DESIGN CHALLENGES IN IMPLEMENTING A BUILDING ENERGY MANAGEMENT SYSTEM

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ABSTRACT

Since the Koyoto protocol was presented almost a decade ago, a great deal of effort has gone into spreading global awareness regarding greenhouse gas emissions and the negative effect it has. South Africa joined the race in 2007 with the founding of the green building council of South Africa. South Africa also adopted the Australian G*reen Star* rating in order to rate buildings based on this rating system.

With the Green Star rating buildings can be evaluated on a wide variety of factors of which energy consumption is only one part. However, because there is no penalty system in place and the Green Building Council of South Africa is a voluntary organisation; many developers do not invest in creating green buildings.

Due to the recent increase in electricity tariffs, developers and end-users have become more energy conscious and are motivated to reduce their overall building energy consumption, rather than creating a green building.

The literature review revealed that the control of light switching through occupancy sensors is an effective method to reduce a building's overall energy consumption. The review further indicated that a saving of between 20 – 26% can be expected for office buildings.

In the case study this energy saving method was expanded to include the HVAC system for offices as well. Due to initial capital investment constraints a large amount of the installation components for the control system was significantly reduced. The associated limitations of the system were not properly conveyed causing misconstrued expectations of the capabilities of the system.

During the commissioning period extreme difficulty was experienced due to the reduced scope of the installation, and commissioning of the system became a tedious and lengthy process. This also created difficulty to determine the overall success of the installation of occupancy sensors as an energy efficiency measure.

Even though the results were not definitive, it was clear that the occupancy sensors did improve the overall energy consumption of the building, when compared to other energy efficient technologies.

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LIST OF ABBREVIATIONS

AHU	Air handling Unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Bacnet	Building Automation and Control Networks
BAS	Building Automation System
BEMS	Building Energy Management System
BEPAC	Building and Environmental Performance Assessment Criteria
BMCS	Building Management Control System
BMS	Building Management System
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CCTV	Closed-Circuit Television
COP	Coefficient of Performance
COV	Change of Value
CSIR	Council of Scientific and Industrial Research
DALI	Digital Addressable Lighting Interface
db	Dry Bulb Temperature
DX	Direct Expansion
ECS	Environmental Control System
EMS	Energy Monitoring System
EMCS	Energy Management Control System
EU	European Union
GHG	Greenhouse Gases
GSSA	Green Star South Africa
HAP	Hourly analysis Program

HVAC	Heat, Ventilation and Air Conditioning
IEQ	Indoor Environment Quality
IP	Internet Protocols
ISO	International Organisation of Standardisation
LEED	Leadership in Energy and Environmental Design
PIR	Passive Infrared
PID	Proportional Integral Derivative
RHDHV	Royal Haskoning DHV
SANS	South African National Standards
SMS	Short Message System
SSI	Stewart Scott International
UNFCCC	United Nations Framework Convention on Climate Change
USGBC	United States Green Building Council
VRV	Variable Refrigerant Volume

LIST OF SYMBOLS

C	Table of Hazen-Williams coefficient
CO_2	Carbon Dioxide

CHAPTER 1

1 INTRODUCTION

This chapter will illustrate the necessity of this research by discussing the development and implementation of green measures in the South African building industry. Comparisons are also made to other countries (both developed and developing) to identify South Africa's position in this regard and to highlight opportunities.

1.1 Global carbon footprints and CO_2 emissions

During the past decade, there has been a worldwide attention shift towards the issues of climate change and global warming [1]. Policies, such as the Kyoto Protocol, aim to reduce the emission of greenhouse gases (GHG) in order to mitigate the negative effects of climate change. Since combustion processes involve production and emission of carbon dioxide CO_2 as a GHG component, its reduction has become an important agenda for many research areas [2].

For any given activity or community, its impact on global warming is measured by calculating it's so called "carbon footprint". This 'carbon footprint' represents the amount of carbon or carbon dioxide (CO_2) equivalent emissions which are associated with that particular activity or community, and is closely related to ecological or environmental footprints [3]. In Figure 1-1 , a typical urban carbon emission and redistribution cycle is illustrated.

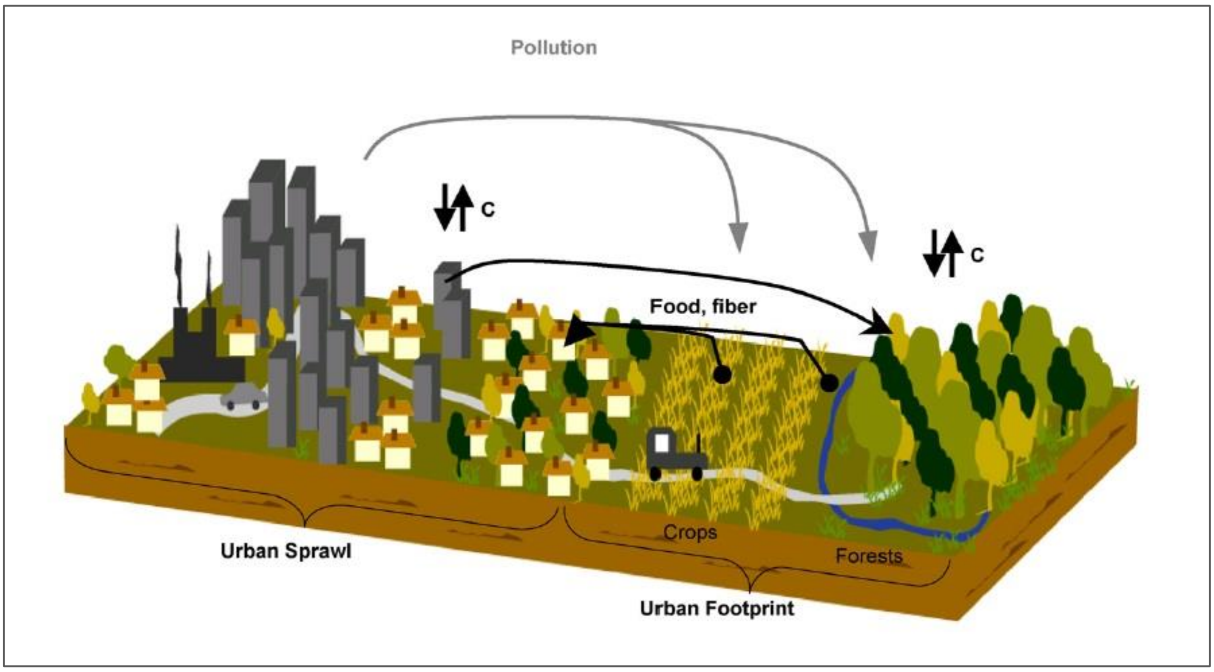

Figure 1-1 : Urban carbon cycle [4].

The flow of carbon dioxide emissions (or carbon fluxes) is illustrated in this figure with black arrows [4].

One of the primary causes of carbon dioxide emissions can be attributed to the combustion of carbon based fuels, such as coal and oil, for energy [5]. In today's circumstances this is significant because the majority of the world's coal consumption can be accounted for by merely six countries namely; China, the United States, India, Japan, Russia and South Africa. Of these, the United States and Japan are developed countries [6].

When placed into context, for South Africa this presents a significant challenge to reduce GHG emissions since South Africa's main energy source for the generation of power, is coal (refer to Figure 1-2 below) [7].

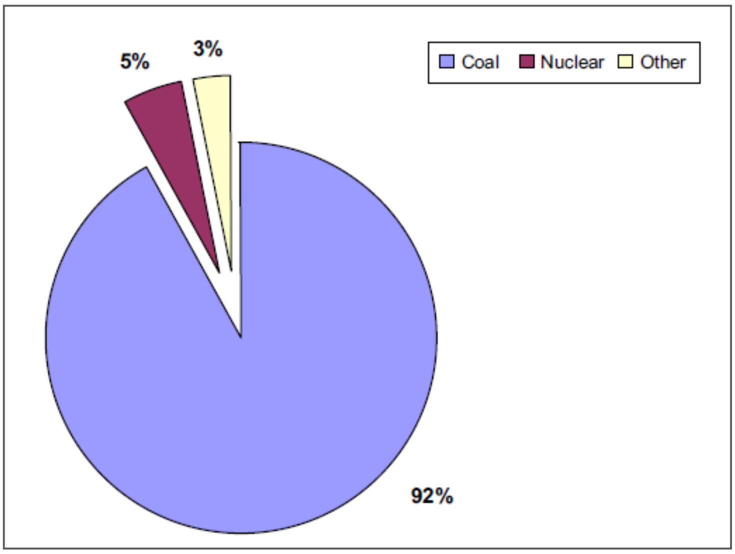

Figure 1-2 : Energy sources used in electricity generation in South Africa [7]

Increased global awareness of the impact of climate change and the drive to reduce greenhouse gases, and in particular CO_2 emissions, have further resulted in a strong drive towards developing countries to also reduce their CO_2 emissions.

When considering the CO_2 emissions of the developing countries in Figure 1-3 [8] it is observed that since the early 1990's only China has been successful in dramatically reducing its carbon footprint. It also demonstrates the significant opportunity available in South Africa to reduce its carbon footprint.

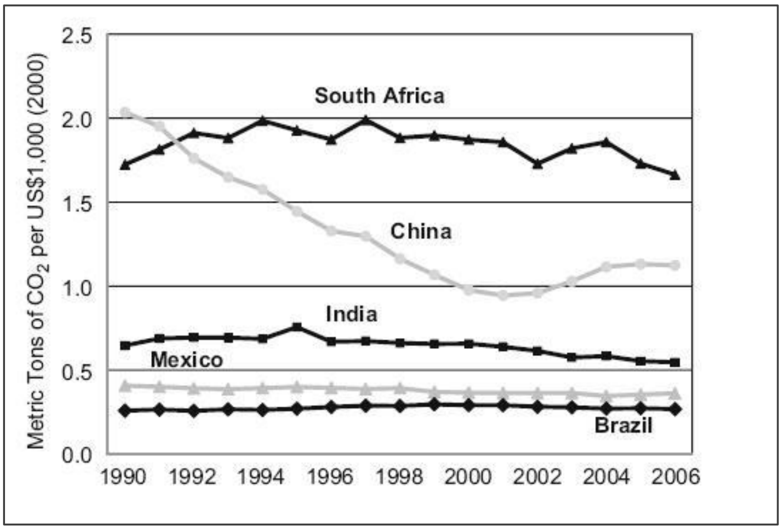

Figure 1-3 : CO_2 intensity graph of developing countries [8]

South Africa's demand for energy was historically dominated by the mining industry which is known to be an energy-intensive sector. Under the new democratic government after 1994, the focus shifted from supply to addressing demand, and particularly broadened to include wider household access to electricity and to make energy services more affordable for the poor [9].

This change in government policy resulted in a slight decline in energy usage from the South African mining industry and shifted the demand towards manufacturing and services by the end of the last decade. Furthermore, the increased availability of comparatively cheap energy – especially electricity – has resulted in the inefficient use thereof [9].

This inefficient use of electricity, therefore, creates an opportunity in especially the commercial or building sector to reduce electricity consumption which reduces the associated carbon footprint.

1.2 Building energy consumption and conservation

The building sector plays an important part in energy conservation as it accounts for a significant percentage of the total national energy consumption of major countries as illustrated in Figure 1-4. It is for this reason that strong efforts are made to reduce energy consumption in buildings [10].

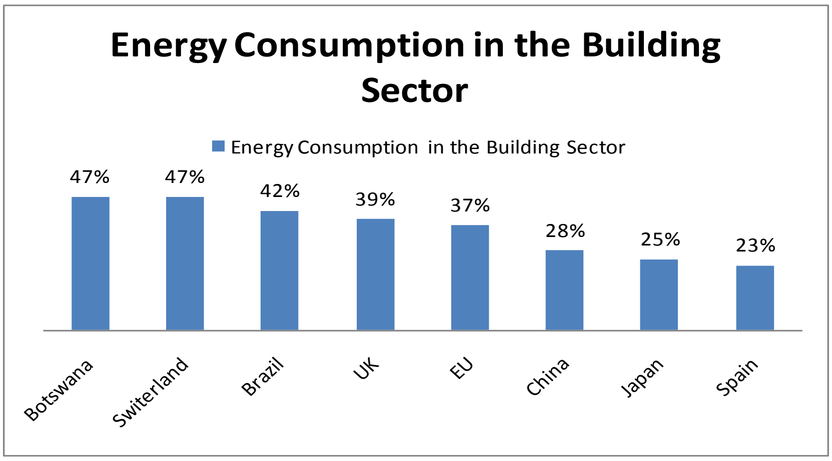

Figure 1-4 : Building sector energy consumption [10]

A further breakdown of the building sector energy consumption (Figure 1-5) demonstrates that building utilities, such as HVAC, lighting and appliances, are accountable for up to 85% of the total energy consumption in a typical office building [11].

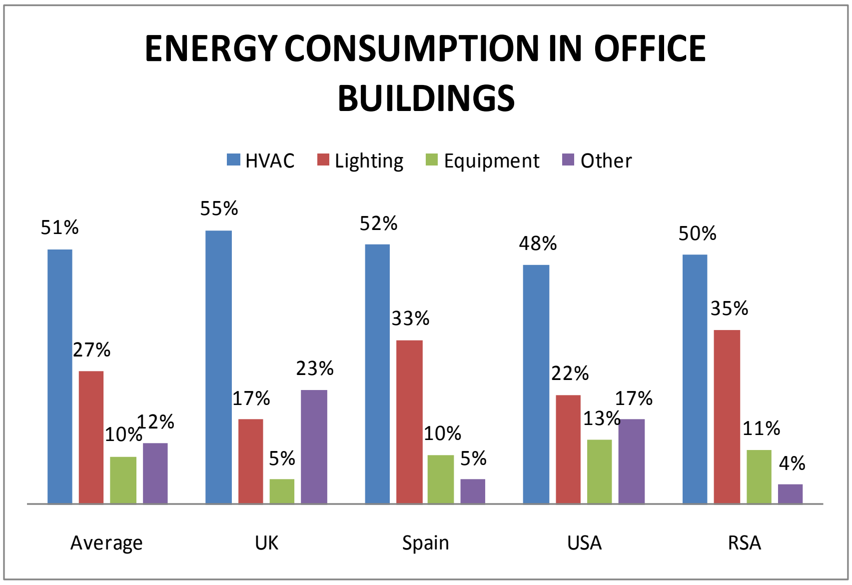

Figure 1-5 : Energy consumption in office buildings [11]

In other studies of office buildings, the HVAC contribution to the total final energy consumption was 49.0% (of which 62.4% for cooling and 37.6% for heating), lighting followed with 32.5% (of which 62% was for indoor space lighting and 16% for security night lighting) and office and electronic equipment was responsible for 18.5% to the building's electricity consumption [12].

In South Africa, approximately 29-35% of the energy is used for lighting [1]. The HVAC component in a commercial building is estimated at 30-50% of the total energy load [13]. When these values are compared to those of the international case studies, a close correlation is observed and supports the significance of the reduction in energy consumption in buildings to reduce carbon footprint.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has developed guidelines to which green commercial buildings should conform. A building model based on these standards, also called the “ASHRAE Budget Building”, has an energy breakdown as illustrated in Figure 1-6.

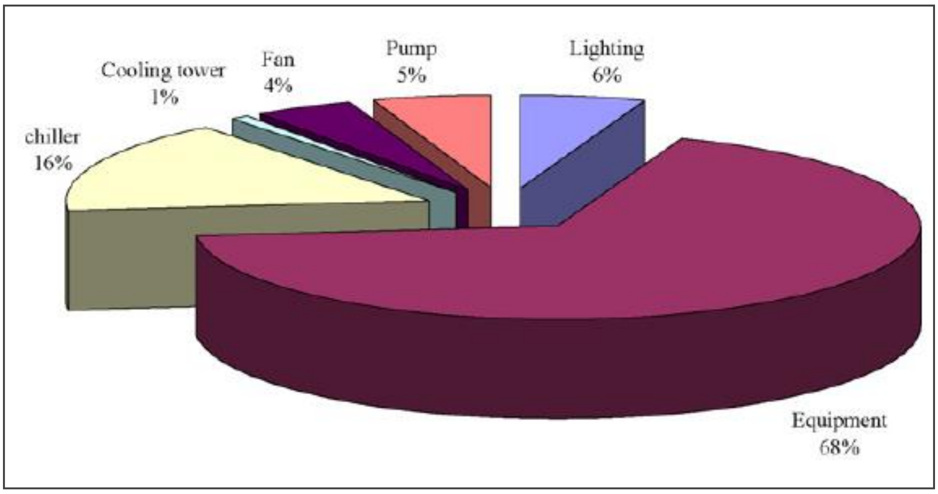

Figure 1-6 : ASHRAE budget building energy consumption [14]

The yearly electricity consumption of the ASHRAE budget building indicates that the biggest electricity consumer in an office building should be the office equipment. HVAC systems do not consume more than 26% and lighting not more than 6% of the total building’s energy consumption [14].

From the above information it is clear that the South African building environment has to reduce its energy consumption of HVAC and lights significantly to conform to these standards. The Green Council of South Africa and the development of the Green star rating tools were founded specifically for this purpose and to promote awareness of sustainable development.

With the implementation of these policies, South Africa plans to reduce its greenhouse gas emissions whilst sustaining future development, as indicated in Figure 1-7.

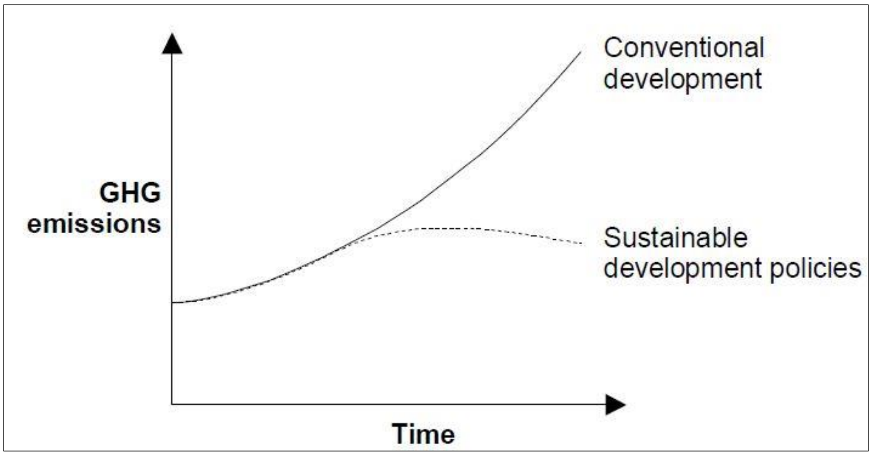

Figure 1-7 : Hypothesis that sustainable design will reduce emissions [15]

South Africa is, however, not the first country to initiate green building awareness, and the green star tools for South Africa are still under development for different building types. The next section is an overview of where green building designs and sustainable development policies originated.

1.3 A brief history of green buildings

The threat of the continuous and excessive emissions of greenhouse gases to the atmosphere and the global environment, has long been recognised in the international community. To combat this threat, the United Nations Framework Convention on Climate Change (UNFCCC) was adopted in 1992 [16]. Their mandate was to ensure 'the stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system' [17].

Three years later at the Berlin Meeting in 1995, the UNFCCC determined that the commitments set out in 1992 would not be adequate to meet their objectives. For that reason the 'Berlin Mandate' was adopted, requiring developed countries to set 'quantified limitation and reduction objectives' for the post-2000 time frame. No targets were required from developing countries at that time [17].

At the UNFCCC meeting in 1997, the Kyoto Protocol was signed. The signing of this protocol was a historic step in reversing the inexorable increase in the emission of the greenhouse gases (GHG) [18]. Countries committing to mitigate greenhouse gas emissions under this protocol would be legally bound to hold to these emission limitations [19].

Following the above sequence of events, many countries became increasingly committed to promote awareness of green buildings through the founding of their own national green building councils. In 1998 the World Green Building Council was founded and in 2002 it was formally opened [a].

The United States Green Building Council (USGBC) was one of the first green building councils and was founded a few years earlier in 1993 [b]. Subsequently Australia (in 2002), the UK (in 2007) and South Africa (in 2007) founded their own green building councils. In this year South Africa also became a member of the World Green Building Council [a].

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*[a] Green Building Council - South Africa Available from: www.gbcsa.org.za/about/worldgbc.php (Accessed 4 September 2011)
*[b] IRG - Think Natural. *Natural Stone and the Green Building Movement* Available from: www.marblecompany.com/think-natural.aspx(Accessed 4 September 2011)

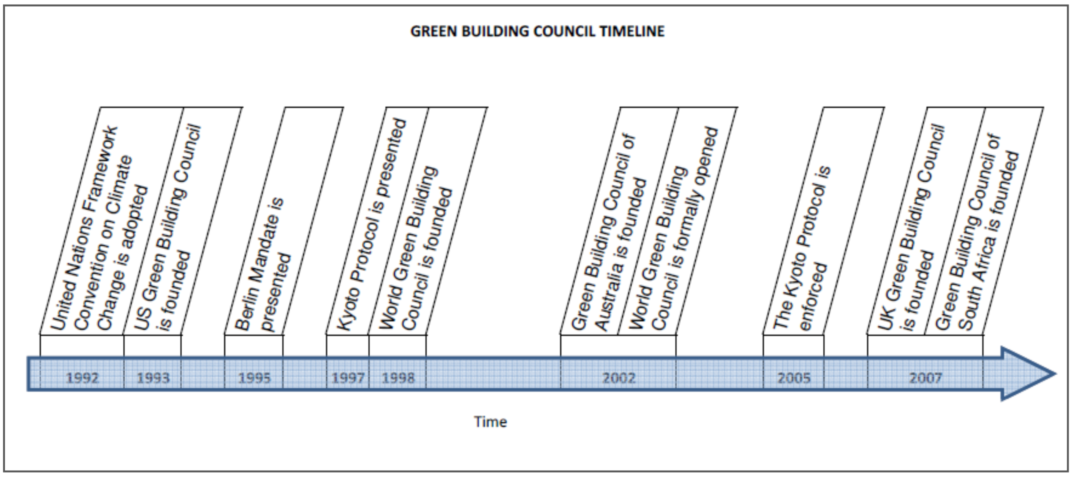

Figure 1-8 : Green building council timeline* [a, b, c, d]

Figure 1-8 illustrates the events that preceded the forming of the Green Building Council of South Africa.

With the assembly of green building councils across the world many methodologies have also been developed to serve as tools in providing methods for measuring the degree to which set environmental goals have been achieved. It also provides guidelines for the planning and design processes for new buildings to ensure that set goals are achieved. The first of these tools was the Building Research Establishment Environmental Assessment Method (BREEAM) [20].

After BREEAM, other methodologies, such as Green Star from Australia, the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan, the Building and Environmental Performance Assessment Criteria (BEPAC) from Canada, and the Leadership in Energy and Environmental Design (LEED) from the United States were developed and are currently widely applied [21].

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*[a] Green Building Council - South Africa Available from: www.gbcsa.org.za/about/worldgbc.php (Accessed 4 September 2011)
*[b] IRG - Think Natural. *Natural Stone and the Green Building Movement* Available from: www.marblecompany.com/think-natural.aspx(Accessed 4 September 2011)
*[c] UK Green Building Council. Available from: http://www.ukgbc.org/site/aboutus (Accessed 4 September 2011)
*[d] Green Building Council of Australia. Available from: http://www.gbca.org.au/ (Accessed 4 September 2011)

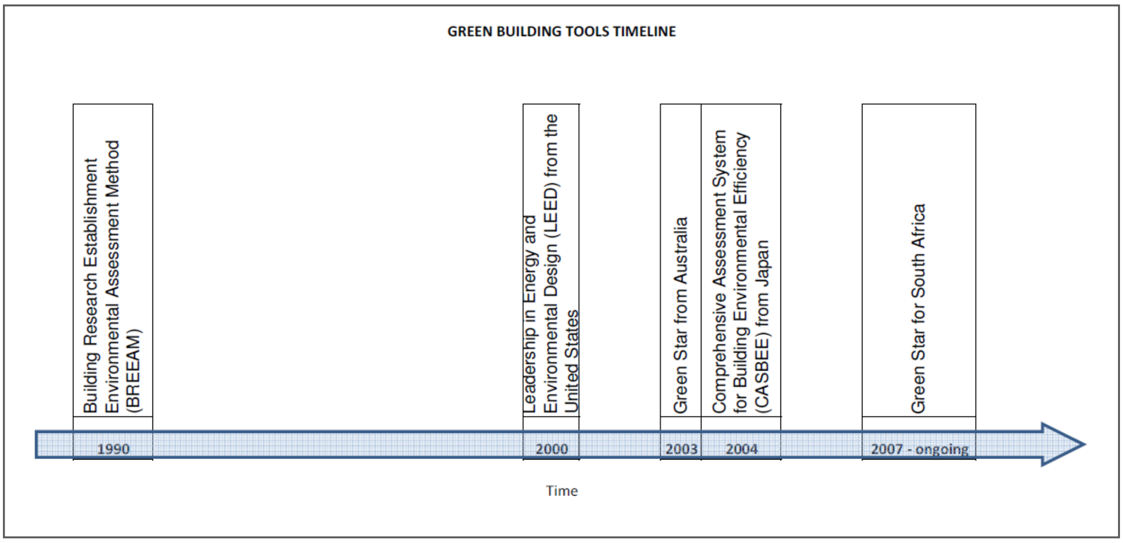

Figure 1-9 : Green building tools timeline [e, f, g, h]

In South Africa, legislation about energy efficiency is in the making and the SANS 204 draft has already been issued, although it is not legislation yet. South Africa is also in the process of adopting the Green Star tool from Australia for South African conditions *[a]. Figure 1-9 illustrates the development of green building tools preceding the Green Star tool for South Africa.

Because South Africa is still relatively new to the green building arena it still has a long way to go in achieving its green building goals but this presents exciting opportunities for the country.

1.4 Need for this research

With South Africa joining the World Green Council and founding its own Green Building Council in the same year, the country saw a change in the market to develop a green aware society.

Globally, commercial buildings consume large amounts of electricity and the same can be said for South African buildings. The majority of a typical office building's energy consumption is caused by HVAC systems and lighting. Implementing green measures to these systems will help to reduce the overall energy consumption of commercial buildings.

*[a] Green Building Council - South Africa Available from: www.gbcsa.org.za/about/worldgbc.php (Accessed 4 September 2011)
*[e] BREEAM® *What is BREEAM?* Available from: http://www.breeam.org/page.jsp?id=66 Accessed 4 September 2011)
*[f] Green Building Council Australia. *Green Star leads property into the future*. (30 July 2003) Available from: www.gbcaus.org Accessed: 4 September 2011)
*[g] Richard Reed, Anita Bilos, Sara Wilkinson, and Karl-Werner Schulte (2009) *International Comparison of Sustainable Rating Tools*. Available from www.costar.com/josre/JournalPdfs/01-Sustainable-Rating-Tools.pdf Accessed 4 September 2011
*[h] USGBC: What LEED is. Available from: http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1988
*[i] Green Building Council - South Africa Available from: www.gbcsa.org.za/about/worldgbc.php (Accessed 4 September 2011)

Despite the potential benefits that Green Buildings initiatives hold, they are not yet perceived as attractive projects because most building developers associate green features with expensive technologies that add cost to the project with minimal financial benefits [11][12][9][21].

The purpose of this study is to investigate the actual energy savings possible when considering a commercial building project with severe budgetary constraints. This thesis focuses on the reduction of energy consumption through the implementation of a building energy management system to control HVAC and lights switching, through occupancy sensing.

1.5 Overview of this document

The building industry in South Africa is striving to be recognised as a competitive green buildings market and as an energy efficient industry.

A green building is a means of being benchmarked in the market with a focus on various aspects regarding efficiency and environmental impact. One of these aspects is energy efficiency and sustainability.

Implementation of a building energy management system is one possible solution to manage the energy usage in a building by regulating the use thereof automatically. In this study this control will be through occupancy sensing.

Chapter 1 provides an overall view of where Green Buildings originated as well as the drive behind the Green Building initiative. It also touches on South Africa’s Green Building initiative.

Chapter 2 takes a comprehensive look at building energy management systems. It focuses mainly on building energy management systems (BEMS) as a potential energy regulating tool as well as the influence of occupant behaviour and appropriate methods to simulate occupant in a building.

Chapter 3 discusses the energy design measures, with a specific focus on Building energy management systems and occupancy sensor technologies. The baseline simulations for the commercial case study building will also be studied.

Chapter 4 focuses on the implementation of occupancy sensors to regulate lighting and HVAC in the case study building. The challenges that occurred during the implementation phase are also discussed.

In Chapter 5 the end results of the implemented BEMS system are discussed, and in chapter 6 the conclusions of this study are discussed.

CHAPTER 2

2 BUILDING MANAGEMENT SYSTEMS WITH ENERGY EFFICIENCY AS AN OUTCOME

It is not surprising that building energy management systems are employed more frequently to promote green buildings when considering a brief definition of a green building that:

"*A green building optimizes efficiencies in resource management and operational performance; and minimizes risks to human health and the environment*" [22].

This chapter will investigate the use of building (energy) management systems with the aim to manage and reduce energy consumption in buildings.

2.1 Building and energy management systems defined

Building automation originated in the 1880s with the invention of a bimetal-based thermostat with a hand-wound spring-powered motor. This device was used to control room temperatures through adjusting a draft damper on a coal-fired boiler. Shortly thereafter the first pneumatic powered controls became available, which revolutionised the control of machinery commonly used in the HVAC industry [23].

When minicomputers and mainframes were the only computers available, management systems for buildings was primarily utilised in larger office buildings and college campuses. With the shift to microprocessor-based controllers for direct digital control, the cost of integrating these functions into controllers has become affordable, for this reason BEMS is a good investment for commercial buildings of all types and sizes [24].

The building management system (BMS) concept emerged early in the 1950s and has since then undergone dramatic changes both in scope and system configuration. System communications evolved from hardwired pneumatic centralization to multiplexed or shared wiring and finally to the most resent two-wire all digital systems. The Energy Management System (EMS) and Building Management Control Systems (BMCS) evolved from poll-response protocols with central control processors to peer-to-peer protocols with distributed control [24].

Today automated energy control has become standard practice for commercial building. Many of the older generation building control systems dealt separately with each kind of controller (heating, ventilation, and lighting) and was therefore unable to optimise the overall multi-controller system [25].

Developments in this field have shown that control integration could be widely beneficial. The potential energy saving for heating and lighting controllers are potentially between: 10 to 30% of the overall building energy consumption [25]. Moreover, an improvement of the indoor comfort provides better working conditions, resulting in higher productivity [25].

The goal of these control systems is now to increase the overall performance and indoor comfort of a building through innovative and integrated control en monitoring systems specifically for heating, ventilation, shading and artificial lighting [25].

Monitoring and control systems have now become commonplace for commercial building and is generally equipped with automatic controllers that interface with a computer as its central processor. These systems are generally referred to as Building Management System (BMS), Energy Management Systems (EMS), Energy Management Control Systems (EMCS), Building Automation Systems (BAS) or Building Energy Management Systems (BEMS) [23].

Even though BEMS are nowadays capable of many advanced features they are frequently under-utilized. For example, the trending and monitoring capabilities of EMS are often not utilised to their full potential. These features are powerful tools for optimising heating, ventilation, air-conditioning (HVAC) systems and lighting ultimately reducing energy usage of the building. Unfortunately most facility managers and maintenance operators are often ill informed with regards to the capabilities of these systems [23].

In order to purchase a suitable BEMS, a facility’s exact energy management needs should be determined. Generally, those responsible for BEMS upgrades or purchases are not suited to do these studies. They may rely on vendors to provide specifications and as a result may not receive the optimal system for their building. Furthermore, the commissioning process, which can be critical to the success of a BEMS, is relatively unknown to most facility staff [23].

Due to the complexity of modern energy management systems it is vital that service contracts be in place to ensure the continued operation of a BEMS. Without proper maintenance and operation, these expensive and sophisticated systems frequently end up underused, overridden, and blamed for any number of problems. Yet low-bid policies are still the norm [23].

2.2 Building energy management systems functionality

The aim of a building energy management system, as a green building tool, is to provide satisfactory levels of specified building performance whilst minimising consumption and environmental loadings over a buildings life cycle [22].

Research has proven that the efficiency of an operating building can be closely linked to the interaction between its sub-systems. As a result, a huge potential for energy savings can be realised when closely related systems' interaction are optimised. One such example is the interaction between the building envelope, HVAC system, and its controllers [26].

Heating, ventilation, and air-conditioning (HVAC) systems in particular require the control of environmental variables such as pressure, temperature, humidity, etc to function properly. As with other industrial applications, most of the controllers commissioned in HVAC systems are of the Proportional Integral Derivative (PID) type. This is mainly because PI or PID controllers are simple yet sufficient for most HVAC application specifications [27].

Tuning a PID controller requires an accurate model of a process and an elective controller design rule. The tuning procedure can be a time-consuming, expensive and difficult task [27].

However, with the development of building energy management systems the turning procedures can now be optimised potentially reducing the time and expense associated therewith.

The rudimentary capabilities of a building energy management should first be understood before the optimisation thereof may be attempted. Features may vary widely from one model to the next, but certain capabilities are almost universal, for example: Scheduling, set-points, alarms, safety protocols and monitoring and trending [23].

Scheduling is one of a BEMS' more commonly known features, and with the advance in technology scheduling is not only used to define ON/OFF times, but set-points as well. Elementary time clocks with multiple scheduling scenarios are available in most BEMS, which can offer significant savings when used correctly. Many EMS software packages allow up to 5 or 7 user-configurable start-and-stop schedules for each piece of machinery for each day of the week [23].

One such example is the scheduling of lighting. Occupant behavioural studies have indicated that occupants do not use controls to switch luminaires off at the end of the working day. BEMS scheduling to enable the automatic switch off of lights would therefore yield considerable savings [28].

This logic may be expanded to incorporate the shutdown of additional equipment when it is not needed. Given the complexity of a building and the amount of equipment with potentially different schedules, this task may be challenging. However, proper scheduling may be the quickest and most cost effective method to realise immediate energy savings [23].

In addition to daily scheduling BEMS scheduling can also include holiday schedules, calendar scheduling. Schedules can be programmed to service unusual events such as production schedules or seasonal changes in occupancy or occupancy hours. Most BEMS allow operators to enter schedules for any number of dates during the year. Depending on the

BEMS software, calendar schedules may be erased once the dates have passed and schedules were successfully implemented [23].

Alternatively, the scheduled dates may repeat in subsequent years (as is the case with holiday schedules) [23].

Set-point control is another commonly used BEMS feature. Depending on the complexity and software of the BEMS, Set-points may range from those inside equipment logic, which are rarely changed, to space temperature set-points, which may need constant adjustment. Some set-points may be defined by the operator and associated with a schedule, whereas others may be adjusted by internal calculations in the BEMS such as reset temperatures or pressures [23].

Of the various set-points commonly used, the control of space temperature may be the most time-consuming and problematic task. Often, the possibilities for reducing energy use by altering space temperature set-points are not investigated for fear of adversely affecting comfort [23].

A commonly used strategy for optimizing space temperature set-points is to create separate heating and cooling set-points or one set-point with a wide dead-band (greater than 4ºC). This lowers the potential for simultaneous or overlapping heating and cooling, thereby reducing wasted energy [23].

The registering and recording of alarms are critical to the correct functioning of building operations and form part of general BEMS functions. In addition to basic alarm functionality, a BEMS provides options in specifying how alarms are monitored, reported, routed, and ultimately dealt with. For any monitored or controlled point, basic alarm functions can be programmed to register and display. Typical alarms include, equipment failures, sensor failures, high and low parameter values for temperature, pressure, etc., manual override of machinery at remote locations and communication malfunction [23].

Alarms are fundamental to generic BEMS and most systems need minimal configuration to provide basic alarm functionality. Alarm messaging may be incorporated which provides additional information regarding the source of the alarm, such as the state of the equipment when the alarm was generated [23].

The BEMS typical alarm routing feature provides flexibility with regards to the alarm delivery messages. It may be programmed to distribute alarm messages to various output displays, such computer screens, printers, or remote monitoring sites via modems. In addition, some systems are programmed with a paging feature that utilises alphanumeric pagers where the alarm text provides the current point values. Automatic pre-programmed alarm handling protocols in the BEMS can be used to provide resolutions for noncritical alarms [23].

Facilities where failure of a certain parameter of function may cause a loss of product, as in pharmaceutical manufacturing, the distinction between an “alarm” and “warning” levels are invaluable. The BEMS may be used to monitor point for example, air flow, and generate a warning if it is slightly out of range but an alarm if it is significantly out of range [23].

The differentiation between “alarm” and “warning” levels provides the user with an early warning system, which may potentially result in significant cost savings.

Safety protocols are sequences programmed into a BEMS that are automatically initiated to protect equipment, property, or life. The condition that initiates the safety sequence may be programmed to generate an alarm such as high duct static fan shut down, freeze condition fan shut down, etc. The use of safety protocols can protect equipment and prevent the building itself from damage [23].

Ideally safety protocols that protect life and equipment, such as smoke detectors for fire detection systems should not rely on the functioning of the BEMS, these devices should be hardwired [23].

In addition to the control of equipment, generic BEMS have the capability to monitor or record various parameters of equipment operation. In BEMS terminology, monitoring is referred to as trending. Trending can be executed on most points that control equipment, for other monitored-only points that may require additional wiring, including additional software where calculated values or virtual point need to be monitored [23].

Monitoring through a BEMS offers significant advantages when compared with other data measurement methods. With the sensors already in place to monitor equipment, the cost of monitoring through a BEMS is often less than that of purchasing or renting of other devices or taking spot measurements with handheld instruments [23].

The communications structure of BEMS facilitates the monitoring of multiple data points simultaneously. Since monitoring data is a record of the real-time performance, BEMS trends are often used to verify equipment operation, energy conservation project results, and energy savings performance contracts [23].

Ideally, a BEMS should be capable of providing these various types of information, namely, temperature, pressure, damper and valve position commands, variable frequency drive control signals, virtual data points, ON/OFF status, Flow rates, current, power demand, energy consumption, and revolutions per minute [23].

Certain types of data points are not commonly used due to the cost of these sensors or transducers. These typically include air and water flow rates, power demand and energy consumption. However, should it subsequently be required it is generally not fairly easy to add it, particularly if open input channels are available in the panel [23].

There are two basic trend types, namely data stream and change of value (COV). Data stream technology stores recorded data at each time interval with the exact time the parameter was polled. A COV trend records the time and parameter value only when the parameter changes by a pre-set amount. Instructions programmed for the BEMS to track more than one data point at the same time [23].

Trends can be useful for dealing with comfort problems (trend the terminal air flow and coil valve position), documenting conditions (trend the space temperature over time) or troubleshooting equipment malfunction (trend change of value for the static pressure sensor to detect hunting) [23].

2.3 BEMS as energy usage and regulating tool

The objective of a BEMS is to centralize and simplify the monitoring, operation, and management of a building. The goal thereof is to improve the efficiency building operation at reduced labour and energy costs and to provide a safe and more comfortable working environment for building occupants [29].

In the process of meeting these objectives, the BEMS has evolved from simple supervisory control to totally integrated computerised control. Some of the advantages of BEMSs are as follows [24]:

- Simplified operations with routine and repetitive functions occurring automatically.
- Streamlined operator training programs through on-screen instructions and supporting graphic displays.
- Faster and better responsiveness to occupant needs and trouble conditions.
- Reduced energy cost through centralized management of control and energy management programs.
- Better management of the facility through historical records, maintenance management programs, and automatic alarm reporting.
- Flexibility of programming for facility requirements, size, organization, and expansion requirements.
- Improved operating-cost through automated record keeping and individual occupants monitoring and billing.
- Improved operation through software and hardware integration of multiple subsystems such as security, access control, or lighting control.

In most mid-sized to large buildings, energy management is an integral part of the Building Management Control Systems (BMCS), with optimized control performed at the system level and with management information and user access provided by the BEMS host [24].

Load levelling or maximum demand control along with starting and loading of the central cooling plant, based upon the demands of air handling systems; require continuous global system coordination. The BEMS makes use of various inputs to monitor these systems to optimise start/stop commands and adjust local loop temperature controllers to achieve optimal results [24].

In larger buildings, the building energy management systems are used to control Heating, Ventilating and Air Conditioning (HVAC) systems and building operation. The two most important functions of these systems are localised control and supervisory control of the HVAC systems [30]. The performance of the BEMS is directly related to the amount of energy consumed in the buildings and the comfort of the buildings' occupants [9].

Thermostats are used to provide feedback of the temperature, to control the HVAC system. To avoid frequent changes to the HVAC system, thermostats are fitted with "dead zone" control logic [29]. These building energy management systems are, however, reactive and not predictive to the climatic conditions, building operation and occupancy interventions [31].

The majority of recent developments in BEMS have followed the advances made in computer technology, telecommunications and information technology. Techniques such as pole-placement, optimal regulator and adaptive control have been used to control HVAC systems [32][33].

More computerised methods, such as genetic algorithms and neural networks have been proposed for the control optimisation of specific HVAC systems, too. Other methods for optimised building systems control have also been proposed, including empirical models, weighted linguistic fuzzy rules, simulation optimisation and online adaptive controls [9].

In the case of lighting control, there are two basic control categories. The first type of control provides an on-off state, and the second allows the level to be set between maximum and minimum levels by dimming (top-up). An on–off type control is designed to switch electrical lighting automatically on and off based on the lighting levels in the room [34].

Independent studies demonstrate that wasted energy from electrical lighting can be minimised when motion sensors automatically turn lights off in unoccupied spaces [35]. Occupant sensors in offices have been demonstrated to save 20-26% lighting energy when compared to (single-level) manual switching alone [36].

A particular problem with this type of lighting control, however, is the rapid and frequent switching of lights on and off, particularly during unstable weather conditions when daylight levels are changing frequently. This can disturb occupants and reduce the lamp life [34].

In reality some BEMS technologies are not refined and occupants' reactions are not always favourable, resulting in occupants avoiding using these designs [37].

Independent studies show that the impact of human factors on the energy performance of buildings can contribute negatively. Results demonstrate that the benefits of an energy-saving design can be easily lost due to human mismanagement. Individual factors such as cultural habits, educational level, etc. seem to strongly affect the thermal performance of buildings [38].

2.4 The impact of occupancy behaviour on building energy consumption

Office buildings often comprise of rooms that are used infrequently, such as boardrooms, and may be heated or cooled needlessly. Having knowledge regarding occupancy and being able to accurately predict usage patterns may allow significant energy-savings by intelligent control of the HVAC systems [39].

Understanding the dynamics of occupancy patterns is central to the approach of occupancy-based building energy management systems. [39].

Human interactions have important implications for a building's energy balance, affecting both the indoor microclimate and the demands for applied energy. People enter an office building, leave it and move inter-floors in stochastic ways. They may engage in overtime work, be absent from work owing to illness or vacations again in stochastic ways. It is clear that the presence of human beings will influence the energy balance interaction in the building [40].

There are four main factors playing a vital part in the energy consumption of a building namely:

- The physical properties of a building, including location, construction, orientation and function.
- The equipment installed to maintain the desired internal environment such as heating ventilation air-conditioning system, electricity or hot water.
- The outdoor environment and the meteorological factors such as temperature, humidity, solar radiation etc. and
- The behaviour of its occupant and associated implications of their presence [40].

Not only may occupants be resistant to new technology due to end-user misperceptions and or designer misconceptions which may result in the inefficient use of BEMS systems [41], but the accurate simulation of occupant behaviour, for the purposes of BEMS designs, may also proof to be challenging.

It is common knowledge that occupants spend less time in an office than 8 hours. Office occupants often leave their seats for various periods of time ranging from a fraction of a day, days or weeks for various reasons such as combined work efforts at other offices or meeting rooms, training, sickness or vacation. As such, it increases the difficulty in modelling the presence and behaviour of building occupancy [40].

Resents studies, focussing on occupant interactions with the building environmental systems, attempts to establish the relationship between user control actions (on/off switching of lighting, opening/closing of windows etc.) with the measuring indoor or outdoor environmental parameter such as temperature, solar radiation [40].

The results of these studies suggest that such interactions are difficult to predict at the level of an individual person. However, general control-related behaviour trends and patterns for groups of building occupants can be extracted from the long-term observation of this data [40].

In a typical office building, occupants may use diverse electrical appliances which influence internal heat gains and the consumption of electricity. Occupants also produce waste, both in the form of solid and vapours. Collectively these effects must be considered when determining the extent of single building’s need for cooling, heating and ventilation, as well as electricity demand, water consumption and wastewater production [40].

Furthermore, occupants often interact with a building to enhance their personal comfort and needs. For example, they may adjust the lighting systems or blinds to optimize their visual comfort and adjust the air-conditioning systems to fit their thermal comfort needs. These interactions, in turn, affect the building’s HVAC system and the resulting energy consumption [40].

If change occurs and produce discomfort, occupants will take action to counteract the change in order to restore their comfort. As human well-being and productivity are strongly affected by the as-built environment, providing comfortable room conditions is a vital part of designing office buildings. As such, it is clear that the physical presence of the human will influence the energy balance of the building [40].

However, in reality, there are great differences in those conditions owing to the variety of occupants’ presence and behaviour. Internal heat loads from people and equipment can contribute to an increase of temperature in the range of 20–24°C depending on additional factors such as the daily humidity, the response of the building’s thermal mass, and varying occupancy levels [41].

It has been observed that offices in commercial buildings are vacant for a large percentage of time during business hours. Independent studies have established that occupants are generally always away from their offices approximately 25–30% of the nominally occupied hours of the day [40].

In order to design HVAC systems and energy simulations various techniques are employed to represent occupant behaviour in buildings. One such widely used technique is the use of diversity factors. This method is passed down from the previous generation of hourly simulation programs [42].

Diversity factors are numbers between zero and one, and are used as multipliers for user-defined maximum loads such as occupants, lighting, and equipment. Load variability, due to absenteeism or power management features of IT equipment, is ordinarily defined by associating different sets of 24-h diversity factors, or diversity profiles, for weekdays, weekends, holidays, etc. Many energy standards and codes either provide, or refer to, typical diversity profiles for performance-based compliance demonstrations [42].

Figure 2-1 illustrates a common diversity profile used to define occupancy in office environments, taken from the standard database of the Canadian-based energy compliance software [43].

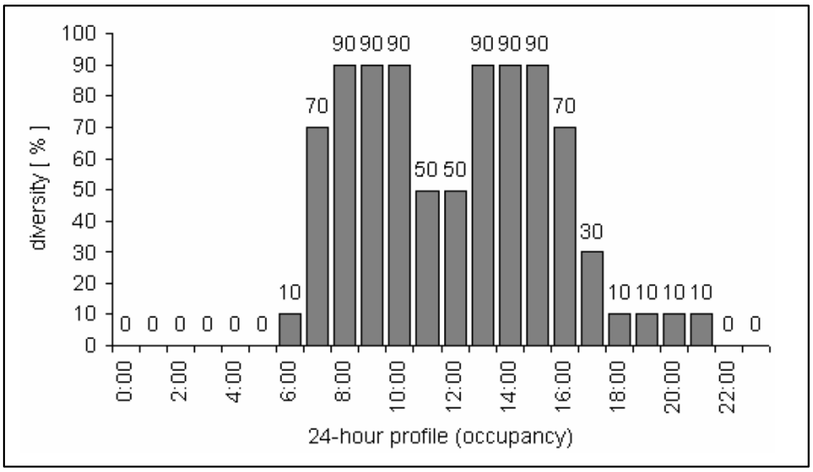

Figure 2-1 : 24-hour diversity profile for typical occupancy loads in offices [43]

The corresponding 24-hour diversity profile for overhead electric lighting loads in office environments is provided in Figure 2-2. Here, an electric lighting base load of 5% occurs during unoccupied hours, while main periods of occupancy are mainly characterized by lighting use of 90%. It can also be seen that overhead lighting use remains at 90% of nominal values from 8:00 to 17:00, despite the lower occupancy loads during lunch. This pattern in lighting use is typical for office environments [43].

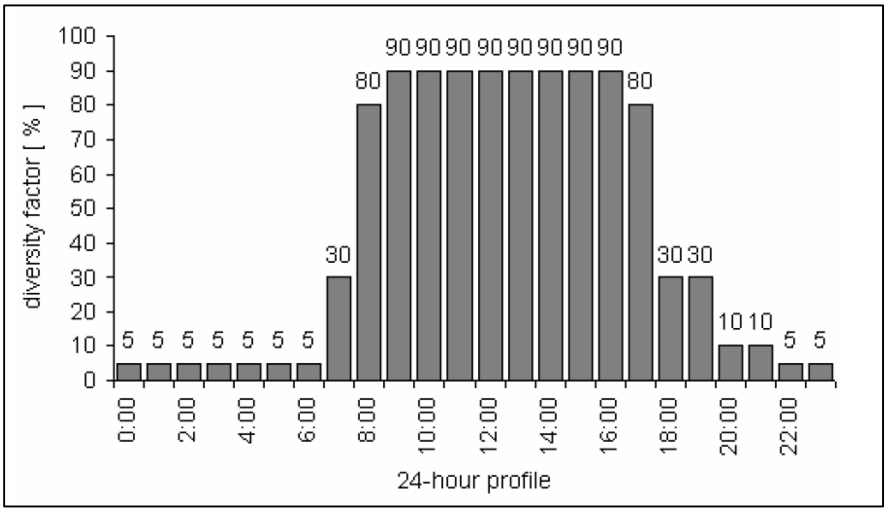

Figure 2-2 : 24-hour diversity profile for typical electric lighting loads in offices [43]

Recent developments in this area include the ASHRAE Research Project 1093. The goal of this project was to compile a library of schedules and diversity factors based on measured electricity use data for energy simulations and peak cooling load calculations in office buildings. This research project derived multiple sets of diversity factors from measured lighting and receptacle loads in 32 office buildings [42].

Occupancy was not monitored during the ASHRAE Research RP-1093, even though related studies established a strong correlation between occupancy levels and lighting loads exist [42].

Moreover independent studies also show occupant behaviour when considering light switching and HVAC systems. These studies show that occupants activate these systems upon arrival at work and that the systems (particularly lighting) remain unaltered for the rest of the day, irrespective of the changing daylight conditions. Lastly these systems are not turned off at the end of the work day [28].

The energy saving potential of systems could therefore be enhanced through the automated switch off. However, reluctance to switch off is well documented. Independent studies have shown that the incidence of occupant switch off at the end of the working day was minimal. An appropriate form of automatic switch off would therefore yield further savings [28].

On an intuitive level, over the course of a day we expect occupancy to increase in the morning when people arrive for work, decrease when people go to lunch, increase when people return from lunch, and then eventually drop to zero when people leave for the day. These are the general increases and decreases of occupancy we can expect based on our real world experiences. The strategy behind this approach is to model each of the increases and decreases separately [39].

However, as the occupancy data from independent sub-monitoring suggest, there may be other regular phenomenon affecting occupancy other than those based on intuition. Figure 2-3 illustrates occupancy dynamics from one such study [39].

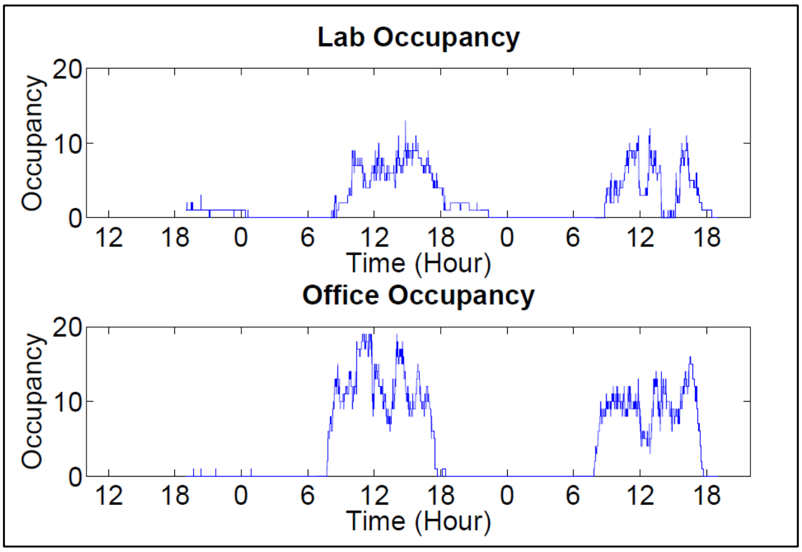

Figure 2-3 : 48h recorded occupancy data [39]

As expected, regular patterns in the occupancy data are observable. The data indicates that the occupancy steadily increases until just after noon. At around 12:00:00, people in the office leave for lunch and then return shortly thereafter. By 18:00:00, the entire office is empty. One noticeable discrepancy can be observed when comparing peak office occupancy of each day [39].

The first day shows maximum office occupancy of 18 whereas the second day shows maximum occupancy of only 13. Further investigation determined that this was due to a large lunch meeting of six people on the first day. Events such as these are difficult to anticipate when simulating building energy consumption [39].

2.5 Conclusion

From chapter 1 it can be seen that carbon foot-printing is used to evaluate the status of a country and where it is on the road to achieving a first world country status. However, due to excessive carbon emissions worldwide and the awareness of global warming, incentives have been put in place to reduce these emissions.

With the founding of the Green Building council of South Africa steps are being taken to reduce the ecological impact it has on the environment and reduce its carbon footprints. This goal can be achieved by reducing the overall electricity consumption.

This chapter have shown that occupant behaviour in office buildings had an adverse effect on the energy consumption of the building and that a potential for reduction in energy consumption exists because thereof.

With the recent developments and functionality within building energy management systems (BEMS) that potential saving can be realised. BEMS have proven a powerful aid in the reduction of electricity consumption through energy efficiency.

However it is vital that BEMS be programmed and well designed so that energy-saving measures do not sacrifice the people’s comfort and health [44].

CHAPTER 3

3 ENERGY DESIGN MEASURES AND INTEGRATION

This chapter will investigate methods for achieving energy efficiency in buildings by taking a closer look at available technologies and control strategies

3.1 Research into energy saving measures

When focussing on energy saving within an office building environment, the overall energy of each system needs to be ascertained to determine the most viable and cost effective implementation.

Heating, ventilation and air-conditioning systems (HVAC) represent an important share of the electricity consumption (about 30%) in a building [45] [46]. Lighting constitutes generally 20-45% of electrical demand [47] although this may vary from one building to another.

This implies that energy and economic savings can be achieved by improving the efficiency in these systems which will also translate to a substantial reduction in the environmental impacts can be also achieved [48].

The energy demand of an HVAC system depends not only on its configuration and operational parameters, but also on the characteristics of the heating and cooling demand of the building [49]. Internal heat gains in office buildings have a significant effect on its thermal behaviour and energy consumption.

To decrease the level of internal gains in an office building, daylight control for the lighting systems can be implemented. Research has shown that by introducing daylight control alone as a measure of saving energy used for lighting, a knock-on saving in cooling energy is also obtained. These savings are approximately 15% to 20%, depending on the type of HVAC system in the building [49].

Energy consumption by ventilation systems can also be reduced through occupancy monitoring in cases where CO_2 monitoring is too expensive [50].

While these sensors can be used to control a variety of load types, their most popular use is to control lighting in commercial buildings [51][52].

Offices in commercial buildings are vacant for a large percentage of the time during business hours [52]. In some cases it has been found that occupants are away from their offices 25–30% of the nominally occupied hours of the day [52].

Occupancy sensor triggered lighting control has shown great potential to save electrical energy when offices are vacant. Case studies have reported electrical energy saving between 3 and 45% in office rooms based on actual measurements [52].

Research suggests that the use of occupancy sensors to control temperature may have potential to save energy during business hours. This particular application, however, may cause occupants to feel uncomfortable when they return to their offices or there may be no adjustment at all during the vacancy, and, therefore, resulting in wasted energy [52].

A range of different occupancy sensors is available, each bringing with it its own advantages and disadvantages. The next section will discuss some of the characteristics which are key to this project.

3.2 Energy efficiency in buildings

3.3 Occupancy sensors

Commercially available technologies currently deployed to detect occupancy for energy management and security are limited by relatively simple sensor data processing and control software: it is still a challenge to ensure that lights and other services are switched off when spaces are unoccupied [53].

In energy management applications, the occupancy sensor functions as a timer, sending a signal to a switch that turns off electrical power after a defined period of time has elapsed during which no signal has been received from the detector (e.g., switch lights off when the space has been unoccupied for 5 min) [53].

These sensor systems use passive infrared (PIR) and/or ultrasonic technologies, which is discussed below [53].

3.3.1 Passive Infrared Sensors (PIR sensors)

Figure 3-1 : PIR sensor *[k]

A Passive Infrared sensor (PIR sensor) is an electronic device which measures infrared light radiating from objects in its field of view. Apparent motion is detected when an infrared source with one temperature, such as a human, passes in front of an infrared source with another temperature, such as a wall. The term 'passive' in this case means the PIR does not emit energy but merely accepts incoming infrared radiation *[l].

This type of sensor can detect a change in the amount of infrared energy only within small distances, approximately up to 10 inches. For detecting movements at a greater distance, infrared radiation has to be focused. This focusing is done through a Fresnel lens *[m].

A Fresnel lens divides the whole area into different zones. Any movement between zones leads to a change in the infrared energy received by the sensor. There are different types of Fresnel lenses depending on the range (distance) and coverage angle required *[m].

For a PIR sensor (Figure 3-1) to be implemented successfully it must be able to detect 'significant changes' in the normal level of a heat signature within the monitored zone. This normal level, or norm, is determined by the circuit controlling the PAR sensors within each zone. When the normal field changes, the circuit will close a switch. A PAR sensor must also be able to 'tolerate' slow changes in the signature within the monitored zone, and remember (Self Calibrate) the new level as the new 'normal'. This is so prevent gradual changes (i.e. sunlight changing throughout the day) from causing a false alarm [l].

*[k] Acquity Brands. *Lighting sensors and Controls*. Available from: http://www.acuitybrands.com/LEDLighting.aspx. Accessed 20 October 2011
*[l] India Rail Info. Available from:http://indiarailinfo.com/file/blog/post/187599/0/passiveinfraredsensor.pdf
*[m] STMicroelectronics (2004) Available at: www.st.com/internet/com/TECHNICAL_RESOURCES/TECHNICAL_LITERATURE/APPLICATION_NOTE/CD00010937.pdf Accessed 4 September 2011

One of the primary limitations of PIR sensors is their inability to detect a stationary or very slowly moving body. Similarly, if someone walks straight towards a PIR sensor, it will not detect the person until they are very close by *[n].

Furthermore, PIR sensors cannot detect motion associated with inanimate objects such as hospital beds, gurneys, shopping carts, etc reducing the possibility triggering a false alarm *[o].

Therefore, should a person be seated behind a desk for long periods at a time, there is a possibility that the PIR sensor may not recognise the heat signature of the person and essentially switch off the lights in the room.

3.3.2 Ultrasonic Sensors

Figure 3-2 : Ultrasonic sensor

Ultrasonic sensors provide an active way to monitor presence in large volumetric spaces and are potentially more sensitive than passive infrared sensors. These sensors have been used for occupant detection in the past. Utilising single element sensors based on either a time-of-flight or Doppler measurement. This, however, only provided binary room-level occupancy information [54].

Ultrasonic occupancy sensors work by emitting sound waves of which the frequency is above that of human hearing. These waves bounce off surrounding objects, and then return to the mounted units, from which they were emitted, for analysis *[p].

Changes in the frequency of the returning waves indicate motion, and will trigger the light, or lights, connected to the sensor to turn on. In many instances, an ultrasonic sensor will not need a direct line of sight to detect movement, implying it can detect movement even if it occurs behind an object, or around a corner *[p].

*[n] Highly Components Pvt.Ltd. Available at: http://energysavingsensors.com/General-Information1.htm Accessed 20 October 2011)

*[o] LCN Passive IR Sensor user guide. Available at: http://www.lcnclosers.com/pdfs/_LCN_Passive_IR_Sensor_.pdf. Accessed 20 October 2011

*[p] www.eHow.com

However, walls comprised of fabric components may pose a challenge to this capability. Other drawbacks include a tendency for the ultrasonic sensors to nuisance switch, or go off accidentally, when there is a strong amount of airflow in a space or if there are vibrations *[q][r].

Ultrasonic sensors are highly suitable for spaces in which a line of sight is not possible, such as partitioned spaces, and in spaces requiring a higher level of sensitivity. Examples of such spaces include restrooms, open offices, enclosed hallways and stairways *[r].

3.3.3 Microphonic Sensors

The Microphonics or duel technology detection is an advanced occupancy technology. It utilises a microphone for detecting sounds that indicate occupancy. This technology was designed as a secondary detection method to passive Infrared technology to ensure the reliability and accuracy of these occupancy sensor *[s].

Microphonic technology is able to distinguish between sounds made by human activity and ambient noise. It will only detect such noises as talking, eating, typing and other sounds that are typical of human activity. It does not pick up noises made by the building or the environment such as the sound of an AC unit or air currents *[s].

It also makes use of Automatic Gain Control to dynamically adapt the sensor to its environment by filtering out constant background noise. This prevents periodic noises such as the ticking of a clock or a television from keeping the lights on unnecessarily. This technology increases the reliability and precision of occupancy sensors *[s].

In the case study for this thesis it was decided to utilise occupancy sensors, to have basic control over lights and console type air conditioning units.

3.4 BMS Control philosophies for HVAC and Lighting

The basic control with regards to occupancy can range from integrated systems control to just basic light switching with time control.

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*[q] www.eHow.com Accessed 20 October 2011

*[r] Craig DiLouie (September 2008) *Occupancy Sensors: Passive Infrared, Ultrasonic and Dual-Technology*. Available from: http://www.facilitiesnet.com/lighting/article/Occupancy-Sensors-Passive-Infrared-Ultrasonic-and-DualTechnology--9608 Accessed 20 October 2011

*[s] Acquity Brands. *Lighting sensors and Controls*. Available from: http://www.acuitybrands.com/LEDLighting.aspx. Accessed 20 October 2011

A computer-based control system such as Building Energy Management Systems (BEMS) can control and monitor the building's mechanical and electrical equipment. BEMS consists of software and hardware components to function. Development of these systems have progressed so much that developers are now producing integrated systems which use Internet protocols (Bacnet over IP) and other open standards such as wireless technologies *[t].

Computer based building management systems are not only limited to a building's internal environment, but it can be linked to access control (turnstiles and access doors) or other security systems such as closed-circuit television (CCTV) and motion detectors. Fire alarm systems and elevators are often linked to a building management system *[t].

For example, if a fire is detected, the system could automatically shut off dampers in the ventilation system to stop smoke spreading and send all the elevators to the ground floor and park them to prevent people from using the elevators during a fire emergency *[t].

BEMS can also be used to estimate a specific system's performance as well as undertake fault finding [55].

This makes the capabilities of a building management system virtually limitless with funding being the constraint in most cases.

A typical BEMS for HVAC systems use the following control logic.

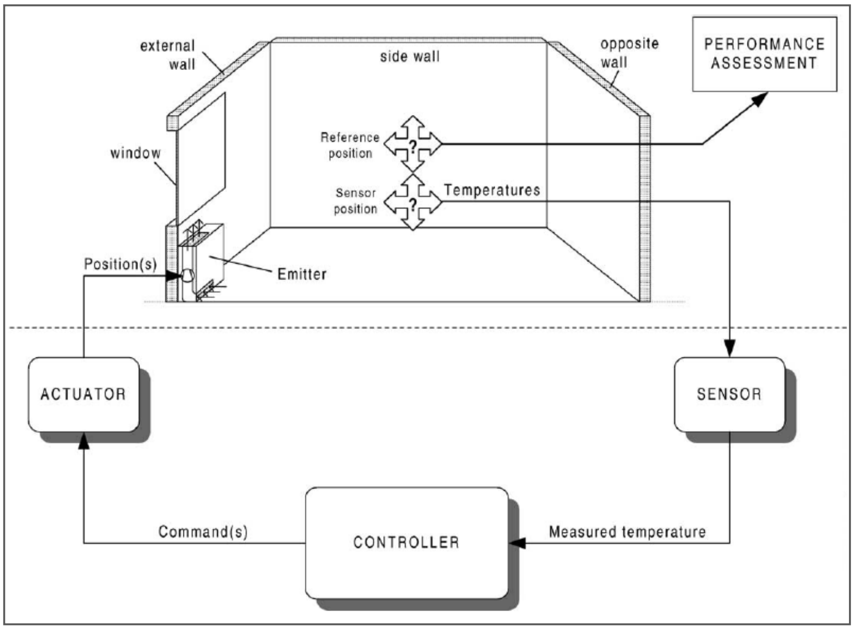

Figure 3-3 : HVAC system's control [56]

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*[t] BMS Available at: http://urvil.wordpress.com/bms-building-management-system/ Accessed 20 October 2011

The BEMS controls for the HVAC system can be implemented as a set of open or closed control loops acting jointly or individually. Each loop comprises of a sensor linked to an actuator via an algorithm; in certain cases loops may be cascaded [57].

A typical control loop as is illustrated in Figure 3-3, functions as follows:

Sensors (e.g. temperature and humidity) measure the critical boundary conditions such as external temperatures and internal conditions (temperature, humidity) and this data is collated in the BEMS. A controller in the BEMS makes a decision based on the sensor readings and changes controller set points. The Actuator controlled by the BEMS then initiates the control action [57].

Depending on the type of sensor, actuator and algorithm used, the BEMS can operate with basic control, proportional–integral–derivative (PID) control or with global sequence controls [57][58].

In the case of lighting controls a room is registered as empty if the occupancy sensor has not detected any movement for a period of time. To avoid the lighting to turn on and off for short absences, a pre-set time delay is set in the BEMS. This means that a person must be absent for more than the pre-set time before the lights switch off [57][58].

In order for a building management system to control lighting in a building it must make use of digital signal interfacing. DALI (digital addressable lighting interface) is an international standard that defines the commands that lighting ballasts need to recognise for this purpose. DALI ballasts can be linked to a central computer or building management system, allowing individual ballasts to be controlled and/or adjusted according to occupancy sensors and lighting levels *[u] [v].

3.5 Resulting conclusion

The design and implementation of energy efficient building HVAC and lighting systems require careful considerations with regards to the type of BEMS that will be used.

Because BEMS have such a vast amount of potential functions, the number of systems and the level of controllability of the BEMS should be carefully considered. It is also clear that the type of sensor and lighting ballasts used in a building can adversely affect the performance of a building energy management system and influence occupancy comfort.

In chapter 4 the implementation of a building energy management system at the Grain building is discussed.

*[u] DALIcontrol Available at: http://www.clipsal.com/dalicontrol/home Accessed 22 October 2011
*[v] Leah B. Garris. *DALI explained.* Available at: http://www.buildings.com/tabid/3334/ArticleID/1463/Default.aspx Accessed on 22 October 2011

CHAPTER 4

4 THE GRAIN BUILDING ENERGY MANAGEMENT (BEMS) IMPLEMENTATION

This chapter focuses on the implementation of the BEMS at the Grain Building, located in Pretoria, as well as the history and decisions made during the construction stage of this building. The purpose of the building is to inspect the grain and the quality thereof in South Africa for grading. This building was selected due to the BMS implementation in the building and the occupancy of the building.

4.1 Project Description

As part of the construction of the new Grain Building, the company SSI (more recently known as RHDHV or Royal Haskoning DHV) was tasked with the mechanical aspects of the construction phase which included the indoor environmental control system. Implementation of the BEMS system for the control of the indoor environment is as such the main focus of this thesis.

The building would include laboratories complying with a classification no higher than ISO 7[i], with associated offices. The scope also included the air-conditioning of multi-tenant offices (rentable area) on two floors, as well as an Auditorium for conference use only.

The perspective view of the Grain Building in Figure 4-1 illustrates the overall concept of the building, as well as the contour lines.

Figure 4-1 : Aerial view of the Grain Building

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[i] ISO 14644-1 cleanroom standards

Figure 4-2 : Grain Building east elevation

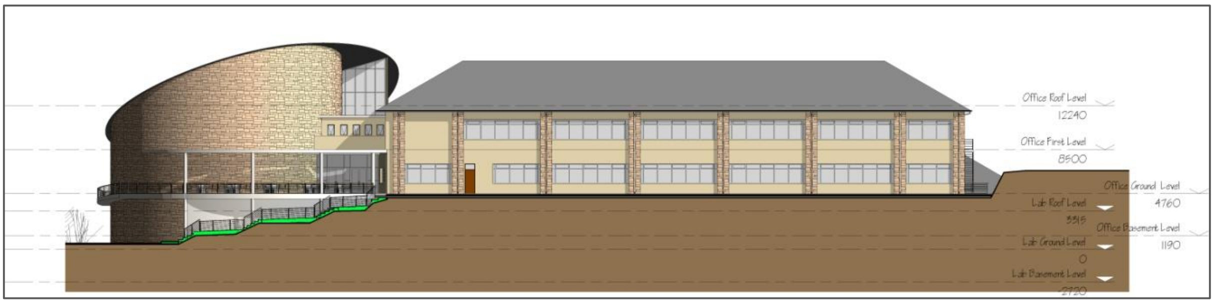


Figure 4-3 : Grain Building south elevation

Figure 4-2 illustrates the east elevation from which the actual slope in relation to the building is clear, whereas Figure 4-3 (the south elevation) indicates the excavation that was needed to present a level construction plane.

A description of the internal layout is as follows:

The basement level consists of four laboratories, undercover/basement car park and offices with the laboratories and car park taking up the bulk of the ground floor space. To maintain pressure cascades and validation in the laboratories the environmental control system for these areas cannot be switched off when the building is unoccupied. Due to the specialised ECS (Environmental control system) requirements the laboratories were excluded from the energy model in this thesis.

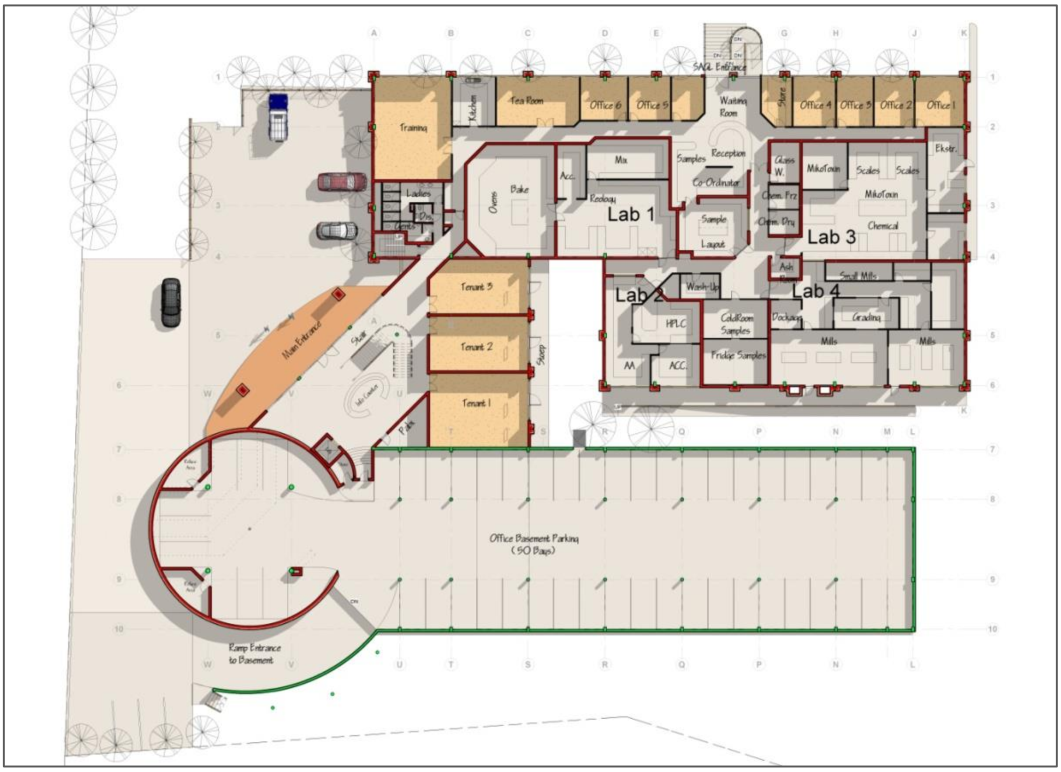


Figure 4-4 : Grain Building basement floor layout

The ground and first floors of the Grain Building comprise of offices (coloured in orange, Figure 4-5 and Figure 4-6). An auditorium was also located on the ground floor (coloured in blue in Figure 4-5).

Figure 4-5 : Grain Building ground floor layout

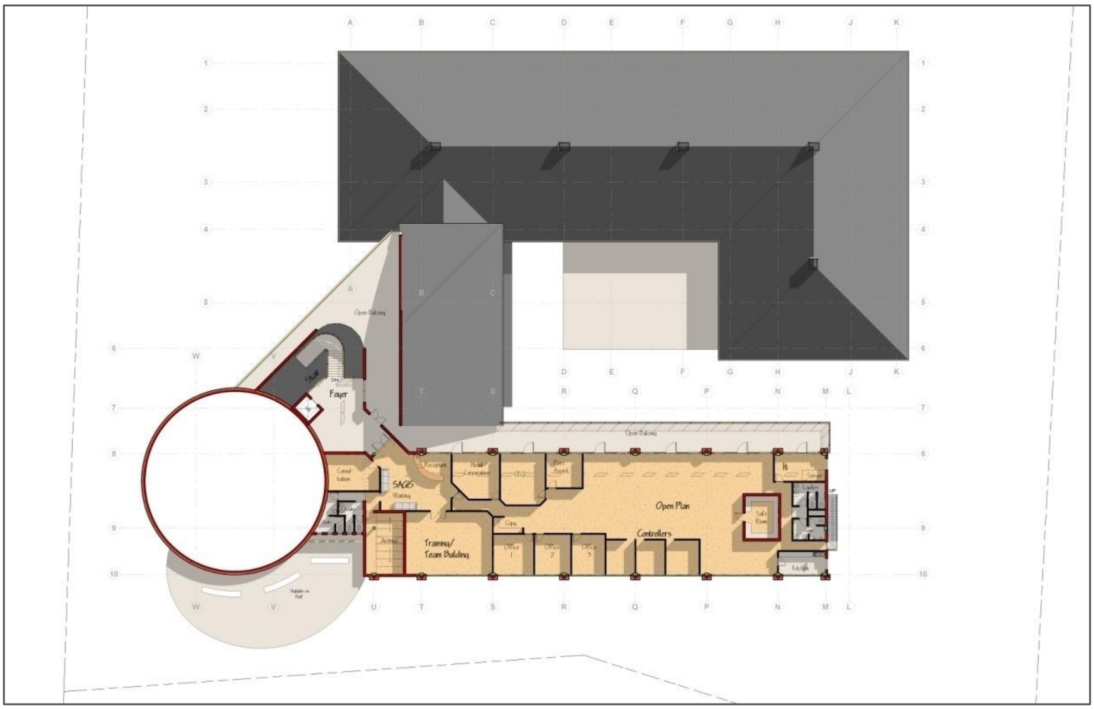


Figure 4-6 : Grain Building first floor layout

Due to the diversity between offices and classified laboratories in the building two ECSs were proposed and installed.

The proposed systems for the HVAC and ECS were as follows:

The indoor environment for the laboratories was to be controlled via a chilled water system. The laboratories would be served by two air handling units to provide appropriately filtered and temperature controlled air.

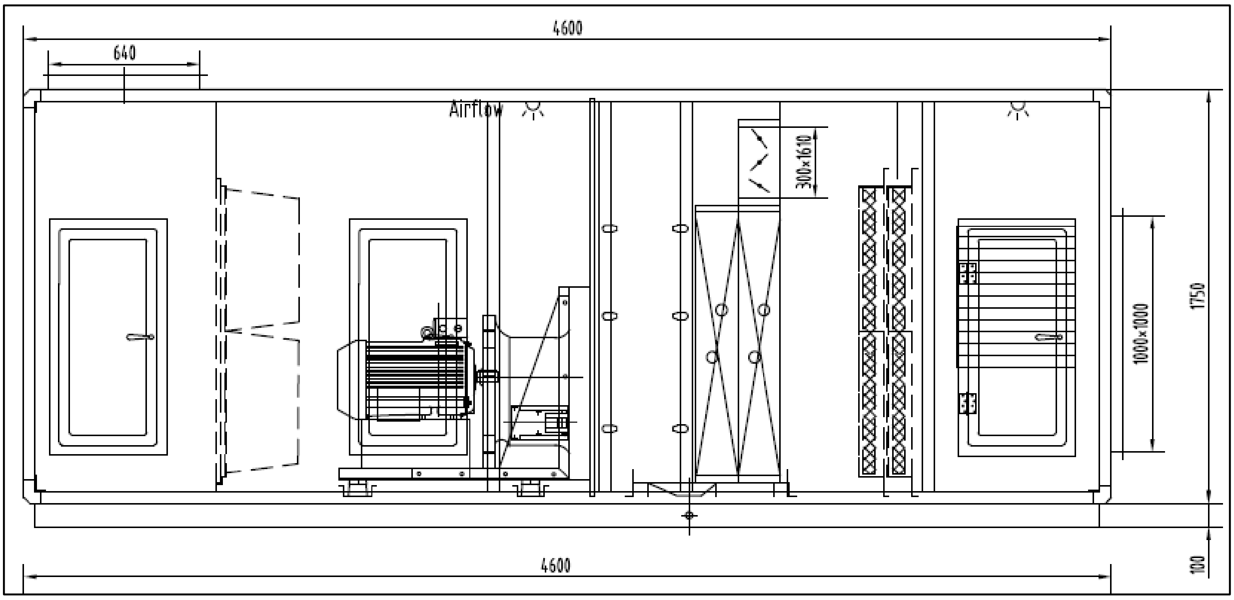


Figure 4-7 : Typical AHU arrangement with cooling coils

The air is cooled via a cooling coil in each AHU. These cooling coils operate as heat exchangers, where chilled water reticulates through the coil and exchanges energy from the air stream passing over it. The chilled water is generated by a closed loop air cooled chiller system. Heating in the laboratories is achieved by using conventional resistive heating elements.

The HVAC system proposed for the offices and auditorium was as follows:

All the offices would be served by conventional direct expansion (DX) units. The building was zoned into two zones, an inner zone and an outer perimeter zone. The outer perimeter allowed for the use of console units and the inner zone laid favour to split type DX units due to its reach.

Figure 4-8 illustrates typical split units, commercially available. These air-conditioning units are called split units because the condensing portion (installed outside the building) of the unit is split from the evaporator (in the room) part of the unit.

Figure 4-8 : Ceiling cassette type split unit

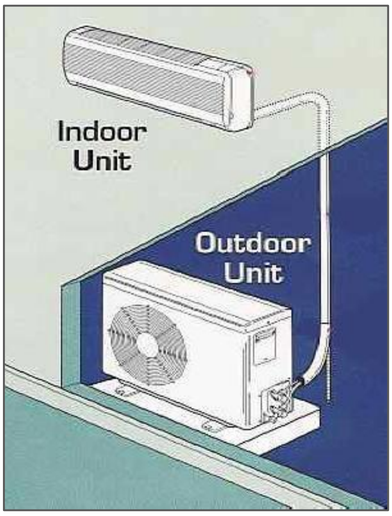


Figure 4-9 : Wall mounted split unit

The outdoor condenser units would need to be installed around the perimeter of the building and/or in dedicated plant rooms that need to be open to the outside, for example, on the rooftop. Fresh air would be reticulated throughout the ceiling voids, via a network of ducted systems to introduce fresh air into the offices as per the National Building Regulations.

The auditorium would be served via its own AHU but draw chilled water from the same production loop as that of the laboratories. Supply and return air ducting would be used to distribute air within the auditorium.

The chilled water system control would be with a localised controller on each AHU controlling the actuator on the 3-way valve to regulate the temperatures inside the laboratories and auditorium. These set points can only be set at the controller inside the individual plant rooms.

The DX-units, console and splits, have individual conform controls and are complete stand alone units. These systems also had no link to the existing BEMS system.

During the final stages of the project a decision was made to expand the localised controller into a BEMS to include the following:

- Remote switching of the console units
- Central temperature control on the AHUs
- Occupancy switching through sensors from the central BEMS
- Load shedding during peak loads
- Temperature logging in the laboratories
- SMS system to facilities manager

The new scope of the BEMS was to include the abovementioned functionality and the design was changed and priced accordingly. In the next chapter more details about the approach will be discussed.

4.2 BEMS design parameters and cost constraints

The initial BEMS scope for this project only required the mechanical equipment to be controlled via a localised controller. The current BEMS was limited to the control and monitoring of the air cooled chiller and air handling units serving the laboratory areas only. The purpose of the BEMS was to monitor the internal temperatures of the laboratory. There was no requirement to control the split units from a centralised point and there was also no requirement for lighting control in the building.

The initial BEMS was designed and supplied by a selected subcontractor, while the role of the consulting engineers was to evaluate, manage and assist in co-ordination and to relay the client's needs.

Subsequently, the client requested that the current BEMS, which included control and monitoring of the air handling units and chiller used for the labs, be expanded to include the console units automated switching including lights switching into the BMS control logic. During the first quarter of 2009, discussions to accommodate this request took place. The meetings included the electrical engineer, mechanical engineer and the BEMS specialists. The cassette units were excluded from the design, due to control interfacing and guarantee problems during the first year.

The concept design for the new BEMS was based on a generic office building and included all the control capabilities that the client requested, such as automated On/ Off switching, temperature monitoring, alarm protocols and maximum demand controls to switch the chiller off.

However the quoted price for this extensive BEMS exceeded the budgeted amount. In order to reduce the price it was agreed to reduce the amount of sensors to a minimum. Alterations to the electrical and mechanical services were not allowed for in the budgeted amount.

All the sensor locations were marked on the floor plan drawings. The decision was taken to allow one sensor per enclosed office and two sensors per lighting zone for the open office areas.

In order to control the console units and the light switches via the BEMS, additional relays and contactors were needed to enable an ON/OFF control command to be sent via motion sensors. This added to the initial cost of the project. This additional amount was deducted from the BEMS budget. The overall scope of the BEMS was, however, not reduced.

The control logic was therefore programmed into the sensor and a signal was sent from the sensor to a local relay which broke the current to the light fitting. If the switch for the light was initiated, a signal was sent to the relay allowing current to the light fitting. Initially the period at which the sensor would switch the light off was 30mins however it was increased to 1 hour and finally it was increased to a period of 2 hours. This duration was determined on a trial and error basis.

The initial extended BEMS was quoted at R700 000. Subsequently, the BEMS implementation cost was reduced to R350 000 by removing feedback communication and reducing the amount of sensors per area. Finally the quote was scrutinised and the final quoted cost came down to R325 000.

Therefore, even though the BEMS implementation cost was reduced by more than half of the original quoted price, the overall scope was not reduced. These savings were achieved by reducing the fault finding capabilities of the system and safeguards within the system.

4.3 Simulating the building energy usage

The new BEMS system was installed to control the HVAC systems in the enclosed and open office areas. At the time of this decision to continue with the installation of the BEMS, the HVAC and lighting systems were already installed. However, the commissioning of the individual systems was not completed yet.

In order to determine the potential saving in electrical consumption a baseline simulation was created based on the design data used for the initial HVAC design. This simulation was then optimised to indicate the saving.

The factors that were considered in this simulation were the building location, envelope and orientation, occupants, lighting and equipment and the fresh air quantities. The simulation also made allowance for the number of occupants and times the building would be occupied according to the design.

Occupants emit sensible and latent heat. Equipment such as printers and computers use electricity to operate and a portion of that electrical energy is emitted in the form of heat when the equipment is operational. The same applies for light fittings and depending on the type of light fitting used the amount of rejected heat can also vary.

The building location determines the ambient temperatures acting on the building. The fresh air temperature is determined by the ambient temperature, and the building envelope determines how much heat is emitted or lost via radiance, emissivity and conductivity.

Weather data from the weather bureau was used to obtain an average ambient temperature profile for the building's location. These values are based on the maximum and minimum average temperatures that were logged over the 15 year period.

The weather data from the CSIR (Council of Scientific and Industrial Research) provided a 24h-profile for a summer and winter period for Pretoria.

A probability of 90% or 95% is awarded to each set of values, indicating the probability that the values provided will not be exceeded. This can be misleading for the purposes of this simulation, because the data may indicate the temperatures in the winter can reach as low as -2 °C db[ii], but this does not imply that -2°C db is the average minimum temperature for every winter month.

[ii] Dry bulb temperature

The 24h profile was adjusted to correlate with the weather bureau's data for each month of the year. The simulated 24h - temperature profile for each month, obtained is displayed in Figure 4-10.

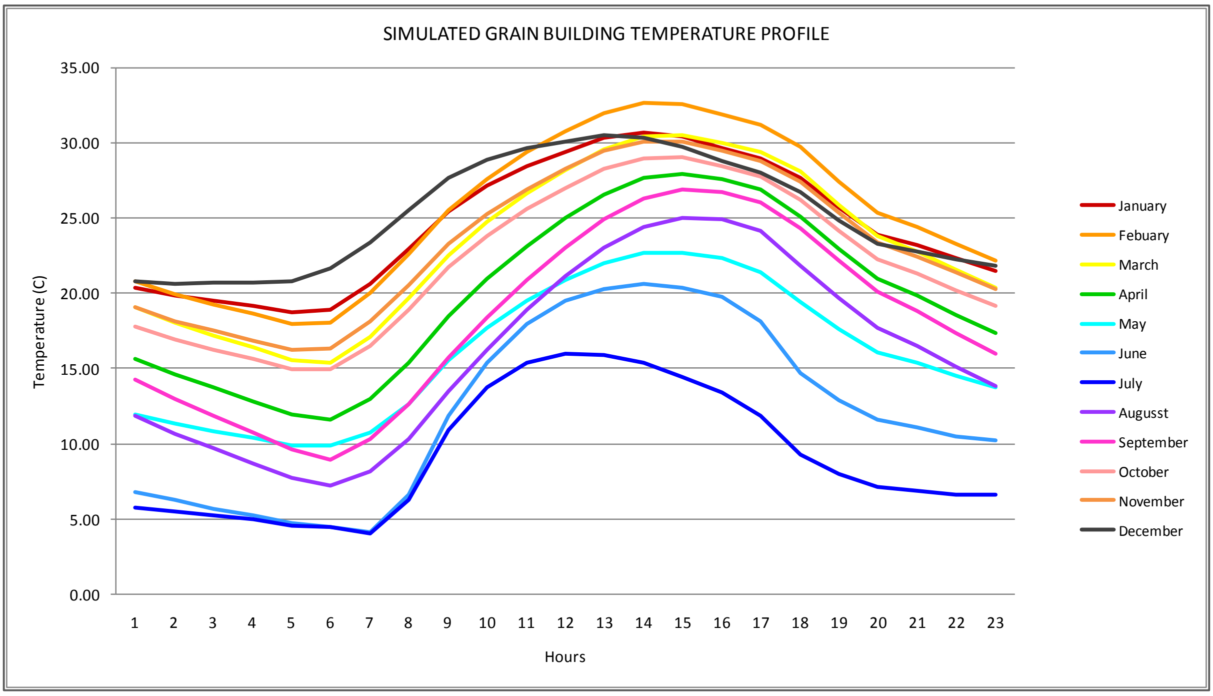


Figure 4-10 : Simulated ambient temperature profile

A heat load analysis was done on the building during the design stage. The heat emitted by the occupants, lighting, equipment and building envelope was calculated using HAP; Carrier's[iii] Heat Analysis Program version 4.5.

As part of the design calculation, it was assumed that the occupants would arrive at 7:00 in the morning and leave after 17:00 in the afternoon. Security lights would not be controlled via light switching, therefore 5% of the lights would remain on during the unoccupied hours.

The equipment (such as computers and printers) was assumed to operate from 7:00 to 17:00 as well. It was assumed that 20% of the computers would not be shut down at the end of each working day and would continue running throughout the evening. The occupancy profile is illustrated in Figure 4-11.

[iii] Carrie is a HVAC equipment supplier and software supplier for heat load analysis of buildings

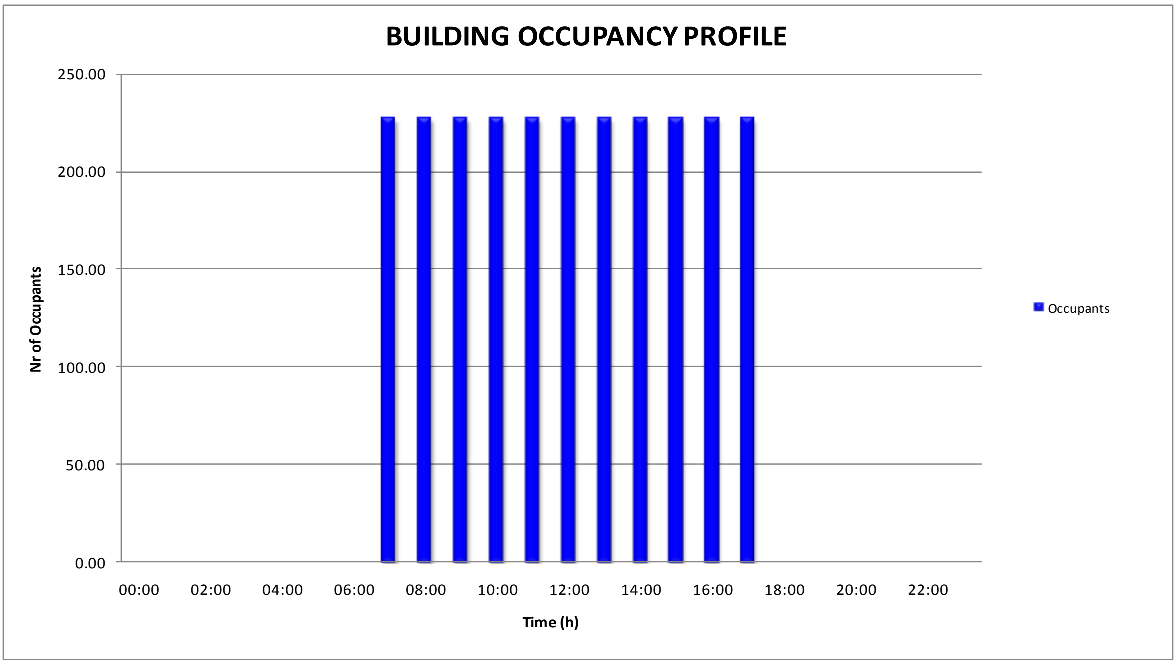


Figure 4-11 : Design building occupancy profile

The thermal loads caused by the building envelope and orientation were also calculated using HAP. The switching of the lights and HVAC system would be dependent on the occupants. It was assumed that 10% of the HVAC system will be operational after hours due to occupant negligence.

The thermal cooling and heating profile due to the building envelope and orientation is illustrated in Figure 4-12.

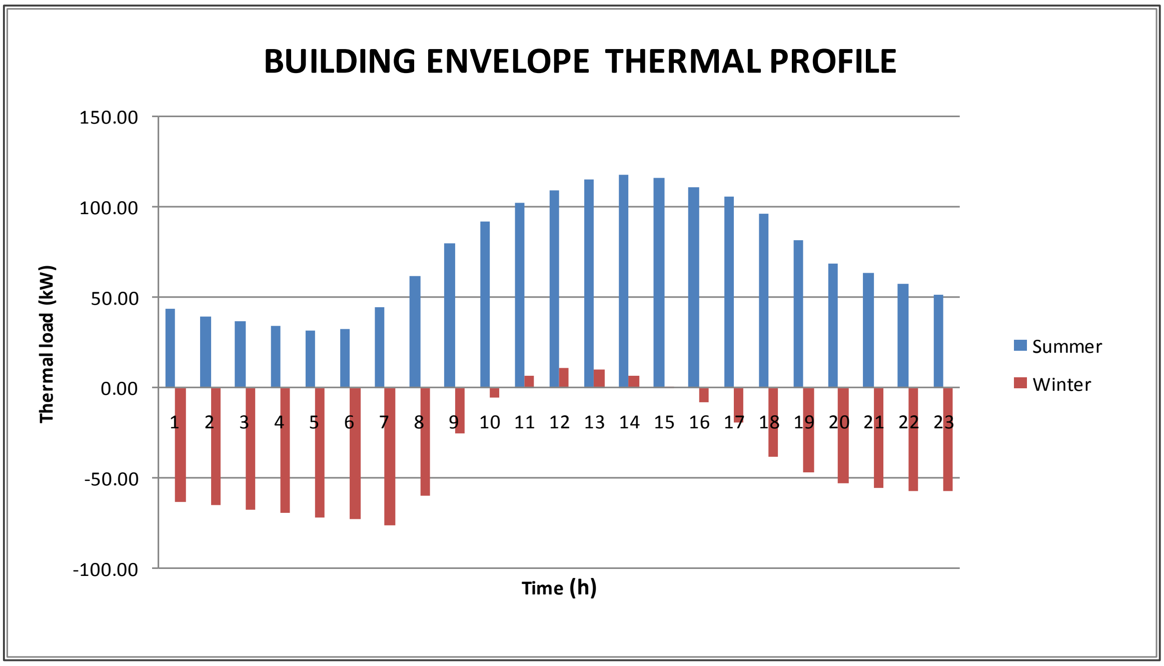


Figure 4-12 : Thermal loads due to building envelope

The negative values in Figure 4-12 indicate the building temperature is below the room set point temperature of 22 °C, therefore heating is required, while the positive values indicate the building temperature is higher than the room set point and cooling is therefore required.

The HVAC design allowed for a central fresh air or outside air system per floor. The air would be filtered, and distributed through a ducted system. A fixed fresh air quantity would be provided to each room according to building regulations. This fresh air system would not be controlled via the BEMS and therefore it will be operational during all hours of the day. The thermal loads associated were calculated at the design stage and these values were used in the simulation.

The simulated building summer and winter thermal loads due to building location, occupant, lighting and equipment, fresh air requirements and building envelope and orientation are illustrated in the Figure 4-13. This profile was generated using the simulated ambient temperature profile as per Figure 4-10.

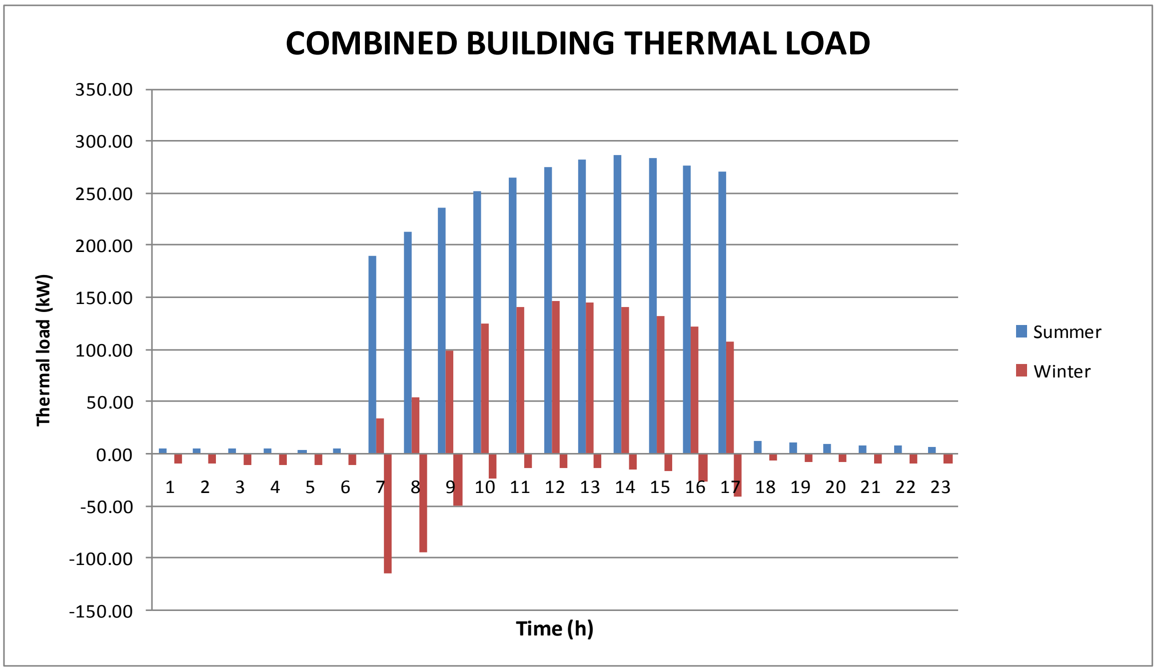


Figure 4-13 : Combined building thermal load

Again the negative values indicate heating is required and the positive values indicate that cooling is required. During the winter period, parts of the building will require heating when cooling is required in other areas.

Up to now, only the thermal calculations were considered. The purpose of this simulation was, however, to determine the potential saving in energy consumption and the potential reduction in maximum demand. Figure 4-14 illustrates the relationship between energy consumption and power demand.

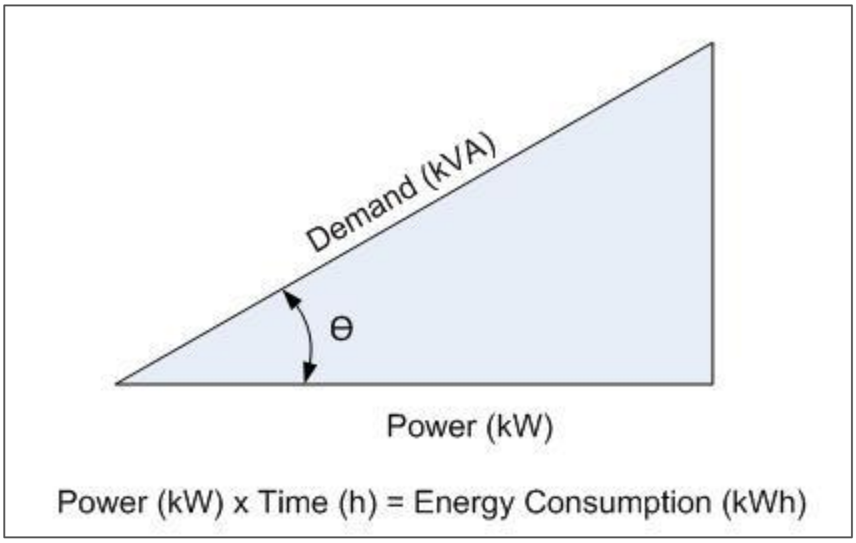


Figure 4-14 : Energy consumption vs. power demand

In order to convert thermal energy to electrical energy, the total thermal load must be divided by the specific equipment's coefficient of performance or COP.

The cooling COP for the DX-units used in the office buildings is 2.4[iv]. DX-Units make use of electrical heating, therefore for each thermal kilowatt of heating required, the unit will use one kilowatt of electricity. Therefore the COP for heating is 1.

The total electrical consumption breakdown of the offices including lights, equipment and fans as well as the HVAC is illustrated below:

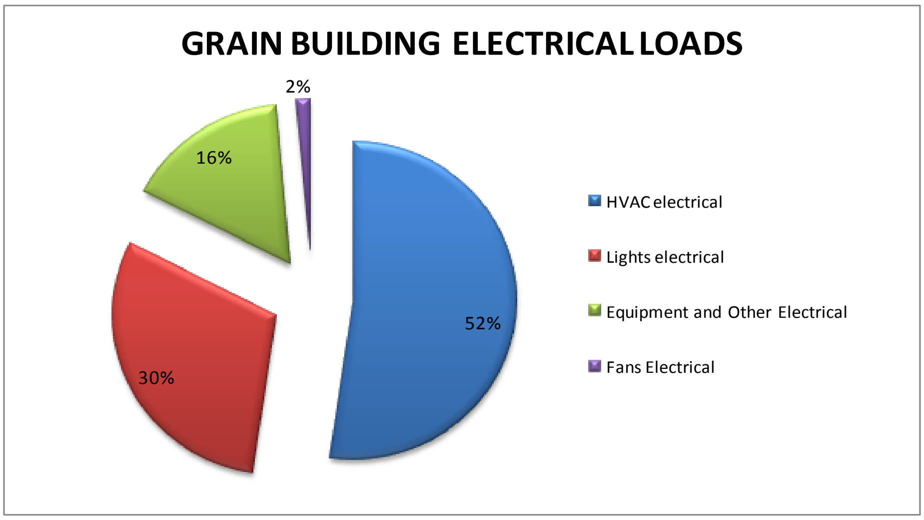


Figure 4-15 : Simulated electrical load breakdown of the Grain Building offices

When comparing these percentages to that of an average office building in South Africa (Figure 1-5), they correlate closely. The 24-h profile for HVAC, light and equipment in the offices in the Grain Building is illustrated in Figure 4-16.

[iv] COP was received from manufacturer

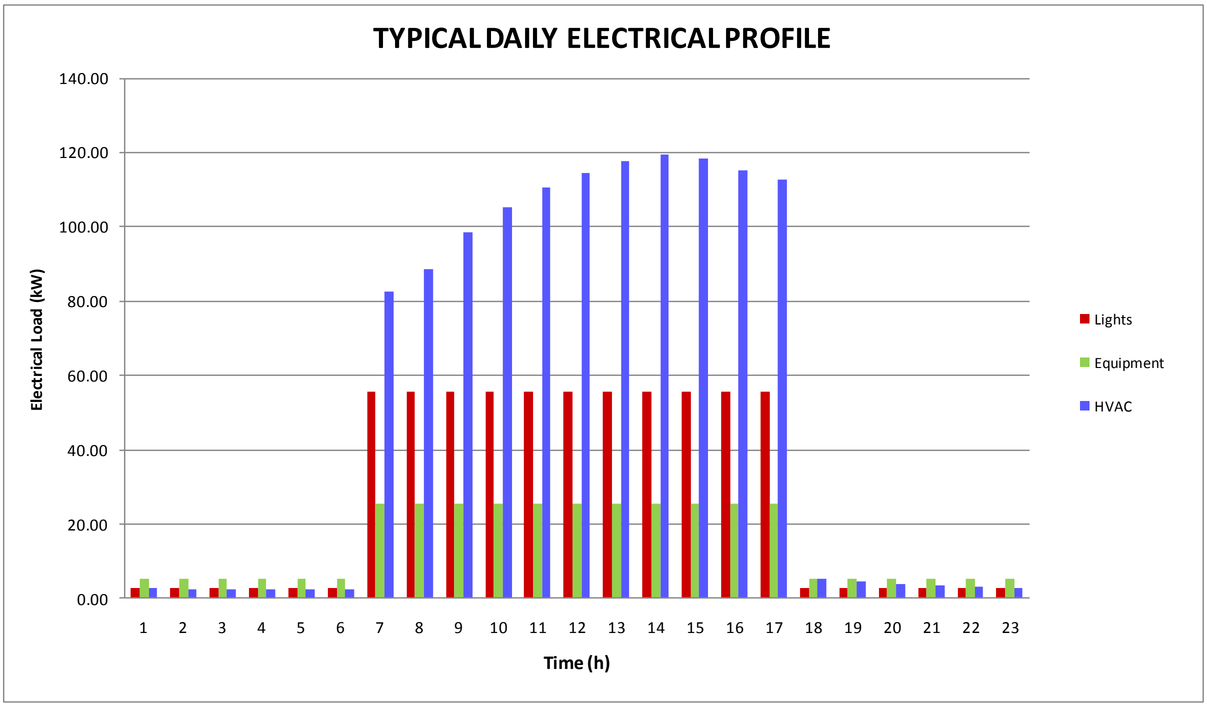


Figure 4-16 : Typical Grain Building daily electrical profile

The resultant energy consumption of the offices and overall building is provided in Table 4-1.

Table 4-1 : Baseline building energy consumption simulation results

BUILDING ENERGY CONSUMPTION SIMULATION RESULTS			
SIMULATION	OFFICE ENERGY CONSUMPTION	OFFICE YEARLY ENERGY CONSUMPTION	OVERALL BUILDING CONSUMPTION
UNITS	kWh / m^2 / an	MWh	kWh / m^2 / an
BASELINE SIMULATION	261	582	436

4.4 Optimised lighting simulation

The switching of lights would only be dependent on the behaviour of the building's occupants. The following assumptions were made with regards to movement of occupants during an average working day.

It was assumed that 50% of the total office occupants would arrive at 7:00 in the morning. It was assumed that 20% of the occupants would be in meetings or having a tea break at 10:00. It was also assumed that 50% of the occupants would take an early lunch and the rest of the people would take lunch from 13:00 to 14:00. It was also assumed that 10% of the occupants would not be in their offices at 16:00 and that 50% of the occupant would be in the office until 17:00.

Therefore, on average, occupants would only be in their offices 80% of an average working day, which correlates with the literature as well as international standards [52].

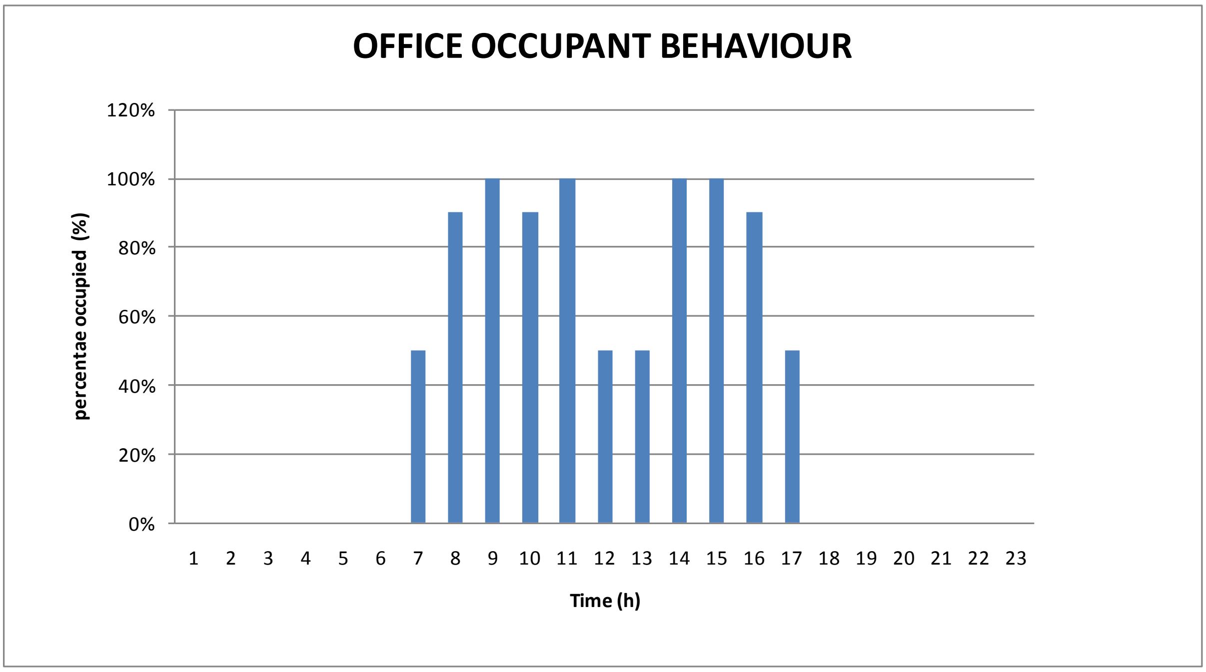


Figure 4-17 : Office occupant behaviour as a percentage

This occupant behaviour was programmed into the simulation, and the first order calculations were based on lighting control alone. The daily electrical usage profile is illustrated in Figure 4-18.

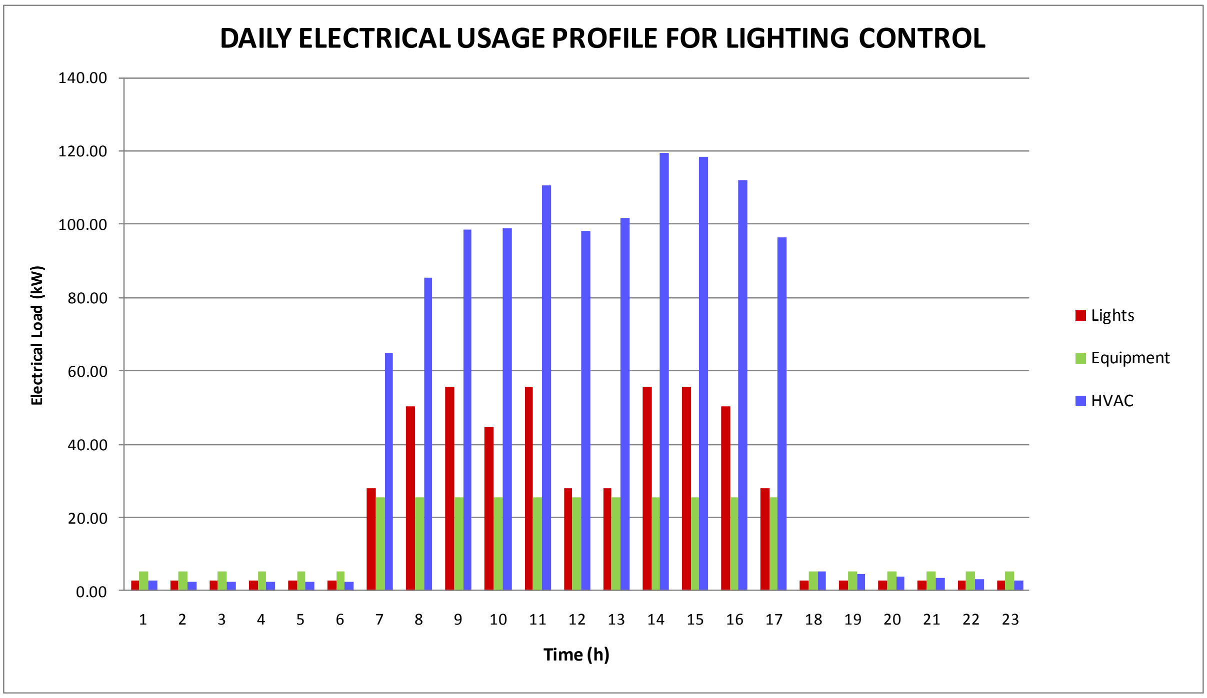


Figure 4-18 : Daily electrical usage profile optimised for lighting control

The resultant reduction in energy consumption generated by interlocking the lighting with the occupancy sensors is indicated in Table 4-2.

Table 4-2 : Optimised lighting control simulation results

BUILDING ENERGY CONSUMPTION SIMULATION RESULTS			
SIMULATION	OFFICE ENERGY CONSUMPTION	OFFICE YEARLY ENERGY CONSUMPTION	OVERALL BUILDING CONSUMPTION
UNITS	kWh / m^2 / an	MWh	kWh / m^2 / an
BASELINE SIMULATION	261	582	436
OPTIMISED LIGHTING CONTROL SIMULATION	232	517	415

The simulation indicates that the office energy consumption is reduced by 11% and the overall building consumption is reduced by 4.8%.

The HVAC systems in the offices would be interlocked with the lights so that the HVAC system switches off when the light is switched off. The typical daily electrical consumption is illustrated in the figure below.

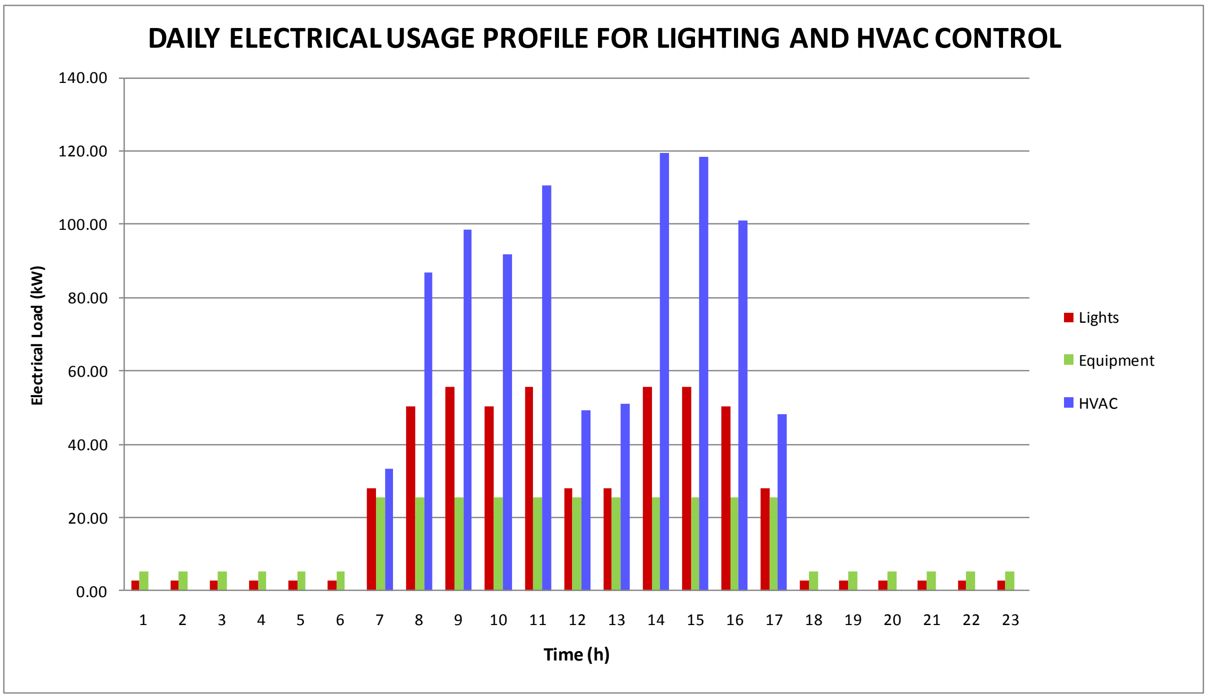


Figure 4-19 : The optimised daily electrical usage profile for lighting and HVAC control

The overall office and building energy consumption resulting from interlocking the HVAC system with the occupancy sensors is indicated in Table 4-3.

Table 4-3 : Optimised lighting and HVAC control simulation results

BUILDING ENERGY CONSUMPTION SIMULATION RESULTS			
SIMULATION	OFFICE ENERGY CONSUMPTION	OFFICE YEARLY ENERGY CONSUMPTION	OVERALL BUILDING CONSUMPTION
UNITS	kWh / m^2 / an	MWh	kWh / m^2 / an
BASELINE SIMULATION	261	582	436
OPTIMISED LIGHTING AND HVAC CONTROL SIMULATION	208	464	398

The simulation indicates that the office energy consumption is reduced by 25% and the overall building consumption is reduced by 9.5%.

The calculations indicated that there could be a significant reduction in the building energy consumption. The implementation thereof would prove to be far more challenging than was initially thought.

The next chapter discusses the challenges related to the implementation of the occupancy control and the interlocking of the lights and HVAC systems, as well as the resultant savings once the system was operational.

CHAPTER 5

5 RESULTS AND METERING

The challenges that were experienced during the construction and commissioning phases are discussed in this chapter, as well as the problems that occurred and the monitoring procedures that were introduced to mitigate the challenges are also discussed in this chapter.

5.1 Monitoring constraints

The BEMS for the Grain Building is based on Siemens Building Technology products. Energy management for the offices formed part of an extension to the initial control system which was limited to control of the Laboratory and Auditorium HVAC systems.

The initial BEMS operated using distributed controllers located in close proximity to the monitoring / control points. These controllers were connected to a communications bus which connected back to the computer based operator workstation or BEMS interface. The Generic name for this system is DESIGO.

The feedback communication components to the extension of the BEMS were omitted in an attempt to reduce the overall installation costs. With no feedback from the BEMS interface and a faulty electrical installation, troubleshooting was a tedious process which caused significant delays during commissioning.

During BEMS commissioning, the technician changed several of the BEMS function parameters as a temporary measure. However, these temporary measures were never corrected. Only after a power outage occurred, were these protocols initiated and a number of the fresh air fans could not be started. After days of troubleshooting, it was determined that the BMS function parameters pertaining to these fans were incorrect.

During the design stage the main electrical connection was designed as a 400 amp connection. The 400 amp connection would have been sufficient if the client had agreed with the installation of high efficiency chillers for the laboratory area. However, during the approval stages of the project the client was unable to procure additional funds and the additional costs for the high efficiency chillers were not approved. Chillers with lower efficiencies were installed and due to miscommunication between the various consultants, the main power connection was never increased.

A current and voltage reader was installed at the main incomer to the building which can provide kVA and kWH readings to the Building Energy Management system. These readings can be used to monitor the building energy consumption. The BEMS was programmed to switch the air conditioning units in the offices off and/or to limit the capacity of the chillers from the BEMS.

Current and voltage readers were not installed on the main incomer to the offices nor to the laboratories. It was therefore difficult to determine the percentage of power used by the laboratories and the offices respectively. The lack of monitoring data made it virtually impossible to accurately determine whether the energy efficiency strategies were successful.

The BEMS also did not record or monitor when the lights and air conditioning units in the offices are switched off, therefore it was not possible to verify whether the assumptions made to simulate the potential savings were accurate.

The client selected an elderly gentleman as building manager. He was trained in the operation of the BMS, but he was computer illiterate and after numerous training sessions he was unable to operate the BMS affectively. Allegations would be made that the system was non-functional, and upon investigation it was found the system was accidentally switched off or was switched to manually override. This caused friction between the client, end-user, consultants and the contractors.

5.2 Complications on lights and console switching using sensors

This building was constructed with a main contractor / sub-contractor agreement. A separate contractor for the controls was appointed as a sub-contractor under the main contractor. The controls contractor had to interconnect with the mechanical and electrical components.

Because the controls contractor was not appointed under either the electrical or mechanical contracts, numerous deadlock situations occurred during the commissioning period. The respective contractors would state that their equipment was functional, even though the control system could not communicate with the individual component.

The controls contractor was only appointed at the end of the project which caused difficulty as the electrical and mechanical contractors were already off-site and were, therefore, entitled to additional compensation each time they were requested to assist the controls contractor on site.

The electrical contractor installed the wrong 2-pole and 4-pole relays on the lights. As a result the controller wiring across that section of the building was also installed incorrectly. When the system was energised, there was no visible indicator that the poles on the relays were installed incorrectly. This fault was only realised when severe inconsistencies were experienced during the commissioning stage of the lighting controls.

The light fittings that were approved and installed during the project stage were low cost fittings and not the DALI enabled type. This caused complications between the sensor signal and the light switching.

In the office areas, ultrasonic movement sensors were used to switch the lighting on/off when movement was detected. The same signal was sent to the local electrical DB to enable the associated zone air conditioning unit/s to start. After a pre-determined time where movement within the zone is not detected, the lighting and air conditioning are automatically switched off.

The ultrasonic sensor proved to be inadequate for this type of application. The lights and air-conditioning would automatically turn off when an individual was stationary for a prolonged period at his desk. After numerous meetings, the client agreed to release funds to upgrade the sensors to the lowest cost Microphonics type sensors.

The remedial work to remove the existing sensors and reinstall the new sensors was commenced after the building was occupied. As a result many of the building maintenance related issues were communicated to the controls contractor, which hampered the installation.

Once the new sensors were installed and the system was commissioned, it was found that the new sensors had severe factory faults. The controls contractor replaced all the sensors with new sensors at his own cost, but this delayed installation significantly. Live and control wire switches were also incorrectly installed, which caused faulty switching once the tenants moved into the building.

An electronic monitoring device was installed at the main incomer to record the amount of power being used at fixed intervals. However, the meter was faulty or incorrectly calibrated, which caused inaccurate readings.

The lighting control system was fully functional and commissioned ± 10 months after the tenant occupied the building.

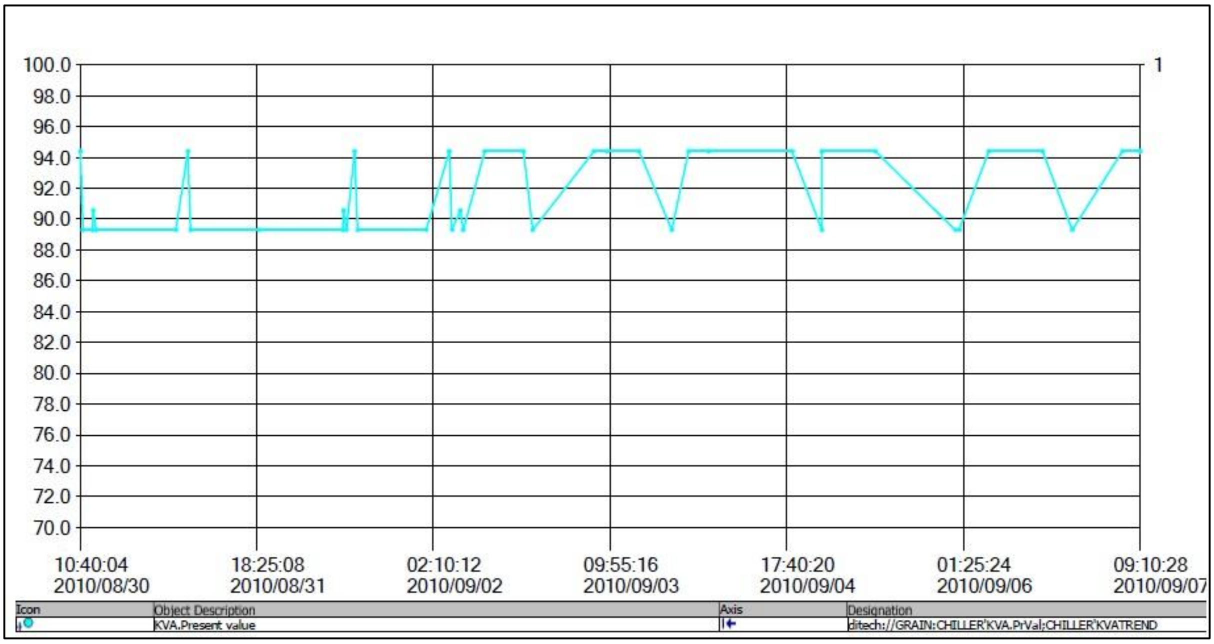
5.3 Data accumulation and analysis

The BEMS has the capability to monitor and record the following points.

- Main incoming kVA
- Main incoming kWh
- Standby Generator kVA
- Standby Generator kWh
- Chiller Start / Stop
- Chiller Water flow
- Chiller water pump run/trip
- Chiller water inlet temperature
- Chiller water leaving temperature

Of the above monitored points the chillers and standby generators are serving the laboratory area. The main incomer kVA and kWh to the building is therefore the only point where measured and recorded by the BEMS of which energy consumption can be determined.

After receiving of the data from the initial 7 day period indicated in Figure 5-1, it was noted that the data did not correspond with the expected values. In addition the BMS could only display the results in a graph format and not in a text or excel file format. Therefore the actual values are not available.



Icon	Object Description	Axis	Designation
●	KVA.Present value	←	ditech://GRAIN:CHILLER'KVA.PrVal;CHILLER'KVATREND

Figure 5-1 : Logged data over a 7 day period (kVA) from the main incomer

Due the situation on site, numerous hours were spent to regulate and eliminate the irregular power consumption. After numerous adjustments to various components, the data was logged for another 7 day period, indicated in Figure 5-2.

Figure 5-2 : Logged data over a 7 day period (kVA) from the main incomer

Once the data was received from the second logging period the results remained unchanged. After a month of testing and logging it was concluded that the loggers were faulty. At this time the client requested an independent energy audit from another consulting firm. Figure 5-3 indicates the values logged over the 35 day period.

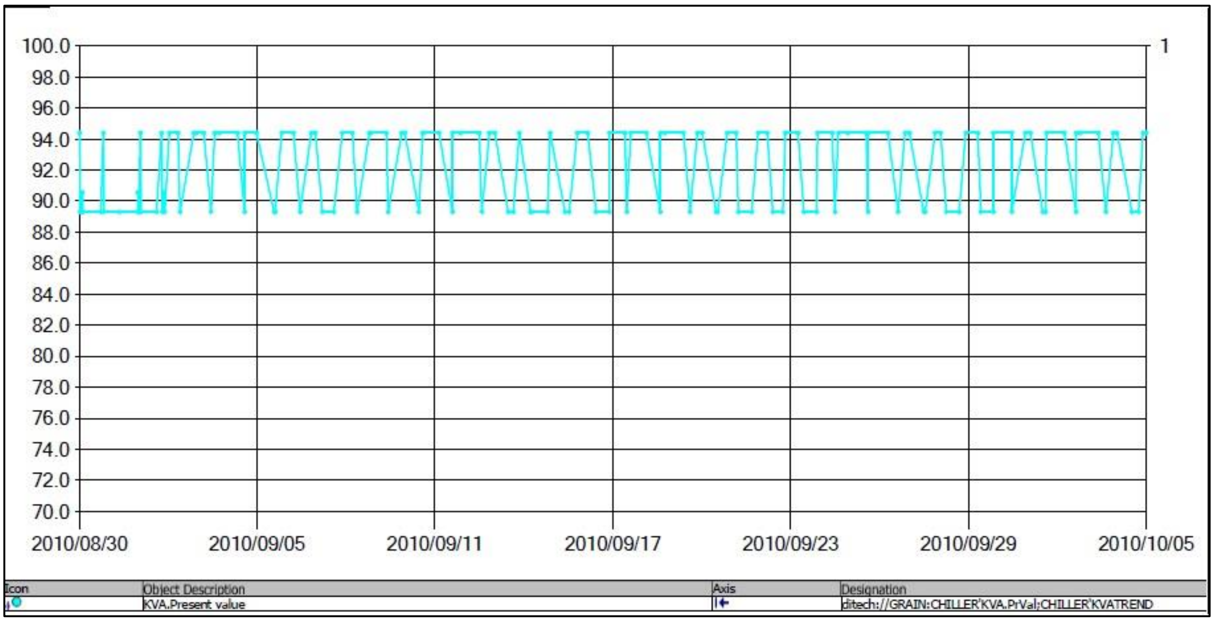


Figure 5-3 : Logged data over a 35 day period (kVA) from the main incomer

5.4 Actual building energy performance

An independent engineering consulting firm conducted a preliminary energy audit at the request of the client. Their report is dated October 2010 and was based on the following parameters and assumptions:

The overall building floor area is 3408m^2 of which 76% is divided into office space and 24% is laboratory space. The building is fully occupied during weekdays and only some areas are occupied during weekends.

According to the design data however, the overall air-conditioned area is 3128.5m^2 of which 71% was office space and 29% was laboratory space.

The independent auditors made use of council account records to conduct their audit. The data was taken from June to September 2010 which is winter and intermediate months. As this building was newly built, no additional historical data was available, and the available data was extrapolated to provide estimated yearly readings.

According to the report the energy consumption per year would be 376.7 kWh / m^2 / an, for the entire building. These values are compared to the benchmark office building value in South Africa and to the SANS 204 energy consumption for office buildings. The laboratories that operate continuously are included in the building consumption, whereas the benchmark and SANS 204 values do not include laboratories.

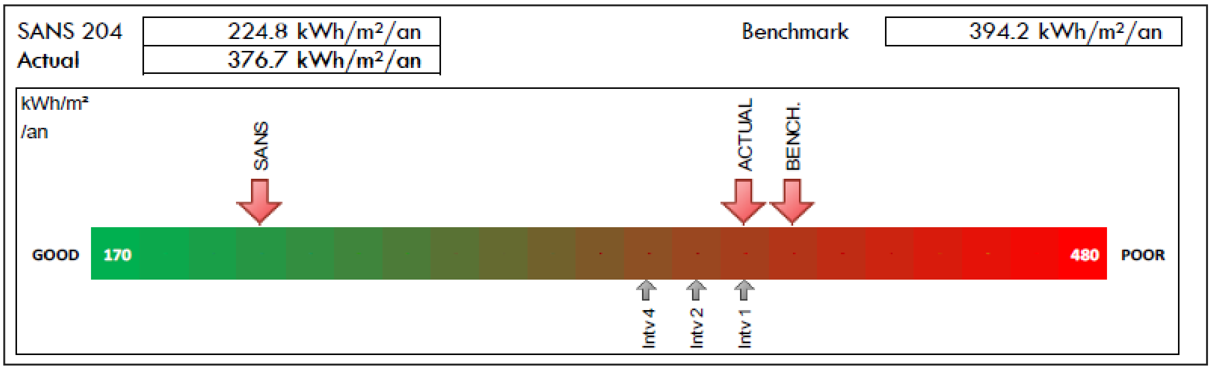


Figure 5-4 : Grain building actual energy consumption measurements

When considering the graph in Figure 5-4, the Grain building performs better than an average office building in South Africa, even with the laboratories included in the figures.

The comparison of these values to the values calculated in the simulation is illustrated in Table 5-1.

Table 5-1 : Building energy actual consumption comparison

BUILDING ENERGY ACTUAL CONSUMPTION COMPARISON			
SIMULATION	OFFICE ENERGY CONSUMPTION	OFFICE YEARLY ENERGY CONSUMPTION	OVERALL BUILDING CONSUMPTION
UNITS	kWh / m^2 / an	MWh	kWh / m^2 / an
OPTIMISED LIGHTING CONTROL SIMULATION	232	517	415
OPTIMISED LIGHTING AND HVAC CONTROL SIMULATION	208	464	**398**
ACTUAL MEASURED VALUES			**376**

As indicated in Table 5-1, the actual recorded consumption as measured by the independent company is 5.5% lower than that of the simulation. Although these results are favourable, the actual consumption of the laboratories is unclear and therefore the actual saving due to the interlocking of the HVAC system with the occupancy control cannot be confirmed.

According to the measurements of the independent auditors as seen in Figure 5-5, the Grain Building performed better than the SANS 204 requirements. It should be noted, however, that these reading were taken in the winter months and these values could increase slightly with the change of the seasons.

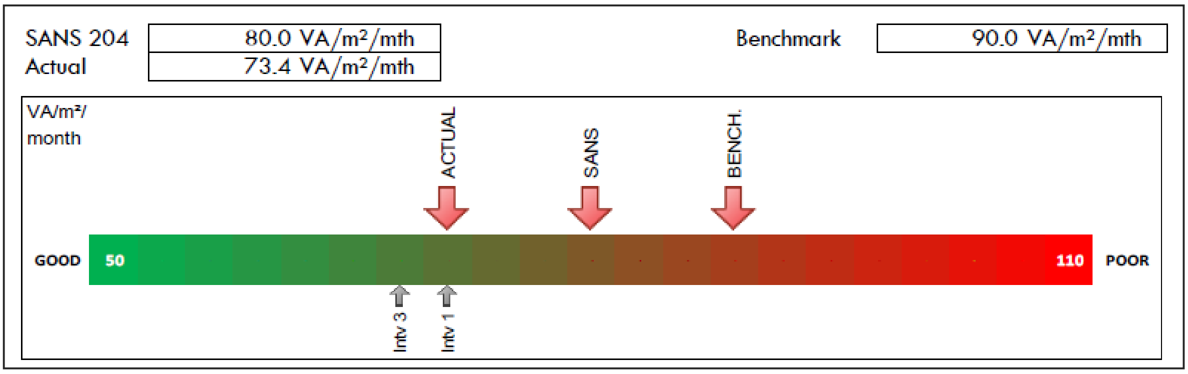


Figure 5-5 : Grain Building maximum demand measurements

The energy consumption and maximum demand values of the Grain Building over the measured month are indicated in Figure 5-6.

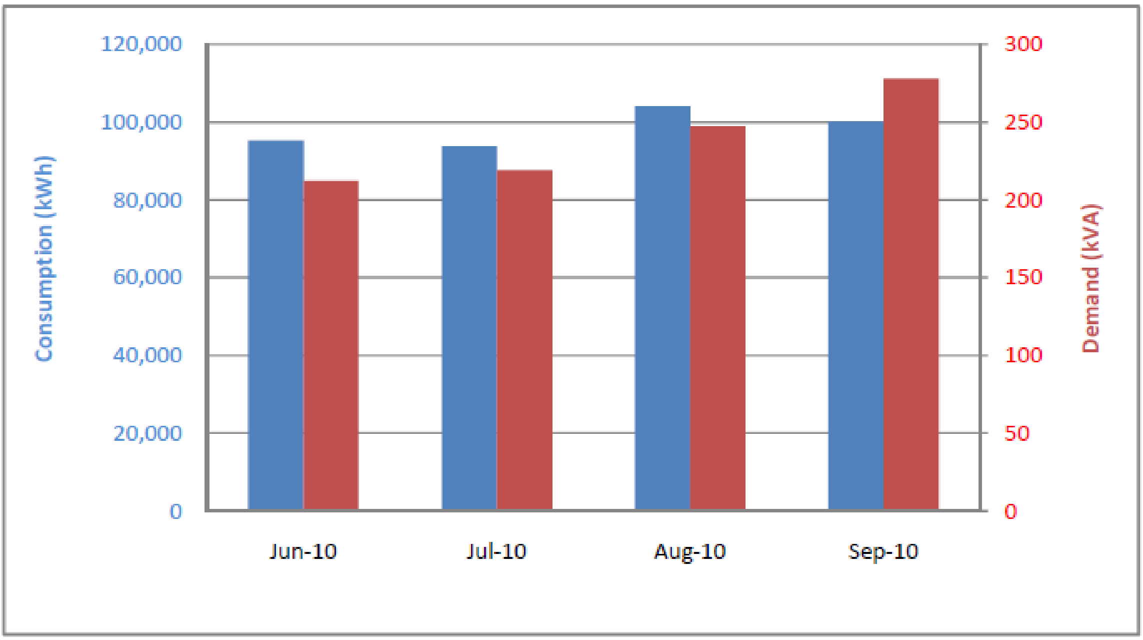


Figure 5-6 : Grain building energy consumption and maximum demand over the measured period

The energy audit report also indicated that the maximum demand values over the logged period were 250kVA. However, it is unclear if these values were measured independently from the laboratories, as these values do not correspond with the expected load for the overall building.

Unfortunately the client did not agree to re-validate the performance of the entire system and, therefore, more recent and reliable data wasn't available.

5.5 Cost comparison

The split and console units installed in the office areas of the Grain Building proved to be an energy efficient installation. These systems are usually not considered as energy efficient due to their relatively low COP values, when compared with other systems. However, because each split/console unit was interconnected with occupancy sensors, the combined energy consumption of the office air-conditioning system resulted in reduced energy consumption of the overall building.

In order to determine whether this type of solution will be worthwhile for future projects, it was decided to compare installation costs with other HVAC systems that are considered energy efficient due to their high COP values.

The following systems were selected for the comparison:

- Four-pipe chilled water fan coil unit system
- VRV (variable refrigerant volume) system

These systems were selected as it is claimed to be energy efficient by the individual suppliers. These systems have also recently been installed on two different projects and consequently their costs are readily available. The projects are still in the construction stage and therefore the individual HVAC systems have not been commissioned yet. The energy efficiency of the various installations is therefore not confirmed.

For the purposes of this comparison an R/m^2 value will be used to compare the different systems, as each project is different in size and cooling requirements. These values can then be used as a reference for high order budgetary costing purposes for future projects.

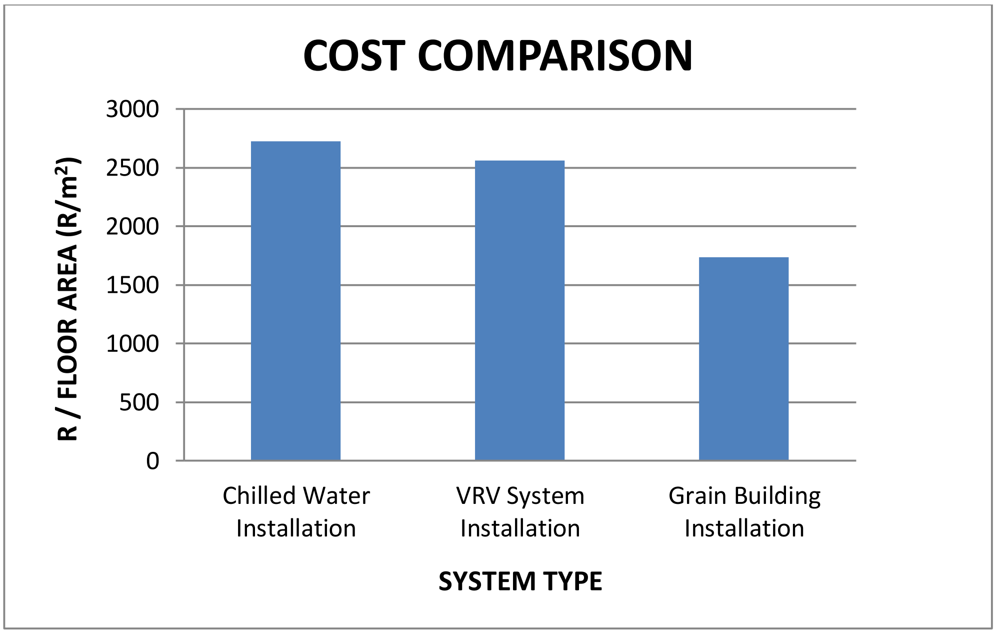


Figure 5-7 : Grain Building cost comparison

It is evident that the system installed at the Grain Building did indeed provide lowered energy consumption as well as being a cost effective option when compared to other energy efficient systems.

CHAPTER 6

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Since the Koyoto protocol was presented almost a decade ago, a great deal of effort has gone into spreading global awareness regarding greenhouse gas emissions and the negative effect it has. South Africa joined the race in 2007 with the founding of the Green Building Council of South Africa. South Africa also adopted the Australian Green Star rating in order to rate buildings based on this rating system.

With the Green Star rating buildings can be evaluated on a wide variety of factors of which energy consumption is only one part. However, because there is no penalty system in place and the Green Building Council of South Africa is a voluntary organisation, many developers do not invest in creating green buildings.

Due to the recent increase in electricity tariffs, developers and end-users have become more aware of energy efficiency and are more determined to reduce their overall building energy consumption, rather than creating a green building.

The literature review revealed that the control of light switching through occupancy sensors is an effective method to reduce a building’s overall energy consumption. The literature indicated that saving of between 20 – 26% can be expected for office buildings.

In the case study this energy saving method was expanded to include the HVAC system for offices as well. Due to initial capital investment constraints a large amount of the installation components for the control system was significantly reduced. The associated limitations of the system were not properly conveyed, causing misconstrued expectations of the capabilities of the system.

During the commissioning period extreme difficulty was experienced due to the reduced scope of the installation and commissioning of the system became a tedious and lengthy process. This also created difficulty to determine the overall success of the installation of occupancy sensors as an energy efficiency measure.

Even though the results were not definitive, it was clear that the occupancy sensors did improve the overall energy consumption of the building.

6.2 Results

The measurement of the building energy consumption and maximum demand was done by an independent company. However, according to the results the overall building's energy consumption was more efficient than that of typical or benchmarked office buildings in South Africa.

According to the report the Grain Building's maximum demand readings were well below that of a typical or benchmarked office building for South Africa. The grain building maximum demand readings also surpassed the requirements for SANS 204.

It is clear from the energy audit, that even though the building is not classified as a green building, its energy consumption was below the expected norms for such a building. Even though the offices are temperature controlled with split and console type units, by interlocking these units with occupancy control sensors it was possible to reduce the overall energy consumption of the HVAC system.

This is remarkable as the installation costs of the units used in the grain building were well below that of HVAC systems considered to be "green" or energy efficient.

The installation of this HVAC system proved to be far more challenging than what was initially anticipated. This can largely be contributed to a lack of adequate funds available and a shortage of skills displayed by the various contractors. As a result the installation had numerous flaws which were only discovered once the installation was complete and the contractor already reached practice completion.

6.3 BMS limitations

The BMS installed at the Grain Building was initially designed to control the HVAC chiller arrangement of the laboratories. The BMS was then expanded, as a last minute measure, to include office split and console units. Limited funds were made available and as a result items were excluded from the final price which proved to be crucial during commissioning.

Items such as feedback loops between the controls, lighting and HVAC system were excluded. The omission of these components made the commissioning process tedious and lengthy.

Many of the monitoring components were also excluded due to the reduction in scope, and as a result it made accurate performance verification of the system impossible.

6.4 Skills shortage

During the commissioning period there was an alarming amount of faulty installations. In addition, the poor quality of the installation was not managed properly by the principal contractor. This resulted in reluctance from the sub-contractors to correct their faulty installations.

Uneducated labourers proved to be the cause of many of the faulty installations. Their flippant attitude and the zero accountability towards their own workmanship caused many of the problems.

6.5 Recommendation

The Green Ideal will not be successful if it is not adopted by the nation. Green and energy saving initiatives should not be viewed as a capital expenditure but rather a management style, which, for it to be successful, should be adopted by developers, landlords and occupants alike.

This thesis proved that even with limited funds available, energy efficiency initiatives can be successfully implemented and can be cost effective.

It is recommended that the importance of certain monitoring controls and equipment be carefully evaluated before being omitted. For example, power metering should be provided as close as possible to the HVAC system. Feedback loops should preferably also be installed to reduce the commissioning period.

It is also recommended that DALI addressable light fittings be specified and installed to eliminate installation complications.

CHAPTER 7

7 Bibliography

[1] *Integrating carbon footprint into supply chain management: the case of Hyundai Motor Company (HMC) in the automobile industry.* ***Lee Ki-Hoon.*** *2011, Journal of Cleaner Production 19 pp.1216-1223*

[2] *Optimal energy planning models with carbon footprint constraints.* ***Pekala Lukasz M, Tan Raymond R, Foo Dominic C.Y, Jezowski Jacek M.*** *2010, Applied Energy 87 pp.1903-1910*

[3] *Carbon footprints in a bipolar, climate-constrained world.* ***Cranston G.R, Hammond G.P.*** *2011, Ecological Indicators*

[4] *Modelling the carbon cycle of urban systems.* ***Churkina Galina.*** *2008, Ecological Modelling 216 pp.107-113*

[5] *The geography of metropolitan carbon footprints.* ***Brown Marilyn A, Southworth Frank, Sarzynski Andrea****. 2009, Policy and Society 27 pp.285-304*

[6] *Differences in coal consumption patterns and economic growth between developed and developing countries.* ***Li Jin-ke, Wang Feng-hua, Song Hua-ling.*** *2009, Procedia Earth and Planetary Science 1 pp.1744-1750*

[7] *Aggregated demand for electricity in South Africa: Analysis using the bounds testing approach to cointegration.* ***Amusa Hammed, Amusa Kafayat, Mabugu Ramos.*** *2009, Energy Policy 37 pp.4167-4175*

[8] *Understanding developing country stances on post-2012 climate change negotiations: Comparative analysis of Brazil, China, India, Mexico, and South Africa.* ***Rong Fang.*** *2010, Energy Policy 38 pp.4582-4591*

[9] *Energy policies for sustainable development in South Africa.* **Winkler Harald**. *2007, Energy for sustainable development, Vol. XI no 1*

[10] *The dark side of occupants' behaviour on building energy use.* **Masoso O.T, Grobler L.J.** *2010, Energy and Buildings 42 pp.173-177*

[11] *A review on buildings energy consumption information.* **Pérez-Lombard Luis,Ortiz Jose, Pout Christine.** *2008, Energy and Buildings 40 pp.394-398*

[12] *Energy consumption and the potential of energy savings in Hellenic office buildings used as bank branches—A case study.* **Spyropoulos Giorgos N, Balaras Constantinos A**. *2011, Energy and Buildings 43 pp.770-778*

[13] *Chapter: Lighting.* **Osburn, Luke.** *1, 2009, Green Building Handbook for South Africa, Vol. 1*

[14] *Energy modeling of two office buildings with data center for green building design.* **Pan Yiqun, Yin Rongxin, Huang Zhizhong.** *2008, Energy and Buildings 40 pp.1145-1152*

[15] *Heating, Ventilation and Cooling.* **Osburn, Luke.** *2009, Green Building Handbook for South Africa, Vol. 1*

[16] *The Kyoto Protocol: provisions and unresolved issues relevant to land-use change and forestry.* **Schlamadinger Bernhard, Marland Gregg.** *1998, Environmental Science and Policy 1 pp.313-327*

[17] *The Berlin Mandate: the cost of meeting post-2000 targets and timetables.* **Alan Manne, Richard Richels.** *1996, Energy Policy 24(3) pp.205-210*

[18] *An economic assessment of the Kyoto Protocol application.* **Dagoumas A.S, Papagiannis G.K, Dokopoulos P.S.** *2006, Energy Policy 34 pp. 26-39*

[19] *Assessment of post-Kyoto climate change mitigation regimes impact on sustainable development.* ***Streimikiene Dalia, Girdzijauskas Stasys.*** *2009, Renewable and Sustainable Energy Reviews 13 pp.129-141*

[20] *BREEAM (Building Research Establishment Environmental Assessment Method) 98 for offices.* ***Baldwin R, Yates A, Howard N, Rao S.*** *1998, Watford: UK s.n.*

[21] *Optimization model for the selection of materials using LEED- based green building rating system in Colombia.* ***Castro-Lacouture Daniel, Sefair Jorge A, Florez Laura, Medaglia Andrés L.*** *2009, Building and Environment 44 pp.1162-1170*

[22] *City buildings - Eco labels and shades of green!.* ***Burnett John.*** *2007, Landscape and Urban Planning 83 pp.29-38*

[23] *Energy management systems, a practical guide.* ***Stum K, Mosier R, Haasl T.*** *1997, Portland Energy Conservation Inc., Portland*

[24] *Optimization of HVAC control strategies by building management systems.* ***Canbay C.S.*** *2003, Izmir Institute of Technology, Turkey*

[25] *An innovative lighting controller integrated in a self-adaptive building control system.* ***Guillemin A, Morel N.*** *2001, Energy and Buildings 33 pp.477-487*

[26] *Needs and trends in building and HVAC system design tools.* ***Ellis M.W, Mathews E.H.*** *2002, Building and Environment 37 pp.461 – 470*

[27] *Advanced controller auto-tuning and its application in HVAC systems.* ***Qiang B, Wen-Jian C, Qing-Guo W, Chang-Chieh H, Eng-Lock L, Yong S, Ke-Dian L, Yong Z, Biao Z.*** *2000, Control Engineering Practice 8 pp.633-644*

[28] *Long-term patterns of use of occupant controlled office lighting.* ***Moore T, Carter D.J, Slater A.I.*** *2003, Lighting Res. Technol. 35 (1) pp.43-59*

[29] *Advanced control systems engineering for energy and comfort management in a building environment - A review.* ***Dounis A.I, Caraiscos C.*** *2009, Renewable and Sustainable Energy Reviews 13 pp.1246-1261*

[30] *Optimal control of time-scheduled heating, ventilating and air conditioning processes in buildings.* ***Zaheer-uddin M, Zheng G.R.*** *2000, Energy Conversion & Management 41 pp.49-60*

[31] *Predictive control techniques for energy and indoor environmental quality management in buildings.* ***Kolokotsa D, Pouliezos A, Stavrakakis G, Lazos C.*** *2009, Building and Environment 44 pp.1850-1853*

[32] *Optimal, sub-optimal and adaptive control methods for the design of temperature controllers for intelligent buildings.* ***Zaheer-Uddin, M.*** *1993, Building and Environment 28(3) pp.311-22*

[33] *Intelligent control strategies for HVAC processes in buildings.* ***Zaheer-Uddin, M.*** *1994, Energy 19(1) pp.67-79*

[34] *An analysis of energy-efficient light fittings and light controls.* ***Li Danny H.W, Cheung K.L, Wong S.L, Lam Tony N.T.*** *2010, Applied Energy 87 pp.558-567*

[35] *Occupant Use of Manual Lighting Controls in Private Offices.* ***Maniccia, Dorene, et al****. 1997, New York : Lighting Research Centre 34(IESNA)*

[36] *Comparison of Control Options in Private Offices in an Advanced Lighting Control Test bed.* ***Jennings Judith D, Rubinstein Francis M, DiBartolomea Dennis, Blanc Steven L.*** *2000, Journal of the Illuminating Engineering Society*

[37] *Implementation of an integrated indoor environment and energy management system.* ***Kolokotsa D, Niachou K, Geros V, Kalaitzakis K, Stavrakakis G.S, Santamouris M.*** *2005, Energy and Buildings 37 pp.93-99*

[38] *Response of conventional energy-saving buildings to design and human dependent factors.* ***Filippin C, Larsen Flores S, Beascochea A, Lesino G****. 2005, Solar Energy 78 pp.455-470*

[39]*Energy efficient building environment control strategies using real-time occupancy measurements.* ***Erickson V.L, Lin Y, Kamthe A, Brahme R, Surana A, Cerpa A.E, Sohn M.D, Narayanan S****. 2009, USA: ACM*

[40] *A study of the importance of occupancy to building cooling load in prediction by intelligent approach.* ***Kwok S.S.K, Lee E.W.M.*** *2011, Energy Conversion and Management 52 pp.2555 – 2564*

[41] *Peak load characteristics of Sydney office buildings and policy recommendations for peak load reduction.* ***Steinfeld J, Bruce A, Watt M.*** *2011, Energy and Buildings 43 pp.2179–2187*

[42] *Adding advanced behavioral models in whole building energy simulation: A study on the total energy impact of manual and automated lighting control.* ***Bourgeois D, Reinhart C, Macdonald I.*** *2006, Energy and Buildings 38 pp.814 – 823*

[43] *Detailed occupancy prediction, occupancy-sensing control and advanced behavioural modelling within whole-building energy simulation master thesis.* ***Bourgeois D****. 2005, University Laval*

[44] *The philosophy behind EN15251: Indoor environmental criteria for design and calculation of energy performance of buildings.* ***Olesen B.W.*** *2007, Energy and Buildings 39 pp.740 – 749*

[45] *Advanced fuzzy logic controllers design and evaluation for buildings' occupants thermal–visual comfort and indoor air quality satisfaction.* ***Kolokotsa, D****. 2001, Energy and Buildings 33(7) pp.513-543*

[46] *Ventilation for Acceptable Indoor Air Quality.* ***ASHRAE.*** *1999, Atlanta : American Society for Heating, Refrigerating and Air-Conditioning Engineers Standard 62-1999*

[47] *Energy saving potential and strategies for electric lighting in future North European, low energy buildings: A literature review.* ***Dubois Marie-Claude, Blomsterberg Áke.*** *2011, Energy Buildings*

[48] *Application of an energy management and control system to assess the potential of different control strategies in HVAC systems.* ***Escrivá-Escrivá Guillermo, Segura-Heras Isidoro, Alcázar-Ortega Manuel.*** *2010, Energy and Buildings 42 pp.2258-2267*

[49] *Influence of building parameters and HVAC systems coupling on building energy performance.* ***Korolija Ivan, Marjanovic-Halburd Ljiljana, Zhang Yi, Hanby Vic I.*** *2011, Energy and Buildings 43 pp.1247-1253*

[50] *Occupancy density and benefits of demand-controlled ventilation in Norwegian primary schools.* ***Mysen Mads, Bernsten Sveinung, Nafstad Per, Schild Peter G.*** *2005, Energy and Buildings 37 pp.1234-1240*

[51] *Smart occupancy sensors to reduce energy consumption.* ***Garg Vishal, Bansal N.K.*** *2000, Energy and Buildings 32 pp.81-87*

[52] *Modeling occupancy in single person offices.* ***Wang Danni, Federspiel Clifford C, Rubinstein Francis.*** *2005, Energy and Buildings 37 pp.121-126*

[53] *Building occupancy detection through sensor belief networks.* ***Dodier Robert H, Henze Gregor P, Tiller Dale K, Guo Xin***. *2006, Energy and Buildings 38 pp.1033-1043*

[54] *Daylight integrated illumination control of LED systems based on enhanced presence sensing.* ***Pandharipande Ashish, Caicedo David.*** *2011, Energy and Building 43 pp.944-950*

[55] *Cross-level fault detection and diagnosis of building HVAC systems.* ***Wu Siyu, Sun Jian-Qiao.*** *2011, Building and Environment 46 pp.1558-1566*

[56] *Influence of sensor position in building thermal control: criteria for zone models.* ***Riederer Peter, Marchio Dominique, Visier Jean Christophe.*** *2002, Energy and Buildings 34, pp. 785-798*

[57] *The effect of suspended ceilings on energy performance and thermal comfort.* ***Høseggen R, Mathisen H.M, Hanssen S.O.*** *2009, Energy and Buildings 41 pp.234-245*

[58] *Simulation-assisted control in building energy management systems.* ***Clarke J.A, Cockroft J, Conner S, Hand J.W, Kelly N.J, Moore R, O'Brien T, Strachan P.*** *2002, Energy and Buildings 34 pp.933-940*

8 Appendixes