given by

Chiller Hours = (Cumulative flow rate) / (Chiller Flow Rate)

Hence, $\text{Chiller Hours}_{\text{February}}$ = 57803.4 / 1920 = 30.11

This value is rounded up to 31

The author is aware that the above calculation is not, strictly speaking, mathematically valid in terms of the units used. It does, however, save multiplication, followed immediately by division by the exactly the same factor.

$$\text{Chiller Hours} = \sum_{i=1}^{3} (Hours_i) \qquad (7\text{-}1)$$

There are 8 hours of off-peak electricity, and 3 chillers, available. This means that 24 off-peak chiller hours are available. It is obvious that as many of the total required chiller hours as possible should be obtained during this off-peak period. There is, however, still a shortfall of 7 chiller hours after the off-peak period. It is logical also that these chiller hours be obtained during the standard period, rather than the peak period.

A choice was required regarding the composition of these additional chiller hours. The question arose as to whether it is better to run all 3 chillers for a shorter duration, or 1 chiller for all 7 hours. In practice, the district cooling system facilities managers (FMG) prefer to run 1 chiller for all 7 hours, as long as this does not result in use of electricity priced at peak rates. The reason for this is that the chillers may then be cycled. In other words, each chiller will be required only once every 3 days. Also, peak current is generated at start-up, hence a reduction in the ratio of number of starts to total running duration will help extend operating life, and also help reduce maintenance costs.

For February, it was decided to run all 3 chillers for 8 hours (during off-peak billing), and run 1 chiller for 7 hours (during standard billing). The best measure of stored cooling is the volume of chilled water remaining in the tank. The tank is rectangular in cross-section, and therefore has a constant area of 592.41 m^2. The height of the thermocline above base level of the tank may, therefore, be used as a measure of the amount of stored cooling remaining.

The thermocline height is shown as a function of time in Figure 7.1. Note that the start of the charging cycle is 10pm.

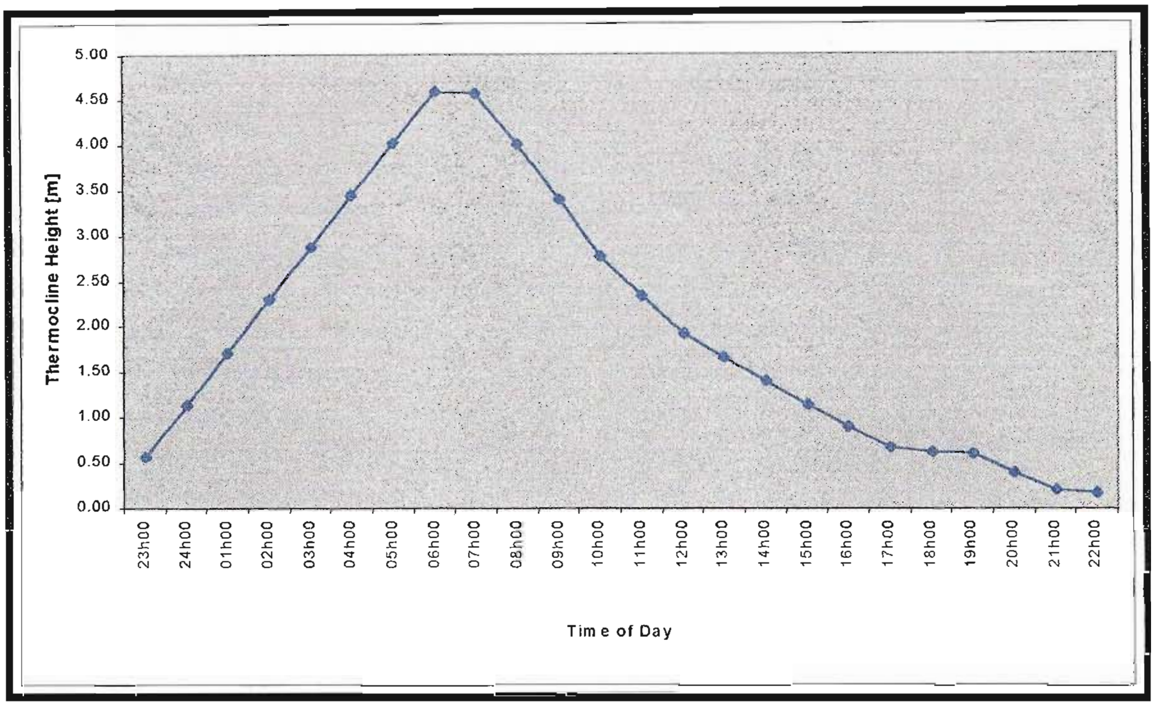


Figure 7.1: Thermocline height as a function of time for February.

It may be seen how the objectives of chiller scheduling have been met. At no stage does the thermocline height drop below zero, which would imply that no chilled water is available to meet demand. In addition, the thermocline height (and hence the stored volume) is minimal at the end of the 24-hour cycle, finishing at a height (volume) of almost zero.

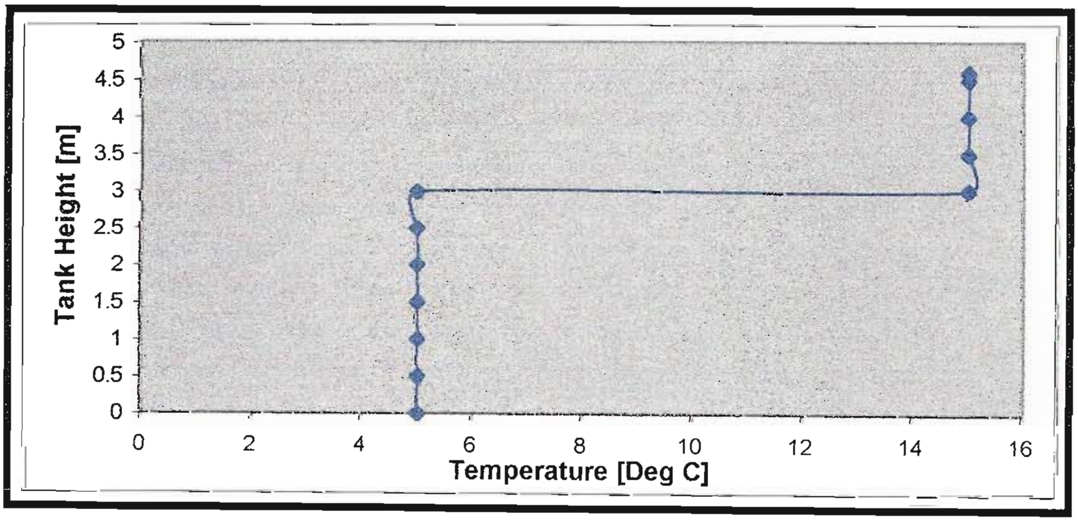


Figure 7.2: Idealised temperature profile through the storage tank for a thermocline height of 3m

The tank temperature profile was also derived. Assuming a thermocline height of 3m, and negligible thermocline thickness, the temperature profile in the tank would look approximately as shown in Figure 7.2.

7.3 The practical situation

In section 7.2, the thickness of the thermocline was always assumed negligible. The thermocline does, however, have a finite thickness, which reflects the change in water temperature from chilled (5^0 C) to warm (15^0C). The thermocline thickness varies from 0.3m to 1.0m, depending on diffuser design and the age of the thermocline. It was assumed (reasonably) that the thermocline thickness was zero at the start of the charging cycle. A further assumption was made that the thermocline thickness would reach a maximum value of 0.5m. This was due to the charging cycle being fairly frequent (daily), and the temperature differential fairly small (10^0C).

Figure 7.3 illustrates the modification in chiller scheduling required to accommodate the thickness of the thermocline. Whereas in Figure 7.2 the restriction was that the thermocline height should not drop below zero, in Figure 7.3 the criterion is that thermocline height should always lie above 0.5m. Again, it was desired that the thermocline height should near it's minimum value at the end of the discharging cycle, which was accomplished. The simplest way to model the thermocline height was to use a spreadsheet to take into account inflows and outflows of chilled water.

It was found that, in order to meet criteria, 33 chiller hours were required. This represents an increase of 2 chiller hours. The same scheduling approach was used, with as many chiller hours as possible being obtained during off-peak billing periods. The chiller schedule consisted of 24 off-peak chiller hours (3 chillers for 8 hours), and 9 standard chiller hours (1 chiller for 9 hours).

Data of the required composition of chiller hours, as well as the thermocline heights for each hour of the day are included in Appendix 8.

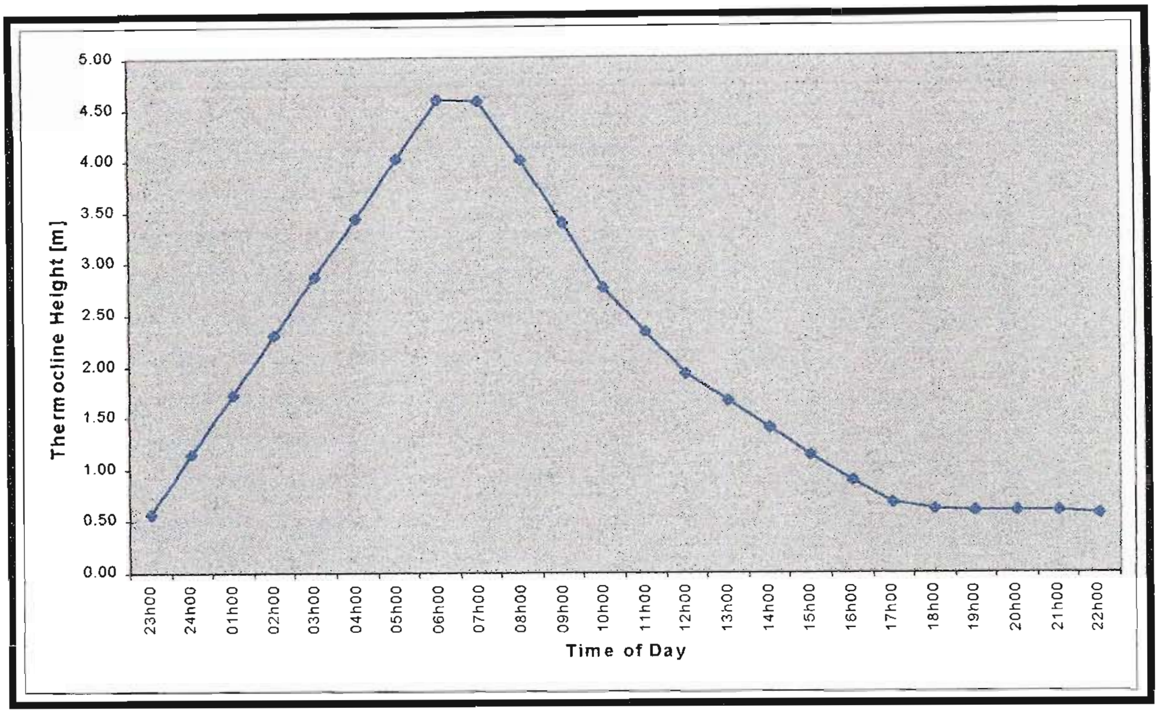


Figure 7.3: Thermocline height as a function of time, assuming a thermocline thickness of 0.5m

7.4 Power consumption of the secondary chilled water pumps

The chiller scheduling was discussed in the preceding sections. The thermocline profiles were stated to depend on the outflow rate of chilled water. Thus far, no mention has been made of the power requirements to move chilled water from the central location (storage tank) to the point of use (individual buildings). Allowance must be made for this power requirement.

There are two important points to note. Firstly, the exact routing of the chilled water piping is badly documented. It is not recorded on drawings, and the best description of routes followed is derived from photographs. Secondly, the power consumption calculated is only the power needed to pump the chilled water from the storage tank to the end user. No allowance was made for power required to move chilled water to various air-handling units within each building. If cooling were obtained from chillers within each building the users would still be required to pump chilled water to air-handling units within the building. Water movement within each building structure is therefore a cost associated with both district cooling and localised cooling. As a result it has not been considered in this study.

There are two types of pressure loss associated with fluid flow in pipes.

7.4.1 Pressure loss due to friction

There are numerous equations presented by Ashrae [26] governing the loss of pressure due to friction between the fluid and piping. It was found that the easiest method of approximating these losses was by means of Figure 7.4. Using the pipe diameter and flow rate (in units of l/s) it was possible to obtain a rough estimate of the pressure loss due to friction.

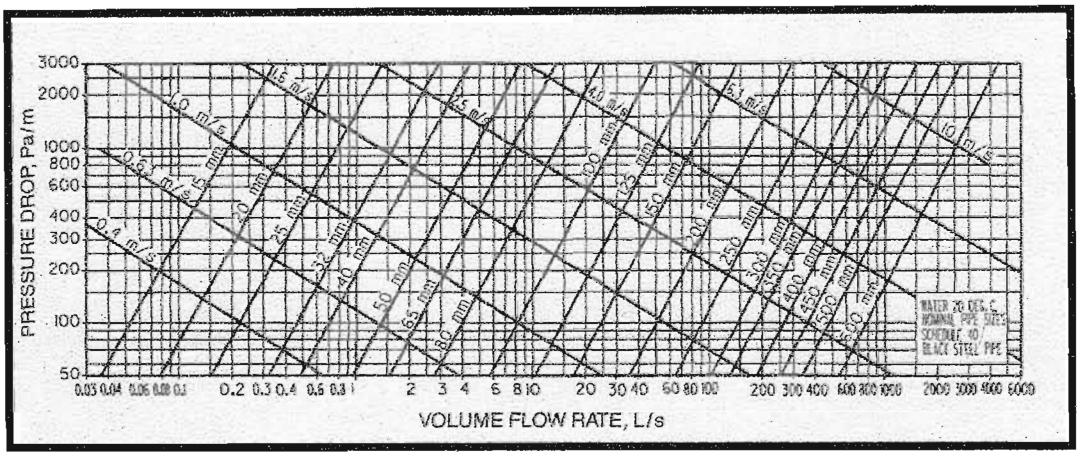


Figure 7.4: Chart used to obtain friction loss for secondary chilled water piping, courtesy of ASHRAE [26]

The chart is designed for water at 20^0C, and the use of Schedule 40 black steel piping. Given the lack of precision in the measurement of piping length and path, however, it was felt that the use of Figure 7.4 would constitute a relatively minor error.

Secondary Chilled Water Pump	Total Pipeline Length [m]	Pipeline Diameter [mm]
1- Shepstone Pump	200	200
2- Howard College Pump	60	80
3- E. G. Malherbe Library Pump	240	80

Table 7.1: Secondary chilled water pipeline data for district cooling system

Figure 7.5 represents the friction loss for each of the three pipelines graphically. It must be remembered that the output from Figure 7.4 is the friction loss in units of Pa/m. Multiplication of the drop per unit length by the pipeline length (Table 7.1) gives the pressure drop in Pascals. The pipeline length includes both the pipe from the tank to the building, and the return pipe

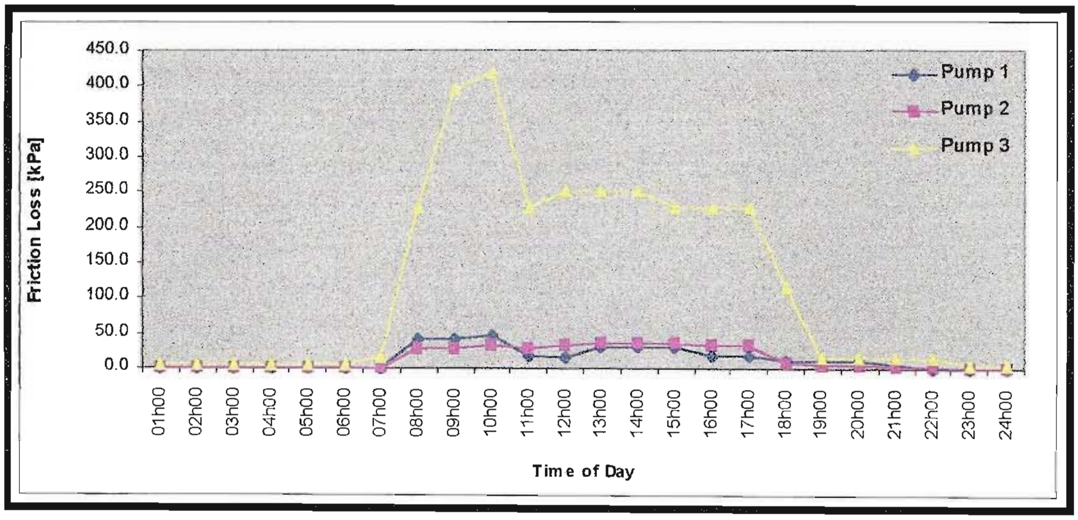


Figure 7.5: Friction losses for each secondary chilled water pipeline

The friction losses in Figure 7.5 have been converted to units of kPa to reduce their magnitudes.

7.4.2 Pressure loss due to pipe fittings

The second type of pressure loss associated with pipelines is a loss due to fitting such as t-pieces and bends. This pressure loss is governed by equation 7-2.

$$\Delta p = (k)(\rho)\left(\frac{V^2}{2}\right) \qquad (7\text{-}2)$$

Where: Δp = Pressure drop [Pa]

k = Loss Coefficient

V = Velocity [m/s]

It was assumed that each pipe-length would be fitted with 6 90^0 elbows. The assumption regarding the pipe layout is probably flawed, but some assumption was required to obtain numeric values. K values were obtained from Ashrae [26] as 0.27 for 200mm, and 0.34 for 80mm diameter piping. The validity of this assumption is difficult to quantify for the same reason that friction loss is difficult to estimate accurately (the pipeline route is very badly documented).

The fitting losses for each pipeline are shown in Figure 7.6, again in units of kPa.

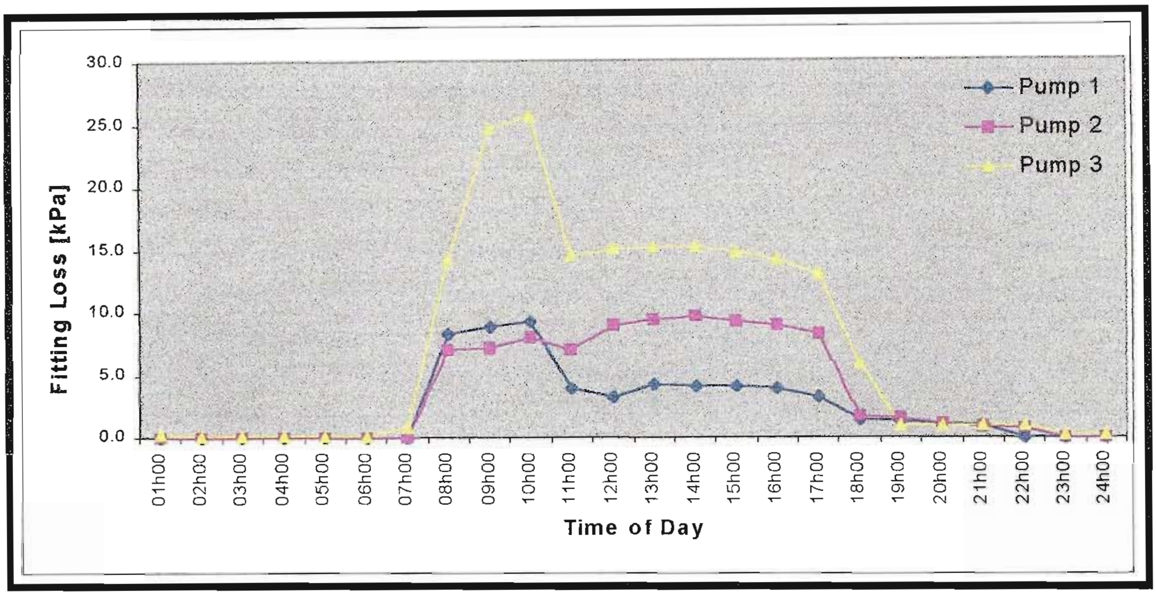


Figure 7.6: Fitting losses for each secondary chilled water pipeline.

It may be seen that the same trends apply to both Figure 7.5 and 7.6. Although the E. G. Malherbe pipeline does not necessarily carry the largest flow of chilled water, the pressure drop in this pipeline is far greater than either of the other two. The shape of each curve can be justified. Losses are very small (or zero) during periods of low cooling load, and increase sharply during the day as cooling load increases.

7.4.3 Total pipeline loss

The total pipeline loss (as considered in this study) is the sum of the losses due to friction, and those due to fittings.

7.4.4 Power requirements of pipelines

Equation 7-3 relates the power required for fluid flow to the total pressure loss and volumetric flow rate of the piping system.

$$P = (\Delta p)(\dot{V}) \qquad (7\text{-}3)$$

Where P = Power required [W]

Δp = Total pressure loss [Pa]

$\dot{V}$ = Flow rate [m^3/s]

7.4.5 Power consumption of each secondary chilled water pump

The power calculated from (7-3) is the amount of power required to transport the fluid through the pipe. The power drawn by each pump is the required power divided by the efficiency of the pump.

The efficiency of each secondary chilled water pump was assumed constant because each is fitted with a variable speed drive to maintain efficiency close to peak design values.

The power drawn by each of the secondary chilled water pumps is shown in Figure 7.7.

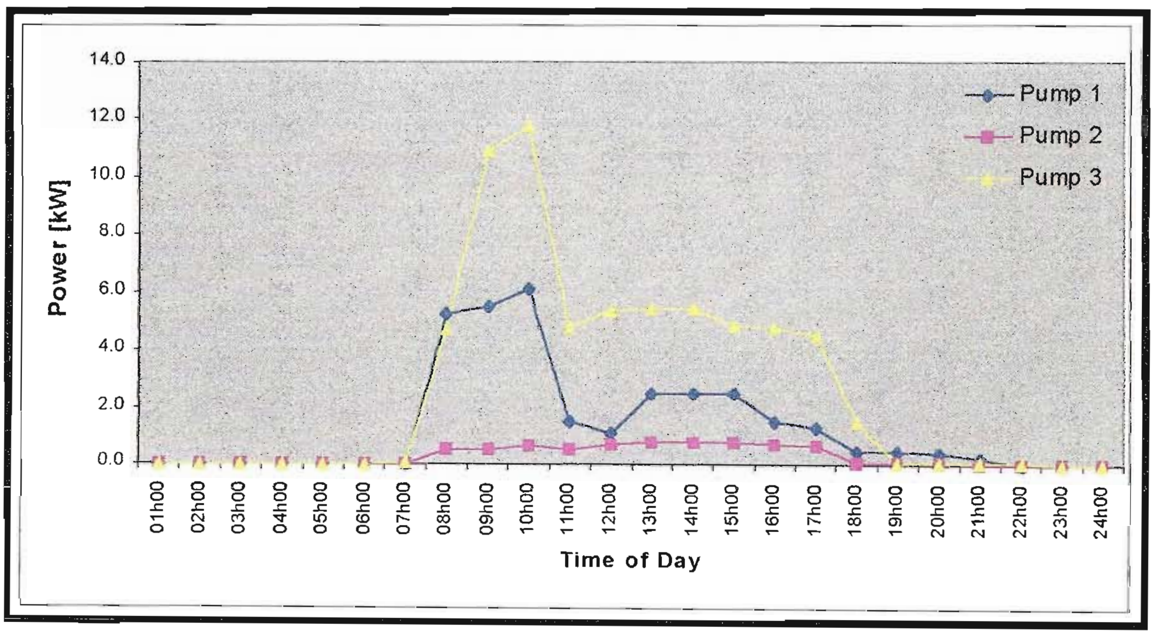


Figure 7.7: Power consumption of each secondary chilled water pump

The same trends that were discussed in 7.4.2 are applicable to Figure 7.7. The important factor to note, however, is the magnitude of power consumed by each of these pumps. There is a peak value of approximately 12 kW (Pump 3). This is very small compared to values of thousands of kilowatts associated with the chillers.

The result is that the power consumption due to water pumping from one location to another (in this instance) is so small that it may be neglected in the interests of simplicity. Although some simplifying assumptions were made regarding the characteristics of each pipeline, it was felt that neglecting the power consumption of these secondary chilled water pumps would not greatly influence the overall operating cost results for the district cooling system.

7.5 Power consumption of the primary chilled water pumps

The primary chilled water pumps transport fluid to the storage tank from Denis Shepstone Building. They are operational only when cooling of the chilled water is occurring. Essentially, the same quantity (mass) of water will be moved in a day by the primary chilled water pumps as by the secondary chilled water pumps.

It was concluded in 7.4.5 that the power consumption of the secondary chilled water pumps could be neglected. The power consumption of the primary chilled water pumps will also be neglected, for the same reasons. If anything, the cost of operating the primary chilled water pumps will be lower than that of the secondary pumps, because the primary pumps operate at the same time as the chillers, predominately at night when advantage may be taken of the off-peak electrical rates.

7.6 Power consumption of the chillers

The power consumption of the chillers forms the bulk of electrical usage by the district cooling system. The scheduling of the chillers assuming a thermocline thickness of 0.5m is shown in Appendix 8.

An estimate of the amount of power consumed by each of the chillers is relatively easy because the chillers only ever operate under conditions of full-load. This means that C.O.P. as a function of loading conditions is largely irrelevant, as we are interested in only one point on the graph. The C.O.P. at full loading is 5.

No Information was supplied regarding the power factor of the chillers currently installed on campus. An approximate value of 0.9 was used, as this was consistent with the other chillers considered in this study.

7.7 Cost of chiller operation

The cost to operate the three chillers according to the schedule in Appendix 8 (assuming a thermocline height of 0.5m) was calculated for each hour of operation. There are two components of the cost, the demand cost and the active energy cost, as described in section 2.13. Total cost is simply the sum of the demand and active energy costs.

It was assumed that little or no cooling would be required over weekends and that 24 chilling cycles would be required each month.

This information is summarised in Table 7.2 and Figure 7.8.

Month	Demand Cost [R]	Active Energy Cost [R]	Total Cost [R]
January	13633.70	23991.42	37625.12
February	13633.70	23991.42	37625.12
March	13633.70	23991.42	37625.12
April	15131.70	24563.06	39694.76
May	15131.70	18922.51	34054.21
June	15131.70	13595.90	28727.60
July	15131.70	12301.06	27432.76
August	15131.70	14890.75	30022.45
September	15131.70	21178.73	36310.43
October	13633.70	21963.12	35596.82
November	13633.70	23991.42	37625.12
December	13633.70	23991.42	37625.12
TOTAL	**172592.40**	**247372.22**	**419964.62**

Table 7.2: Cost of chiller operation for district cooling system

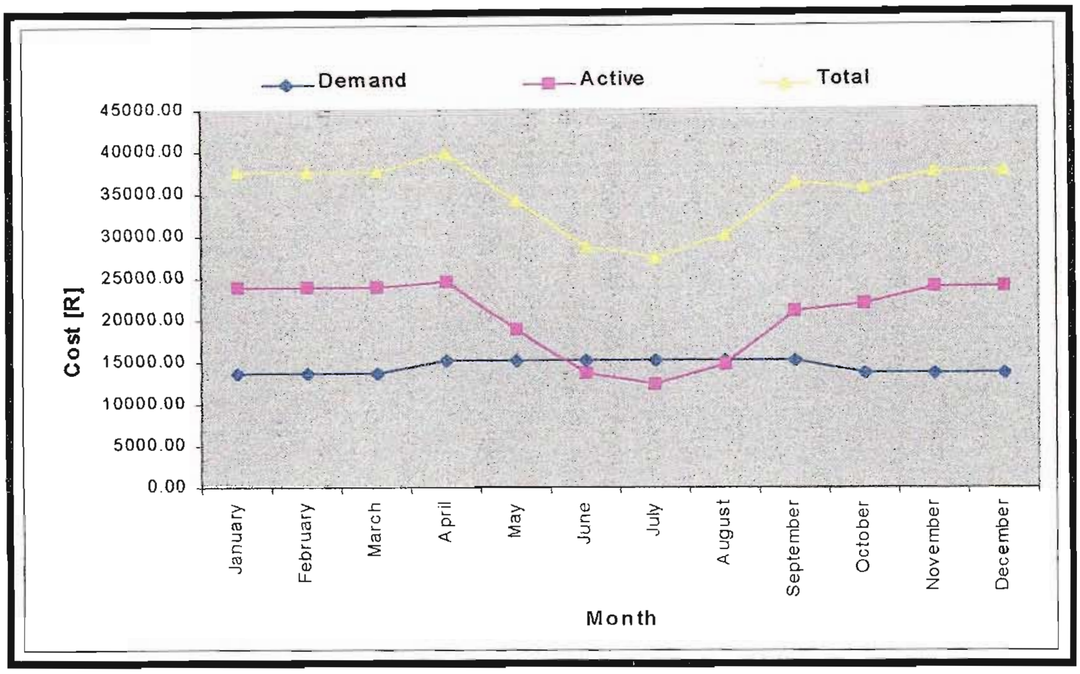


Figure 7.8: Cost of chiller operation for district cooling system

7.8 Maintenance costs

The costs considered thus far have only been the operating costs (in other words, the cost of electricity). Another cost to be considered is that of servicing and maintenance of the equipment associated with the district cooling system.

The information regarding the cost of maintenance for the three chillers, and the pumping equipment was obtained from FMG, the facilities managers entrusted with the operation of the district cooling system. The maintenance costs for the year are summarised in Table 7.3.

	Chiller Maintenance [R]	Pump Room Maintenance [R]
Annually	27780.00	11000.00
Monthly	2315.00	916.66

Table 7.3: Annual and monthly maintenance costs for the year

The total monthly maintenance cost of R3231.66 (R2315.00 + R916.66) was added to the total cost of chiller operation from Table 7.2. The result is an overall cost of district cooling system operation throughout the year, as shown in Table 7.4 and Figure 7.9.

Month	Overall Cost [R]
January	40856.78
February	40856.78
March	40856.78
April	42926.42
May	37285.87
June	31959.26
July	30664.42
August	33254.11
September	39542.09
October	38828.48
November	40856.78
December	40856.78
Total	**458744.54**

Table 7.4: Overall cost of district cooling system operation

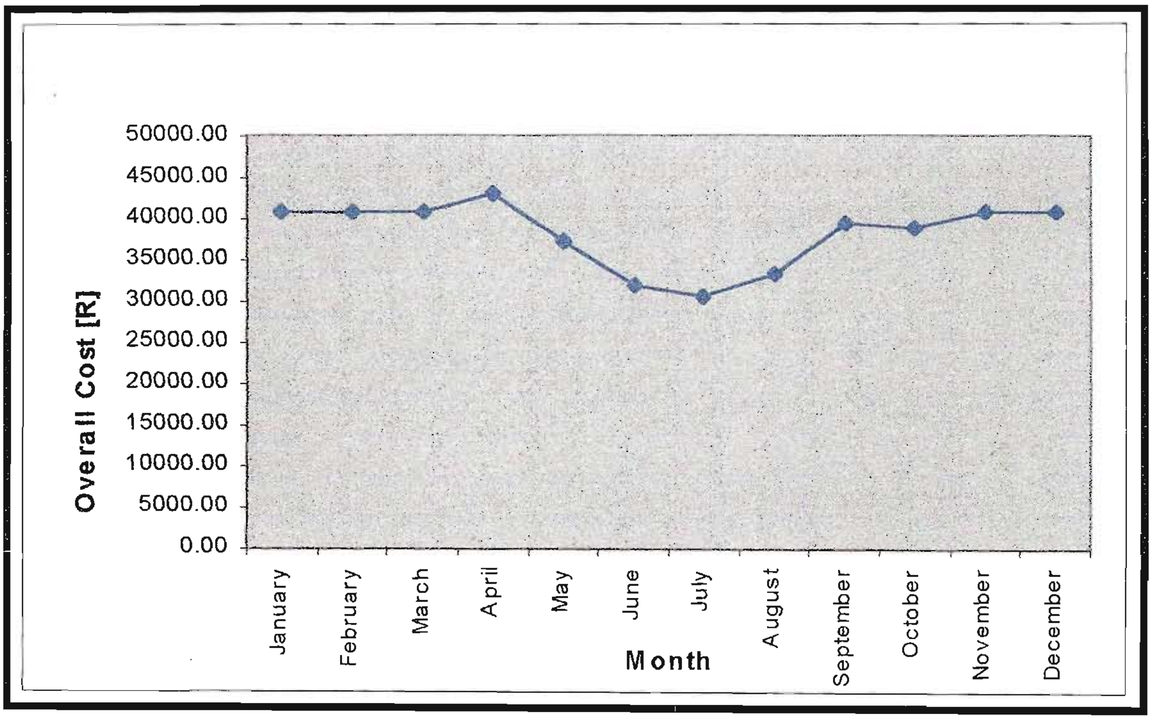


Figure 7.9: Overall cost of district cooling system operation

7.9 Capital costs associated with district cooling system

Chapter 7 has, thus far, been concerned only with the operating costs of the district cooling system. The operating costs are composed of cooling costs and maintenance costs, as described in 7.8. There are, however, fixed (capital) costs associated with the district cooling system. These arise from the purchase/construction of equipment such as the chillers, thermal storage tank, pipelines and variable speed drives.

No allowance was made for the cost of cooling towers, cost of chiller installation or pumping equipment. As will be shown in Chapter 8 the total installed cooling capacity for both types of cooling system is approximately equal. It was therefore thought reasonable to assume that the total installed cooling tower capacity (and hence cost) would be the same for both cooling systems. The same is true regarding the cost of chiller installation It was also assumed that the cost of pumping equipment would be roughly the same for both systems. This is because some of the pumps currently installed were part of the original cooling system on campus and therefore did not constitute a capital cost

7.9.1 Cost of cooling equipment.

The chillers selected in the UND district cooling system are manufactured by Trane, model RTHC E36A4A.

Model	Number Required	Unit cost [R]	Total Cost [R]
RTHC E36A4A	3	785000	2355000.00
Add 14 % VAT			329 700.00
Total			**2 684 700.00**

Table 7.5: Chiller costs for district cooling system on the UND campus

This information was supplied by Alder [30]. The cost of Trane Chillers is based on the Rand/Dollar exchange rate, the significance of which will be shown later.

7.9.2 Cost of thermal storage tank

The cost of the thermal storage tank was very kindly calculated by Mr. George Norval, based on a layout designed by Professor W. King, both members of the School of Civil Engineering at the University of Natal. An additional 10 percent was allowed for the design/installation of the diffuser and associated piping in the pump-house. This information is detailed in Appendix 9.

The total cost of the thermal storage tank was found to be R **1 135 597.20**.

7.9.3 Cost of secondary chilled water piping

The cost of piping (and insulation) of the size installed was supplied by Mr. Noel Smith of Richard Pearce and Partners.

Item	Length	Price [R/m]	Cost [R]
Pipelines 200mm	200 m	540/m	108000.00
Pipelines 80mm	300 m	278/m	83400.00
Piping cost			191400.00
Add 10% for Wastage			19140.00
Add 30% for Laying			63162.00
Add 14% VAT			38318.28
Total Pipeline cost			**503420.00**

Table 7.6: Piping costs for the UND district cooling system

7.9.4 Cost of variable speed drives

The secondary chilled water pumps are fitted with variable speed drives, which maintain high pumping efficiency, even as flow-rate changes. The total secondary chilled water pumping capacity is 158.5 kW. Mr. Sydney Parsons of Parsons & Lumsden (the designers of the district cooling system on the UND campus) estimated that variable speed drives cost R 1200 / kW.

The total cost due to variable speed drives is therefore R **216 828.00**.

7.10 Summary of capital costs associated with the UND district cooling system

The capital costs necessary to create the UND district cooling system were discussed briefly in 7.9. Table 7.7 summarises these capital costs

Item	Cost [R]
Chillers	2 684 700.00
Thermal storage tank	1 135 597.20.
Piping	503 420.00
Variable speed drives	216 828.00
Total	**4 540 545.20**

Table 7.7: Summary of the Capital costs associated with the district cooling system on the UND campus

7.11 Closure

This Chapter covers most of the important aspects regarding the district cooling system on the UND campus. This includes the operating strategy employed to ensure that adequate cooling is always available. It was explained how allowance must be made for the degradation of a thermocline over time. Incidentally, in practice, the coordinators of the district cooling system find that a total of 31 chiller hours is usually sufficient to provide adequate cooling in the summer. Our estimate of 33 chiller hours in 7.3 is relatively accurate. An implication of this fact is that the cooling load estimates derived in Chapter 6 must also reflect the actual operating conditions. The operating cost of the system is a sum of the cooling costs and the maintenance costs, both of which were calculated. As a conclusion to the chapter the capital costs associated with the district cooling system were obtained.

Chapter 8 will show how cooling could be provided to these buildings, by means of equipment in each building. This is a more traditional approach to cooling buildings, and was introduced in 2.4. Cooling by means of this approach will be discussed along the same outline as in Chapter 7. The aim is to contrast the two types of systems so that the economic benefit of the district cooling system (if any) may be quantified.

CHAPTER 8

PROPOSAL FOR INDIVIDUAL CHILLER UNITS

The history of the district cooling system was discussed briefly in Chapter 5. It was stated that the main reason for the establishment of a district cooling system on the UND campus was that a shortfall in cooling capacity was experienced. As was explained in Chapter 3, cooling capacity must be sufficient to meet cooling load at any given time, in order to maintain internal conditions at design levels. In the case of the University of Natal most air-conditioning is comfort air-conditioning. A lack of cooling capacity would mean that offices and lecture theatres become warmer and/or more humid than desired.

Chapter 7 discussed the operation, the scheduling parameters and the cost of operating the district cooling system on the UND campus. In addition, the capital costs were calculated. The purpose of this chapter is the proposal of another means of cooling each of the buildings served by the district cooling system. An alternative to the district cooling system would be for each of the 6 buildings to have a self-contained cooling plant serving only that building. It must be remembered that cooling used to be supplied from self-contained cooling equipment in each building on the UND campus. The choice of cooling plant is dictated largely by cooling load, and by economic considerations. Firstly, the cooling plant must be sufficiently large to meet the maximum expected cooling load. Secondly, the plant should provide cooling as efficiently as possible. This is based largely on the C.O.P. value of the plant.

Consideration must, however, be paid to the shape of the cooling load curve. Some buildings may have a relatively flat load curve, meaning that the plant is operating at peak load for a large portion of the time. Other buildings may experience sharp cooling load peaks of very low duration. In the latter case the cooling plant would be operating at partial load for a greater percentage of the time than at full load. The cooling plant should be selected based not only on the full load C.O.P., but also the partial load values.

In this study, it was desired to utilise screw compressors as far as possible, simply for some degree of conformity. In addition chiller information was obtained mostly from Carrier [27], due largely to their very informative electronic product catalogue [28]

Cooling equipment was selected for each of the buildings served by the district cooling system. The selection was based largely on the peak cooling load of each building in February. As was stated earlier, the partial load C.O.P. values are very important.

Following the proposal to investigate the suitability of individual cooling equipment in each building, these are the most important criteria when selecting the equipment

- Peak cooling load for February
- Model selected
- Cooling capacity of unit
- Number of Units required
- Full load C.O.P.
- Purchase price in Rands (excluding VAT)
- Power Factor

Wherever possible a list of part load C.O.P. values was also obtained. It was impossible to relate chiller power factor as a function of loading. As a result, full load power factor was used in all calculations. In some instances (Denis Shepstone Building and Howard College) no equipment was available to exactly meet the peak cooling load. The safety factor used in Loadest cooling load calculations for the University (10%) meant that equipment could be selected with little or no overcapacity. This safety factor is roughly equal to the recommended overcapacity for cooling equipment. For example, the cooling capacity selected for Denis Shepstone is very slightly undercapacity according to Loadest. Selection of the next largest capacity equipment would have resulted in large overcapacity and, accordingly, a large increase in capital cost.

The following pages summarise this information for each of the 6 buildings.

8.1 Denis Shepstone Building

The following data, applicable to the selection of cooling equipment for Denis Shepstone Building, are summarised in Table 8.1 and Figure 8.1.

Peak Cooling Load in February	2528kW
Model Selected	Carrier 30HXC375
Cooling capacity of unit	1261kW
Number of units required	2
Full Load C.O.P.	4.80
Purchase price Excluding VAT	R1 055 326
Full load Power Factor	0.87

Table 8.1: Selection data for cooling plant to serve Denis Shepstone Building

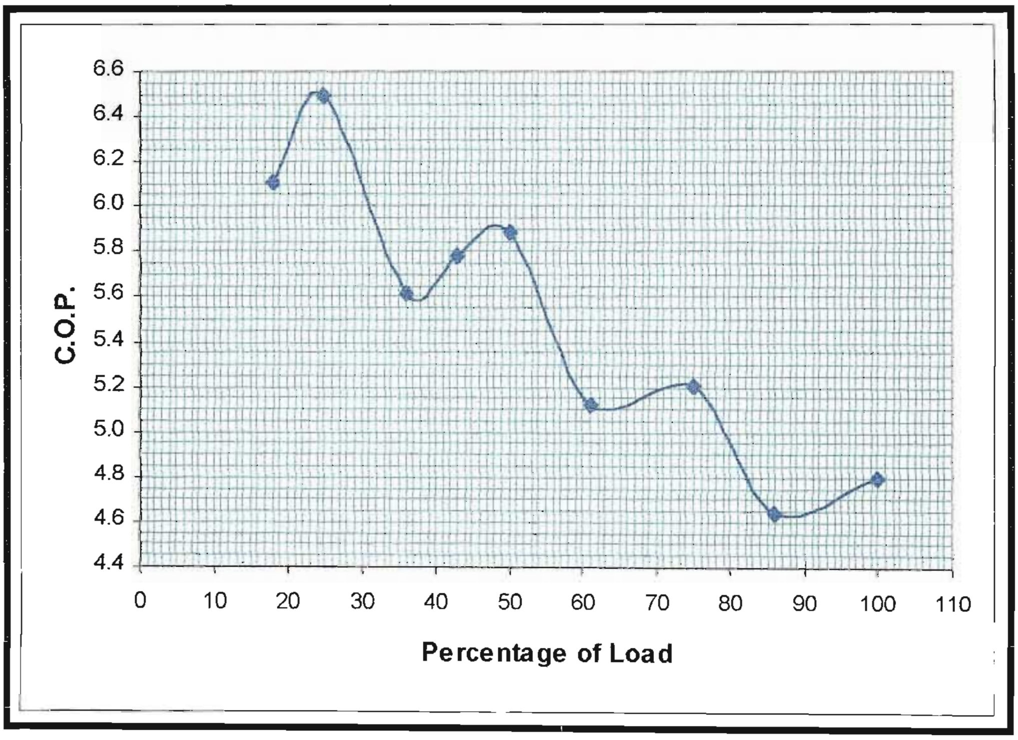


Figure 8.1: C.O.P. as a function of loading for Carrier model 30HXC375

8.2 Howard College

The following data, applicable to the selection of the cooling equipment for Howard College, are summarised in Table 8.2 and Figure 8.2.

Peak Cooling Load in February	366kW
Model Selected	Carrier 30HXC110
Cooling capacity of unit	367kW
Number of units required	1
Full Load C.O.P.	4.79
Purchase price Excluding VAT	R383 063
Full load Power Factor	0.87

Table 8.2: Selection data for cooling plant to serve Howard College

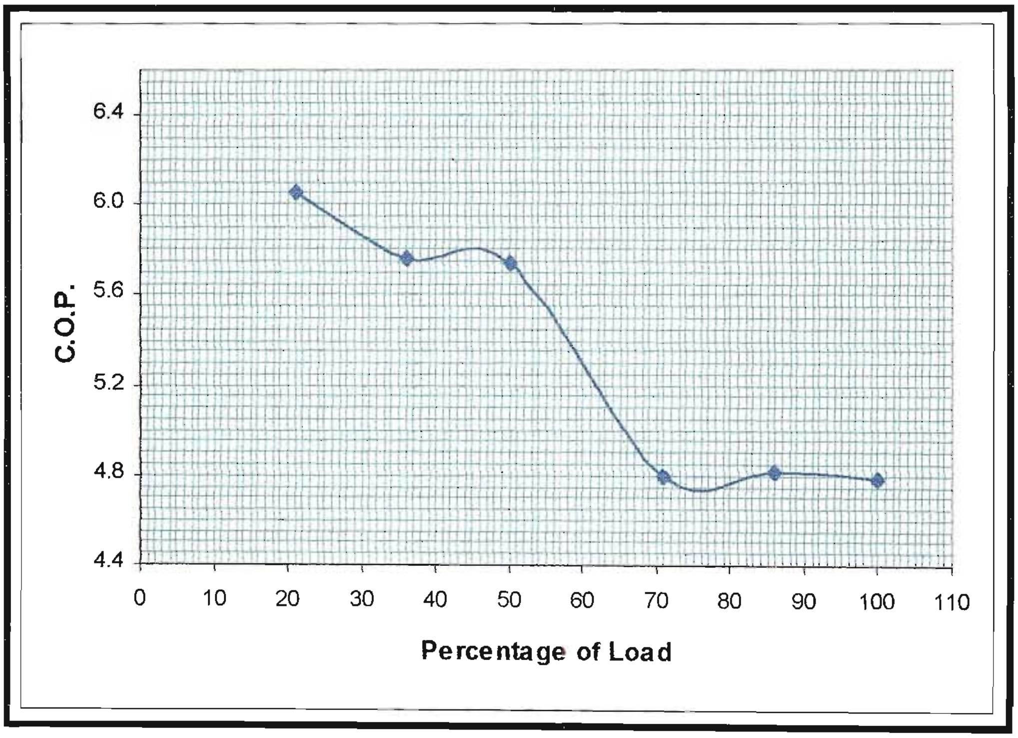


Figure 8.2: C.O.P. as a function of loading for Carrier model 30HXC110

8.3 E. G. Malherbe Library

The following data, applicable to the selection of the cooling equipment for the E. G. Malherbe Library, are summarised in Table 8.3 and Figure 8.3.

Peak Cooling Load in February	259.1kW
Model Selected	Carrier 30HXC080
Cooling capacity of unit	291kW
Number of units required	1
Full Load C.O.P.	4.97
Purchase price Excluding VAT	R310 967
Full load Power Factor	0.87

Table 8.3: Selection data for cooling plant to serve E. G. Malherbe Library

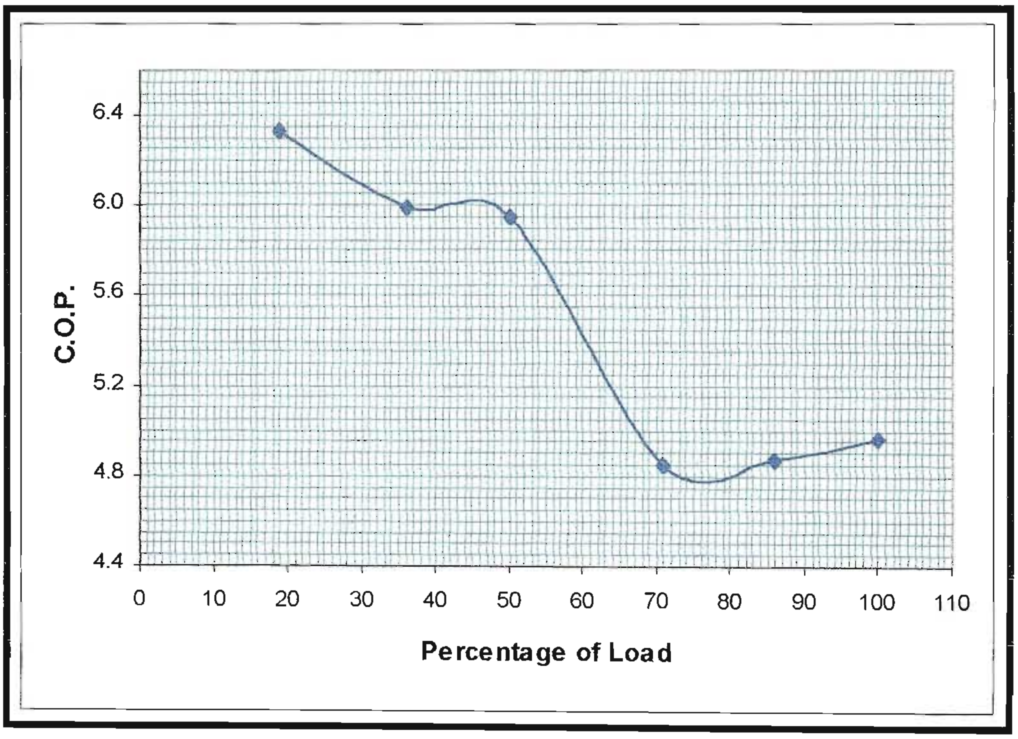


Figure 8.3: C.O.P. as a function of loading for Carrier model 30HXC080

8.4 The Business Concourse

The following data, applicable to the selection of the cooling equipment for The Business Concourse, are summarised in Table 8.4 and Figure 8.4.

Peak Cooling Load in February	208.9
Model Selected	Carrier 30GK082
Cooling capacity of unit	243kW
Number of units required	1
Full Load C.O.P.	2.94
Purchase price Excluding VAT	R421 880
Full load Power Factor	0.85

Table 8.4: Selection data for cooling plant to serve The Business Concourse

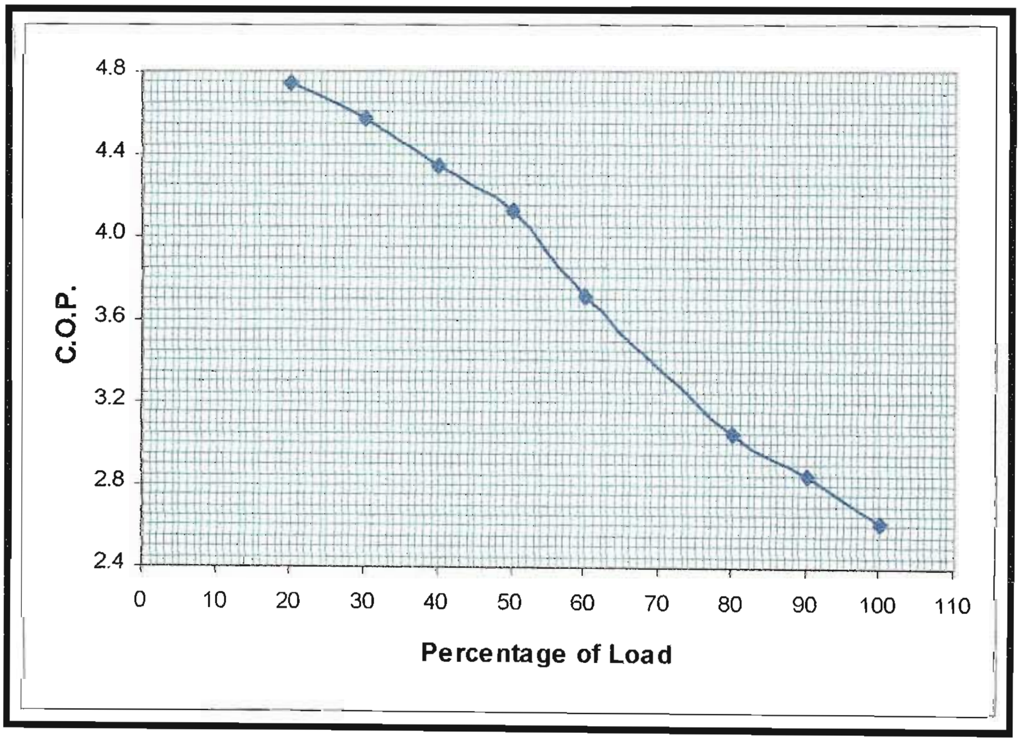


Figure 8.4: C.O.P. as a function of loading for Carrier model 30GK082

8.5 The New Chemistry Laboratory

The data applicable to the selection of the cooling equipment for the new Chemistry Laboratory are summarised in Table 8.5

Peak Cooling Load in February	106.5kW
Model Selected	Carrier 50HZ040
Cooling capacity of unit	112
Number of units required	1
Full Load C.O.P.	2.18
Purchase price Excluding VAT	R176 215
Full load Power Factor	0.9 (Assumed)

Table 8.5: Selection data for cooling plant to serve The New Chemistry Laboratory

8.6 Chemical Engineering Bulding

The following data applicable to the selection of the cooling equipment for the offices in the Chemical Engineering Building are summarised in Table 8.6.

Peak Cooling Load in February	26.9kW
Model Selected	Samsung AS12AOME
Cooling capacity of unit	3.52kW
Number of units required	8
Full Load C.O.P.	3
Purchase price Excluding VAT	R6 000
Full load Power Factor	0.9 (Assumed)

Table 8.6: Selection data for cooling plant to serve Chemical Engineering Building

No detailed performance data were available for the models Carrier 50HZ040 and Samsung AS12AOME. As a result the full C.O.P. was used in all calculations, even when operating only at part load. This is a source of error, but any discrepancy should be fairly minor, as each of these cooling units is relatively small.

8.7 Cost of operation for each individual cooling unit

The cost of chiller operation for the district cooling system was discussed in 7.7. A similar method was used to calculate the cost of operation for each of the cooling equipment selected earlier in this chapter. The cost of operation is a function of the cooling load and the equipment characteristics, and is summarised in Tables 8.7 to 8.9, and Figure 8.5.

The cost calculation for individual units was far more laborious than for the district cooling system because each unit may operate at partial load. It was mentioned that the district cooling system chillers almost invariably operate at full-load. The result is that C.O.P. is almost always constant. In the case of individual cooling equipment, however, the loading percentage may vary quite significantly, and each degree of loading is associated with a different value of C.O.P.

8.7.1 Demand cost

	Shepstone Building	**Howard College**	**Malherbe Library**	**Business Concourse**	**Chemistry Laboratory**	**Chem Eng**
January	8952.82	1155.30	825.70	1332.50	757.40	125.30
February	8921.29	1152.70	825.70	1255.10	739.60	122.10
March	8805.63	1151.50	825.90	1220.90	730.60	120.60
April	9634.80	1249.80	898.40	1183.00	760.50	117.70
May	7978.68	1088.10	570.80	814.00	661.30	93.30
June	6263.06	880.90	264.90	504.60	568.70	67.30
July	5753.80	766.60	129.30	432.00	539.60	60.40
August	6574.09	963.70	324.00	585.90	620.10	77.20
September	8937.83	1132.30	684.10	969.00	738.90	110.10
October	8652.89	1104.80	763.50	1109.80	715.60	113.50
November	8924.29	1151.40	825.90	1307.50	745.40	124.10
December	8964.58	1153.30	825.70	1383.20	759.10	126.20
Total	**98363.76**	**12950.40**	**7763.90**	**12097.50**	**8336.80**	**1257.80**

Table 8.7: Demand costs for each of the 6 buildings, assuming individual cooling units

8.7.2 Active Energy cost

	Shepstone Building	Howard College	Malherbe Library	Business Concourse	Chemistry Laboratory	Chem Eng
January	20912.20	4088.69	2872.50	2162.30	1812.90	291.70
February	20806.40	4070.81	2872.00	2049.40	1782.70	285.90
March	20464.70	4063.82	2872.60	2009.80	1766.40	283.50
April	26016.30	4658.45	3411.90	2262.60	2010.50	307.90
May	20790.90	3702.18	2095.80	1607.20	1729.70	245.30
June	17202.10	2625.82	930.70	1047.30	1460.50	179.40
July	14948.80	2222.11	376.00	888.20	1359.70	159.30
August	18309.30	2883.78	1181.70	1202.50	1589.10	203.70
September	23026.60	4059.94	2496.00	1864.10	1913.30	284.60
October	19843.20	3862.36	2637.50	1850.10	1718.20	267.40
November	20774.30	4066.26	2872.60	2121.60	1790.70	288.40
December	20900.60	4081.91	2869.30	2226.20	1815.90	292.90
Total	**243995.40**	**44386.13**	**27488.60**	**21291.30**	**20749.60**	**3090.00**

Table 8.8: Active energy costs for each of the 6 buildings, assuming individual cooling units

8.7.3 Total cooling costs

The total cooling cost is simply the sum of the demand and active energy costs, which were found in 8.7.1 and 8.7.2 respectively.

	Shepstone Building	Howard College	Malherbe Library	Business Concourse	Chemistry Laboratory	Chem Eng
Jan	29865.02	5243.99	3698.20	3494.80	2570.30	417.00
Feb	29727.69	5223.51	3697.70	3304.50	2522.30	408.00
Mar	29270.33	5215.32	3698.50	3230.70	2497.00	404.10
Apr	35651.10	5908.25	4310.30	3445.60	2771.00	425.60
May	28769.58	4790.28	2666.60	2421.20	2391.00	338.60
Jun	23465.16	3506.72	1195.60	1551.90	2029.20	246.70
Jul	20702.60	2988.71	505.30	1320.20	1899.30	219.70
Aug	24883.39	3847.48	1505.70	1788.40	2209.20	280.90
Sep	31964.43	5192.24	3180.10	2833.10	2652.20	394.70
Oct	28496.09	4967.16	3401.00	2959.90	2433.80	380.90
Nov	29698.59	5217.66	3698.50	3429.10	2536.10	412.50
Dec	29865.18	5235.21	3695.00	3609.40	2575.00	419.10
Total	**342359.16**	**57336.53**	**35252.50**	**33388.80**	**29086.40**	**4347.80**

Table 8.9: Total costs for each of the 6 buildings, assuming individual cooling units

8.7.4 Maintenance costs

The topic of maintenance costs was discussed briefly in 7.8, with regard to the district cooling system. The maintenance costs were found to be R27 780 for equipment totaling 4035 kW (3 x 1350 kW). This corresponds to a maintenance cost of R6.88 per $kW_{installed}$ per year.

The same maintenance cost was used when considering cooling from individual units. There are, of course, differences between the two setups. For example cooling by means of individual units would require more units in total (14), and yet a smaller installed capacity (3559.16 kW).

There are, however, similarities, in that screw chillers were selected wherever possible. It was decided that spending more time trying to get a more accurate value for maintenance costs would be pedantic, and there are two reasons why it isn't justifiable. Firstly, maintenance costs are very subjective and, secondly, the amounts concerned are relatively small.

The maintenance cost for the year was found to be (R6.88/kW)*(3559.16kW)

= R24487.02

= **R2040.59/month**

8.7.5 Total operational cost for individual cooling

The total running (operational) costs for cooling by means of individual equipment was found by adding maintenance cost to total cooling cost, as was the case with the district cooling system. This information is summarised in Figure 8.5.

The term "Total 1" refers to total cooling costs, the cost only of electricity used in cooling. The term "Total 2" is analogous to total operational cost, the sum of both cooling cost and maintenance costs

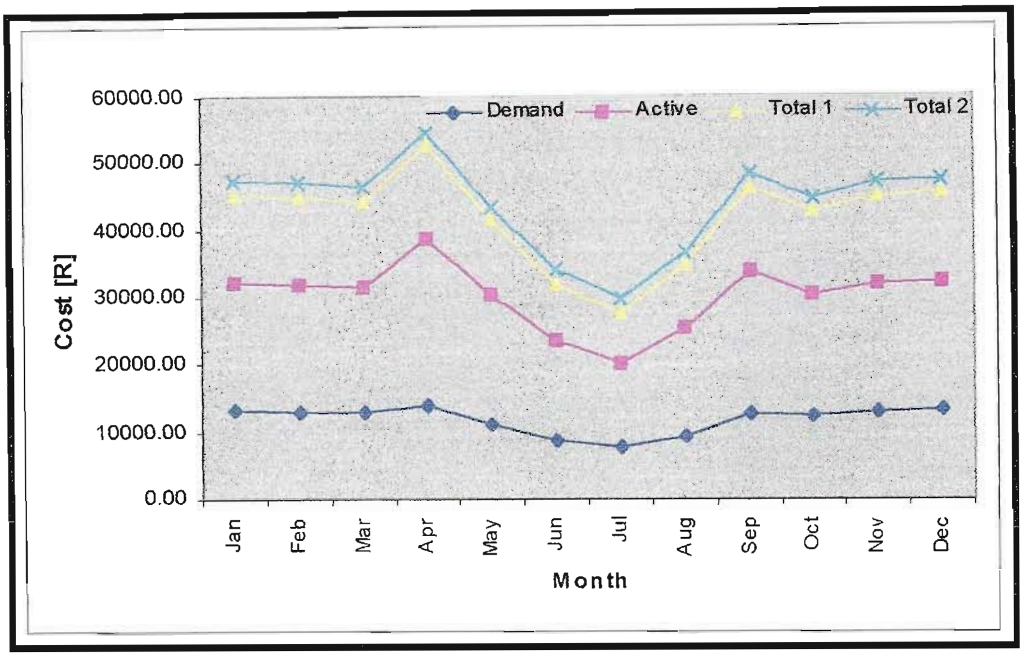


Figure 8.5: Total operational cost for cooling of the 6 buildings, assuming individual cooling

8.8 Capital costs associated with cooling through the use of equipment in each building

Chapter 7 concluded with an analysis of the capital costs associated with the district cooling system. In a similar way, the capital costs associated with cooling through individual equipment in each building will also be analysed.

The only capital costs found to be specific to this type of cooling were the cost of the equipment itself. No additional pipelines or tanks were required in this instance. The equipment costs were shown in Tables 8.1 to 8.6. This information is reproduced in Table 8.10, as a summary.

It must be remembered that the cost of Carrier equipment is based on the Rand/Euro exchange rate. The significance of this fact will be illustrated in Chapter 9. Chapter 9 will compare the information contained in Chapter 7 and 8. This comparison will answer the question of which method of cooling (district or individual equipment) is economically favourable.

Item	Number	Price [R]	Cost [R]
30HXC375	2	1055326	2110653
30HXC110	1	383063	383063
30HXC080	1	310967	310967
30GK082	1	421880	421880
50HZ040	1	176215	176215
AS12AOME	8	6000	48000
Total before VAT			3450778
Add 14% VAT			483109
Total after VAT			**3933887**

Table 8.10: Summary of the cost of cooling equipment selected to cool each building

CHAPTER 9

COMPARISON BETWEEN DISTRICT COOLING & COOLING FROM INDIVIDUAL UNITS

The title of this dissertation is "economic evaluation of a district cooling system incorporating thermal storage". Two types of cooling systems have been presented in Chapters 7 and 8, the district cooling system, and a more conventional approach in which each building is cooled by means of it's own cooling equipment. The operating and capital costs have already been derived, but are summarised again in Table 9.1.

	District Cooling	Individual Units
Yearly operating cost [R]	458 744.54	526 258.27
Capital cost [R]	4 540 545.20	3 933 887.00

Table 9.1: Cost summary of the two systems considered

9.1 Characteristics of the two systems

It may be seen that the district cooling system has a lower operating cost, offering a yearly saving of R 67 513.73. The district cooling system does, however, involve an additional capital outlay of R 606 658.20.

This argument is analogous to the purchase of a new car. A more fuel-efficient car may be more expensive initially, but delivers savings on running costs. In the same manner, the district cooling system is cheaper to operate. There are some simple mathematical formulae available to evaluate these savings.

9.2 Simple payback period

The simple payback period determines how many years are required to recoup capital expenditure. Payback period is governed by Equation 9-1.

$$\text{Simple Payback} = \frac{\text{Capital Outlay}}{\text{Yearly savings}} \qquad (9\text{-}1)$$

Based on the values in Table 9.1, the simple payback period is 9 years. The same information may be derived from Figure 9.1. This figure shows the accumulated cost (capital and operating) of each system, over the course of a ten-year period. It may be seen that the two curves intersect after approximately 9 years. This is in agreement with the result obtained through the use of Equation 9-1.

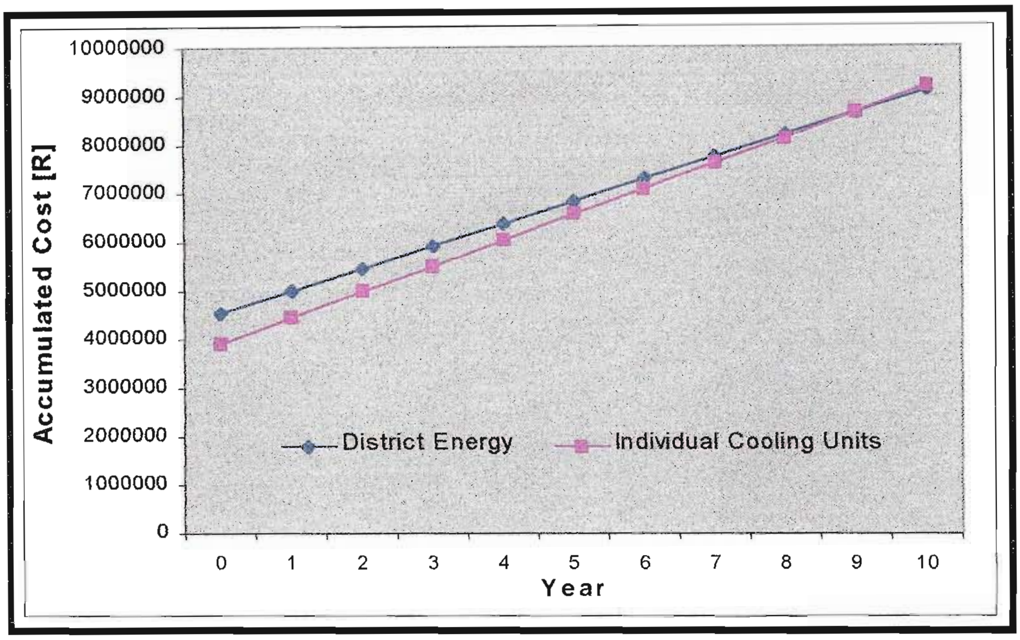


Figure 9.1: Accumulated cost for each of the cooling systems considered in this study

The result of the simple payback period seems quite attractive, suggesting that the capital outlay could be recovered within a decade. There is, however, a problem associated with the use of the simple payback period. The effect of interest and inflation rates is not taken into account. Capital expended in a project such as the district cooling system could be deposited into an interest earning bank account. Alternately, it may be necessary to borrow money from the bank to finance the scheme.

9.3 Life cycle cost analysis

Another method used in the viability evaluation of a capital expenditure project is life cycle cost analysis, often shortened to life cycle costing (LCC). LCC is a technique to establish the total cost of ownership of an asset. It is a structured approach, used to quantify each cost element over the anticipated lifetime of an asset. Gottschalk [29] suggests that a service life of 20 years be used for chillers. The lifespan of concrete tanks was not discussed but may, intuitively, be expected to be slightly longer. In this analysis it was assumed that a straight line depreciation of 20 years and 30 years existed for the cooling equipment and storage tank/piping respectively.

Total LCC = first costs plus all future costs (operating, maintenance, repair and replacement costs and functional-use costs) minus salvage value (value of an asset at the end of economic life or study period).

As explained by Rakhra [31], life-cycle costs are spread over a period of many years, and must be converted to a common value (present or annual value) in order to make them comparable over a period of time.

An LCC analysis requires the following steps;

1. Specify the objectives and constraints of the analysis.
2. Identify options to achieve the objectives.
3. Specify various assumptions regarding discount rate, inflation rate, economic life etc.
4. Identify and estimate relevant costs.
5. Convert all costs into constant dollars and to a common base.
6. Compare the total life-cycle costs for each option and select the one with the minimum total costs.
7. Analyse the results for sensitivity to the initial assumptions.

Steps 1 and 2 are dictated by the fact this study compares only two systems, district cooling and individual cooling. It was stated earlier that a service life of 20 years was assumed for both systems, although this may be slightly inaccurate. In the cooling cost analysis it was assumed that the cost of electricity would increase between 6% and 8% per year over this 20 year period. This was based on information from Durban Electricity personnel regarding tariff increases over the past few years. Maintenance costs were assumed to escalate between 6% and 10% per year. This value was based on government's inflation target of approximately 6%. The relevant costs for each system were calculated in the Chapters 7 and 8.

Cooling and maintenance costs for each of the 20 theoretical years were based on current costs, and adjusted via the following equation;

$$C_n = C_0 * (1+i)^n \qquad (9\text{-}2)$$

where C_n = Cost for year n

C_0 = Current cost (ie for year 0)

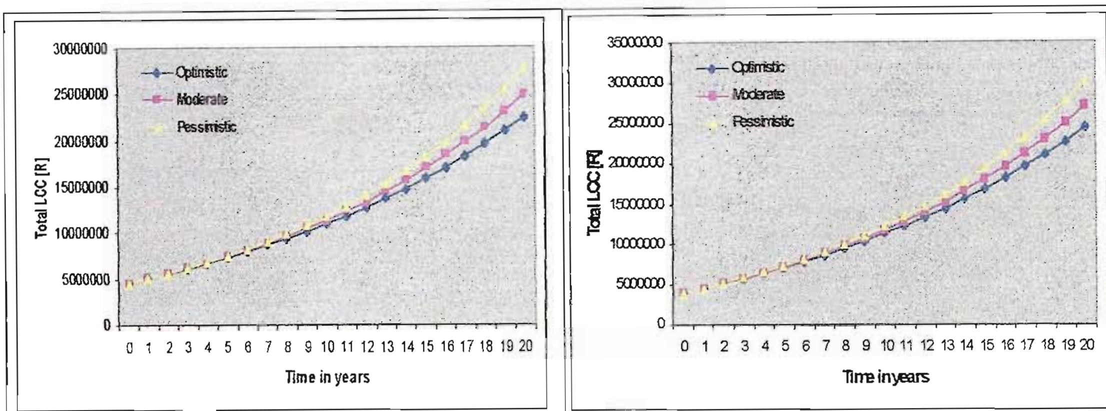
i = Cost escalation rate (linked to inflation)

n = year number

For each system the total life cycle costs were calculated for each year of operation. Three different economic scenarios were evaluated;

- Optimistic - Cooling cost and maintenance cost increases = 6% p.a.
- Moderate - Cooling cost and maintenance cost increases = 7% and 8% p.a. respectively
- Pessimistic - Cooling cost and maintenance cost increases = 8% and 10% p.a. respectively

The terms optimistic, moderate and pessimistic are very generic terms, used only to describe the general economic climate in South Africa. Figure 9.2 shows the total LCC for each of these 3 scenarios. The actual values are tabulated in Appendix 10.



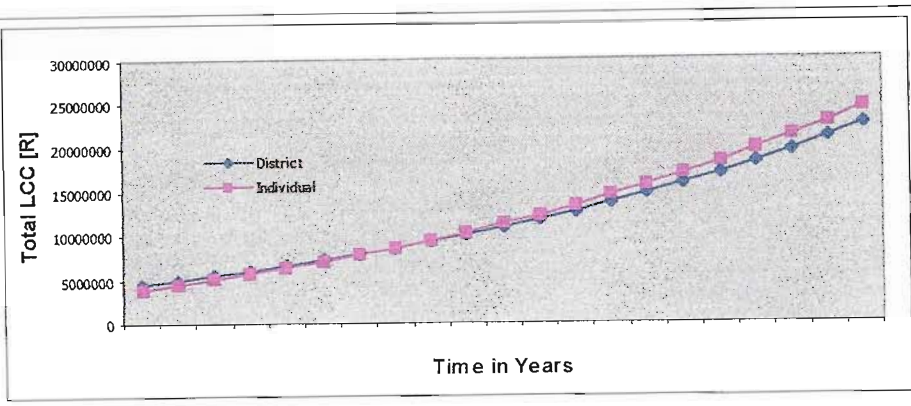
(a) District Cooling

(b) Individual Cooling

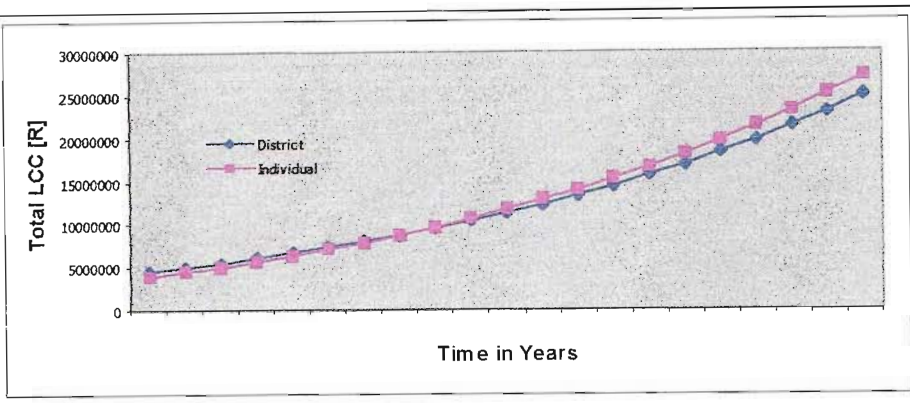
Figure 9.2 (a) – (b): Total LCC neglecting salvage value

The effect of inflation may be seen from the shape of the graphs. Those assuming higher inflation/cost escalation rates curve more steeply than those assuming optimistic economic conditions.

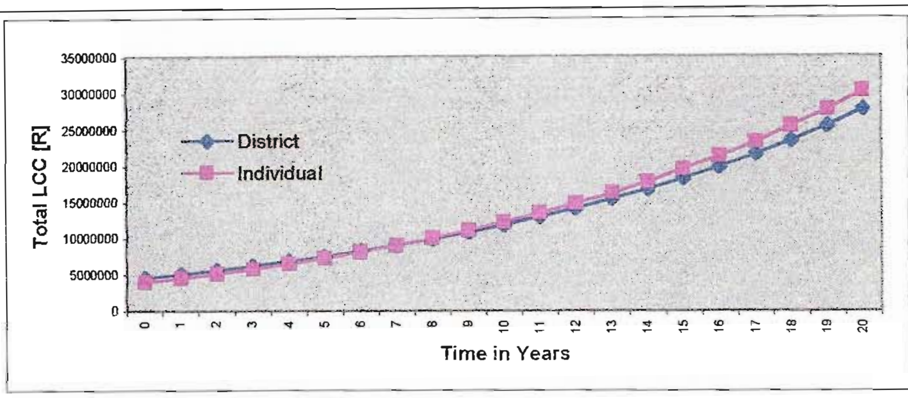
The total LCC may be compared for each of the three economic scenarios more effectively in Figure 9.3. The Total LCC graphs for both the district cooling system and the individual cooling option are plotted on the same set of axes. In Figure 9.3, however, no allowance was made for the salvage value of the equipment at any stage during the 20 year operating period. It was assumed that the salvage value of each system would be zero at the end of this period, with salvage value being irrelevant during the period.



(a) Optimistic



(b) Moderate



(c) Pessimistic

Figure 9.3 (a) – (c): Total LCC for optimistic, moderate and pessimistic outlooks neglecting salvage value

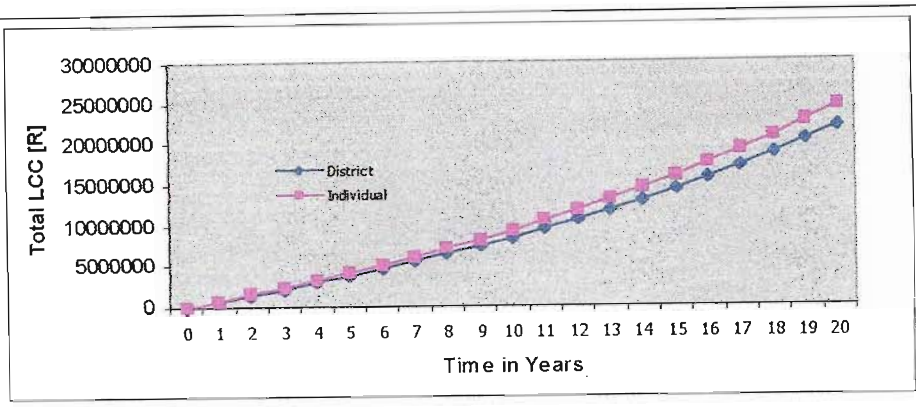
It may be seen that, in each graph, the curves have some initial total LCC (the capital expenditure) and thereafter slope upwards. This initial value is independent of economic outlook (fixed) but the slope of each curve is a function of yearly electricity and maintenance cost increases. In each instance the curves for district cooling and individual cooling options intersect. This intersection point occurs at a time period of between 6 and 7 years. It was noted that the larger the cost increases the sooner this intersection point occurred. It was found, however, that there was a relatively small variation in the time value at which this intersection occurred for each of the scenarios.

The curves show that prior to the intersection point the total LCC for the individual cooling option is lower than that for the district cooling option. At the intersection point the total LCC for each option is exactly equal. After the intersection point, however, the total LCC for the district cooling option is lower than that for individual cooling. This is because the yearly increases in cooling and maintenance cost have made savings in running costs more significant than the difference in capital costs. It is important to note that this intersection point (approximately 6 years) lies well within the lifespan of the two cooling systems (20 years). It was concluded that (neglecting salvage values) the district cooling system is economically preferable to the individual cooling system because total LCC benefits are recognised within the expected useful life of the equipment.

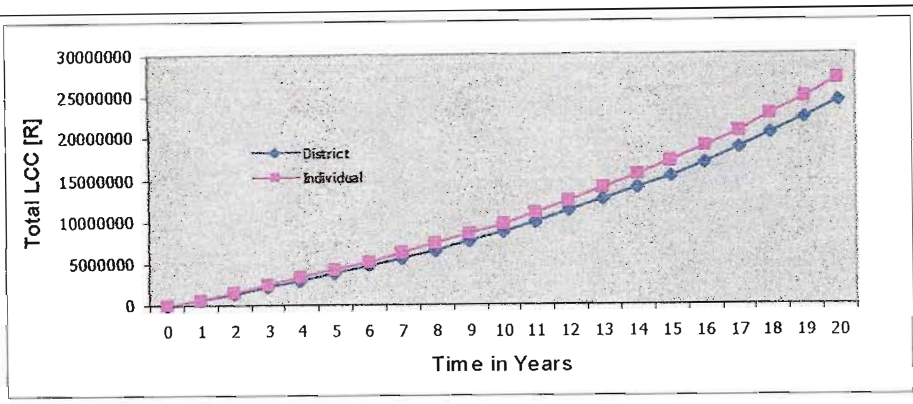
This analysis was then adjusted to reflect the salvage value of the equipment at any given time within the 20 year period. This was done by assuming that the cooling equipment would depreciate at a fixed rate over a 20 year period and that the chilled water storage tank would depreciate at a fixed rate over a 30 year period. These results are shown in Figure 9.4.

Figure 9.4 consists of 3 graphs, optimistic, moderate and pessimistic outlooks. As was the case in Figure 9.3 there are two curves for each graph, to compare the total LCC for district cooling and individual cooling systems. The graphs looks slightly different from those in Figure 9.3 because, although they have a similar shape as a function of time, they appear to start from a total LCC value of zero in each case. This is because the salvage value of the equipment was taken into account. At the start of the analysis period (time = 0) the only costs incurred had been the capital cost for each system. Only during and after the first year of operation would running costs begin to accumulate.

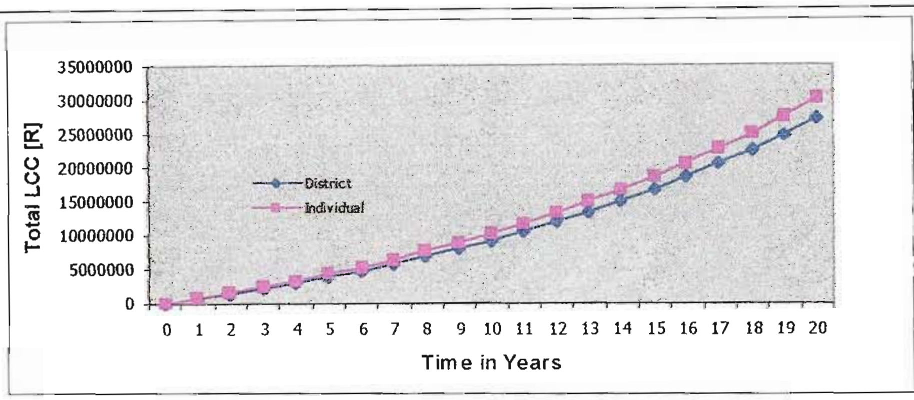
The salvage value of both the systems at time = 0 was assumed to be the total capital cost of each system. The total LCC cost at time = 0 is comprised of the capital cost plus the operational cost (which amounts to 0) less the capital cost (salvage value), and therefore amounts to zero. As time increases the total LCC increases due to operational costs and the fact that the salvage value decreases over time. The manner in which salvage value was taken into account is not strictly correct because no allowance was made for installation costs which would increase capital costs above what could ever be recovered as salvage value. This analysis did, however, afford a more comprehensive approximation of total LCC as a function of time.



(a) Optimistic



(b) Moderate



(c) Pessimistic

Figure 9.4 (a) – (c): Total LCC for optimistic, moderate and pessimistic outlooks taking into account salvage value

It may be seen that the curve of total LCC for the district cooling system always lies below that of the individual cooling option. This is due to lower operating cost and the fact that both options have an initial total LCC of zero. This is a slightly contrived situation, as the two curves would show more differentiation if the lifespans for the two systems under consideration were markedly different, or if installation costs could be more accurately accounted for.

The total LCC cost situation in this instance is best reflected by the graphs in Figure 9.3 which clearly illustrate differences in capital cost, the effect of increases in running costs and the point at which the total LCC for one system starts to increase above that of the other.

9.4 Exchange rate effects

As was stated in the introduction the World is in a state of intense disorder at the time of writing. Some of the major features include potential war in the Middle East, ongoing conflict in Israel and protracted striking in Venezuela. One of the repurcusions of all these factors has been turmoil in the area of exchange rates, as shown in Figure 9.5.

(a) Rand/Dollar exchange rate

(b) Euro/Dollar Exchange rate

Figure 9.5: Applicable exchange rates for this study

It may be seen in Figure 9.5 that the US Dollar has lost value against both the South African Rand and the Euro. The exchange rates used in this study were;

- 1 Dollar = R9.04
- 1 Euro = R9.64

It must be remembered that as the Euro gains value against the Dollar, goods which are priced in Dollars appear relatively cheap, and goods priced in Euros relatively expensive. This was the case in this study. The chillers installed in the district cooling system are manufactured by Trane and hence priced in Dollars. The cooling equipment selected for the comparative case were manufactured largely by Carrier and hence priced in Euros.

The result is that the district cooling system appears relatively cheap and the comparative system relatively expensive compared a year ago. It is therefore important that one realises that the merit of the district cooling system cannot be judged on a "once-off" basis. Should exchange rates continue to vary greatly, or should suitable equipment be available at favourable rates then the economic viability of the district cooling system would change.

CHAPTER 10

CONCLUSIONS

The aim of this dissertation was to investigate the feasibility of district cooling, a system which, in many situations, is enjoying increasing popularity. District cooling involves the replacement of cooling units in each building with a centralized cooling unit serving two or more separate buildings. This technology has the potential to realise many financial and environmental benefits. The University of Natal campus currently operates such a system, serving six buildings. Although the title focuses on economic feasibility, much of the dissertation concentrated on the background steps required before economic evaluation could be attempted. The actual economic comparison between district cooling and a conventional system is entirely theoretical in nature and aims to determine which system would be economically advantageous if a choice were to be made between these two systems at this point in time.

The first step towards accomplishing the objective was to determine the cooling load of each of these six buildings. Two theoretical methods were introduced for the calculation of cooling load, the TFM method and the CLTD/SCL/CLF method. These methods were found to be too time consuming to create realistic cooling load estimates of the buildings, hence a computer program, LOADEST, was selected for use. The accuracy of the cooling load estimates predicted by LOADEST was found to agree well with those predicted using the CLTD/SCL/CLF method. The reason for validating the LOADEST software was twofold. Firstly, the use of software should be justified by demonstrating good correlation with theory. Secondly, the validation process enhanced understanding of cooling load calculations and allowed for better interpretation of the results obtained from LOADEST. The only discrepancies discovered existed in the estimate of cooling load due to heat gain through external walls and solar gain.

The calculation of cooling loads for each building allowed a composite cooling load to be derived for the district cooling system as a whole. The cost of meeting this overall cooling load was determined. Also, the theoretical chiller scheduling required to meet the cooling load was found to accurately reflect actual operating practices. The cost of the capital equipment required for the district cooling system was also estimated.

The district cooling system was compared with a scenario whereby each building would be fitted with cooling equipment to serve only it's needs. The capital cost as well as the operating cost of this type of system was evaluated.

It was found that the district cooling system does meet the objective of reducing cooling costs. The conventional cooling system (whereby each building would contain plant to meet only it's own cooling load) was found to require lower capital costs.

The payback period (neglecting interest rates) for the district cooling system is approximately 9 years (Figure 9.1). A second method (total LCC) was also used to determine if the district cooling system were economically advantageous compared to a conventional cooling system. It was found that if equipment salvage values were neglected the total LCC costs for the district cooling system would be lower than that of the conventional system after only 7 years. It was estimated that the lifespan of cooling equipment is approximately 20 years. The conclusion was therefore that, if a new cooling system were required for the 6 buildings in this study, the district cooling system would be economically preferable to a conventional cooling system. This is because total LCC savings would be realised within the economic life of the equipment under consideration.

Taking salvage value of the cooling equipment into account during total LCC analysis showed that total LCC for the district cooling system would always be lower than that of a conventional cooling system. This result might have been different had it been within the scope of this study to more accurately quantify installation and salvage value costs.

Current exchange rates (Rand vs Dollar and Dollar vs Euro) were found to have influenced the total LCC of each system. It was concluded that the economic viability of a district cooling system is influenced by exchange rates and the choice of equipment vendor.

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APPENDICES

- Appendix 1 – Durban temperatures
- Appendix 2 – Cooling load estimates assuming full ventilation
- Appendix 3 – Cooling load estimates assuming zero ventilation
- Appendix 4 – Cooling load estimates taking into account ventilation diversity
- Appendix 5 – Estimates of instantaneous cooling loads
- Appendix 6 – Estimates of pull-down cooling loads
- Appendix 7 – Estimates of overall cooling loads
- Appendix 8 – Cumulative chilled water flow rates through the three secondary chilled water pumps
- Appendix 9 – Estimate of the capital cost to construct a 2750 m^3 thermal storage tank
- Appendix 10 – Life cycle cost analysis data

APPENDIX 1

DURBAN TEMPERATURES

- Monthly temperatures for Durban, as used in Loadest
- Actual average monthly temperatures for Durban

All values are in degrees Celsius

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
01h00	23.2	23.2	23.2	22.2	20.2	17.7	17.1	18.2	20.7	22.2	23.2	23.2
02h00	22.8	22.8	22.8	21.8	19.8	17.3	16.7	17.8	20.3	21.8	22.8	22.8
03h00	22.5	22.5	22.5	21.5	19.5	17.0	16.4	17.5	20.0	21.5	22.5	22.5
04h00	22.3	22.3	22.3	21.3	19.3	16.8	16.2	17.3	19.8	21.3	22.3	22.3
05h00	22.1	22.1	22.1	21.1	19.1	16.6	16.0	17.1	19.6	21.1	22.1	22.1
06h00	22.7	22.7	22.7	21.7	19.7	17.2	16.6	17.7	20.2	21.7	22.7	22.7
07h00	24.2	24.2	24.2	23.3	21.3	18.8	17.6	17.8	20.3	23.3	24.2	24.2
08h00	25.9	25.9	25.9	24.9	22.9	20.4	19.8	20.9	22.4	24.9	25.9	25.9
09h00	27.8	27.8	27.8	26.8	24.8	22.3	21.7	22.8	25.3	26.8	27.8	27.8
10h00	28.6	28.6	28.6	27.6	25.6	23.1	22.5	23.6	26.1	27.6	28.6	28.6
11h00	29.0	29.0	29.0	28.0	26.0	23.5	22.9	24.0	26.5	28.0	29.0	29.0
12h00	29.5	29.5	29.5	28.5	26.5	24.0	23.4	24.5	27.0	28.5	29.5	29.5
13h00	29.5	29.5	29.5	28.5	26.5	24.0	23.4	24.5	27.0	28.5	29.5	29.5
14h00	29.4	29.4	29.4	28.4	26.4	23.9	23.3	24.4	26.9	28.4	29.4	29.4
15h00	28.8	28.8	28.8	27.8	25.8	23.3	22.7	23.8	26.3	27.8	28.8	28.8
16h00	28.0	28.0	28.0	27.0	25.0	22.5	21.9	23.0	25.5	27.0	28.0	28.0
17h00	27.2	27.2	27.2	26.2	24.2	21.7	21.1	22.2	24.7	26.2	27.2	27.2
18h00	26.5	26.5	26.5	25.5	23.5	21.0	20.4	20.5	23.0	25.5	26.5	26.5
19h00	25.8	25.8	25.8	24.8	22.8	20.3	19.7	20.8	23.3	24.8	25.8	25.8
20h00	25.3	25.3	25.3	24.3	22.3	19.8	19.1	20.2	22.7	24.3	25.3	25.3
21h00	24.9	24.9	24.9	23.9	21.9	19.4	18.8	19.9	22.4	23.9	24.9	24.9
22h00	24.6	24.6	24.6	23.6	21.6	19.1	18.5	19.6	22.1	23.6	24.6	24.6
23h00	24.1	24.1	24.1	23.1	21.1	18.6	18.0	19.1	21.6	23.1	24.1	24.1
24h00	23.8	23.8	23.8	22.8	20.8	18.3	17.7	18.8	21.3	22.8	23.8	23.8

Table A1.1: Monthly temperatures for Durban, as used in Loadest

	2001												2002				
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
01h00	22.5	22.5	22.6	20.2	17.0	16.0	14.6	16.3	17.2	19.3	20.7	21.8	22.9	22.0	22.8	20.6	17.2
02h00	22.4	22.2	22.3	20.0	16.8	15.6	14.3	16.0	16.8	19.0	20.6	21.6	22.7	21.5	22.4	20.4	16.5
03h00	22.1	21.8	22.0	19.7	16.3	15.3	14.2	15.8	16.3	18.9	20.4	21.4	22.5	21.2	22.2	20.1	16.0
04h00	21.8	21.6	21.7	19.4	15.8	14.6	13.6	15.1	16.2	18.8	20.1	21.1	22.3	21.1	21.9	19.7	15.8
05h00	21.7	21.5	21.5	19.4	15.7	14.2	13.5	14.8	16.0	18.7	20.2	20.9	22.2	21.1	21.8	19.2	15.4
06h00	22.0	21.5	21.4	19.2	15.3	14.0	13.1	14.6	16.1	18.9	20.8	21.6	22.5	21.0	21.6	19.0	15.5
07h00	23.3	22.7	22.7	19.7	15.7	14.3	13.5	15.1	17.1	20.1	21.8	22.8	23.6	22.1	22.5	19.6	15.7
08h00	24.3	24.2	24.5	21.5	18.2	16.6	15.6	17.4	19.1	21.2	23.0	24.1	24.6	23.5	24.2	21.6	18.4
09h00	25.3	25.6	25.9	23.4	21.0	19.9	18.6	20.1	20.6	22.1	23.8	24.8	25.6	24.5	25.6	23.8	21.1
10h00	25.9	26.4	26.9	24.2	23.2	22.5	20.7	22.0	21.3	22.6	24.5	25.2	26.3	25.2	26.3	25.1	23.1
11h00	26.2	26.9	27.4	24.7	24.2	23.7	21.9	22.7	21.9	22.8	24.8	25.5	26.8	25.8	26.8	25.8	24.0
12h00	26.4	26.9	27.3	24.8	24.6	24.1	22.4	22.8	22.2	23.0	25.0	25.6	26.9	26.2	27.3	25.9	24.3
13h00	26.6	27.0	27.6	24.9	24.6	24.0	22.3	22.9	22.3	23.1	24.9	25.6	27.1	26.3	27.5	26.0	24.2
14h00	26.3	26.9	27.3	24.6	24.3	23.8	22.3	22.7	22.2	23.2	24.6	25.5	27.0	26.1	27.3	25.9	24.1
15h00	26.1	26.4	26.8	24.3	23.8	23.2	21.7	22.3	21.8	22.8	24.2	25.0	26.5	25.6	26.7	25.7	23.7
16h00	25.3	25.8	26.1	23.8	23.1	22.3	21.0	21.6	21.2	22.2	23.7	24.6	25.8	25.3	26.1	25.0	22.8
17h00	24.7	25.2	25.4	23.1	21.8	20.7	19.5	20.7	20.4	21.7	23.1	24.2	25.2	24.7	25.4	24.1	21.5
18h00	24.1	24.6	24.6	22.5	21.0	20.1	18.8	20.0	19.7	21.1	22.6	23.7	24.6	24.1	24.6	23.4	20.9
19h00	23.5	24.1	24.3	22.2	20.4	19.6	18.1	19.7	19.4	20.8	22.3	23.2	24.0	23.6	24.4	22.9	20.2
20h00	23.3	23.9	24.1	21.9	19.5	18.7	17.3	19.3	19.1	20.8	22.1	22.9	23.8	23.5	24.3	22.4	19.3
21h00	23.3	23.6	24.0	21.5	18.7	18.2	16.7	18.6	18.7	20.6	21.8	22.8	23.5	23.1	24.1	22.0	18.9
22h00	23.1	23.5	23.6	21.1	18.1	17.5	16.1	18.0	18.2	20.4	21.5	22.6	23.4	22.8	23.8	21.4	18.6
23h00	22.9	23.1	23.3	20.9	17.5	17.1	15.4	17.2	17.9	20.0	21.3	22.2	23.3	22.6	23.3	21.1	18.1
24h00	22.7	22.8	23.0	20.4	17.3	16.5	14.9	16.7	17.6	19.7	21.0	22.1	23.2	22.4	23.1	20.8	17.6

Table A1.2: Actual average monthly temperatures for Durban

APPENDIX 2

COOLING LOAD ESTIMATES ASSUMING FULL VENTILATION

- Cooling load estimate for Denis Shepstone Building assuming full ventilation
- Cooling load estimate for Howard College assuming full ventilation
- Cooling load estimate for the E. G. Malherbe Library assuming full ventilation
- Cooling load estimate for the Business Concourse assuming full ventilation
- Cooling load estimate for the New Chemistry Laboratory assuming full ventilation
- Cooling load estimate for the Chemical Engineering Building assuming full ventilation

All values are in kilowatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	1006.6	1005.4	1007.0	963.8	605.9	230.6	35.9	324.0	702.1	897.2	1003.2	1005.9
02h00	973.8	972.9	974.6	932.2	574.9	199.9	5.0	292.4	669.6	864.8	970.9	973.1
03h00	949.1	948.8	950.5	908.6	551.7	176.7	-18.3	268.9	645.6	840.6	946.5	948.3
04h00	928.5	928.4	930.2	888.9	532.4	157.6	-37.6	249.1	625.4	820.3	926.2	927.8
05h00	905.7	906.1	950.5	867.5	511.4	136.9	-58.5	227.7	603.2	798.0	903.8	904.5
06h00	945.4	942.1	908.0	895.1	536.5	161.3	-33.5	255.3	636.9	834.0	942.4	945.4
07h00	1043.2	1035.8	941.8	982.9	622.5	246.6	52.4	343.1	728.8	927.7	1039.0	1045.4
08h00	1752.1	1742.4	1033.7	1686.0	1324.4	948.3	754.4	1046.2	1434.5	1634.3	1747.1	1754.9
09h00	1852.5	1842.4	1739.4	1785.1	1422.4	1045.9	852.4	1145.3	1535.1	1734.3	1846.5	1855.7
10h00	1913.0	1900.2	1840.0	1837.2	1472.3	1095.1	902.3	1197.4	1591.7	1792.1	1905.6	1916.3
11h00	1953.3	1942.2	1896.5	1882.2	1517.2	1139.7	947.2	1242.5	1635.3	1834.0	1945.2	1955.7
12h00	1787.9	1780.4	1940.2	1727.3	1363.1	985.7	793.1	1087.6	1476.6	1672.2	1779.4	1789.2
13h00	2001.4	1996.9	1781.6	1949.8	1586.2	1208.7	1016.2	1310.1	1695.8	1888.8	1992.4	2000.9
14h00	1992.0	1990.8	2000.7	1949.8	1586.9	1209.3	1016.9	1310.1	1692.6	1882.7	1982.5	1990.0
15h00	1981.7	1982.1	1997.5	1943.0	1579.3	1201.0	1009.3	1303.3	1685.7	1873.9	1971.1	1978.3
16h00	1943.5	1943.8	1990.6	1904.6	1540.2	1161.9	970.2	1264.9	1647.7	1835.7	1932.3	1940.3
17h00	1791.0	1788.9	1952.6	1745.4	1379.8	1001.0	809.7	1105.7	1491.0	1680.8	1779.4	1788.5
18h00	1519.8	1516.7	1795.9	1469.3	1103.4	724.7	533.3	829.6	1216.9	1408.5	1509.1	1517.7
19h00	1444.0	1440.4	1521.8	1392.4	1027.6	656.7	457.6	752.6	1139.0	1332.6	1434.7	1442.5
20h00	1387.3	1384.1	1443.9	1337.1	973.7	596.1	403.7	697.4	1082.1	1275.9	1379.3	1385.5
21h00	1322.0	1319.2	1386.9	1273.6	911.9	534.9	341.9	633.9	1016.5	1211.0	1315.5	1320.6
22h00	1219.9	1217.3	1321.4	1172.9	812.6	436.2	242.6	533.2	913.9	1109.2	1214.6	1219.1
23h00	1130.8	1128.2	1218.8	1084.1	724.6	348.6	154.5	444.4	824.5	1020.0	1126.2	1130.0
24h00	1074.9	1073.1	1129.4	1030.4	671.9	296.3	101.9	390.7	769.6	964.9	1071.1	1074.6
TOTAL	**34819.3**	**34728.7**	**34653.6**	**33609.3**	**24932.9**	**15899.8**	**11252.5**	**18255.2**	**27460.0**	**32133.5**	**34664.0**	**34810.1**

Table A2.1: Cooling load estimate for Denis Shepstone Building assuming full ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	182.4	181.9	181.5	172.8	106.2	36.2	0.5	53.8	124.5	161.5	181.9	182.0
02h00	174.7	174.4	174.3	165.8	99.5	29.6	-6.2	46.8	117.2	154.1	174.4	174.7
03h00	169.7	169.5	169.5	161.2	95.0	25.0	-10.7	42.2	112.3	149.2	169.3	168.9
04h00	165.4	165.3	165.5	157.3	91.1	21.2	-14.6	38.3	108.3	145.0	165.1	164.8
05h00	161.2	161.4	161.6	153.6	87.6	17.8	-18.1	34.6	104.5	141.0	161.0	160.7
06h00	208.4	208.5	208.8	200.7	134.7	65.0	29.0	81.8	151.7	188.2	208.1	207.5
07h00	263.1	263.5	263.9	256.2	190.4	120.8	84.7	137.2	206.7	243.1	263.0	262.4
08h00	334.4	334.9	335.3	327.7	262.1	192.5	156.4	208.6	278.2	314.6	334.4	333.7
09h00	341.5	341.8	342.3	333.9	267.9	198.2	162.2	214.9	285.1	321.4	341.3	341.1
10h00	363.5	362.1	361.6	350.6	283.4	213.4	177.7	231.7	304.5	341.8	362.6	363.3
11h00	382.9	381.4	380.8	369.7	302.2	232.0	196.5	250.8	323.7	361.0	381.8	382.9
12h00	424.1	422.7	422.1	411.1	343.3	273.0	237.6	292.1	365.1	402.4	423.0	423.9
13h00	433.2	432.0	431.6	421.0	353.2	282.7	247.5	302.0	374.4	411.6	431.9	433.0
14h00	437.1	436.2	435.8	426.1	358.4	287.9	252.7	307.1	378.8	415.9	435.8	436.2
15h00	429.9	429.3	429.2	419.3	351.4	280.6	245.7	300.3	372.0	408.9	428.5	428.9
16h00	421.0	420.4	420.3	410.4	342.1	271.3	236.4	291.3	363.3	400.1	419.3	419.8
17h00	406.8	405.5	405.1	394.1	325.3	254.2	219.6	275.1	347.9	385.2	404.8	405.9
18h00	289.1	287.4	286.6	275.0	206.0	134.8	100.3	156.0	229.5	267.1	287.0	288.6
19h00	278.1	276.5	275.8	264.4	195.5	124.5	89.9	145.4	218.6	256.2	276.2	277.2
20h00	254.8	253.4	252.8	241.7	173.2	102.3	67.6	122.8	195.7	233.0	253.1	254.2
21h00	238.7	237.1	236.2	225.7	157.8	87.1	52.1	106.8	179.1	216.8	237.4	238.6
22h00	225.7	224.2	223.0	213.0	145.5	74.9	39.8	94.1	166.0	203.9	224.8	225.5
23h00	214.0	212.8	212.0	202.5	135.4	65.0	29.7	83.5	154.8	192.5	213.3	214.0
24h00	202.8	202.0	201.5	192.5	125.7	55.6	20.0	73.5	144.4	181.6	202.2	202.5
TOTAL	**7002.4**	**6984.1**	**6977.1**	**6746.3**	**5132.6**	**3445.6**	**2596.0**	**3890.5**	**5606.3**	**6496.0**	**6980.1**	**6990.5**

Table A2.2: Cooling load estimate for Howard College assuming full ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	261.7	261.8	263.8	249.5	143.6	30.5	-23.6	59.9	171.2	228.6	260.1	261.2
02h00	250.2	250.2	252.0	237.6	132.0	19.2	-35.2	48.0	159.3	217.0	248.8	249.5
03h00	242.6	242.8	244.4	230.2	124.7	12.0	-42.5	40.7	151.9	209.5	241.2	241.9
04h00	235.5	235.7	237.3	223.1	117.8	5.2	-49.4	33.5	144.7	202.4	234.4	235.2
05h00	227.4	227.6	228.9	214.6	109.5	-2.9	-57.7	25.0	136.3	194.3	226.5	226.8
06h00	369.4	369.0	369.9	354.3	248.0	134.9	80.8	164.7	277.3	335.7	367.9	368.8
07h00	540.2	537.8	537.3	519.8	412.0	297.9	244.9	330.2	444.8	504.5	537.9	540.1
08h00	653.4	651.0	651.4	633.9	525.4	410.7	358.3	444.3	558.8	617.7	650.3	652.7
09h00	694.6	692.7	694.5	677.5	568.6	453.3	401.4	488.0	601.9	659.5	690.9	693.8
10h00	712.0	711.5	715.4	700.5	591.9	476.6	424.8	510.9	622.9	678.2	708.0	710.6
11h00	719.7	721.6	728.8	717.4	610.2	495.3	443.0	527.8	636.2	688.4	715.8	718.2
12h00	727.3	731.2	741.1	732.8	626.8	512.3	459.6	543.2	648.5	698.0	723.3	724.9
13h00	728.5	734.2	746.3	741.0	636.2	522.3	469.0	551.4	653.8	701.0	724.8	726.6
14h00	735.7	741.9	755.0	750.3	645.6	531.6	478.5	560.7	662.4	708.6	731.7	733.3
15h00	740.1	745.5	757.8	751.5	645.7	531.0	478.5	562.0	665.2	712.2	735.7	737.5
16h00	740.5	744.4	755.3	746.8	639.7	524.2	472.5	557.3	662.8	711.1	735.5	738.4
17h00	736.3	737.9	746.2	734.3	625.5	509.4	458.4	544.7	653.6	704.6	731.0	734.2
18h00	726.3	726.9	732.9	718.5	608.7	492.3	441.6	528.9	640.3	693.6	721.1	724.1
19h00	702.5	702.5	707.0	691.8	582.8	467.0	415.6	502.3	614.4	669.2	698.1	700.6
20h00	683.8	683.6	687.2	672.0	563.6	448.5	396.4	482.4	594.6	650.3	680.1	682.1
21h00	664.6	664.4	667.5	652.4	544.7	430.2	377.6	462.8	575.0	631.2	661.5	663.6
22h00	374.0	374.0	376.7	362.1	255.1	141.2	87.9	172.5	284.2	340.7	371.4	373.0
23h00	356.8	356.9	359.5	345.2	238.7	125.2	71.6	155.6	266.9	323.7	354.6	356.2
24h00	343.8	343.9	346.2	332.0	225.9	112.7	58.7	142.4	253.6	310.6	341.9	342.7
TOTAL	**13166.9**	**13189.1**	**13302.8**	**12989.2**	**10422.8**	**7680.6**	**6410.6**	**8439.1**	**11080.5**	**12390.7**	**13092.7**	**13135.9**

Table A2.3: Cooling load estimate for the E. G. Malherbe Library assuming full ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	53.0	52.1	51.8	48.4	27.7	5.7	-4.8	11.3	33.5	45.5	52.7	53.6
02h00	50.9	50.1	49.8	46.5	25.9	3.8	-6.7	9.4	31.5	43.5	50.6	51.4
03h00	49.3	48.6	48.4	45.0	24.5	2.5	-8.1	7.9	30.1	41.9	49.0	49.7
04h00	47.9	47.3	47.2	43.9	23.4	1.4	-9.2	6.8	28.9	40.7	47.7	48.3
05h00	46.4	46.0	45.9	42.7	22.2	0.3	-10.3	5.6	27.6	39.4	46.2	46.7
06h00	62.6	61.8	61.5	57.5	36.7	14.6	4.1	20.4	43.2	55.2	62.3	63.0
07h00	86.2	84.0	83.2	78.5	57.2	35.0	24.7	41.4	64.9	77.4	85.5	87.2
08h00	107.9	105.1	103.9	98.8	77.3	54.9	44.7	61.7	85.6	98.5	107.0	109.3
09h00	112.5	109.3	107.9	102.4	80.8	58.2	48.2	65.3	89.6	102.7	111.5	114.1
10h00	116.8	113.3	111.7	106.5	84.7	62.1	52.2	69.4	93.4	106.6	115.7	118.6
11h00	121.5	118.2	116.6	111.4	89.7	67.1	57.2	74.4	98.4	111.6	120.4	123.4
12h00	123.1	119.8	118.4	113.5	91.9	69.3	59.3	76.4	100.1	113.2	122.0	125.0
13h00	124.2	120.9	119.7	115.0	93.6	71.0	61.0	77.9	101.4	114.3	123.1	126.1
14h00	122.9	119.6	118.5	114.0	92.7	70.1	60.1	76.9	100.2	113.0	121.8	124.9
15h00	121.8	118.7	117.9	113.6	92.3	69.8	59.7	76.5	99.6	112.1	120.6	123.6
16h00	120.1	117.1	116.5	112.4	91.2	68.6	58.6	75.3	98.2	110.5	118.9	121.9
17h00	107.3	104.4	103.9	99.9	78.7	56.2	46.2	62.8	85.6	97.8	106.1	109.1
18h00	76.3	74.2	73.9	70.1	49.1	26.7	16.5	33.0	55.6	67.6	75.3	77.6
19h00	72.4	70.7	70.5	66.8	45.9	23.6	13.4	29.8	55.2	64.1	71.5	73.5
20h00	69.5	68.1	68.0	64.4	43.6	21.3	11.0	27.3	49.7	61.5	68.7	70.4
21h00	64.8	63.4	63.1	59.5	38.8	16.6	6.2	22.4	44.8	56.8	64.2	65.7
22h00	61.1	59.7	59.3	55.8	35.1	12.9	2.5	18.7	41.0	53.1	60.6	61.9
23h00	58.2	56.9	56.5	52.9	32.2	10.1	-0.3	15.8	38.2	50.3	57.8	59.0
24h00	56.1	54.9	54.6	51.0	30.4	8.3	-2.2	14.0	36.3	48.3	55.7	56.8
TOTAL	**2032.8**	**1984.2**	**1968.7**	**1870.5**	**1365.6**	**830.1**	**584.0**	**980.4**	**1532.6**	**1825.6**	**2014.9**	**2060.8**

Table A2.4: Cooling load estimate for the Business Concourse assuming full ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	24.7	24.5	24.3	22.9	14.7	6.2	2.0	8.7	17.5	22.0	24.5	24.7
02h00	23.1	22.8	22.8	21.5	13.4	4.9	0.7	7.3	16.0	20.5	22.9	23.1
03h00	22.2	22.0	22.0	20.7	12.6	4.2	0.0	6.6	15.2	19.7	22.0	22.2
04h00	21.3	21.1	21.1	19.9	11.9	3.5	-0.7	5.8	14.3	18.7	21.1	21.3
05h00	20.4	20.3	20.3	19.3	11.3	3.0	-1.4	5.1	13.5	17.9	20.3	20.3
06h00	27.9	27.5	27.2	25.6	17.3	8.9	4.7	11.4	20.5	25.1	27.8	28.0
07h00	37.7	37.1	36.8	34.7	26.3	17.9	13.7	20.6	30.0	34.7	37.4	37.8
08h00	53.6	53.0	52.7	50.5	42.2	33.8	29.6	36.4	45.9	50.5	53.3	53.8
09h00	56.3	55.7	55.6	53.5	45.1	36.7	32.5	39.3	48.8	53.3	56.0	56.4
10h00	58.6	58.0	57.8	55.6	47.1	38.7	34.5	41.5	51.0	55.6	58.2	58.7
11h00	60.7	60.3	60.0	57.8	49.2	40.7	36.5	43.7	53.3	57.8	60.3	60.8
12h00	62.7	62.3	62.0	60.0	51.4	42.8	38.7	45.8	55.3	59.9	62.3	62.8
13h00	64.9	64.2	64.0	61.9	53.1	44.6	40.5	47.7	57.2	61.9	64.3	64.9
14h00	66.6	65.9	65.6	63.4	54.7	46.0	42.0	49.2	58.9	63.5	66.0	66.6
15h00	67.9	67.2	66.8	64.6	55.6	46.8	43.0	50.4	60.1	64.8	67.2	67.9
16h00	68.5	67.8	67.4	65.0	56.1	47.1	43.4	50.9	60.6	65.4	67.9	68.5
17h00	68.6	67.8	67.2	64.8	55.6	46.7	43.0	50.6	60.5	65.4	67.9	68.7
18h00	40.5	39.6	39.0	36.5	27.4	18.5	14.7	22.4	32.2	37.2	39.8	40.5
19h00	38.5	37.7	37.1	34.7	25.7	16.8	13.0	20.6	30.3	35.2	37.8	38.6
20h00	36.2	35.5	35.0	32.8	23.9	15.1	11.3	18.6	28.2	33.0	35.6	36.2
21h00	33.2	32.5	32.1	30.1	21.4	12.6	8.7	16.0	25.4	30.1	32.7	33.2
22h00	30.5	30.0	29.6	27.8	19.2	10.5	6.6	13.6	22.8	27.5	30.1	30.6
23h00	28.4	27.9	27.5	25.9	17.4	8.9	4.8	11.7	20.8	25.4	28.0	28.4
24h00	26.2	25.9	25.7	24.2	16.0	7.5	3.3	10.0	19.0	23.5	26.0	26.2
TOTAL	**1039.2**	**1026.6**	**1019.5**	**974.0**	**768.5**	**562.6**	**465.3**	**633.8**	**857.3**	**968.8**	**1029.7**	**1040.3**

Table A2.5: Cooling load estimate for the New Chemistry Laboratory assuming full ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	5.0	4.9	4.8	4.2	2.4	0.5	-0.3	1.0	3.2	4.3	5.0	5.1
02h00	4.8	4.7	4.6	4.0	2.2	0.2	-0.6	0.8	2.9	4.0	4.7	4.8
03h00	4.5	4.4	4.4	3.8	2.0	0.1	-0.7	0.6	2.7	3.8	4.5	4.5
04h00	4.3	4.3	4.2	3.7	1.9	0.0	-0.8	0.5	2.5	3.6	4.3	4.4
05h00	4.1	4.1	4.0	3.5	1.8	-0.2	-1.0	0.3	2.4	3.5	4.1	4.2
06h00	6.7	6.6	6.6	6.0	4.3	2.4	1.5	2.9	4.9	6.0	6.6	6.7
07h00	6.5	6.4	6.4	5.9	4.1	2.2	1.4	2.7	4.7	5.8	6.4	6.5
08h00	9.8	9.7	9.7	9.2	7.4	5.5	4.7	6.0	8.0	9.1	9.7	9.8
09h00	13.2	13.2	13.2	12.7	10.9	9.0	8.2	9.5	11.5	12.5	13.1	13.1
10h00	13.7	13.8	13.8	13.3	11.5	9.6	8.8	10.1	12.2	13.1	13.7	13.7
11h00	14.0	14.1	14.1	13.6	11.8	9.9	9.1	10.5	12.5	13.4	13.9	14.0
12h00	14.3	14.4	14.5	14.0	12.2	10.2	9.4	10.8	12.8	13.7	14.2	14.3
13h00	14.3	14.3	14.4	13.9	12.1	10.2	9.4	10.7	12.8	13.7	14.2	14.3
14h00	14.3	14.3	14.4	13.8	12.0	10.1	9.3	10.7	12.7	13.7	14.2	14.3
15h00	12.1	12.0	11.9	11.3	9.4	7.5	6.7	8.1	10.3	11.3	12.0	12.1
16h00	9.4	9.2	9.1	8.2	6.3	4.3	3.6	5.0	7.4	8.5	9.3	9.4
17h00	9.5	9.1	8.9	7.8	5.7	3.8	3.0	4.6	7.2	8.5	9.3	9.6
18h00	8.8	8.3	8.0	6.7	4.6	2.6	1.9	3.5	6.3	7.6	8.6	8.9
19h00	8.0	7.5	7.3	6.1	4.1	2.1	1.3	2.9	5.6	6.9	7.8	8.1
20h00	7.4	7.0	6.8	5.8	3.8	1.8	1.0	2.6	5.1	6.4	7.3	7.5
21h00	6.7	6.4	6.3	5.4	3.5	1.5	0.8	2.2	4.6	5.8	6.6	6.8
22h00	6.2	6.0	5.9	5.1	3.2	1.3	0.2	1.9	4.2	5.4	6.1	6.3
23h00	5.8	5.6	5.5	4.8	2.9	1.0	0.2	1.6	3.8	5.0	5.7	5.8
24h00	5.4	5.3	5.2	4.5	2.7	0.8	0.0	1.3	3.5	4.6	5.4	5.5
TOTAL	**208.8**	**205.6**	**204.0**	**187.3**	**142.8**	**96.4**	**77.1**	**110.8**	**163.8**	**190.2**	**206.7**	**209.7**

Table A2.6: Cooling load estimate for the Chemical Engineering Building assuming full ventilation

APPENDIX 3

COOLING LOAD ESTIMATES ASSUMING ZERO VENTILATION

- Cooling load estimate for Denis Shepstone Building assuming zero ventilation
- Cooling load estimate for Howard College assuming zero ventilation
- Cooling load estimate for the E. G. Malherbe Library assuming zero ventilation
- Cooling load estimate for the Business Concourse assuming zero ventilation
- Cooling load estimate for the New Chemistry Laboratory assuming zero ventilation
- Cooling load estimate for the Chemical Engineering Building assuming zero ventilation

All values are in kiloWatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	262.9	261.8	263.4	248.3	222.9	194.3	189.1	204.6	236.1	250.8	259.6	262.6
02h00	241.3	240.5	242.1	227.8	203.2	174.8	169.4	184.2	214.8	229.6	238.5	241.0
03h00	225.1	224.7	226.4	212.6	188.3	160.0	154.5	169.0	199.2	213.8	222.5	224.6
04h00	210.0	209.9	211.8	198.6	174.6	146.4	140.7	154.9	184.5	199.0	207.7	209.4
05h00	192.8	193.2	195.1	182.6	159.2	131.3	125.4	139.0	167.8	182.3	190.9	192.1
06h00	219.6	216.2	215.9	197.1	171.0	142.6	137.2	153.4	188.6	205.3	216.6	220.0
07h00	280.4	272.8	270.5	247.7	219.7	190.5	185.9	204.0	243.3	261.9	276.2	282.7
08h00	933.8	924.0	920.8	895.2	866.1	836.6	832.3	851.5	893.5	913.1	928.8	937.2
09h00	981.0	970.8	968.2	941.0	910.7	880.9	876.9	897.3	940.9	959.8	974.9	984.3
10h00	1019.3	1006.2	1002.4	970.8	938.3	907.7	904.5	927.2	975.2	995.4	1011.8	1023.3
11h00	1048.4	1037.0	1034.8	1004.6	972.0	941.0	938.1	961.0	1007.5	1026.0	1040.2	1051.4
12h00	874.5	866.8	867.8	841.5	809.7	778.8	775.8	797.8	840.5	855.9	865.9	875.9
13h00	1084.4	1079.8	1083.5	1060.5	1029.4	998.5	995.6	1016.9	1056.2	1068.9	1075.4	1084.3
14h00	1077.8	1076.5	1083.2	1063.5	1033.0	1002.1	999.2	1019.9	1055.9	1065.7	1068.4	1076.1
15h00	1084.6	1084.8	1093.2	1073.7	1042.4	1011.1	1008.6	1030.0	1065.9	1073.9	1073.9	1081.6
16h00	1068.9	1069.1	1077.8	1057.8	1025.9	994.3	992.1	1014.2	1050.5	1058.1	1057.6	1065.8
17h00	938.9	936.7	943.7	921.2	888.0	855.9	854.2	877.5	916.4	925.8	927.2	936.6
18h00	701.2	698.0	703.0	678.5	645.2	613.2	611.3	634.9	675.8	687.1	690.4	699.2
19h00	645.1	641.4	644.8	621.4	589.1	557.6	555.2	577.7	617.6	630.5	635.8	643.7
20h00	602.3	599.0	601.9	580.1	549.3	518.4	515.5	536.5	574.7	588.2	594.3	601.2
21h00	548.2	545.3	547.4	527.8	498.6	468.3	464.8	484.1	520.1	534.4	541.6	547.4
22h00	454.4	451.7	453.2	435.4	407.6	377.8	373.8	391.8	426.0	440.8	449.1	453.9
23h00	379.2	376.6	377.8	360.5	333.6	304.2	299.7	316.9	350.5	365.7	374.7	379.0
24h00	331.7	329.8	331.2	315.2	289.2	260.3	255.4	271.6	304.0	318.9	327.8	331.5
TOTAL	15405.7	15312.8	15360.0	14863.7	14167.4	13446.7	13355.4	13816.0	14705.4	15050.8	15249.8	15405.0

Table A3.1: Cooling load estimate for Denis Shepstone Building assuming zero ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.3	1.8	1.5	-2.1	-8.3	-15.3	-16.6	-12.9	-5.2	-0.9	1.8	2.3
02h00	-3.3	-3.6	-3.7	-7.1	-13.0	-19.9	-21.2	-17.7	-10.4	-6.2	-3.6	-3.4
03h00	-6.9	-7.0	-7.0	-10.2	-16.0	-22.9	-24.3	-20.8	-13.7	-9.7	-7.2	-7.0
04h00	-10.1	-10.1	-10.0	-13.1	-18.9	-25.7	-27.1	-23.8	-16.7	-12.8	-10.4	-10.3
05h00	-13.3	-13.1	-12.9	-15.7	-21.3	-28.1	-29.6	-26.4	-19.5	-15.7	-13.5	-13.4
06h00	30.8	31.0	31.2	28.4	22.8	16.0	14.5	17.7	24.6	28.4	30.6	30.7
07h00	77.9	78.2	78.6	76.1	70.8	64.1	62.5	65.4	72.0	75.6	77.7	77.7
08h00	140.5	141.0	141.4	138.9	133.7	127.1	125.4	128.2	134.7	138.3	140.5	140.3
09h00	137.8	138.1	138.6	135.4	129.8	123.1	121.5	124.7	131.9	135.5	137.6	137.7
10h00	155.7	154.3	153.9	148.0	141.1	134.1	132.8	137.4	147.2	151.7	154.8	155.9
11h00	173.0	171.5	171.1	165.1	157.9	150.6	149.7	154.4	164.3	168.9	172.0	173.1
12h00	211.7	210.3	209.8	203.9	196.5	189.2	188.2	193.2	203.1	207.6	210.5	211.7
13h00	220.8	219.6	219.2	213.7	206.4	198.9	198.1	203.0	212.5	217.0	219.5	220.7
14h00	225.2	224.4	224.0	219.4	212.1	204.6	203.9	208.6	217.3	221.6	223.9	224.9
15h00	221.2	220.5	220.4	215.7	208.1	200.4	199.8	205.0	213.7	217.8	219.6	220.6
16h00	216.3	215.7	215.7	210.8	203.0	195.2	194.8	200.2	209.0	213.0	214.6	215.7
17h00	206.1	204.9	204.4	198.6	190.2	182.1	182.0	187.9	197.8	202.3	204.2	205.7
18h00	92.1	90.4	89.6	83.1	74.5	66.4	66.3	72.5	82.9	87.7	90.0	91.7
19h00	84.7	83.1	82.3	76.1	67.7	59.6	59.4	65.4	75.7	80.4	82.7	84.3
20h00	64.0	62.6	61.9	56.1	48.0	40.0	39.7	45.3	55.3	59.9	62.2	63.6
21h00	49.9	48.3	47.4	42.1	34.5	26.8	26.2	31.4	40.8	45.7	48.6	49.9
22h00	38.5	36.9	35.8	30.9	23.8	16.2	15.5	20.3	29.1	34.3	37.6	38.6
23h00	29.3	28.1	27.2	22.9	16.2	8.9	8.0	12.2	20.6	25.4	28.6	29.4
24h00	19.6	18.9	18.3	14.4	8.1	1.0	-0.2	3.8	11.6	16.2	19.1	19.7
TOTAL	**2363.9**	**2345.8**	**2338.8**	**2231.2**	**2067.9**	**1892.4**	**1869.2**	**1975.1**	**2178.6**	**2281.9**	**2341.3**	**2360.0**

Table A3.2: Cooling load estimate for Howard College assuming zero ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	11.3	11.3	13.4	6.7	-8.5	-27.0	-29.3	-20.2	-3.4	4.6	9.6	10.8
02h00	2.9	4.6	4.6	-2.0	-17.0	-35.2	-37.9	-29.0	-12.3	-3.9	1.4	2.5
03h00	-2.5	-0.6	-0.6	-7.1	-21.9	-40.1	-42.8	-34.1	-17.5	-9.1	-3.9	-2.9
04h00	-8.0	-6.2	-6.2	-12.8	-27.4	-45.3	-48.2	-39.6	-23.1	-14.5	-9.2	-8.3
05h00	-14.6	-13.1	-13.1	-19.7	-34.1	-51.9	-55.0	-46.6	-30.0	-21.2	-15.5	-14.9
06h00	122.8	123.3	123.3	115.3	99.8	81.3	79.0	88.5	106.4	115.7	121.3	122.3
07h00	282.1	279.6	279.2	269.3	252.3	232.8	231.4	242.3	262.4	272.9	279.7	282.2
08h00	382.1	379.7	380.2	370.3	352.6	332.5	331.7	343.4	363.3	373.0	379.1	382.1
09h00	408.7	406.9	408.7	399.3	381.1	360.4	360.3	372.5	391.9	400.1	405.0	408.3
10h00	420.0	419.5	423.4	416.1	398.3	377.6	377.5	389.2	406.6	412.7	416.0	419.2
11h00	424.6	426.6	433.7	430.0	413.4	393.2	392.6	403.0	416.8	419.7	420.7	423.4
12h00	428.3	432.3	442.1	441.5	426.3	406.4	405.4	414.6	425.3	425.5	424.4	426.6
13h00	429.6	435.3	447.4	449.7	435.6	416.4	414.8	422.7	430.6	428.6	425.8	427.6
14h00	437.5	443.7	456.8	459.8	445.9	426.5	425.0	432.9	439.9	437.0	433.5	435.4
15h00	446.5	451.9	464.3	465.7	450.6	430.4	429.7	438.7	447.4	445.2	442.1	444.4
16h00	453.0	457.0	467.9	467.1	450.7	429.8	429.8	440.2	451.1	450.2	448.1	451.0
17h00	455.0	456.6	464.9	460.7	442.8	421.2	421.8	433.9	448.1	449.9	449.7	453.4
18h00	450.4	451.0	457.0	450.2	431.3	409.5	410.4	423.3	440.2	444.3	445.3	448.7
19h00	432.0	432.0	436.5	429.1	410.8	389.6	389.9	402.1	419.7	425.3	427.6	430.7
20h00	417.1	417.0	420.6	413.0	395.4	374.9	374.6	386.1	403.8	410.3	413.5	416.1
21h00	401.1	400.9	404.0	396.6	379.6	359.7	358.7	369.7	387.2	394.2	398.0	400.2
22h00	112.7	112.7	115.5	108.5	92.3	73.0	71.5	81.6	98.7	106.0	110.2	112.1
23h00	99.5	99.5	102.1	95.4	79.8	60.8	58.9	68.5	85.3	92.8	97.3	98.9
24h00	88.7	88.8	91.1	84.6	69.3	50.7	48.4	57.6	74.3	82.1	86.9	88.3
TOTAL	6680.9	6710.3	6816.7	6687.5	6299.1	5827.2	5798.0	6041.3	6412.5	6541.3	6606.6	6657.9

Table A3.3: Cooling load estimate for the E. G. Malherbe Library assuming zero ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	14.7	13.8	13.5	11.5	8.0	3.8	3.0	5.1	9.5	12.2	14.4	15.3
02h00	13.2	12.3	12.1	10.2	6.7	2.5	1.7	3.8	8.1	10.7	12.9	13.7
03h00	12.0	11.2	11.1	9.2	5.7	1.6	0.8	2.8	7.1	9.6	11.7	12.4
04h00	10.9	10.3	10.2	8.3	4.9	0.8	-0.1	1.9	6.1	8.7	10.6	11.3
05h00	9.7	9.3	9.2	7.4	4.1	-0.1	-0.9	1.0	5.2	7.7	9.5	10.0
06h00	25.0	24.2	23.9	21.4	17.6	13.4	12.7	14.9	19.9	22.6	24.7	25.4
07h00	46.4	44.3	43.4	40.2	36.0	31.6	31.1	33.7	39.4	42.7	45.7	47.4
08h00	65.6	62.8	61.7	58.0	53.6	49.1	48.7	51.6	57.7	61.2	64.8	67.0
09h00	67.5	64.3	62.9	58.9	54.3	49.6	49.4	52.5	58.9	62.7	66.5	69.1
10h00	70.7	67.1	65.5	61.7	57.1	52.4	52.2	55.3	61.5	65.5	69.6	72.4
11h00	74.8	71.4	69.9	66.2	61.6	56.8	56.6	59.7	65.9	69.8	73.7	76.6
12h00	75.7	72.3	70.9	67.4	63.0	58.2	58.0	61.0	66.9	70.7	74.6	77.5
13h00	76.7	73.4	72.2	69.0	64.7	60.0	59.7	62.6	68.2	71.8	75.6	78.6
14h00	75.6	72.3	71.2	68.1	63.9	59.2	58.9	61.7	67.2	70.7	74.5	77.5
15h00	75.3	72.3	71.4	68.6	64.4	59.7	59.4	62.1	67.4	70.6	74.1	77.1
16h00	74.8	71.9	71.2	68.5	64.5	59.7	59.5	62.1	67.2	70.2	73.6	76.6
17h00	63.2	60.3	59.7	57.2	53.2	48.4	48.2	50.8	55.7	58.7	61.9	65.0
18h00	33.2	31.1	30.8	28.4	24.5	20.0	19.6	22.0	26.8	29.5	32.2	34.4
19h00	30.3	28.6	28.4	26.2	22.4	17.9	17.4	19.8	24.4	27.0	29.4	31.4
20h00	28.1	26.7	26.6	24.5	20.8	16.4	15.8	18.1	22.6	25.1	27.4	29.0
21h00	24.0	22.6	22.3	20.2	16.5	12.2	11.6	13.8	18.3	21.0	23.4	24.9
22h00	20.7	19.4	19.0	16.9	13.3	9.0	8.3	10.5	15.0	17.8	20.3	21.6
23h00	18.6	17.3	16.9	14.7	11.2	6.9	6.2	8.3	12.9	15.7	18.2	19.4
24h00	16.9	15.7	15.4	13.3	9.8	5.5	4.8	6.9	11.4	14.1	16.5	17.6
TOTAL	**1023.6**	**974.9**	**959.4**	**896.0**	**801.8**	**694.6**	**682.6**	**742.0**	**863.3**	**936.3**	**1005.8**	**1051.2**

Table A3.4: Cooling load estimate for the Business Concourse assuming zero ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	8.2	7.9	7.8	7.0	6.2	5.4	5.4	6.1	7.1	7.7	8.0	8.2
02h00	6.8	6.6	6.5	5.8	5.1	4.4	4.4	4.9	5.9	6.3	6.6	6.8
03h00	6.2	5.9	5.8	5.3	4.5	3.9	3.8	4.3	5.3	5.8	6.0	6.2
04h00	5.3	5.2	5.1	4.6	3.9	3.2	3.2	3.6	4.5	4.9	5.2	5.3
05h00	4.5	4.5	4.5	4.1	3.5	2.8	2.8	3.2	3.9	4.2	4.5	4.5
06h00	11.7	11.3	11.0	10.0	9.2	8.4	8.4	9.1	10.4	11.0	11.5	11.8
07h00	20.6	19.9	19.6	18.2	17.2	16.5	16.4	17.3	19.0	19.7	20.3	20.7
08h00	35.4	34.7	34.5	33.0	32.0	31.3	31.2	32.0	33.9	34.5	35.2	35.6
09h00	36.9	36.3	36.1	34.7	33.7	33.0	33.0	33.8	35.6	36.0	36.5	36.9
10h00	38.7	38.1	37.9	36.4	35.2	34.5	34.5	35.5	37.3	37.8	38.3	38.9
11h00	40.5	40.1	39.9	38.3	37.0	36.2	36.3	37.3	39.3	39.9	40.1	40.7
12h00	42.3	41.8	41.6	40.2	38.9	38.1	38.2	39.2	41.0	41.6	41.8	42.4
13h00	44.4	43.8	43.5	42.0	40.7	39.8	40.0	41.1	42.9	43.6	43.8	44.4
14h00	46.2	45.5	45.2	43.7	42.3	41.3	41.6	42.7	44.6	45.3	45.6	46.2
15h00	47.9	47.1	46.8	45.1	43.6	42.4	42.8	44.2	46.2	46.9	47.2	47.9
16h00	49.0	48.3	47.9	46.2	44.5	43.3	43.7	45.2	47.2	48.0	48.4	49.0
17h00	49.7	48.8	48.2	46.3	44.6	43.4	43.9	45.4	47.6	48.5	48.8	49.7
18h00	21.9	21.0	20.4	18.5	16.8	15.6	16.0	17.6	19.8	20.7	21.1	22.0
19h00	20.3	19.5	19.0	17.2	15.6	14.3	14.8	16.3	18.3	19.3	19.7	20.4
20h00	18.4	17.7	17.2	15.6	14.1	13.0	13.4	14.7	16.5	17.4	17.8	18.4
21h00	15.6	14.9	14.5	13.1	11.7	10.8	11.0	12.2	13.9	14.7	15.1	15.6
22h00	13.1	12.6	12.2	11.0	9.8	8.8	9.1	10.0	11.6	12.3	12.7	13.2
23h00	11.3	10.8	10.4	9.4	8.3	7.5	7.6	8.5	9.9	10.5	10.9	11.3
24h00	9.3	9.0	8.7	7.9	7.0	6.2	6.3	7.0	8.2	8.7	9.1	9.4
TOTAL	**604.1**	**591.1**	**584.3**	**553.6**	**525.4**	**504.1**	**507.8**	**531.0**	**570.0**	**585.4**	**594.3**	**605.3**

Table A3.5: Cooling load estimate for the New Chemistry Laboratory assuming zero ventilation

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.5	2.3	2.3	1.7	1.1	0.3	0.2	0.6	1.6	2.1	2.4	2.5
02h00	2.3	2.1	2.1	1.6	0.9	0.2	0.0	0.4	1.4	1.9	2.2	2.3
03h00	2.0	1.9	1.9	1.4	0.8	0.0	-0.1	0.3	1.2	1.6	2.0	2.0
04h00	1.9	1.8	1.7	1.3	0.7	-0.1	-0.2	0.2	1.0	1.5	1.8	1.9
05h00	1.7	1.6	1.6	1.2	0.5	-0.2	-0.3	0.0	0.9	1.3	1.7	1.7
06h00	4.2	4.1	4.1	3.6	3.0	2.3	2.1	2.5	3.3	3.8	4.1	4.2
07h00	3.8	3.8	3.7	3.3	2.7	1.9	1.8	2.2	3.0	3.5	3.8	3.8
08h00	6.9	6.9	6.9	6.5	5.8	5.1	5.0	5.3	6.2	6.6	6.9	6.9
09h00	10.2	10.2	10.2	9.8	9.2	8.4	8.3	8.7	9.5	9.9	10.1	10.1
10h00	10.7	10.7	10.7	10.3	9.7	8.9	8.8	9.2	10.0	10.4	10.6	10.6
11h00	10.9	10.9	11.0	10.6	10.0	9.2	9.1	9.5	10.3	10.7	10.8	10.8
12h00	11.1	11.2	11.3	10.9	10.2	9.5	9.3	9.7	10.6	10.9	11.1	11.1
13h00	11.1	11.2	11.3	10.8	10.2	9.5	9.3	9.7	10.5	10.9	11.1	11.1
14h00	11.2	11.2	11.2	10.8	10.1	9.4	9.2	9.6	10.5	10.9	11.1	11.1
15h00	9.0	8.9	8.8	8.3	7.6	6.8	6.7	7.1	8.1	8.6	8.9	9.0
16h00	6.4	6.1	6.0	5.3	4.5	3.7	3.6	4.1	5.3	5.9	6.3	6.4
17h00	6.5	6.1	5.9	4.9	4.0	3.2	3.1	3.8	5.2	5.8	6.4	6.6
18h00	5.9	5.4	5.1	3.9	3.0	2.2	2.1	2.8	4.4	5.1	5.7	6.0
19h00	5.2	4.7	4.5	3.4	2.5	1.7	1.6	2.3	3.8	4.4	5.0	5.3
20h00	4.6	4.3	4.0	3.1	2.2	1.5	1.4	2.0	3.3	4.0	4.5	4.8
21h00	4.0	3.7	3.6	2.8	2.0	1.2	1.1	1.7	2.9	3.4	3.9	4.1
22h00	3.5	3.3	3.2	2.5	1.8	1.0	0.9	1.4	2.5	3.0	3.5	3.6
23h00	3.1	2.9	2.9	2.2	1.5	0.8	0.6	1.1	2.1	2.7	3.1	3.2
24h00	2.8	2.7	2.6	2.0	1.3	0.6	0.4	0.9	1.9	2.4	2.8	2.8
TOTAL	**141.5**	**138.0**	**136.6**	**122.2**	**105.3**	**87.1**	**84.0**	**95.1**	**119.5**	**131.3**	**139.8**	**141.9**

Table A3.6: Cooling load estimate for the Chemical Engineering Building assuming zero ventilation

APPENDIX 4

COOLING LOAD ESTIMATES TAKING INTO ACCOUNT VENTILATION DIVERSITY

- Cooling load estimate for Denis Shepstone Building taking into account ventilation diversity
- Cooling load estimate for Howard College taking into account ventilation diversity
- Cooling load estimate for the E. G. Malherbe Library taking into account ventilation diversity
- Cooling load estimate for the Business Concourse taking into account ventilation diversity
- Cooling load estimate for the New Chemistry Laboratory taking into account ventilation diversity
- Cooling load estimate for the Chemical Engineering Building taking into account ventilation diversity

All values are in kiloWatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	262.9	261.8	263.4	248.3	222.9	194.3	189.1	204.6	236.1	250.8	259.6	262.6
02h00	241.3	240.5	242.1	227.8	203.2	174.8	169.4	184.2	214.8	229.6	238.5	241.0
03h00	225.1	224.7	226.4	212.6	188.3	160.0	154.5	169.0	199.2	213.8	222.5	224.6
04h00	210.0	209.9	211.8	198.6	174.6	146.4	140.7	154.9	184.5	199.0	207.7	209.4
05h00	192.8	193.2	195.1	182.6	159.2	131.3	125.4	139.0	167.8	182.3	190.9	192.1
06h00	219.6	216.2	215.9	197.1	171.0	142.6	137.2	153.4	188.6	205.3	216.6	220.0
07h00	280.4	272.8	270.5	247.7	219.7	190.5	185.9	204.0	243.3	261.9	276.2	282.7
08h00	1479.3	1469.6	996.1	1422.4	1171.6	911.0	780.3	981.3	1254.2	1393.9	1474.3	1482.4
09h00	1562.0	1551.9	1482.3	1503.7	1251.9	990.9	860.6	1062.6	1337.0	1476.2	1555.9	1565.2
10h00	1615.1	1602.2	1560.8	1548.4	1294.3	1032.6	903.0	1107.3	1386.2	1526.5	1607.7	1618.6
11h00	1651.7	1640.4	1609.3	1589.7	1335.4	1073.5	944.2	1148.6	1426.0	1564.7	1643.5	1654.3
12h00	1483.4	1475.9	1582.7	1432.0	1178.7	916.8	787.4	991.0	1264.6	1400.1	1474.9	1484.8
13h00	1695.7	1691.2	1548.9	1653.4	1400.6	1138.6	1009.3	1212.3	1482.6	1615.5	1686.7	1695.4
14h00	1687.3	1686.0	1694.9	1654.4	1402.3	1140.3	1011.0	1213.4	1480.3	1610.3	1677.8	1685.4
15h00	1682.7	1683.0	1696.1	1653.3	1400.3	1137.7	1009.1	1212.2	1479.1	1607.2	1672.1	1679.4
16h00	1651.9	1652.2	1686.3	1622.3	1368.8	1106.0	977.5	1181.3	1448.6	1576.5	1640.7	1648.8
17h00	1506.9	1504.9	1616.3	1470.7	1215.9	952.6	824.5	1029.6	1299.5	1429.1	1495.3	1504.5
18h00	974.0	970.9	1067.3	942.1	797.9	650.4	585.3	699.8	856.1	927.6	963.3	972.0
19h00	911.4	907.7	937.1	878.4	735.3	590.6	522.7	636.0	791.4	864.5	902.1	910.0
20h00	864.0	860.7	882.6	832.5	690.8	544.3	478.2	590.1	743.8	817.4	855.9	862.7
21h00	806.1	803.3	827.3	776.4	636.4	490.5	423.8	534.0	685.6	759.9	799.5	805.1
22h00	454.4	451.7	453.2	435.4	407.6	377.8	373.8	391.8	426.0	440.8	449.1	453.9
23h00	379.2	376.6	377.8	360.5	333.6	304.2	299.7	316.9	350.5	365.7	374.7	379.0
24h00	331.7	329.8	331.2	315.2	289.2	260.3	255.4	271.6	304.0	318.9	327.8	331.5
TOTAL	**22369.1**	**22277.3**	**21975.4**	**21605.6**	**18249.6**	**14758.1**	**13148.2**	**15789.1**	**19449.8**	**21237.5**	**22213.6**	**22365.4**

Table A4.1: Cooling load estimate for Denis Shepstone Building taking into account ventilation diversity

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.3	1.8	1.5	-2.1	-8.3	-15.3	-16.6	-12.9	-5.2	-0.9	1.8	2.3
02h00	-3.3	-3.6	-3.7	-7.1	-13.0	-19.9	-21.2	-17.7	-10.4	-6.2	-3.6	-3.4
03h00	-6.9	-7.0	-7.0	-10.2	-16.0	-22.9	-24.3	-20.8	-13.7	-9.7	-7.2	-7.0
04h00	-10.1	-10.1	-10.0	-13.1	-18.9	-25.7	-27.1	-23.8	-16.7	-12.8	-10.4	-10.3
05h00	-13.3	-13.1	-12.9	-15.7	-21.3	-28.1	-29.6	-26.4	-19.5	-15.7	-13.5	-13.4
06h00	30.8	31.0	31.2	28.4	22.8	16.0	14.5	17.7	24.6	28.4	30.6	30.7
07h00	77.9	78.2	78.6	76.1	70.8	64.1	62.5	65.4	72.0	75.6	77.7	77.7
08h00	269.8	270.2	270.7	264.8	219.3	170.7	146.0	181.8	230.4	255.8	269.8	269.3
09h00	273.6	273.9	274.4	267.7	221.9	173.2	148.6	184.9	234.1	259.4	273.4	273.3
10h00	294.2	292.8	292.4	283.1	236.0	186.9	162.7	200.2	252.1	278.4	293.3	294.1
11h00	312.9	311.4	310.9	301.5	254.1	204.9	180.9	218.6	270.6	297.0	311.8	313.0
12h00	353.3	351.9	351.3	342.0	294.4	245.0	221.2	259.1	311.1	337.5	352.1	353.2
13h00	362.4	361.2	360.8	351.9	304.2	254.8	231.0	269.0	320.4	346.8	361.1	362.2
14h00	366.4	365.6	365.2	357.2	309.7	260.1	236.4	274.3	324.9	351.2	365.2	365.8
15h00	360.3	359.7	359.6	351.5	303.6	253.9	230.4	268.5	319.3	345.2	358.8	359.4
16h00	352.8	352.2	352.1	343.9	295.7	245.9	222.5	261.0	311.8	337.7	351.1	351.8
17h00	339.9	338.6	338.2	328.9	280.3	230.2	207.1	246.1	297.9	324.2	337.9	339.2
18h00	157.8	156.0	155.3	147.1	118.4	89.2	77.6	100.3	131.8	147.5	155.7	157.3
19h00	149.2	147.5	146.8	138.9	110.3	81.2	69.5	92.1	123.3	139.0	147.2	148.6
20h00	127.6	126.2	125.5	118.0	89.7	60.8	49.0	71.1	102.1	117.6	125.8	127.2
21h00	112.8	111.2	110.3	103.3	75.6	46.9	34.9	56.5	86.9	102.7	111.5	112.8
22h00	100.9	99.3	98.2	91.6	64.3	35.8	23.6	44.9	74.7	90.8	100.0	100.9
23h00	29.3	28.1	27.2	22.9	16.2	8.9	8.0	12.2	20.6	25.4	28.6	29.4
24h00	19.6	18.9	18.3	14.4	8.1	1.0	-0.2	3.8	11.6	16.2	19.1	19.7
TOTAL	4060.3	4042.2	4035.1	3884.8	3217.9	2517.6	2207.5	2726.0	3454.6	3831.0	4038.0	4053.7

Table A4.2: Cooling load estimate for Howard College taking into account ventilation diversity

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	54.3	54.3	54.3	52.6	32.9	12.4	1.2	17.4	37.8	48.5	54.3	54.3
02h00	53.6	53.2	53.6	51.9	32.3	11.8	0.6	16.7	37.2	47.8	53.6	53.5
03h00	53.1	52.7	53.1	51.4	31.8	11.3	0.1	16.2	36.7	47.4	53.1	53.1
04h00	52.8	52.4	52.8	51.1	31.4	10.9	-0.3	15.9	36.4	47.0	52.8	52.8
05h00	52.4	52.1	52.4	50.8	31.1	10.6	-0.6	15.5	36.0	46.7	52.4	52.4
06h00	53.4	53.2	53.4	51.8	32.1	11.6	0.4	16.5	37.0	47.7	53.4	53.4
07h00	111.9	111.9	111.9	108.5	69.2	28.2	5.8	38.1	79.0	100.4	111.9	111.8
08h00	117.5	117.6	117.5	114.2	74.9	33.9	11.5	43.7	84.7	106.1	117.5	117.2
09h00	247.7	247.7	247.7	241.1	162.5	80.5	35.6	100.1	182.1	224.8	247.7	247.4
10h00	253.1	253.1	253.1	246.4	167.8	85.8	41.0	105.5	187.5	230.1	253.1	252.6
11h00	255.7	255.7	255.7	249.0	170.5	88.5	43.7	108.1	190.2	232.8	255.7	255.5
12h00	259.1	259.1	259.2	252.5	173.8	91.8	47.0	111.5	193.4	236.2	259.1	258.6
13h00	259.1	259.1	259.1	252.5	173.8	91.8	47.0	111.5	193.4	236.1	259.2	259.1
14h00	258.4	258.4	258.4	251.7	173.1	91.1	46.4	110.8	192.8	235.4	258.4	258.2
15h00	254.4	254.4	254.4	247.7	169.1	87.1	42.4	106.8	188.8	231.4	254.4	254.1
16h00	249.1	249.1	249.1	242.4	163.8	81.8	37.0	101.4	183.5	226.1	249.1	249.0
17h00	243.7	243.8	243.7	237.1	158.4	76.4	31.7	96.1	178.1	220.7	243.7	243.3
18h00	239.1	239.1	239.1	232.5	153.8	71.8	27.0	91.5	173.4	216.1	239.1	238.6
19h00	117.2	117.2	117.2	113.9	74.5	33.6	11.1	43.4	84.4	105.7	117.2	117.0
20h00	115.6	115.5	115.5	112.2	72.9	31.9	9.5	41.7	82.7	104.0	115.5	115.2
21h00	114.2	114.2	114.2	110.9	71.6	30.5	8.2	40.4	81.4	102.7	114.2	114.2
22h00	113.2	113.2	113.2	109.9	70.5	29.6	7.1	39.4	80.4	101.7	113.2	113.1
23h00	55.8	55.8	55.8	54.1	34.4	14.0	2.7	18.9	39.3	50.0	55.8	55.7
24h00	55.3	55.3	55.3	53.6	33.9	13.4	2.2	18.4	38.9	49.5	55.3	55.1
TOTAL	**3639.7**	**3638.2**	**3639.9**	**3539.9**	**2360.3**	**1130.5**	**458.3**	**1425.4**	**2655.1**	**3295.0**	**3639.8**	**3635.2**

Table A4.3: Cooling load estimate for the E. G. Malherbe Library taking into account ventilation diversity

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	14.7	13.8	13.5	11.5	8.0	3.8	3.0	5.1	9.5	12.2	14.4	15.3
02h00	13.2	12.3	12.1	10.2	6.7	2.5	1.7	3.8	8.1	10.7	12.9	13.7
03h00	12.0	11.2	11.1	9.2	5.7	1.6	0.8	2.8	7.1	9.6	11.7	12.4
04h00	10.9	10.3	10.2	8.3	4.9	0.8	-0.1	1.9	6.1	8.7	10.6	11.3
05h00	9.7	9.3	9.2	7.4	4.1	-0.1	-0.9	1.0	5.2	7.7	9.5	10.0
06h00	25.0	24.2	23.9	21.4	17.6	13.4	12.7	14.9	19.9	22.6	24.7	25.4
07h00	46.4	44.3	43.4	40.2	36.0	31.6	31.1	33.7	39.4	42.7	45.7	47.4
08h00	107.9	105.1	103.9	98.8	77.3	54.9	44.7	61.7	85.6	98.5	107.0	109.3
09h00	112.5	109.3	107.9	102.4	80.8	58.2	48.2	65.3	89.6	102.7	111.5	114.1
10h00	116.8	113.3	111.7	106.5	84.7	62.1	52.2	69.4	93.4	106.6	115.7	118.6
11h00	121.5	118.2	116.6	111.4	89.7	67.1	57.2	74.4	98.4	111.6	120.4	123.4
12h00	123.1	119.8	118.4	113.5	91.9	69.3	59.3	76.4	100.1	113.2	122.0	125.0
13h00	124.2	120.9	119.7	115.0	93.6	71.0	61.0	77.9	101.4	114.3	123.1	126.1
14h00	122.9	119.6	118.5	114.0	92.7	70.1	60.1	76.9	100.2	113.0	121.8	124.9
15h00	121.8	118.7	117.9	113.6	92.3	69.8	59.7	76.5	99.6	112.1	120.6	123.6
16h00	120.1	117.1	116.5	112.4	91.2	68.6	58.6	75.3	98.2	110.5	118.9	121.9
17h00	107.3	104.4	103.9	99.9	78.7	56.2	46.2	62.8	85.6	97.8	106.1	109.1
18h00	33.2	31.1	30.8	28.4	24.5	20.0	19.6	22.0	26.8	29.5	32.2	34.4
19h00	30.3	28.6	28.4	26.2	22.4	17.9	17.4	19.8	24.4	27.0	29.4	31.4
20h00	28.1	26.7	26.6	24.5	20.8	16.4	15.8	18.1	22.6	25.1	27.4	29.0
21h00	24.0	22.6	22.3	20.2	16.5	12.2	11.6	13.8	18.3	21.0	23.4	24.9
22h00	20.7	19.4	19.0	16.9	13.3	9.0	8.3	10.5	15.0	17.8	20.3	21.6
23h00	18.6	17.3	16.9	14.7	11.2	6.9	6.2	8.3	12.9	15.7	18.2	19.4
24h00	16.9	15.7	15.4	13.3	9.8	5.5	4.8	6.9	11.4	14.1	16.5	17.6
TOTAL	**1481.8**	**1433.2**	**1417.8**	**1339.9**	**1074.4**	**788.8**	**679.2**	**879.2**	**1178.8**	**1344.7**	**1464.0**	**1509.8**

Table A4.4: Cooling load estimate for the Business Concourse taking into account ventilation diversity

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	8.2	7.9	7.8	7.0	6.2	5.4	5.4	6.1	7.1	7.7	8.0	8.2
02h00	6.8	6.6	6.5	5.8	5.1	4.4	4.4	4.9	5.9	6.3	6.6	6.8
03h00	6.2	5.9	5.8	5.3	4.5	3.9	3.8	4.3	5.3	5.8	6.0	6.2
04h00	5.3	5.2	5.1	4.6	3.9	3.2	3.2	3.6	4.5	4.9	5.2	5.3
05h00	4.5	4.5	4.5	4.1	3.5	2.8	2.8	3.2	3.9	4.2	4.5	4.5
06h00	11.7	11.3	11.0	10.0	9.2	8.4	8.4	9.1	10.4	11.0	11.5	11.8
07h00	20.6	19.9	19.6	18.2	17.2	16.5	16.4	17.3	19.0	19.7	20.3	20.7
08h00	53.6	53.0	52.7	50.5	42.2	33.8	29.6	36.4	45.9	50.5	53.3	53.8
09h00	56.3	55.7	55.6	53.5	45.1	36.7	32.5	39.3	48.8	53.3	56.0	56.4
10h00	58.6	58.0	57.8	55.6	47.1	38.7	34.5	41.5	51.0	55.6	58.2	58.7
11h00	60.7	60.3	60.0	57.8	49.2	40.7	36.5	43.7	53.3	57.8	60.3	60.8
12h00	62.7	62.3	62.0	60.0	51.4	42.8	38.7	45.8	55.3	59.9	62.3	62.8
13h00	64.9	64.2	64.0	61.9	53.1	44.6	40.5	47.7	57.2	61.9	64.3	64.9
14h00	66.6	65.9	65.6	63.4	54.7	46.0	42.0	49.2	58.9	63.5	66.0	66.6
15h00	67.9	67.2	66.8	64.6	55.6	46.8	43.0	50.4	60.1	64.8	67.2	67.9
16h00	68.5	67.8	67.4	65.0	56.1	47.1	43.4	50.9	60.6	65.4	67.9	68.5
17h00	68.6	67.8	67.2	64.8	55.6	46.7	43.0	50.6	60.5	65.4	67.9	68.7
18h00	40.5	39.6	39.0	36.5	27.4	18.5	14.7	22.4	32.2	37.2	39.8	40.5
19h00	20.3	19.5	19.0	17.2	15.6	14.3	14.8	16.3	18.3	19.3	19.7	20.4
20h00	18.4	17.7	17.2	15.6	14.1	13.0	13.4	14.7	16.5	17.4	17.8	18.4
21h00	15.6	14.9	14.5	13.1	11.7	10.8	11.0	12.2	13.9	14.7	15.1	15.6
22h00	13.1	12.6	12.2	11.0	9.8	8.8	9.1	10.0	11.6	12.3	12.7	13.2
23h00	11.3	10.8	10.4	9.4	8.3	7.5	7.6	8.5	9.9	10.5	10.9	11.3
24h00	9.3	9.0	8.7	7.9	7.0	6.2	6.3	7.0	8.2	8.7	9.1	9.4
TOTAL	**820.3**	**807.5**	**800.4**	**762.9**	**653.6**	**547.7**	**505.1**	**594.9**	**718.5**	**777.8**	**810.6**	**821.4**

Table A4.5: Cooling load estimate for the New Chemistry Laboratory taking into account ventilation diversity

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.5	2.3	2.3	1.7	1.1	0.3	0.2	0.6	1.6	2.1	2.4	2.5
02h00	2.3	2.1	2.1	1.6	0.9	0.2	0.0	0.4	1.4	1.9	2.2	2.3
03h00	2.0	1.9	1.9	1.4	0.8	0.0	-0.1	0.3	1.2	1.6	2.0	2.0
04h00	1.9	1.8	1.7	1.3	0.7	-0.1	-0.2	0.2	1.0	1.5	1.8	1.9
05h00	1.7	1.6	1.6	1.2	0.5	-0.2	-0.3	0.0	0.9	1.3	1.7	1.7
06h00	4.2	4.1	4.1	3.6	3.0	2.3	2.1	2.5	3.3	3.8	4.1	4.2
07h00	3.8	3.8	3.7	3.3	2.7	1.9	1.8	2.2	3.0	3.5	3.8	3.8
08h00	9.8	9.7	9.7	9.2	7.4	5.5	4.7	6.0	8.0	9.1	9.7	9.8
09h00	13.2	13.2	13.2	12.7	10.9	9.0	8.2	9.5	11.5	12.5	13.1	13.1
10h00	13.7	13.8	13.8	13.3	11.5	9.6	8.8	10.1	12.2	13.1	13.7	13.7
11h00	14.0	14.1	14.1	13.6	11.8	9.9	9.1	10.5	12.5	13.4	13.9	14.0
12h00	14.3	14.4	14.5	14.0	12.2	10.2	9.4	10.8	12.8	13.7	14.2	14.3
13h00	14.3	14.3	14.4	13.9	12.1	10.2	9.4	10.7	12.8	13.7	14.2	14.3
14h00	14.3	14.3	14.4	13.8	12.0	10.1	9.3	10.7	12.7	13.7	14.2	14.3
15h00	12.1	12.0	11.9	11.3	9.4	7.5	6.7	8.1	10.3	11.3	12.0	12.1
16h00	9.4	9.2	9.1	8.2	6.3	4.3	3.6	5.0	7.4	8.5	9.3	9.4
17h00	9.5	9.1	8.9	7.8	5.7	3.8	3.0	4.6	7.2	8.5	9.3	9.6
18h00	8.8	8.3	8.0	6.7	4.6	2.6	1.9	3.5	6.3	7.6	8.6	8.9
19h00	5.2	4.7	4.5	3.4	2.5	1.7	1.6	2.3	3.8	4.4	5.0	5.3
20h00	4.6	4.3	4.0	3.1	2.2	1.5	1.4	2.0	3.3	4.0	4.5	4.8
21h00	4.0	3.7	3.6	2.8	2.0	1.2	1.1	1.7	2.9	3.4	3.9	4.1
22h00	3.5	3.3	3.2	2.5	1.8	1.0	0.9	1.4	2.5	3.0	3.5	3.6
23h00	3.1	2.9	2.9	2.2	1.5	0.8	0.6	1.1	2.1	2.7	3.1	3.2
24h00	2.8	2.7	2.6	2.0	1.3	0.6	0.4	0.9	1.9	2.4	2.8	2.8
TOTAL	**175.0**	**171.6**	**170.2**	**154.6**	**124.9**	**93.9**	**83.6**	**105.1**	**142.6**	**160.7**	**173.0**	**175.7**

Table A4.6: Cooling load estimate for the Chemical Engineering Building taking into account ventilation diversity

APPENDIX 5

ESTIMATES OF INSTANTANEOUS COOLING LOADS

- Estimate of instantaneous cooling load for Denis Shepstone Building
- Estimate of instantaneous cooling load for Howard College
- Estimate of instantaneous cooling load for the E. G. Malherbe Library
- Estimate of instantaneous cooling load for the Business Concourse
- Estimate of instantaneous cooling load for the New Chemistry Laboratory
- Estimate of instantaneous cooling load for the Chemical Engineering Building

All values are in kiloWatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	1479.3	1469.6	996.1	1422.4	1171.6	911.0	780.3	981.3	1254.2	1393.9	1474.3	1482.4
09h00	1562.0	1551.9	1482.3	1503.7	1251.9	990.9	860.6	1062.6	1337.0	1476.2	1555.9	1565.2
10h00	1615.1	1602.2	1560.8	1548.4	1294.3	1032.6	903.0	1107.3	1386.2	1526.5	1607.7	1618.6
11h00	1651.7	1640.4	1609.3	1589.7	1335.4	1073.5	944.2	1148.6	1426.0	1564.7	1643.5	1654.3
12h00	1483.4	1475.9	1582.7	1432.0	1178.7	916.8	787.4	991.0	1264.6	1400.1	1474.9	1484.8
13h00	1695.7	1691.2	1548.9	1653.4	1400.6	1138.6	1009.3	1212.3	1482.6	1615.5	1686.7	1695.4
14h00	1687.3	1686.0	1694.9	1654.4	1402.3	1140.3	1011.0	1213.4	1480.3	1610.3	1677.8	1685.4
15h00	1682.7	1683.0	1696.1	1653.3	1400.3	1137.7	1009.1	1212.2	1479.1	1607.2	1672.1	1679.4
16h00	1651.9	1652.2	1686.3	1622.3	1368.8	1106.0	977.5	1181.3	1448.6	1576.5	1640.7	1648.8
17h00	1506.9	1504.9	1616.3	1470.7	1215.9	952.6	824.5	1029.6	1299.5	1429.1	1495.3	1504.5
18h00	974.0	970.9	1067.3	942.1	797.9	650.4	585.3	699.8	856.1	927.6	963.3	972.0
19h00	911.4	907.7	937.1	878.4	735.3	590.6	522.7	636.0	791.4	864.5	902.1	910.0
20h00	864.0	860.7	882.6	832.5	690.8	544.3	478.2	590.1	743.8	817.4	855.9	862.7
21h00	806.1	803.3	827.3	776.4	636.4	490.5	423.8	534.0	685.6	759.9	799.5	805.1
22h00												
23h00												
24h00												
TOTAL	**19571.6**	**19500.0**	**19188.0**	**18979.7**	**15880.1**	**12675.8**	**11116.9**	**13599.7**	**16935.1**	**18569.4**	**19450.0**	**19568.5**

Table A5.1: Estimate of instantaneous cooling load for Denis Shepstone Building

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	269.8	270.2	270.7	264.8	219.3	170.7	146.0	181.8	230.4	255.8	269.8	269.3
09h00	273.6	273.9	274.4	267.7	221.9	173.2	148.6	184.9	234.1	259.4	273.4	273.3
10h00	294.2	292.8	292.4	283.1	236.0	186.9	162.7	200.2	252.1	278.4	293.3	294.1
11h00	312.9	311.4	310.9	301.5	254.1	204.9	180.9	218.6	270.6	297.0	311.8	313.0
12h00	353.3	351.9	351.3	342.0	294.4	245.0	221.2	259.1	311.1	337.5	352.1	353.2
13h00	362.4	361.2	360.8	351.9	304.2	254.8	231.0	269.0	320.4	346.8	361.1	362.2
14h00	366.4	365.6	365.2	357.2	309.7	260.1	236.4	274.3	324.9	351.2	365.2	365.8
15h00	360.3	359.7	359.6	351.5	303.6	253.9	230.4	268.5	319.3	345.2	358.8	359.4
16h00	352.8	352.2	352.1	343.9	295.7	245.9	222.5	261.0	311.8	337.7	351.1	351.8
17h00	339.9	338.6	338.2	328.9	280.3	230.2	207.1	246.1	297.9	324.2	337.9	339.2
18h00	157.8	156.0	155.3	147.1	118.4	89.2	77.6	100.3	131.8	147.5	155.7	157.3
19h00	149.2	147.5	146.8	138.9	110.3	81.2	69.5	92.1	123.3	139.0	147.2	148.6
20h00	127.6	126.2	125.5	118.0	89.7	60.8	49.0	71.1	102.1	117.6	125.8	127.2
21h00	112.8	111.2	110.3	103.3	75.6	46.9	34.9	56.5	86.9	102.7	111.5	112.8
22h00	100.9	99.3	98.2	91.6	64.3	35.8	23.6	44.9	74.7	90.8	100.0	100.9
23h00												
24h00												
TOTAL	**3934.0**	**3918.0**	**3911.7**	**3791.2**	**3177.4**	**2539.5**	**2241.4**	**2728.4**	**3391.3**	**3730.8**	**3914.9**	**3928.0**

Table A5.2: Estimate of instantaneous cooling load for Howard College

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	54.3	54.3	54.3	52.6	32.9	12.4	1.2	17.4	37.8	48.5	54.3	54.3
02h00	53.6	53.2	53.6	51.9	32.3	11.8	0.6	16.7	37.2	47.8	53.6	53.5
03h00	53.1	52.7	53.1	51.4	31.8	11.3	0.1	16.2	36.7	47.4	53.1	53.1
04h00	52.8	52.4	52.8	51.1	31.4	10.9	-0.3	15.9	36.4	47.0	52.8	52.8
05h00	52.4	52.1	52.4	50.8	31.1	10.6	-0.6	15.5	36.0	46.7	52.4	52.4
06h00	53.4	53.2	53.4	51.8	32.1	11.6	0.4	16.5	37.0	47.7	53.4	53.4
07h00	111.9	111.9	111.9	108.5	69.2	28.2	5.8	38.1	79.0	100.4	111.9	111.8
08h00	117.5	117.6	117.5	114.2	74.9	33.9	11.5	43.7	84.7	106.1	117.5	117.2
09h00	247.7	247.7	247.7	241.1	162.5	80.5	35.6	100.1	182.1	224.8	247.7	247.4
10h00	253.1	253.1	253.1	246.4	167.8	85.8	41.0	105.5	187.5	230.1	253.1	252.6
11h00	255.7	255.7	255.7	249.0	170.5	88.5	43.7	108.1	190.2	232.8	255.7	255.5
12h00	259.1	259.1	259.2	252.5	173.8	91.8	47.0	111.5	193.4	236.2	259.1	258.6
13h00	259.1	259.1	259.1	252.5	173.8	91.8	47.0	111.5	193.4	236.1	259.2	259.1
14h00	258.4	258.4	258.4	251.7	173.1	91.1	46.4	110.8	192.8	235.4	258.4	258.2
15h00	254.4	254.4	254.4	247.7	169.1	87.1	42.4	106.8	188.8	231.4	254.4	254.1
16h00	249.1	249.1	249.1	242.4	163.8	81.8	37.0	101.4	183.5	226.1	249.1	249.0
17h00	243.7	243.8	243.7	237.1	158.4	76.4	31.7	96.1	178.1	220.7	243.7	243.3
18h00	239.1	239.1	239.1	232.5	153.8	71.8	27.0	91.5	173.4	216.1	239.1	238.6
19h00	117.2	117.2	117.2	113.9	74.5	33.6	11.1	43.4	84.4	105.7	117.2	117.0
20h00	115.6	115.5	115.5	112.2	72.9	31.9	9.5	41.7	82.7	104.0	115.5	115.2
21h00	114.2	114.2	114.2	110.9	71.6	30.5	8.2	40.4	81.4	102.7	114.2	114.2
22h00	113.2	113.2	113.2	109.9	70.5	29.6	7.1	39.4	80.4	101.7	113.2	113.1
23h00	55.8	55.8	55.8	54.1	34.4	14.0	2.7	18.9	39.3	50.0	55.8	55.7
24h00	55.3	55.3	55.3	53.6	33.9	13.4	2.2	18.4	38.9	49.5	55.3	55.1
TOTAL	**3639.7**	**3638.2**	**3639.9**	**3539.9**	**2360.3**	**1130.5**	**458.3**	**1425.4**	**2655.1**	**3295.0**	**3639.8**	**3635.2**

Table A5.3: Estimate of instantaneous cooling load for the E. G. Malherbe Library

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	107.9	105.1	103.9	98.8	77.3	54.9	44.7	61.7	85.6	98.5	107.0	109.3
09h00	112.5	109.3	107.9	102.4	80.8	58.2	48.2	65.3	89.6	102.7	111.5	114.1
10h00	116.8	113.3	111.7	106.5	84.7	62.1	52.2	69.4	93.4	106.6	115.7	118.6
11h00	121.5	118.2	116.6	111.4	89.7	67.1	57.2	74.4	98.4	111.6	120.4	123.4
12h00	123.1	119.8	118.4	113.5	91.9	69.3	59.3	76.4	100.1	113.2	122.0	125.0
13h00	124.2	120.9	119.7	115.0	93.6	71.0	61.0	77.9	101.4	114.3	123.1	126.1
14h00	122.9	119.6	118.5	114.0	92.7	70.1	60.1	76.9	100.2	113.0	121.8	124.9
15h00	121.8	118.7	117.9	113.6	92.3	69.8	59.7	76.5	99.6	112.1	120.6	123.6
16h00	120.1	117.1	116.5	112.4	91.2	68.6	58.6	75.3	98.2	110.5	118.9	121.9
17h00	107.3	104.4	103.9	99.9	78.7	56.2	46.2	62.8	85.6	97.8	106.1	109.1
18h00												
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**1178.1**	**1146.4**	**1135.0**	**1087.5**	**872.9**	**647.3**	**547.2**	**716.6**	**952.1**	**1080.3**	**1167.1**	**1196.0**

Table A5.4: Estimate of instantaneous cooling load for the Business Concourse

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	53.6	53.0	52.7	50.5	42.2	33.8	29.6	36.4	45.9	50.5	53.3	53.8
09h00	56.3	55.7	55.6	53.5	45.1	36.7	32.5	39.3	48.8	53.3	56.0	56.4
10h00	58.6	58.0	57.8	55.6	47.1	38.7	34.5	41.5	51.0	55.6	58.2	58.7
11h00	60.7	60.3	60.0	57.8	49.2	40.7	36.5	43.7	53.3	57.8	60.3	60.8
12h00	62.7	62.3	62.0	60.0	51.4	42.8	38.7	45.8	55.3	59.9	62.3	62.8
13h00	64.9	64.2	64.0	61.9	53.1	44.6	40.5	47.7	57.2	61.9	64.3	64.9
14h00	66.6	65.9	65.6	63.4	54.7	46.0	42.0	49.2	58.9	63.5	66.0	66.6
15h00	67.9	67.2	66.8	64.6	55.6	46.8	43.0	50.4	60.1	64.8	67.2	67.9
16h00	68.5	67.8	67.4	65.0	56.1	47.1	43.4	50.9	60.6	65.4	67.9	68.5
17h00	68.6	67.8	67.2	64.8	55.6	46.7	43.0	50.6	60.5	65.4	67.9	68.7
18h00	40.5	39.6	39.0	36.5	27.4	18.5	14.7	22.4	32.2	37.2	39.8	40.5
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**668.9**	**661.9**	**658.2**	**633.7**	**537.5**	**442.4**	**398.5**	**477.8**	**583.8**	**635.3**	**663.1**	**669.5**

Table A5.5: Estimate of instantaneous cooling load for the New Chemistry Laboratory

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	9.8	9.7	9.7	9.2	7.4	5.5	4.7	6.0	8.0	9.1	9.7	9.8
09h00	13.2	13.2	13.2	12.7	10.9	9.0	8.2	9.5	11.5	12.5	13.1	13.1
10h00	13.7	13.8	13.8	13.3	11.5	9.6	8.8	10.1	12.2	13.1	13.7	13.7
11h00	14.0	14.1	14.1	13.6	11.8	9.9	9.1	10.5	12.5	13.4	13.9	14.0
12h00	14.3	14.4	14.5	14.0	12.2	10.2	9.4	10.8	12.8	13.7	14.2	14.3
13h00	14.3	14.3	14.4	13.9	12.1	10.2	9.4	10.7	12.8	13.7	14.2	14.3
14h00	14.3	14.3	14.4	13.8	12.0	10.1	9.3	10.7	12.7	13.7	14.2	14.3
15h00	12.1	12.0	11.9	11.3	9.4	7.5	6.7	8.1	10.3	11.3	12.0	12.1
16h00	9.4	9.2	9.1	8.2	6.3	4.3	3.6	5.0	7.4	8.5	9.3	9.4
17h00	9.5	9.1	8.9	7.8	5.7	3.8	3.0	4.6	7.2	8.5	9.3	9.6
18h00	8.8	8.3	8.0	6.7	4.6	2.6	1.9	3.5	6.3	7.6	8.6	8.9
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**133.4**	**132.4**	**132.0**	**124.5**	**103.9**	**82.7**	**74.1**	**89.5**	**113.7**	**125.1**	**132.2**	**133.5**

Table A5.6: Estimate of instantaneous cooling load for the Chemical Engineering Building

APPENDIX 6

ESTIMATES ON PULL-DOWN COOLING LOADS

- Estimate of pull-down cooling load for Denis Shepstone Building
- Estimate of pull-down cooling load for Howard College
- Estimate of pull-down cooling load for the E. G. Malherbe Library
- Estimate of pull-down cooling load for the Business Concourse
- Estimate of pull-down cooling load for the New Chemistry Laboratory
- Estimate of pull-down cooling load for the Chemical Engineering Building

All values are in kilowatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	262.9	261.8	263.4	248.3	222.9	194.3	189.1	204.6	236.1	250.8	259.6	262.6
02h00	241.3	240.5	242.1	227.8	203.2	174.8	169.4	184.2	214.8	229.6	238.5	241.0
03h00	225.1	224.7	226.4	212.6	188.3	160.0	154.5	169.0	199.2	213.8	222.5	224.6
04h00	210.0	209.9	211.8	198.6	174.6	146.4	140.7	154.9	184.5	199.0	207.7	209.4
05h00	192.8	193.2	195.1	182.6	159.2	131.3	125.4	139.0	167.8	182.3	190.9	192.1
06h00	219.6	216.2	215.9	197.1	171.0	142.6	137.2	153.4	188.6	205.3	216.6	220.0
07h00	280.4	272.8	270.5	247.7	219.7	190.5	185.9	204.0	243.3	261.9	276.2	282.7
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00												
19h00												
20h00												
21h00												
22h00	454.4	451.7	453.2	435.4	407.6	377.8	373.8	391.8	426.0	440.8	449.1	453.9
23h00	379.2	376.6	377.8	360.5	333.6	304.2	299.7	316.9	350.5	365.7	374.7	379.0
24h00	331.7	329.8	331.2	315.2	289.2	260.3	255.4	271.6	304.0	318.9	327.8	331.5
TOTAL	**2797.5**	**2777.4**	**2787.4**	**2626.0**	**2369.5**	**2082.3**	**2031.3**	**2189.4**	**2514.6**	**2668.2**	**2763.6**	**2797.0**

Table A6.1: Estimate of pull-down cooling load for Denis Shepstone Building

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.3	1.8	1.5	-2.1	-8.3	-15.3	-16.6	-12.9	-5.2	-0.9	1.8	2.3
02h00	-3.3	-3.6	-3.7	-7.1	-13.0	-19.9	-21.2	-17.7	-10.4	-6.2	-3.6	-3.4
03h00	-6.9	-7.0	-7.0	-10.2	-16.0	-22.9	-24.3	-20.8	-13.7	-9.7	-7.2	-7.0
04h00	-10.1	-10.1	-10.0	-13.1	-18.9	-25.7	-27.1	-23.8	-16.7	-12.8	-10.4	-10.3
05h00	-13.3	-13.1	-12.9	-15.7	-21.3	-28.1	-29.6	-26.4	-19.5	-15.7	-13.5	-13.4
06h00	30.8	31.0	31.2	28.4	22.8	16.0	14.5	17.7	24.6	28.4	30.6	30.7
07h00	77.9	78.2	78.6	76.1	70.8	64.1	62.5	65.4	72.0	75.6	77.7	77.7
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00												
19h00												
20h00												
21h00												
22h00												
23h00	29.3	28.1	27.2	22.9	16.2	8.9	8.0	12.2	20.6	25.4	28.6	29.4
24h00	19.6	18.9	18.3	14.4	8.1	1.0	-0.2	3.8	11.6	16.2	19.1	19.7
TOTAL	**126.4**	**124.2**	**123.3**	**93.6**	**40.5**	**-21.9**	**-33.9**	**-2.5**	**63.3**	**100.2**	**123.1**	**125.7**

Table A6.2: Estimate of pull-down cooling load for Howard College

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00												
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table A6.3: Estimate of pull-down cooling load for the E. G. Malherbe Library

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	14.7	13.8	13.5	11.5	8.0	3.8	3.0	5.1	9.5	12.2	14.4	15.3
02h00	13.2	12.3	12.1	10.2	6.7	2.5	1.7	3.8	8.1	10.7	12.9	13.7
03h00	12.0	11.2	11.1	9.2	5.7	1.6	0.8	2.8	7.1	9.6	11.7	12.4
04h00	10.9	10.3	10.2	8.3	4.9	0.8	-0.1	1.9	6.1	8.7	10.6	11.3
05h00	9.7	9.3	9.2	7.4	4.1	-0.1	-0.9	1.0	5.2	7.7	9.5	10.0
06h00	25.0	24.2	23.9	21.4	17.6	13.4	12.7	14.9	19.9	22.6	24.7	25.4
07h00	46.4	44.3	43.4	40.2	36.0	31.6	31.1	33.7	39.4	42.7	45.7	47.4
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00	33.2	31.1	30.8	28.4	24.5	20.0	19.6	22.0	26.8	29.5	32.2	34.4
19h00	30.3	28.6	28.4	26.2	22.4	17.9	17.4	19.8	24.4	27.0	29.4	31.4
20h00	28.1	26.7	26.6	24.5	20.8	16.4	15.8	18.1	22.6	25.1	27.4	29.0
21h00	24.0	22.6	22.3	20.2	16.5	12.2	11.6	13.8	18.3	21.0	23.4	24.9
22h00	20.7	19.4	19.0	16.9	13.3	9.0	8.3	10.5	15.0	17.8	20.3	21.6
23h00	18.6	17.3	16.9	14.7	11.2	6.9	6.2	8.3	12.9	15.7	18.2	19.4
24h00	16.9	15.7	15.4	13.3	9.8	5.5	4.8	6.9	11.4	14.1	16.5	17.6
TOTAL	**303.7**	**286.8**	**282.8**	**252.4**	**201.5**	**141.5**	**132.0**	**162.6**	**226.7**	**264.4**	**296.9**	**313.8**

Table A6.4: Estimate of pull-down cooling load for the Business Concourse

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	8.2	7.9	7.8	7.0	6.2	5.4	5.4	6.1	7.1	7.7	8.0	8.2
02h00	6.8	6.6	6.5	5.8	5.1	4.4	4.4	4.9	5.9	6.3	6.6	6.8
03h00	6.2	5.9	5.8	5.3	4.5	3.9	3.8	4.3	5.3	5.8	6.0	6.2
04h00	5.3	5.2	5.1	4.6	3.9	3.2	3.2	3.6	4.5	4.9	5.2	5.3
05h00	4.5	4.5	4.5	4.1	3.5	2.8	2.8	3.2	3.9	4.2	4.5	4.5
06h00	11.7	11.3	11.0	10.0	9.2	8.4	8.4	9.1	10.4	11.0	11.5	11.8
07h00	20.6	19.9	19.6	18.2	17.2	16.5	16.4	17.3	19.0	19.7	20.3	20.7
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00												
19h00	20.3	19.5	19.0	17.2	15.6	14.3	14.8	16.3	18.3	19.3	19.7	20.4
20h00	18.4	17.7	17.2	15.6	14.1	13.0	13.4	14.7	16.5	17.4	17.8	18.4
21h00	15.6	14.9	14.5	13.1	11.7	10.8	11.0	12.2	13.9	14.7	15.1	15.6
22h00	13.1	12.6	12.2	11.0	9.8	8.8	9.1	10.0	11.6	12.3	12.7	13.2
23h00	11.3	10.8	10.4	9.4	8.3	7.5	7.6	8.5	9.9	10.5	10.9	11.3
24h00	9.3	9.0	8.7	7.9	7.0	6.2	6.3	7.0	8.2	8.7	9.1	9.4
TOTAL	**151.4**	**145.6**	**142.2**	**129.2**	**116.1**	**105.3**	**106.6**	**117.0**	**134.6**	**142.6**	**147.4**	**151.9**

Table A6.5: Estimate of pull-down cooling load for the New Chemistry Laboratory

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	2.5	2.3	2.3	1.7	1.1	0.3	0.2	0.6	1.6	2.1	2.4	2.5
02h00	2.3	2.1	2.1	1.6	0.9	0.2	0.0	0.4	1.4	1.9	2.2	2.3
03h00	2.0	1.9	1.9	1.4	0.8	0.0	-0.1	0.3	1.2	1.6	2.0	2.0
04h00	1.9	1.8	1.7	1.3	0.7	-0.1	-0.2	0.2	1.0	1.5	1.8	1.9
05h00	1.7	1.6	1.6	1.2	0.5	-0.2	-0.3	0.0	0.9	1.3	1.7	1.7
06h00	4.2	4.1	4.1	3.6	3.0	2.3	2.1	2.5	3.3	3.8	4.1	4.2
07h00	3.8	3.8	3.7	3.3	2.7	1.9	1.8	2.2	3.0	3.5	3.8	3.8
08h00												
09h00												
10h00												
11h00												
12h00												
13h00												
14h00												
15h00												
16h00												
17h00												
18h00												
19h00	5.2	4.7	4.5	3.4	2.5	1.7	1.6	2.3	3.8	4.4	5.0	5.3
20h00	4.6	4.3	4.0	3.1	2.2	1.5	1.4	2.0	3.3	4.0	4.5	4.8
21h00	4.0	3.7	3.6	2.8	2.0	1.2	1.1	1.7	2.9	3.4	3.9	4.1
22h00	3.5	3.3	3.2	2.5	1.8	1.0	0.9	1.4	2.5	3.0	3.5	3.6
23h00	3.1	2.9	2.9	2.2	1.5	0.8	0.6	1.1	2.1	2.7	3.1	3.2
24h00	2.8	2.7	2.6	2.0	1.3	0.6	0.4	0.9	1.9	2.4	2.8	2.8
TOTAL	**41.6**	**39.2**	**38.2**	**30.1**	**21.0**	**11.2**	**9.5**	**15.6**	**28.9**	**35.6**	**40.8**	**42.2**

Table A6.6: Estimate of pull-down cooling load for the Chemical Engineering Building

APPENDIX 7

ESTIMATES OF OVERALL COOLING LOADS

- Estimate of overall cooling load for Denis Shepstone Building
- Estimate of overall cooling load for Howard College
- Estimate of overall cooling load for the E. G. Malherbe Library
- Estimate of overall cooling load for the Business Concourse
- Estimate of overall cooling load for the New Chemistry Laboratory
- Estimate of overall cooling load for the Chemical Engineering Building
- Estimate of overall cooling load for the district cooling system as a whole

All values are in kiloWatts

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	2411.8	2395.4	1925.2	2297.7	1961.4	1605.1	1457.4	1711.1	2092.4	2283.3	2395.5	2414.7
09h00	2494.5	2477.7	2411.4	2379.0	2041.7	1685.0	1537.7	1792.4	2175.3	2365.5	2477.1	2497.5
10h00	2547.6	2528.0	2490.0	2423.7	2084.2	1726.7	1580.1	1837.1	2224.4	2415.9	2528.8	2550.9
11h00	1651.7	1640.4	1609.3	1589.7	1335.4	1073.5	944.2	1148.6	1426.0	1564.7	1643.5	1654.3
12h00	1483.4	1475.9	1582.7	1432.0	1178.7	916.8	787.4	991.0	1264.6	1400.1	1474.9	1484.8
13h00	1695.7	1691.2	1548.9	1653.4	1400.6	1138.6	1009.3	1212.3	1482.6	1615.5	1686.7	1695.4
14h00	1687.3	1686.0	1694.9	1654.4	1402.3	1140.3	1011.0	1213.4	1480.3	1610.3	1677.8	1685.4
15h00	1682.7	1683.0	1696.1	1653.3	1400.3	1137.7	1009.1	1212.2	1479.1	1607.2	1672.1	1679.4
16h00	1651.9	1652.2	1686.3	1622.3	1368.8	1106.0	977.5	1181.3	1448.6	1576.5	1640.7	1648.8
17h00	1506.9	1504.9	1616.3	1470.7	1215.9	952.6	824.5	1029.6	1299.5	1429.1	1495.3	1504.5
18h00	974.0	970.9	1067.3	942.1	797.9	650.4	585.3	699.8	856.1	927.6	963.3	972.0
19h00	911.4	907.7	937.1	878.4	735.3	590.6	522.7	636.0	791.4	864.5	902.1	910.0
20h00	864.0	860.7	882.6	832.5	690.8	544.3	478.2	590.1	743.8	817.4	855.9	862.7
21h00	806.1	803.3	827.3	776.4	636.4	490.5	423.8	534.0	685.6	759.9	799.5	805.1
22h00												
23h00												
24h00												
TOTAL	**22369.1**	**22277.3**	**21975.4**	**21605.6**	**18249.6**	**14758.1**	**13148.2**	**15789.1**	**19449.8**	**21237.5**	**22213.6**	**22365.4**

Table A7.1: Overall cooling load estimate for Denis Shepstone Building

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	311.9	311.7	311.8	295.9	232.8	163.4	134.7	181.0	251.5	289.2	310.8	311.2
09h00	315.8	315.3	315.5	298.9	235.4	165.9	137.3	184.0	255.2	292.8	314.4	315.2
10h00	336.4	334.3	333.5	314.3	249.5	179.6	151.4	199.4	273.2	311.8	334.4	336.0
11h00	312.9	311.4	310.9	301.5	254.1	204.9	180.9	218.6	270.6	297.0	311.8	313.0
12h00	353.3	351.9	351.3	342.0	294.4	245.0	221.2	259.1	311.1	337.5	352.1	353.2
13h00	362.4	361.2	360.8	351.9	304.2	254.8	231.0	269.0	320.4	346.8	361.1	362.2
14h00	366.4	365.6	365.2	357.2	309.7	260.1	236.4	274.3	324.9	351.2	365.2	365.8
15h00	360.3	359.7	359.6	351.5	303.6	253.9	230.4	268.5	319.3	345.2	358.8	359.4
16h00	352.8	352.2	352.1	343.9	295.7	245.9	222.5	261.0	311.8	337.7	351.1	351.8
17h00	339.9	338.6	338.2	328.9	280.3	230.2	207.1	246.1	297.9	324.2	337.9	339.2
18h00	157.8	156.0	155.3	147.1	118.4	89.2	77.6	100.3	131.8	147.5	155.7	157.3
19h00	149.2	147.5	146.8	138.9	110.3	81.2	69.5	92.1	123.3	139.0	147.2	148.6
20h00	127.6	126.2	125.5	118.0	89.7	60.8	49.0	71.1	102.1	117.6	125.8	127.2
21h00	112.8	111.2	110.3	103.3	75.6	46.9	34.9	56.5	86.9	102.7	111.5	112.8
22h00	100.9	99.3	98.2	91.6	64.3	35.8	23.6	44.9	74.7	90.8	100.0	100.9
23h00												
24h00												
TOTAL	**4060.3**	**4042.2**	**4035.1**	**3884.8**	**3217.9**	**2517.6**	**2207.5**	**2726.0**	**3454.6**	**3831.0**	**4038.0**	**4053.7**

Table A7.2: Overall cooling load estimate for Howard College

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	54.3	54.3	54.3	52.6	32.9	12.4	1.2	17.4	37.8	48.5	54.3	54.3
02h00	53.6	53.2	53.6	51.9	32.3	11.8	0.6	16.7	37.2	47.8	53.6	53.5
03h00	53.1	52.7	53.1	51.4	31.8	11.3	0.1	16.2	36.7	47.4	53.1	53.1
04h00	52.8	52.4	52.8	51.1	31.4	10.9	-0.3	15.9	36.4	47.0	52.8	52.8
05h00	52.4	52.1	52.4	50.8	31.1	10.6	-0.6	15.5	36.0	46.7	52.4	52.4
06h00	53.4	53.2	53.4	51.8	32.1	11.6	0.4	16.5	37.0	47.7	53.4	53.4
07h00	111.9	111.9	111.9	108.5	69.2	28.2	5.8	38.1	79.0	100.4	111.9	111.8
08h00	117.5	117.6	117.5	114.2	74.9	33.9	11.5	43.7	84.7	106.1	117.5	117.2
09h00	247.7	247.7	247.7	241.1	162.5	80.5	35.6	100.1	182.1	224.8	247.7	247.4
10h00	253.1	253.1	253.1	246.4	167.8	85.8	41.0	105.5	187.5	230.1	253.1	252.6
11h00	255.7	255.7	255.7	249.0	170.5	88.5	43.7	108.1	190.2	232.8	255.7	255.5
12h00	259.1	259.1	259.2	252.5	173.8	91.8	47.0	111.5	193.4	236.2	259.1	258.6
13h00	259.1	259.1	259.1	252.5	173.8	91.8	47.0	111.5	193.4	236.1	259.2	259.1
14h00	258.4	258.4	258.4	251.7	173.1	91.1	46.4	110.8	192.8	235.4	258.4	258.2
15h00	254.4	254.4	254.4	247.7	169.1	87.1	42.4	106.8	188.8	231.4	254.4	254.1
16h00	249.1	249.1	249.1	242.4	163.8	81.8	37.0	101.4	183.5	226.1	249.1	249.0
17h00	243.7	243.8	243.7	237.1	158.4	76.4	31.7	96.1	178.1	220.7	243.7	243.3
18h00	239.1	239.1	239.1	232.5	153.8	71.8	27.0	91.5	173.4	216.1	239.1	238.6
19h00	117.2	117.2	117.2	113.9	74.5	33.6	11.1	43.4	84.4	105.7	117.2	117.0
20h00	115.6	115.5	115.5	112.2	72.9	31.9	9.5	41.7	82.7	104.0	115.5	115.2
21h00	114.2	114.2	114.2	110.9	71.6	30.5	8.2	40.4	81.4	102.7	114.2	114.2
22h00	113.2	113.2	113.2	109.9	70.5	29.6	7.1	39.4	80.4	101.7	113.2	113.1
23h00	55.8	55.8	55.8	54.1	34.4	14.0	2.7	18.9	39.3	50.0	55.8	55.7
24h00	55.3	55.3	55.3	53.6	33.9	13.4	2.2	18.4	38.9	49.5	55.3	55.1
TOTAL	**3639.7**	**3638.2**	**3639.9**	**3539.9**	**2360.3**	**1130.5**	**458.3**	**1425.4**	**2655.1**	**3295.0**	**3639.8**	**3635.2**

Table A7.3: Overall cooling load estimate for the E. G. Malherbe Library

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	209.1	200.7	198.2	182.9	144.5	102.1	88.7	115.9	161.2	186.6	206.0	213.9
09h00	213.7	204.9	202.2	186.5	148.0	105.4	92.2	119.5	165.2	190.8	210.5	218.7
10h00	218.0	208.9	206.0	190.6	151.9	109.3	96.2	123.6	169.0	194.7	214.7	223.2
11h00	121.5	118.2	116.6	111.4	89.7	67.1	57.2	74.4	98.4	111.6	120.4	123.4
12h00	123.1	119.8	118.4	113.5	91.9	69.3	59.3	76.4	100.1	113.2	122.0	125.0
13h00	124.2	120.9	119.7	115.0	93.6	71.0	61.0	77.9	101.4	114.3	123.1	126.1
14h00	122.9	119.6	118.5	114.0	92.7	70.1	60.1	76.9	100.2	113.0	121.8	124.9
15h00	121.8	118.7	117.9	113.6	92.3	69.8	59.7	76.5	99.6	112.1	120.6	123.6
16h00	120.1	117.1	116.5	112.4	91.2	68.6	58.6	75.3	98.2	110.5	118.9	121.9
17h00	107.3	104.4	103.9	99.9	78.7	56.2	46.2	62.8	85.6	97.8	106.1	109.1
18h00												
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**1481.8**	**1433.2**	**1417.8**	**1339.9**	**1074.4**	**788.8**	**679.2**	**879.2**	**1178.8**	**1344.7**	**1464.0**	**1509.8**

Table A7.4: Overall cooling load estimate for the Business Concourse

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	104.1	101.5	100.1	93.6	80.9	68.9	65.1	75.4	90.8	98.1	102.4	104.4
09h00	106.8	104.3	103.0	96.5	83.8	71.8	68.0	78.3	93.6	100.8	105.1	107.0
10h00	109.1	106.5	105.2	98.7	85.8	73.8	70.0	80.5	95.9	103.1	107.4	109.4
11h00	60.7	60.3	60.0	57.8	49.2	40.7	36.5	43.7	53.3	57.8	60.3	60.8
12h00	62.7	62.3	62.0	60.0	51.4	42.8	38.7	45.8	55.3	59.9	62.3	62.8
13h00	64.9	64.2	64.0	61.9	53.1	44.6	40.5	47.7	57.2	61.9	64.3	64.9
14h00	66.6	65.9	65.6	63.4	54.7	46.0	42.0	49.2	58.9	63.5	66.0	66.6
15h00	67.9	67.2	66.8	64.6	55.6	46.8	43.0	50.4	60.1	64.8	67.2	67.9
16h00	68.5	67.8	67.4	65.0	56.1	47.1	43.4	50.9	60.6	65.4	67.9	68.5
17h00	68.6	67.8	67.2	64.8	55.6	46.7	43.0	50.6	60.5	65.4	67.9	68.7
18h00	40.5	39.6	39.0	36.5	27.4	18.5	14.7	22.4	32.2	37.2	39.8	40.5
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**820.3**	**807.5**	**800.4**	**762.9**	**653.6**	**547.7**	**505.1**	**594.9**	**718.5**	**777.8**	**810.6**	**821.4**

Table A7.5: Overall cooling load estimate for the New Chemistry Laboratory

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00												
02h00												
03h00												
04h00												
05h00												
06h00												
07h00												
08h00	23.7	22.8	22.4	19.2	14.4	9.2	7.9	11.2	17.6	21.0	23.3	23.9
09h00	27.1	26.3	25.9	22.7	17.9	12.7	11.4	14.7	21.1	24.4	26.7	27.2
10h00	27.6	26.9	26.5	23.3	18.5	13.3	12.0	15.3	21.8	25.0	27.3	27.8
11h00	14.0	14.1	14.1	13.6	11.8	9.9	9.1	10.5	12.5	13.4	13.9	14.0
12h00	14.3	14.4	14.5	14.0	12.2	10.2	9.4	10.8	12.8	13.7	14.2	14.3
13h00	14.3	14.3	14.4	13.9	12.1	10.2	9.4	10.7	12.8	13.7	14.2	14.3
14h00	14.3	14.3	14.4	13.8	12.0	10.1	9.3	10.7	12.7	13.7	14.2	14.3
15h00	12.1	12.0	11.9	11.3	9.4	7.5	6.7	8.1	10.3	11.3	12.0	12.1
16h00	9.4	9.2	9.1	8.2	6.3	4.3	3.6	5.0	7.4	8.5	9.3	9.4
17h00	9.5	9.1	8.9	7.8	5.7	3.8	3.0	4.6	7.2	8.5	9.3	9.6
18h00	8.8	8.3	8.0	6.7	4.6	2.6	1.9	3.5	6.3	7.6	8.6	8.9
19h00												
20h00												
21h00												
22h00												
23h00												
24h00												
TOTAL	**175.0**	**171.6**	**170.2**	**154.6**	**124.9**	**93.9**	**83.6**	**105.1**	**142.6**	**160.7**	**173.0**	**175.7**

Table A7.6: Overall cooling load estimate for the Chemical Engineering Building

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	54.3	54.3	54.3	52.6	32.9	12.4	1.2	17.4	37.8	48.5	54.3	54.3
02h00	53.6	53.2	53.6	51.9	32.3	11.8	0.6	16.7	37.2	47.8	53.6	53.5
03h00	53.1	52.7	53.1	51.4	31.8	11.3	0.1	16.2	36.7	47.4	53.1	53.1
04h00	52.8	52.4	52.8	51.1	31.4	10.9	**-0.3**	15.9	36.4	47.0	52.8	52.8
05h00	52.4	52.1	52.4	50.8	31.1	10.6	**-0.6**	15.5	36.0	46.7	52.4	52.4
06h00	53.4	53.2	53.4	51.8	32.1	11.6	0.4	16.5	37.0	47.7	53.4	53.4
07h00	111.9	111.9	111.9	108.5	69.2	28.2	5.8	38.1	79.0	100.4	111.9	111.8
08h00	3178.1	3149.6	2675.2	3003.7	2508.8	1982.6	1765.3	2138.3	2698.2	2984.2	3155.5	3185.3
09h00	3405.6	3376.1	3305.7	3224.8	2689.2	2121.3	1882.2	2289.1	2892.4	3199.2	3381.6	3413.0
10h00	3491.7	3457.6	3414.3	3297.1	2757.6	2188.6	1950.7	2361.4	2971.8	3280.6	3465.7	3499.9
11h00	2416.5	2400.2	2366.7	2323.1	1910.7	1484.4	1271.5	1603.9	2051.0	2277.3	2405.7	2421.0
12h00	2295.9	2283.4	2388.2	2214.0	1802.3	1376.0	1163.0	1494.6	1937.3	2160.5	2284.7	2298.6
13h00	2520.6	2510.9	2366.8	2448.5	2037.6	1610.9	1398.2	1729.2	2167.8	2388.2	2508.6	2522.0
14h00	2516.0	2509.9	2517.0	2454.5	2044.5	1617.7	1405.2	1735.3	2169.9	2387.1	2503.5	2515.2
15h00	2499.2	2495.0	2506.7	2441.9	2030.4	1602.8	1391.2	1722.5	2157.2	2372.1	2485.2	2496.5
16h00	2451.9	2447.6	2480.6	2394.3	1981.8	1553.8	1342.6	1674.8	2110.1	2324.8	2437.0	2449.5
17h00	2276.0	2268.6	2378.3	2209.2	1794.6	1366.0	1155.5	1489.8	1928.8	2145.7	2260.3	2274.4
18h00	1420.2	1414.0	1508.6	1364.9	1102.0	832.4	706.6	917.5	1199.9	1335.9	1406.4	1417.4
19h00	1177.8	1172.5	1201.1	1131.1	920.1	705.4	603.4	771.5	999.1	1109.3	1166.5	1175.5
20h00	1107.1	1102.4	1123.6	1062.7	853.4	637.0	536.6	703.0	928.6	1039.0	1097.3	1105.1
21h00	1033.1	1028.7	1051.8	990.6	783.5	568.0	466.9	630.9	853.8	965.3	1025.3	1032.0
22h00	214.1	212.5	211.4	201.5	134.9	65.4	30.7	84.2	155.1	192.5	213.2	214.0
23h00	55.8	55.8	55.8	54.1	34.4	14.0	2.7	18.9	39.3	50.0	55.8	55.7
24h00	55.3	55.3	55.3	53.6	33.9	13.4	2.2	18.4	38.9	49.5	55.3	55.1
TOTAL	**32546**	**32370**	**32038**	**31287**	**25680**	**19836**	**17081**	**21519**	**27599**	**30646**	**32338**	**32561**

Table A7.7: Overall cooling load estimate for the district cooling system as a whole

APPENDIX 8

CUMULATIVE CHILLED WATER FLOW RATES THROUGH THE THREE SECONDARY CHILLED WATER PUMPS

- Cumulative chilled water flow rate through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 7^0C
- Cumulative chilled water flow rate through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 8^0C
- Cumulative chilled water flow rate through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 9^0C
- Chiller scheduling and total chiller hours required to meet cooling load, assuming a thermocline thickness of 0.5m
- Thermocline heights for each month, assuming a thermocline thickness of 0.5m, and chiller scheduling as detailed in Table A8.4

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	110.8	110.8	110.8	107.3	67.2	25.4	2.5	35.4	77.2	99.0	110.8	110.7
02h00	109.4	108.6	109.4	106.0	65.9	24.0	1.2	34.1	75.9	97.6	109.4	109.2
03h00	108.4	107.6	108.3	105.0	64.8	23.0	0.1	33.1	74.9	96.6	108.4	108.3
04h00	107.7	107.0	107.7	104.3	64.2	22.3	0.0	32.4	74.2	95.9	107.7	107.7
05h00	107.0	106.4	107.0	103.6	63.5	21.7	0.0	31.7	73.5	95.3	107.0	106.9
06h00	109.1	108.6	109.1	105.7	65.5	23.7	0.8	33.7	75.5	97.3	109.1	109.0
07h00	228.3	228.3	228.3	221.5	141.3	57.6	11.9	77.7	161.3	204.8	228.3	228.1
08h00	6485.9	6427.8	5459.6	6129.9	5120.1	4046.0	3602.7	4364.0	5506.5	6090.2	6439.9	6500.5
09h00	6950.1	6890.1	6746.4	6581.3	5488.2	4329.1	3841.2	4671.6	5902.9	6529.0	6901.1	6965.4
10h00	7125.9	7056.3	6968.0	6728.8	5627.8	4466.5	3981.1	4819.2	6064.8	6695.1	7072.8	7142.6
11h00	4931.6	4898.3	4829.9	4741.0	3899.4	3029.5	2595.0	3273.3	4185.7	4647.6	4909.6	4940.8
12h00	4685.6	4659.9	4873.8	4518.4	3678.1	2808.1	2373.4	3050.2	3953.7	4409.1	4662.6	4691.1
13h00	5144.1	5124.3	4830.3	4997.0	4158.3	3287.6	2853.5	3528.9	4424.2	4873.9	5119.6	5146.9
14h00	5134.6	5122.3	5136.8	5009.2	4172.4	3301.5	2867.8	3541.4	4428.4	4871.7	5109.1	5133.0
15h00	5100.4	5091.9	5115.8	4983.5	4143.7	3271.1	2839.2	3515.3	4402.3	4841.0	5071.7	5094.9
16h00	5003.8	4995.1	5062.4	4886.3	4044.6	3171.0	2740.0	3418.0	4306.4	4744.4	4973.5	4998.9
17h00	4644.9	4629.8	4853.6	4508.6	3662.4	2787.7	2358.1	3040.4	3936.3	4379.0	4612.8	4641.6
18h00	2898.3	2885.6	3078.8	2785.5	2249.0	1698.9	1442.0	1872.4	2448.7	2726.4	2870.3	2892.6
19h00	2403.6	2392.8	2451.3	2308.4	1877.7	1439.6	1231.3	1574.6	2039.0	2263.8	2380.6	2399.0
20h00	2259.4	2249.8	2293.1	2168.7	1741.7	1299.9	1095.2	1434.6	1895.0	2120.5	2239.3	2255.2
21h00	2108.3	2099.4	2146.5	2021.6	1599.0	1159.1	952.8	1287.6	1742.5	1970.0	2092.4	2106.2
22h00	437.0	433.7	431.5	411.2	275.3	133.4	62.7	171.9	316.5	392.9	435.1	436.7
23h00	113.8	113.8	113.8	110.4	70.3	28.5	5.6	38.5	80.3	102.1	113.8	113.8
24h00	112.8	112.8	112.8	109.4	69.2	27.4	4.6	37.5	79.3	101.1	112.8	112.5
TOTAL	**66420.7**	**66061.0**	**65384.9**	**63852.4**	**52409.3**	**40482.6**	**34862.7**	**43917.4**	**56325.0**	**62544.2**	**65997.6**	**66451.4**

Table A8.1: Cumulative chilled water flow rate (l/min) through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 7^0C

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	96.9	96.9	96.9	93.9	58.8	22.2	2.2	31.0	67.6	86.6	96.9	96.9
02h00	95.7	95.0	95.7	92.7	57.6	21.0	1.0	29.8	66.4	85.4	95.7	95.5
03h00	94.8	94.2	94.8	91.8	56.7	20.1	0.1	28.9	65.5	84.6	94.8	94.7
04h00	94.2	93.6	94.2	91.3	56.2	19.5	0.0	28.3	64.9	83.9	94.2	94.2
05h00	93.6	93.1	93.6	90.6	55.5	18.9	0.0	27.7	64.3	83.4	93.6	93.5
06h00	95.4	95.1	95.4	92.5	57.3	20.7	0.7	29.5	66.1	85.1	95.4	95.4
07h00	199.7	199.7	199.7	193.8	123.6	50.4	10.4	68.0	141.1	179.2	199.7	199.6
08h00	5675.2	5624.3	4777.2	5363.7	4480.1	3540.3	3152.4	3818.5	4818.2	5328.9	5634.9	5688.0
09h00	6081.3	6028.8	5903.1	5758.6	4802.2	3788.0	3361.1	4087.6	5165.0	5712.9	6038.5	6094.7
10h00	6235.2	6174.3	6097.0	5887.7	4924.3	3908.2	3483.4	4216.8	5306.7	5858.2	6188.7	6249.8
11h00	4315.2	4286.0	4226.2	4148.4	3411.9	2650.8	2270.6	2864.2	3662.5	4066.6	4295.9	4323.2
12h00	4099.9	4077.4	4264.6	3953.6	3218.3	2457.0	2076.7	2668.9	3459.5	3858.0	4079.7	4104.7
13h00	4501.1	4483.8	4226.5	4372.4	3638.5	2876.7	2496.8	3087.8	3871.1	4264.7	4479.7	4503.5
14h00	4492.8	4482.0	4494.7	4383.1	3650.8	2888.8	2509.4	3098.7	3874.8	4262.7	4470.5	4491.3
15h00	4462.9	4455.4	4476.3	4360.5	3625.7	2862.2	2484.3	3075.9	3852.0	4235.9	4437.8	4458.0
16h00	4378.3	4370.7	4429.6	4275.5	3539.0	2774.6	2397.5	2990.8	3768.1	4151.4	4351.9	4374.1
17h00	4064.3	4051.1	4246.9	3945.0	3204.6	2439.2	2063.3	2660.3	3444.3	3831.6	4036.2	4061.4
18h00	2536.0	2524.9	2694.0	2437.3	1967.8	1486.5	1261.7	1638.4	2142.6	2385.6	2511.5	2531.0
19h00	2103.2	2093.7	2144.9	2019.8	1643.0	1259.7	1077.4	1377.7	1784.1	1980.8	2083.0	2099.1
20h00	1977.0	1968.6	2006.5	1897.6	1524.0	1137.4	958.3	1255.3	1658.1	1855.4	1959.4	1973.3
21h00	1844.8	1837.0	1878.2	1768.9	1399.2	1014.2	833.7	1126.7	1524.7	1723.8	1830.8	1842.9
22h00	382.4	379.5	377.6	359.8	240.9	116.7	54.9	150.4	277.0	343.8	380.7	382.1
23h00	99.6	99.6	99.6	96.6	61.5	24.9	4.9	33.7	70.3	89.3	99.6	99.5
24h00	98.7	98.7	98.7	95.7	60.6	24.0	4.0	32.8	69.4	88.4	98.7	98.4
TOTAL	**58118.1**	**57803.4**	**57211.8**	**55870.9**	**45858.2**	**35422.3**	**30504.8**	**38427.7**	**49284.4**	**54726.2**	**57747.9**	**58145.0**

Table A8.2: Cumulative chilled water flow rate (l/min) through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 8^0C

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	86.1	86.1	86.1	83.5	52.3	19.8	2.0	27.6	60.1	77.0	86.1	86.1
02h00	85.1	84.5	85.1	82.4	51.2	18.7	0.9	26.5	59.0	75.9	85.1	84.9
03h00	84.3	83.7	84.3	81.6	50.4	17.9	0.1	25.7	58.2	75.2	84.3	84.2
04h00	83.7	83.2	83.7	81.1	49.9	17.4	0.0	25.2	57.7	74.6	83.7	83.7
05h00	83.2	82.8	83.2	80.6	49.4	16.8	0.0	24.6	57.2	74.1	83.2	83.1
06h00	84.8	84.5	84.8	82.2	51.0	18.4	0.6	26.2	58.8	75.7	84.8	84.8
07h00	177.6	177.6	177.6	172.3	109.9	44.8	9.2	60.4	125.4	159.3	177.6	177.4
08h00	5044.6	4999.4	4246.4	4767.7	3982.3	3146.9	2802.1	3394.2	4282.8	4736.8	5008.8	5056.0
09h00	5405.6	5358.9	5247.2	5118.8	4268.6	3367.1	2987.6	3633.4	4591.1	5078.1	5367.5	5417.5
10h00	5542.4	5488.3	5419.5	5233.5	4377.2	3473.9	3096.4	3748.3	4717.1	5207.3	5501.1	5555.4
11h00	3835.7	3809.8	3756.6	3687.4	3032.8	2356.2	2018.3	2545.9	3255.5	3614.8	3818.6	3842.9
12h00	3644.3	3624.4	3790.8	3514.3	2860.7	2184.0	1846.0	2372.4	3075.1	3429.3	3626.4	3648.6
13h00	4000.9	3985.6	3756.9	3886.6	3234.2	2557.0	2219.4	2744.7	3441.0	3790.8	3981.9	4003.1
14h00	3993.6	3984.0	3995.3	3896.1	3245.2	2567.8	2230.5	2754.4	3444.3	3789.1	3973.7	3992.3
15h00	3967.0	3960.4	3978.9	3876.0	3222.9	2544.2	2208.3	2734.1	3424.0	3765.2	3944.7	3962.7
16h00	3891.8	3885.1	3937.4	3800.4	3145.8	2466.4	2131.1	2658.5	3349.4	3690.1	3868.3	3888.1
17h00	3612.7	3601.0	3775.0	3506.7	2848.6	2168.2	1834.1	2364.7	3061.6	3405.9	3587.8	3610.1
18h00	2254.2	2244.4	2394.6	2166.5	1749.2	1321.3	1121.5	1456.3	1904.5	2120.5	2232.4	2249.8
19h00	1869.5	1861.1	1906.6	1795.4	1460.5	1119.7	957.7	1224.7	1585.9	1760.7	1851.6	1865.9
20h00	1757.3	1749.9	1783.6	1686.8	1354.6	1011.1	851.8	1115.8	1473.9	1649.2	1741.7	1754.1
21h00	1639.8	1632.9	1669.5	1572.3	1243.7	901.5	741.0	1001.5	1355.3	1532.2	1627.4	1638.1
22h00	339.9	337.4	335.6	319.9	214.1	103.8	48.8	133.7	246.2	305.6	338.4	339.6
23h00	88.5	88.5	88.5	85.9	54.7	22.2	4.4	29.9	62.5	79.4	88.5	88.5
24h00	87.7	87.7	87.7	85.1	53.8	21.3	3.6	29.1	61.7	78.6	87.7	87.5
TOTAL	**51660.5**	**51380.8**	**50855.0**	**49663.0**	**40762.8**	**31486.5**	**27115.4**	**34158.0**	**43808.4**	**48645.5**	**51331.4**	**51684.4**

Table A8.3: Cumulative chilled water flow rate (l/min) through the three secondary chilled water pumps, assuming a temperature differential across the cooling load of 9^0C

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	3	3	3	3	3	3	3	3	3	3	3	3
02h00	3	3	3	3	3	3	3	3	3	3	3	3
03h00	3	3	3	3	3	3	3	3	3	3	3	3
04h00	3	3	3	3	3	3	3	3	3	3	3	3
05h00	3	3	3	3	3	3	1	3	3	3	3	3
06h00	3	3	3	3	3	0	0	2	3	3	3	3
07h00	0	0	0	0	0	0	0	0	0	0	0	0
08h00	0	0	0	0	0	0	0	0	0	0	0	0
09h00	0	0	0	0	0	0	0	0	0	0	0	0
10h00	0	0	0	0	0	0	0	0	0	0	0	0
11h00	0	0	0	1	1	1	1	1	1	0	0	0
12h00	0	0	0	1	1	0	0	0	1	0	0	0
13h00	1	1	1	1	1	0	0	0	1	1	1	1
14h00	1	1	1	1	0	0	0	0	1	1	1	1
15h00	1	1	1	1	0	0	0	0	1	1	1	1
16h00	1	1	1	1	0	0	0	0	0	1	1	1
17h00	1	1	1	1	0	0	0	0	0	1	1	1
18h00	1	1	1	1	0	0	0	0	0	1	1	1
19h00	1	1	1	0	0	0	0	0	0	1	1	1
20h00	1	1	1	0	0	0	0	0	0	1	1	1
21h00	1	1	1	0	0	0	0	0	0	1	1	1
22h00	0	0	0	0	0	0	0	0	0	0	0	0
23h00	3	3	3	3	3	3	3	3	3	3	3	3
24h00	3	3	3	3	3	3	3	3	3	3	3	3
TOTAL	**33**	**33**	**33**	**32**	**27**	**21**	**19**	**23**	**29**	**33**	**33**	**33**

Table A8.4: Chiller scheduling and total chiller hours required to meet cooling load, assuming a thermocline thickness of 0.5m This table represents the number of chillers to be run at any given time to ensure adequate cooling.

TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01h00	1.72	1.72	1.72	1.72	1.73	1.74	1.75	1.74	1.73	1.72	1.72	1.72
02h00	2.29	2.29	2.29	2.30	2.31	2.32	2.33	2.32	2.31	2.30	2.29	2.29
03h00	2.87	2.87	2.87	2.87	2.89	2.91	2.92	2.90	2.88	2.87	2.87	2.87
04h00	3.44	3.44	3.44	3.44	3.46	3.49	3.50	3.48	3.46	3.45	3.44	3.44
05h00	4.02	4.02	4.02	4.02	4.04	4.07	3.69	4.06	4.04	4.02	4.02	4.02
06h00	4.59	4.59	4.59	4.59	4.62	4.07	3.69	4.45	4.61	4.60	4.59	4.59
07h00	4.57	4.57	4.57	4.57	4.61	4.06	3.69	4.44	4.60	4.58	4.57	4.57
08h00	3.99	4.00	4.09	4.03	4.15	3.70	3.37	4.05	4.11	4.04	4.00	3.99
09h00	3.38	3.39	3.49	3.45	3.67	3.32	3.03	3.64	3.59	3.46	3.39	3.38
10h00	2.75	2.76	2.87	2.85	3.17	2.92	2.68	3.21	3.05	2.87	2.76	2.74
11h00	2.31	2.33	2.44	2.62	3.02	2.65	2.45	2.92	2.87	2.46	2.32	2.30
12h00	1.89	1.92	2.01	2.42	2.89	2.41	2.24	2.65	2.72	2.07	1.91	1.89
13h00	1.63	1.66	1.78	2.17	2.71	2.11	1.99	2.34	2.52	1.83	1.65	1.63
14h00	1.37	1.40	1.52	1.92	2.34	1.82	1.73	2.03	2.32	1.59	1.39	1.37
15h00	1.11	1.14	1.26	1.67	1.98	1.53	1.48	1.71	2.13	1.36	1.14	1.11
16h00	0.87	0.89	1.00	1.43	1.62	1.25	1.24	1.41	1.74	1.13	0.89	0.86
17h00	0.65	0.68	0.77	1.23	1.29	1.00	1.03	1.14	1.40	0.94	0.68	0.64
18h00	0.59	0.62	0.69	1.18	1.09	0.85	0.90	0.98	1.18	0.89	0.62	0.58
19h00	0.57	0.60	0.67	0.97	0.93	0.73	0.79	0.84	1.00	0.88	0.60	0.56
20h00	0.56	0.59	0.66	0.78	0.77	0.61	0.70	0.71	0.83	0.69	0.60	0.56
21h00	0.57	0.60	0.66	0.60	0.63	0.51	0.61	0.60	0.68	0.52	0.61	0.57
22h00	0.53	0.56	0.62	0.56	0.61	0.50	0.61	0.58	0.65	0.49	0.57	0.53
23h00	0.57	0.57	0.57	0.57	0.58	0.58	0.58	0.58	0.58	0.57	0.57	0.57
24h00	1.15	1.15	1.15	1.15	1.15	1.16	1.17	1.16	1.15	1.15	1.15	1.15

Table A8.5: Thermocline heights for each month, assuming a thermocline thickness of 0.5m, and chiller scheduling as detailed in Table A8.4

APPENDIX 9

ESTIMATE OF THE CAPITAL COST TO CONSTRUCT A 2750 m^3 THERMAL STORAGE TANK

Item	Cost [R]	Accumulated Cost [R]
Bulk Excavation	70280.00	70280.00
Return and light compaction of same on completion	2979.00	73259.00
Cart off site surplas soil	57276.00	130535.00
Concrete (low bleed and low shrinkage) in retaining wall base 35 MPa	44800.00	175335.00
Concrete as above in retaining wall stem	83160.00	258495.00
Formwork to sides of wall	77860.00	336355.00
Waterstops to wall in construction joint	15920.00	352275.00
Reinforcement in base and stem	58716.00	410991.00
Concrete as above in surfacebed	52700.00	463691.00
and 100 mm riversand binder	5664.00	469355.00
and Underlay	2832.00	472187.00
and Mesh	9440.00	481627.00
Waterstops to surfacebed	15520.00	497147.00
Power float floor surface	5920.00	503067.00
Concrete as above in slab	76260.00	579327.00
Centering to slab	47360.00	626687.00
Reinforcement in slab	74058.00	700745.00
Concrete as above in bases, columns and column heads	11700.00	712445.00
Reinforcement	9420.00	721865.00
Formwork to edge not exceeding 300 mm high	5425.00	727290.00
Column side formwork	4240.00	731530.00
Formwork to column head 1.2 x 1.2 reducing to 300 x 300 over a height of 500 mm	4200.00	735730.00
Provide 200 diam. Vent pipe through slab, 700 mm long with cowel	1500.00	737230.00
Provide access opening with cover	650.00	737880.00
Add 12.5 % preliminaries	92235.00	830115.00
Add VAT at 14 %	116216.00	946331.00
Add Professional fees of say 10 %	94633.1	**1040964.10**
Add another 10 % for diffusers	94633.1	**1135597.20**

Table A9.1: Estimate of the capital cost to construct a 2750 m^3 thermal storage tank

APPENDIX 10

TOTAL LIFE CYCLE COSTING DATA

- Total life cycle costing for district cooling system
- Total life cycle costing for individual cooling equipment in each building

Note that costs are in South African Rands

	Neglecting Salvage Value			Salvage Value		Including Salvage Value		
Years	Optimistic	Moderate	Pessimistic	Chiller Salvage value	Tank Salvage value	Optimistic	Moderate	Pessimistic
0	4540545	4540545	4540545	2901528	1639017	0	0	0
1	5026814.7	5031789.95	5036765.2	2756452	1584383	685980	690955.25	695931
2	5542260.582	5557840.871	5573536.176	2611375	1529749	1401136.182	1416716.471	1432412
3	6088633.217	6121167.685	6154187.306	2466299	1475115	2147219.117	2179753.585	2212773
4	6667788.21	6724415.894	6782322.85	2321222	1420481	2926084.41	2982712.094	3040619
5	7281692.503	7370419.074	7461844.794	2176146	1365848	3739699.003	3828425.574	3919851
6	7932431.053	8062212.282	8196977.604	2031070	1311214	4590147.853	4719929.082	4854694
7	8622213.916	8803046.405	8992295.063	1885993	1256580	5479641.016	5660473.505	5849722
8	9353383.751	9596403.538	9852749.342	1740917	1201946	6410521.151	6653540.938	6909887
9	10128423.78	10446013.46	10783702.53	1595840	1147312	7385271.476	7702861.16	8040550
10	10949966.2	11355871.29	11790960.8	1450764	1092678	8406524.202	8812429.292	9247519
11	11820801.17	12330256.4	12880811.44	1305688	1038044	9477069.475	9986524.702	10537080
12	12743886.25	13373752.68	14060063	1160611	983410	10599864.85	11229731.28	11916042
13	13722356.42	14491270.24	15336088.86	1015535	928776	11778045.32	12546959.14	13391778
14	14759534.8	15688068.71	16716874.37	870458	874142	13014934	13943467.91	14972274
15	15858943.89	16969782.11	18211068.05	725382	819509	14314053.39	15424891.61	16666178
16	17024317.53	18342445.61	19828037.11	580306	764875	15679137.33	16997265.41	18482857
17	18259613.58	19812524.14	21577927.55	435229	710241	17114143.68	18667054.24	20432458
18	19569027.39	21386943.03	23471729.47	290153	655607	18623267.79	20441183.43	22525970
19	20957006.04	23073120.91	25521347.82	145076	600973	20210956.74	22327071.61	24775299
20	22428263.4	24879004.86	27739679.13	0	546339	21881924.4	24332665.86	27193340

Table A10.1: Life cycle costing for the district cooling system including and excluding salvage values

	Neglecting Salvage value				Including Salvage Value		
Years	Optimistic	Moderate	Pessimistic	Chiller Salvage value	Optimistic	Moderate	Pessimistic
0	3933887	3933887	3933887	3933887	0	0	0
1	4491719	4497227	4502734	3737193	754527	760034	765542
2	5083022	5100265	5117628	3540498	1542523	1559767	1577130
3	5709802	5745801	5782306	3343804	2365998	2401997	2438502
4	6374190	6436834	6500810	3147110	3227080	3289724	3353700
5	7078440	7176572	7277511	2950415	4128025	4226156	4327096
6	7824946	7968451	8117137	2753721	5071225	5214730	5363416
7	8616242	8816150	9024801	2557027	6059215	6259124	6467775
8	9455015	9723608	10006033	2360332	7094683	7363276	7645700
9	10344116	10695042	11066812	2163638	8180478	8531404	8903174
10	11286562	11734965	12213609	1966944	9319618	9768021	10246665
11	12285555	12848211	13453420	1770249	10515305	11077962	11683171
12	13344487	14039956	14793813	1573555	11770932	12466401	13220258
13	14466956	15315739	16242974	1376860	13090095	13938879	14866114
14	15656772	16681493	17809759	1180166	14476606	15501327	16629593
15	16917978	18143569	19503747	983472	15934506	17160098	18520275
16	18254855	19708768	21335299	786777	17468078	18921990	20548521
17	19671946	21384369	23315626	590083	19081863	20794286	22725543
18	21174062	23178168	25456854	393389	20780673	22784779	25063465
19	22766305	25098511	27772104	196694	22569611	24901817	27575409
20	24454082	27154336	30275568	0	24454082	27154336	30275568

Table A10.2: Life cycle costing for cooling using individual equipment in each building, including and excluding salvage values