OPTIMISATION OF HVAC SYSTEMS FOR ENERGY EFFICIENCY IN PUBLIC BUILDINGS

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A dissertation submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, Johannesburg in fulfilment of the requirements for the degree of Master of Science in Building.

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DECLARATION

This dissertation is my own unaided work and has not been submitted before for any degree or examination in any university. It is being submitted to the University of the Witwatersrand, Johannesburg in fulfilment of the requirements for degree of Master of Science (Building).

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Date: 26 October 2009

DEDICATION

This dissertation is dedicated to my mother Yunis, my sister Elizabeth and my wife Eunice.

ABSTRACT

This research was motivated by the twin needs of increasing access to energy as a resource and reducing carbon dioxide emission levels in South Africa. This took into account that South Africa's electricity sector is highly carbon intensive and that in 2007-2008 the country experienced irregular electricity supply due to "low electricity production reserve". To effectively address its energy challenges South Africa must undertake strategic electricity demand reduction via the practice of energy efficiency. It is approximated that 30% to 40% of all primary energy is used in buildings worldwide, and a good portion of this ends up servicing the heating, ventilation and air conditioning (HVAC) systems. Indeed, certain quarters' report that 50% to 65% of the world's electrical energy in the commercial sector is used by HVAC systems. This indicates that any meaningful electricity demand management in the commercial and public building sector must lay emphasis on the efficiency of the HVAC system. This study examined how the concept of 'optimisation for energy efficiency' can be used to reduce electricity consumption by HVAC systems in public buildings. A case study approach was adopted in which HVAC systems in public library buildings in the Southern region of Ekurhuleni Metropolitan Municipality, the University of the Witwatersrand and CSIR complex were surveyed. Using a combination of structured observation, questionnaires and interviews with key informants, key data were collected and evaluated on ordinal scale. The items evaluation were public conversance with HVAC operation, availability of placard, responsibility assignment for energy management, energy consumption budget, design philosophy, schedule of operation, control type, occupants conversance with HVAC controls, energy measurements and monitoring systems, maintenance planning, response time in correcting faults, contact details for reporting faults, maintenance responsibility, age of equipment/retrofits and installation and commissioning. It was revealed that over 70% of HVAC systems in public buildings failed to meet the basic requirements for energy efficiency and could hence be categorised as 'energy inefficient'. At the end of the study a series of prescriptive and prophylactic interventions are proposed to optimize HVAC systems for energy efficiency in public buildings in South Africa.

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Not to be forgotten are my friends. Thank you for the encouragement during this period. Finally, I would like to express heartfelt appreciation to my family for their love, prayers and support during my studies.

ABBREVIATIONS

ASHRAE:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CIBSE:	Chartered Institution of Building Services Engineer
CV:	Constant Volume Systems
DME:	Department of Minerals and Energy
EIA:	Energy Information Department
ESKOM:	South Africa's Electricity Supply Commission
HVAC:	Heating, Ventilation and Air Conditioning
OPEC:	Organisation of Oil Producing Countries
UNDP:	United Nations Development Programme
UNEP:	United Nations Environmental Programme
VAV:	Variable Air Volume Systems
TDV:	Thermal Displacement Method
SA:	South Africa

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Heating, Ventilation and Air Conditioning (HVAC) systems are used to maintain a comfortable indoor environment (that is, indoor temperature, humidity and air cleanliness) where this cannot be achieved naturally. There are several types of HVAC systems used in buildings. These include single zone or multiple zone types when classified according to the number thermal zone created or constant volume or variable air volume when categorised according to air flow mode. The use of a particular HVAC type depends on building type, thermal requirements as well as location and purpose for which it is designed (American Institute of Architects, 1993). It is therefore necessary for studies focussing on energy use in HVAC systems to be building specific; this would ensure increased applicability to the already existing buildings.

The London-based Chartered Institution of Building Services Engineers (CIBSE) defines an energy efficient building as that which provides the required internal environment and services with minimum energy use in a cost effective and environmental friendly manner (CIBSE, 2004). In concurrence, the Energy Information Administration (EIA) is of the opinion that energy efficiency is best measured by energy intensity, that is to say that the best indicator for energy efficiency is the ratio of energy consumption of the system to some measure of demand for energy services by the system (EIA, 2004).

Buys (2002) idealises the HVAC systems as being composed of a sub systems like cooling plant, air handling units, ducting, piping and insulation, air conditioning control and instrumentation, cooling towers, electrical panel and wiring, ventilation fans and pumps. These systems consume energy during their operations; part of the energy does useful work whereas another part is lost as heat and in unnecessary air movement/disturbance. Taking cue from the positions advanced by EIA (2004) and

CIBSE (2004), energy efficiency of HVAC systems can therefore be defined as the ratio of the energy used to do useful work (energy output) to the total energy input of the system. It also a conceived opinion that as long as research goes on the efficiency levels will continually improve as new ways are discovered to reduce the total energy input.

Optimisation of a function is the process of finding its relative maximum or minimum (Dowling, 2001). While affirming Dowling's concept, Papalambros (2002) states that optimisation may either involve mathematical selection process of proper functional form among various alternatives or broadly entail fine tuning aspects of performance of systems. In this research 'optimisation' was used in the context of making better as described by the broad definition given by Papalambros (2002:1). Energy efficiency in the context of this research can be described as overall demand reduction of electricity requirement by HVAC systems via continuous practices and techniques that consume less power while not compromising the standard of task performance. In the optimisation of HVAC system for energy purposes, focus is on surpassing the base level of energy efficiency according to the best established practices and standards.

The study was undertaken with a background of serious electricity power outages and load shedding mainly because of the low electricity production reserve experienced by the main electricity producing body in South Africa (ESKOM). It is reported that South Africa's electricity production reserve was between 8-10% during 2007 and 2008 (Republic of South Africa, 2008). The world's recommended electricity production reserve ranges from 15% to 18% (ESKOM, 2007). This forced the South African government to embark on a multi-pronged approach to remedy the situation by expanding and rehabilitation the existing power stations as well as engaging in campaigns to reduce electricity demand. This is evidenced in the 2005 Energy Efficiency Strategy paper released by South Africa's government which sets out to accomplish electricity demand reduction through energy efficiency by 12% before 2014 (Department of Minerals and Energy, 2005:12).

This study examines how the concept of 'optimisation for energy efficiency' can be used during the design, installation, commissioning, operations and maintenance of HVAC systems in public buildings.

1.2 PROBLEM STATEMENT

The main motivation for this research were the twin needs of increasing access to energy as a resource and reducing carbon dioxide emission levels in South Africa. These needs are closely tied in South Africa since over 79% of South Africa's electricity is derived from coal (Department of Minerals and Energy, 2005) and South Africa has a relatively high Green House Gas (GHG) emissions ranking at 37th position in the world (with 7.8 tons of CO_2 per annum). This is against the background that energy related activities account for over 78% of the GHG emissions in South Africa (United Nations Development Programme, 2007).

While advocating for energy efficiency in buildings and particularly in HVAC systems, one must not lose site of the fact that 30% to 40% of the world's total energy is used in buildings (UNEP, 2007). Any reduction in the amount of energy consumed by building would therefore reflect greatly on the total global energy consumption. It is further noted that a significant amount of energy is used in HVAC systems. In South Africa Mathews *et al* (2002:2) estimated that 50% of energy in the commercial sector in South Africa is utilised for air conditioning. The actual portion of energy used by HVAC systems in buildings is not known. However Buys (2002) notes that the savings potential in HVAC system's energy use generally ranges from 30% to 70%. It is on this premise that this research set out to investigate energy efficiency practices associated with HVAC systems in buildings.

It must be noted that previous studies like Mathews and Kruger (1990) Buys (2000), Mathews and Botha (2003) amongst others did not examine HVAC systems in public buildings and were largely unspecific to this area. Price (2006) promotes this thought by insisting that energy efficient maintenance of HVAC systems is building specific and system focused. As such standardised and minimalist interventions should be discarded for total solutions which address the distinct internal environmental requirements of the building (Price, 2006). This therefore underlines the significance of this study.

1.3 RATIONALE

This study yielded tailor-made recommendations on energy efficiency of HVAC systems in public buildings in South Africa. This is in line with South Africa's energy efficiency strategy that motivates for achievement of electricity demand reduction by 12% from the level in 2004 come the year 2014(Department of Minerals and Energy, 2005). In view of the fact that South Africa's electricity production reserve is less than the conventional norm, it is hoped that the energy efficiency practices promoted as a result of by this study would go some way in freeing up the extra electricity thus contributing to the stability of electricity supply. By extension this would improve the energy security situation in South Africa and allow for increased electricity supply needed for improved living conditions and general economic growth.

In addition the study will contribute to formulation of energy efficiency policies and programmes required for public buildings in South Africa. Earlier studies by Ntsoane (2005) and later Reinink (2007) both underline the importance of concrete policy frameworks and programmes in energy efficiency implementation. Such policies are often based on practical research work, hence the basis of this study.

1.4 OBJECTIVES

The study aimed at identifying the extent and effects of optimisation for energy efficiency on the design, installation, commissioning, operations, control and maintenance of HVAC systems for existing public buildings in Johannesburg. The research set out to make a detailed analysis of available methods, factors and conditions

affecting the management, design, installation, commissioning, control, operations and maintenance of HVAC systems with a view to optimising them for energy efficiency.
The specific objectives of the research were:

i. To establish the current state of energy efficiency practices in HVAC systems in public buildings in Greater Johannesburg.

ii. To analyse for energy efficiency the management, design, operations, controls, maintenance, installation and commissioning of HVAC systems installed in selected existing public buildings in Greater Johannesburg

iii. To identify possible optimisation practices of the HVAC systems for energy efficiency in selected existing public buildings in Greater Johannesburg

iv. To identify the possible effects of optimisation of HVAC systems for energy efficiency in selected existing public buildings in Greater Johannesburg

1.5 RESEARCH QUESTIONS

This research was guided by the following main question:

> 'To what extents are the HVAC systems in selected existing public buildings in Greater Johannesburg currently optimised for energy efficiency and what are the effects of their optimisation?'

To effectively answer the research question the following sub questions were generated:

1. 'What is the current state of HVAC systems in selected existing public buildings in Greater Johannesburg?'

2. ‘To what extent are the practices associated with the management, design, operations, controls, maintenance, installation and commissioning of HVAC systems energy-efficient in selected public buildings in Greater Johannesburg?’

3. ‘What are the possible optimisation practices, techniques and standards applicable for energy efficiency improvement of HVAC systems in selected existing public buildings in Greater Johannesburg?’

1.6 SCOPE AND LIMITATIONS

The research used selected case studies of public facilities in the greater Johannesburg area. This was motivated by the necessity to have uniform data. Uniformity of climate and building types studied ensured that there were no difficulties in data analysis and classification. Public buildings were specifically chosen for the simple reason that they provide the best options for pioneering the implementation of energy efficiency issues in HVAC systems taken that they already exist in a defined administrative and management structure. Case based studies of buildings was particularly encouraged on the basis that buildings are all unique and specific in their construction, design purpose, location and hence comfort requirement. Much general based research has been done but it is important to undertake further case studies to specifically address individual building’s energy management needs.

In this respect, the idea of zeroing in on public buildings and particularly library based ones in Johannesburg is advocated with an understanding that unique results and insight would be gained in the process. Additionally, whereas in the private sector the utility bills are treated as profit reduction factors, the public sector is mainly driven towards service delivery rather than profit. Hence laxities often exist with regards to cost reductions and control.

The study excludes any discussion on contribution of HVAC systems to global climate change through emission or use of CFCs (Chlorofluorocarbons) or HCFCs (Hydrocholoroflorocarbons). This was mainly because in as much as the energy efficiency studies are partly motivated by the need to reduce GHG emissions it was assumed that the greatest agenda problem in South Africa are the energy related emissions[1] as reported by the United Nations Development Programme (2007).

1.7 STRUCTURE OF THE THESIS

This work is arranged into six chapters namely introduction, literature review, methodology, presentation of results, discussion and conclusions and recommendations.

- Chapter One: The Introduction, gives a background to the study and presents the core issues (like objectives, research questions and scope) underpinning the research.
- Chapter Two: The Literature review presents the theoretical framework associated with energy efficiency in buildings, while also delving into recognised norms of practice for HVAC systems in this area.
- Chapter Three: The Methodology, presents selected methods and the methodological framework used in the study while also comparing them with other options available.
- Chapter Four: The Presentation of Findings, gives a summarised outcome of the case studies.
- Chapter Five: The Analysis, explains the implications of results while also exploring meanings associated with issues arising from the study.

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[1] Energy-related GHG emissions are pegged at 78% of the total according to a report by United Nations Development Programme (2007).

- Chapter Six, Conclusions and Recommendations, summarizes the study findings, and gives implications and associated recommendations. This chapter discusses emerging study themes beyond the data analysed.
- The Sections containing references and appendices appear at the end of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents an overview of main concepts applied in the energy optimisation of HVAC systems in buildings. The chapter is divided into seven sections. The first section presents background information on energy efficiency studies, energy and the electricity situation in South Africa and goes on to identify key concerns in the sector. The second and third sections discuss energy use and efficiency issues in buildings, percentage energy consumptions in the life-cycle context are given in addition to approaches for efficiency programs.

The fourth and fifth sections specifically dwell on HVAC systems and optimisation strategies in buildings. The optimisation strategies in HVAC systems for energy use in buildings are thematically reviewed under the banners of design, management, operations, controls, maintenance, installation and commissioning. The sixth section analyses the proposed energy efficiency standards in buildings, while the last section presents a summary of the literature review.

Energy efficiency studies trace their roots back to the 1970's during the oil crisis when member countries of the 'Organisation of Petroleum Exporting Countries' (OPEC) instituted an oil embargo which crippled the world. Up to that time the world worried minimally about energy resource usage. However the resulting scarcity and increase in price of the commodity made several countries critically examine 'energy efficiency' as a way of unlocking additional energy resources for use (Matsugawa et al, 1993). Other factors that motivate energy efficiency studies include the realisation that the world's resources are slowly getting depleted, constantly increasing prices and insatiable demand for existing energy resources, stiff competition for the available energy resources and the threat of global climate change.

This study concentrates on HVAC systems that use electricity as the only source of energy. It therefore makes sense that background information on the electricity supply situation in South Africa be presented. In the year 2005, South Africa's total energy production was 6 Quadrillion BTu against a comparative consumption of 5 Quadrillion Btu.

Table 2.1a Total Primary Energy in S.A. (Quadrillion BTu)

	2005				2006
	S. Africa	Africa	World	Rank	S. Africa
Production (Quadrillion BTu)	6	35	460	11	NA
Consumption (Quadrillion BTu)	5	14	463	12	NA

(Source: Energy Information Administration, 2007)

Table 2.1 b: Total Electricity production in S. A. (billion Kilowatt-hours)

Description	2005				2006
	S. Africa	Africa	World	Rank	S. Africa
Production (Billion Kilowatt-hours)	228	533	17,351	15	NA
Consumption (Billion Kilowatt-hours)	211	474	15,747	15	NA
Net Exports/Imports(-)	40	107	3,872	18	NA

(Source: Energy Information Administration, 2007)

The corresponding electricity production and consumption for that year was 228 Billion Kilowatt-hours and 211 Billion Kilowatt-hours respectively (Energy Information Administration, 2007). Tables' 2.1a and 2.1b give key details on South Africa's energy supply.

The electricity production and consumption data highlight the key issue of overall access to clean energy as it can be clearly noted that the existing reserve is currently very low. In their annual report for the business year 2005, the main electricity producing company in South Africa, ESKOM, openly declared that at 8% the country's electricity production reserve was below the world's recommended level which is 15% (ESKOM, 2007). The result of this has been persistent power supply interruptions at peak demand times in 2008.

To effectively solve this problem, South Africa can resort to three solutions, firstly electricity demand reduction, secondly optimal electricity demand scheduling and lastly increase the quantity of electricity generation. All the three methods can play a significant role in alleviating the persistent energy problem. However, the strategic demand reduction via the practice of energy efficiency seems the most effective and cost-efficient method. This is because it involves the use of the same amount of electricity input to undertake a greater amount of work.

It should be noted that whilst acknowledging that electricity demand reduction is made difficult by the perceived low price of power, lack of knowledge and understanding of the concepts, institutional barriers, resistance to change and lack of overall investors' confidence due to lengthy payback period the South African Energy Efficiency Strategy remains focussed on an overall electricity demand reduction of 12% by the year 2015 as a means of alleviating energy poverty (Department of Minerals and Energy, 2005). The promise of increased access to electricity via demand reduction makes a convincing argument for energy efficiency studies.

Another issue of concern in the South Africa's energy sector is high carbon dioxide intensity. This is mainly due to the fact that coal remains the dominant total energy supply source at 70% of the country's primary energy followed by electricity and natural gas at 28% and 2% respectively; in addition coal fuels 93% of electricity production (Department of Minerals and Energy, 2005). Available data indicate that the South Africa's energy sector remains the highest contributor to carbon dioxide gas emissions to the atmosphere at approximately 70% (United Nations Development Programme, 2007). It is therefore true to assert that any demand reduction as a result of energy efficiency would greatly contribute to a reduction in greenhouse gas emissions especially Carbon Dioxide.

2.2 ENERGY IN BUILDINGS: FROM PRODUCTION TO OPERATION

In a report the United Nations Environmental Programme observed that 30%-40% of all primary energy is used in buildings worldwide (UNEP, 2007). The report further states that residential buildings use more energy compared to non residential ones. In developing countries the former accounts for up to 90% of primary energy use in the sector (UNEP, 2007). Nevertheless it must be realised that in as much as the residential sector accounts for the bulk of energy use in buildings, the study of the non residential buildings is equally important if progress is to be made in energy demand reduction.

In South Africa studies have shown that the building Industry (commercial sector and residential sector) jointly account for 27% of electricity use and 12% of the final energy use (Department of Minerals and Energy *et al.*, 2002). The details are shown in Figure 2.2a and Figure 2.2b.

In an earlier study, Anderssen *et al.* (1995) revealed that South Africa's commercial sector in municipal areas accounts for 20% to 27% of energy whereas the residential buildings use 40% to 47%. This succinctly underlies the fact that the building sector needs to develop means of reducing electricity demand to accommodate expanded access to the utility.

That residential buildings use of more energy compared to commercial buildings is further underlined by studies by Earth Trends (2005); however the actual amounts varies according to geographical location, economic development and cultural orientation. This is illustrated in Figure 2.2 c.

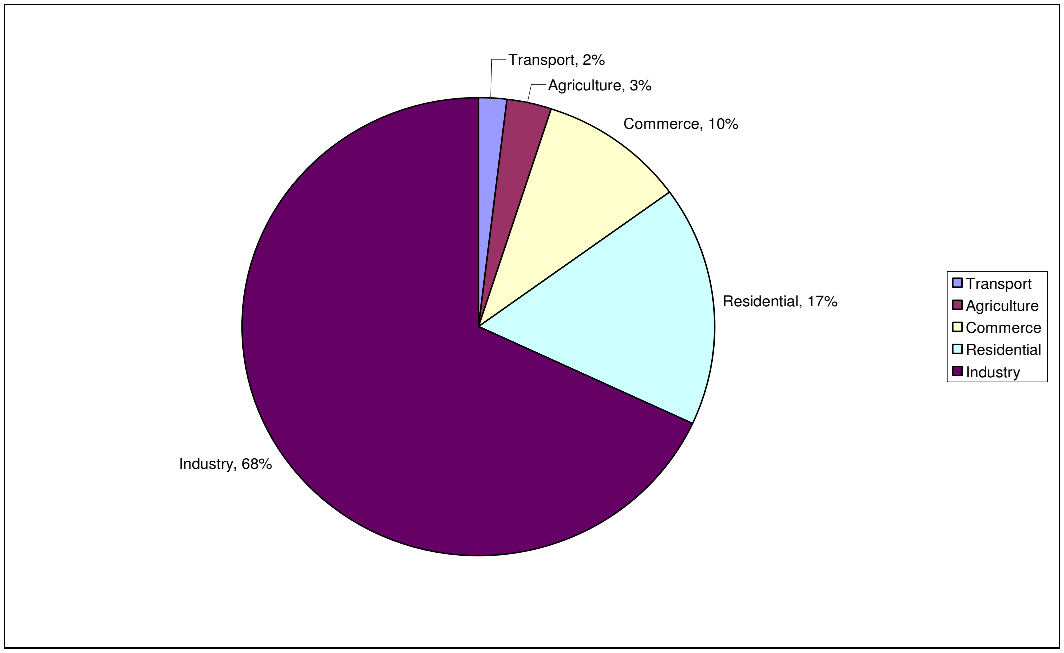

Figure 2.2 a: Electricity Demand by Sector in SA (Source: DME *et al.*, 2002)

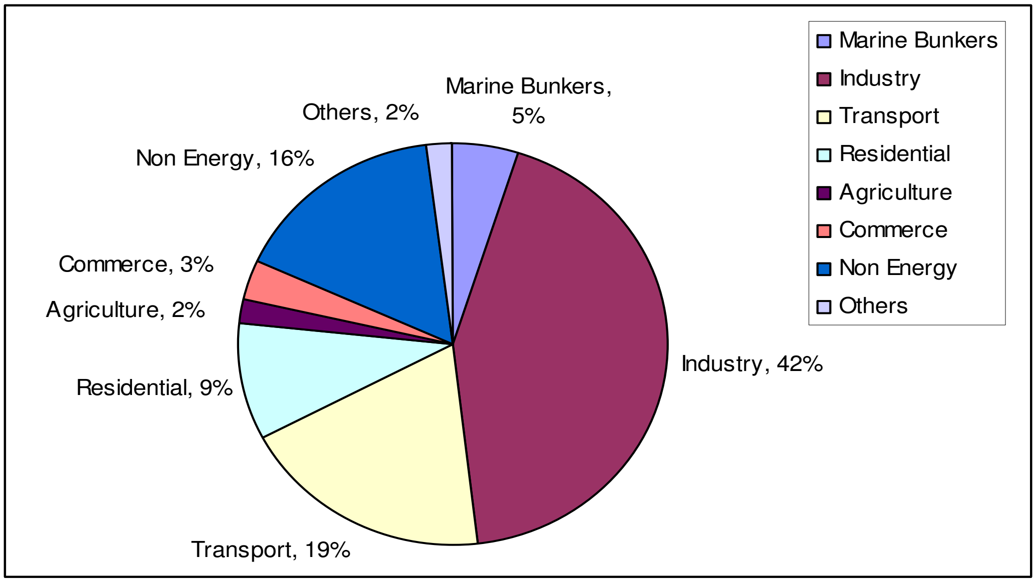

Figure 2.2 b: Final Energy Demand by Sector in SA (Source: *DME et al.*, 2002)

Jones (1998) categorises building energy as embodied, grey, induced, operational or demolition-recycling.

Jones (1998) and later Sartori and Hestnes (2006) amongst others give the following definitions of different categories of energy:

1. *Embodied ener*gy is defined as the energy used in manufacturing of the building materials or in its extraction or mining.
2. *G*rey *energy* is that energy used in the transportation of the building materials between the plant to the site.
3. *Induced energy* is defined as the actual energy used during construction process while operation energy is that used during the occupancy period
4. *Demolition-recycling energy* is defined by Jones (1998) as that energy which is used when demolishing the building or recycling its components. It is thus manifest at the end of the life cycle of the building.

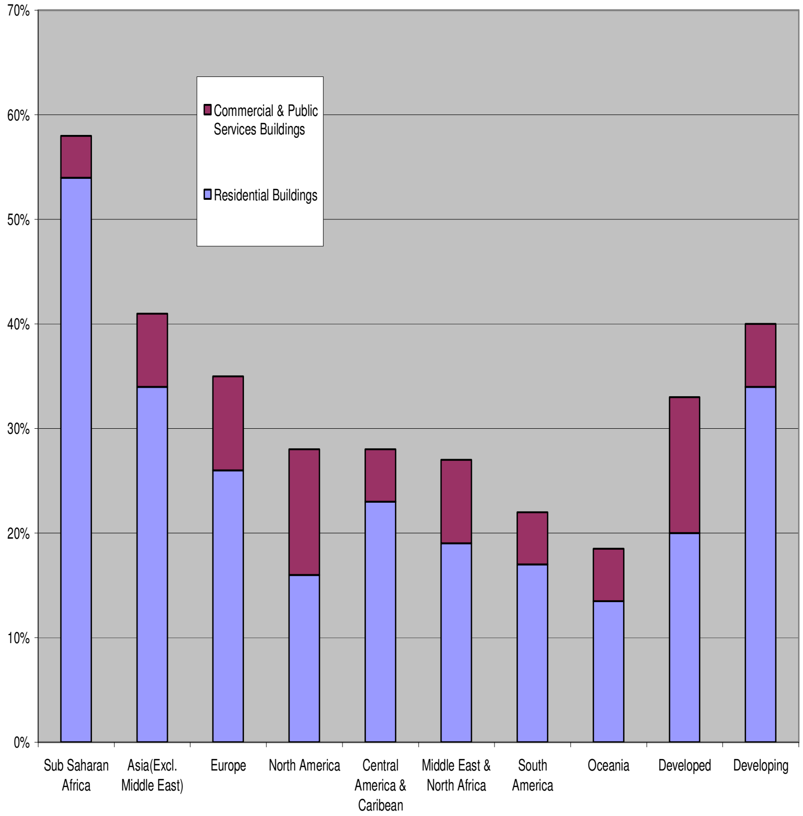

Figure 2.2c: Shares of Energy Use in Different Building Types (Source: Earth Trends, 2005)

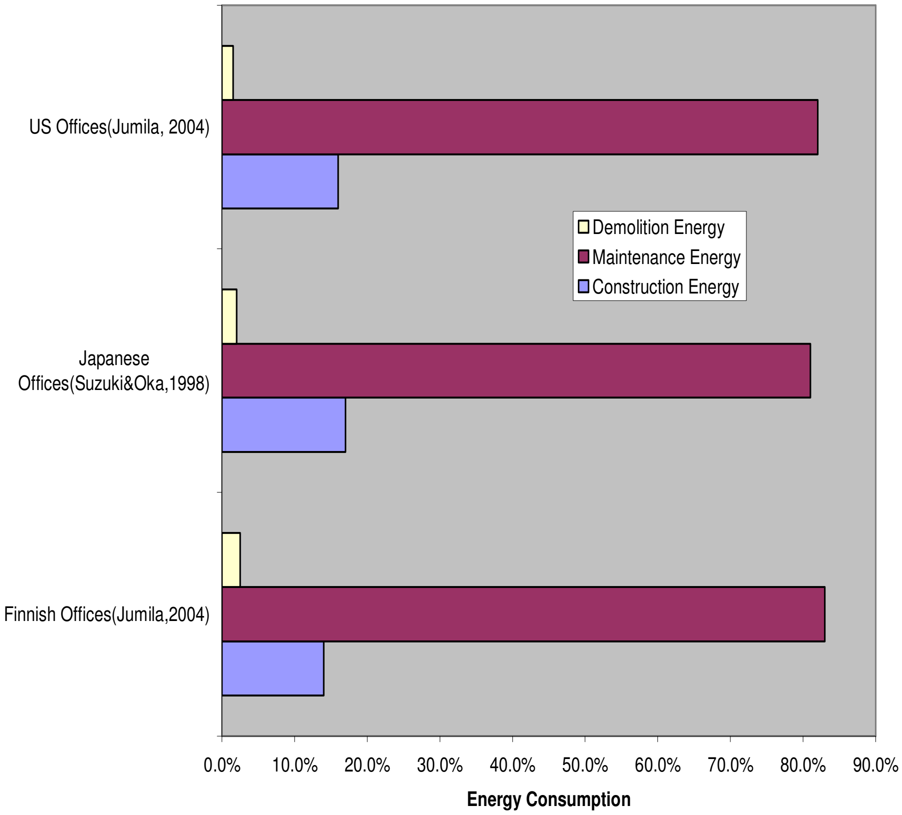

Figure 2.2d: Energy Consumption by Life Cycle Phase for Selected Cases, Source: Jumila (2004)

Figure 2.2d is used to illustrate different energy compositions for commercial buildings for selected case studies. From the cases shown in Figure 2.2d it is evident that the greatest amount of energy in the life cycle of a building is that used during the occupancy period. Energy use in buildings during the occupancy period is thus of major concern if significant demand reduction is to be achieved. It should also be noted that energy use in buildings vary depending on the building type and use to which its put as well as design considerations and climatic conditions.

2.3 ENERGY EFFICIENCY IN BUILDINGS

Energy efficiency in buildings is motivated by the twin issues of economic returns due to savings in energy use and reduction in the emissions of carbon dioxide gas in the atmosphere. Stewart (1990) reports that in the 1980's the US Federal Government embarked on a programme which led to a cumulative cost saving of 317 × 1012 BTu or a cumulative financial saving of $\$1.9 \times 10^9$ in energy use by institutional buildings . In South Africa, the Energy Efficiency Strategy paper asserts that 25% savings is possible in the commercial and public building sector (Department of Minerals and Energy, 2005). In a nutshell enormous opportunities exist for energy savings by enhanced efficiency measures in buildings.

In a more recent study, Liang *et al.*, (2007) recognises that improving energy efficiency in buildings is one of the most cost-effective ways to reduce greenhouse gas emissions particularly CO_2 emission. It is primarily because of this that China has set an agenda to reduce energy consumption for buildings by 50%. This is highly significant taking into account that China's buildings sector accounts for 23% of China's total energy use and that the country is second in the release of greenhouse gas emissions (mainly as carbon dioxide) to the atmosphere (Liang *et al.*, 2007).

An issue of concern in building is whether to focus energy efficiency programmes on new buildings or on already existing buildings. In commenting on this Holness (2008) observes that whereas most of the energy efficiency efforts realistically target new construction or, to a limited extent, portions of existing buildings undergoing major renovation, it is evident that approximately 86% of building construction expenditures relate to renovation of existing buildings, not to new construction. Holness (2008) goes on to state that for most new buildings, performance significantly deteriorates in the first three years of operation by as much as 30%. This implies that to effectively reach meaningful energy demand reduction in buildings it is important to have a consistent energy efficiency programme for existing buildings.

Energy portfolio management through programmes like ‘Energy Star’ run by the U.S. Environmental Protection Agency (EPA) and the American Institute of Architects (AIA) Sustainability 2030 programme among others should be encouraged to increase energy efficiency in buildings. At the same time Holness (2008) advises that initiatives for energy efficiency should not only focus on the selection and energy management techniques for systems and equipment but must in addition lay emphasis on operation and maintenance. While supporting the principle of ‘first time right’ Holness (2008) goes on to advise that the design must be energy efficient from the onset (Holness, 2008).

Another key intervention worth mentioning is the idea of building labelling for example the green building concept. Green buildings concepts include ‘Leadership in Energy and Environmental Design’ (LEED), the Canadian Energy labelling initiative (EnerGuide), Green Star (different countries like Australia, South Africa and the US), ‘Comprehensive Assessment System for Building Environmental Efficiency’ (CASBEE), and BRE Environmental Assessment Method (BREAM) among others. Kats (2003) reports that on average, green buildings use 30% less energy than conventional buildings. This reduction is primarily from reduced electricity purchases and secondarily from reduced peak energy demand.

2.4 HVAC SYSTEMS

Heating, Ventilation, and Air-Conditioning (HVAC) system in buildings are used for improving indoor air quality and provision of adequate thermal comfort (US EPA, 2008). It is reported that in the world 65% of the electrical energy in the commercial sector is used by HVAC systems (Buys, 2002). This percentage is specifically 50% in the US and also in South Africa (US EIA, 1994; Mathews *et al.*, 2002). This indicates that any meaningful electricity demand management in the commercial and public building sector must lay emphasis on the efficiency of the HVAC system.

The improvement of the performance of HVAC system relies heavily on a clear understanding of its processes and sub-systems. Krarti (2000) identifies components in

HVAC system as the air handling unit which is composed of dampers to control the amount of air distributed by the system and the preheat coil to warm the outside air to avoid freezing problems, other components are the filter, which ensures that the supplied air is not polluted by dirt, cooling coils to condition the air supply to meet the cooling load, humidifiers to add moisture to the air supply where humidity control is provided and a distribution system composed of ducts and duct systems (Krarti,2000).

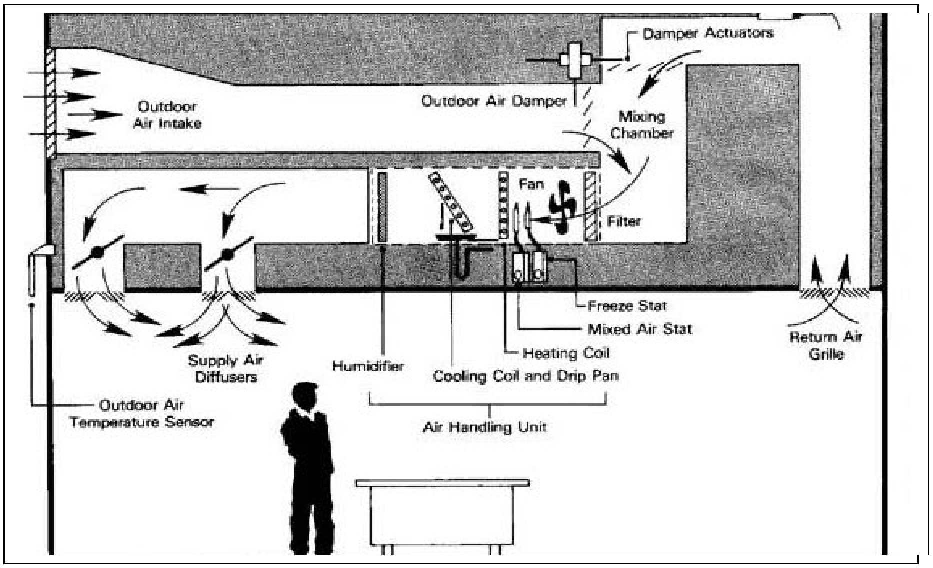

Figure 2.4: Main components in HVAC systems (Source: EPA, undated)

The consumption of energy by HVAC systems is mainly determined by a combination of various types of arrangements in the air handling units. Krarti (2000) describes these arrangements as either constant air volume (CAV) systems or variable air volume (VAV) systems, VAV systems are flouted as generally more energy efficient than CAV systems; key energy interventions in HVAC systems are (Krarti, 2000):

i. Operation of HVAC systems only during occupancy and when needed
ii. Elimination of overcooling and overheating of conditioned spaces
iii. Reduction of reheat

iv. Use of economiser cycles to provide free cooling and heating whenever possible or heat recovery systems to eliminate mechanical air conditioning
v. Reduction of supply air

The key to effective energy efficiency therefore relies on optimisation of HVAC systems based on the above guidelines.

2.5 OPTIMISATION OF HVAC SYSTEMS FOR ENERGY

This research is on core energy efficiency issues in the use of Heating, Ventilation and Air Conditioning (HVAC) Systems in buildings. This is of paramount importance because over 30% of the world's energy is used in building and construction industry (International Energy Agency, 2005). Furthermore, it is reported that of the energy used by the commercial sector in South Africa, approximately 50% is accounted for by HVAC systems (Mathews *et al.,* 2002.

This would mean that a minor energy savings in HVAC system would have a marked impact on electricity demand in South Africa. At the moment great energy savings potentials exist in HVAC systems in buildings, Buys (2002) approximates the potential as ranging from 30% to 70%. From the foregoing, this would therefore imply that minimal energy savings of 30% in HVAC systems would imply an overall energy savings of approximately 15% in the commercial sector. The sections below review energy efficiency options for HVAC systems in buildings.

2.5.1 Management

This section reviews energy efficiency issues in HVAC systems relating to ownership, the use to which the building is put, accountability of staff, budgeting and conservation.

Ownership of buildings

Wilkinson and Reed (2006) observe that tenants have the capacity to implement energy efficiency retrofits. The tenants must therefore not be ignored while planning for energy efficiency in HVAC systems. Another issue worth taking into account is the barrier created by ownership and management structures in buildings and how they affect energy efficiency in HVAC systems. The World Energy Council (2008) contend that outsourcing energy efficient management for HVAC systems in public systems may be frustrated by over-cautiousness related to perceived job losses and loss of controls, protracted public procurement rules apart from the associated cumbersome and tedious administrative work (World Energy Council, 2008, Sardianou, 2008).

Use of Building

HVAC systems are often purpose-built to suit building operations. As an example a personal office or multiple working space office with various zones may have customised thermostat setting and would a use dual-speed system thermostat or a programmable thermostat to allow for multiple zone settings whereas an entertainment theatre or hall would successfully use a single thermal setting as the HVAC system is a single zone type (Air Force Heat and Air, 2008). Where the public or a large number of people are allowed into the building Wulfinghoff (1999) recommends that a clearly visible placard explaining the details of operations and contact numbers of the staff to report malfunctioning of the HVAC systems to must be displayed therein. This limits the number of down times while also eliminating the energy wastage or vandalism that is associated with inappropriate operations.

Accountability for energy management

To have clear chain of command and to delineate proper responsibility for energy efficiency, Bream (1986) clearly articulates the importance of an energy manager to be accountable for energy management programs. Bream (1986) further identifies ways of appointing the energy manager as including appointing a member of the organisation then training him for the task, appointing of a suitably skilled person for the task, use of an outsourced consultant or purchase of a commercial energy technology or lastly the use of a specialist energy company. Whichever method chosen for having somebody responsible for energy management, the key issue would be to formulate and implement an energy management programme.

Energy Consumption Budget

According to Bream (1986), finance is the means by which we quantity energy saving measures and also the means by which the success of energy saving programs are judged. This implies that to formulate a focussed energy management programme a firm budget for energy consumption must be put in place. The actual consumption will then be benchmarked against the budget.

Energy use in HVAC systems must not be an exception; indeed Olofsson *et al.* (2004) assert that a negotiated, statistical based or life cycle based energy consumption budget forms a key role in assessment of energy efficiency performance in buildings.

Energy conservation

A typical energy conservation activity would involve capital investment, improvement in operation of the plant equipment, improvement in general housekeeping and an effective management of information (Talbot, 1986). It should be taken into account that energy conservation programmes may be a low capital or high capital venture. Low capital investment energy conservation measures entail readjusting operating conditions like space air temperature, air supply velocity, chilled water temperatures, and the resetting of operation conditions to match seasonal changes, and peak or off peak situations and a reduction of operation time (Fong *et al.*, 2003).

2.5.2 Design

Even though several design issues exist, this study focussed mainly on the issues of competing design philosophies, power density and equipment selection. These issues follow in sections below.

Competing Design Philosophies

The philosophy of design greatly affects the energy use in engineering and the built environment. Currently there are two competing philosophies of design in HVAC systems: these are the conventional/mixing method and the Thermal Displacement Ventilation Method (TDV).

The TDV technique of HVAC systems is based on the buoyancy theory and operates on the principle that that warm and more polluted air has a low density and will tend to rise in the indoor environment (Lunneburg, 2003; Massachusetts Institute of Technology, 1999).

In TDV systems, conditioned air is supplied at low velocity near the floor and polluted air is extracted near the ceiling (Lunneburg, 2003; Massachusetts Institute of Technology, 1999). On the other hand, conventional HVAC systems use the mixing technique whereby air is supplied to the ceiling at relatively high velocity at about -7^{O} C below the desired room temperature. The supplied air then mixes with the room air to provide a nearly uniform temperature which recirculates thereafter (Massachusetts Institute of Technology, 1999). Figure 2.5 illustrates this.

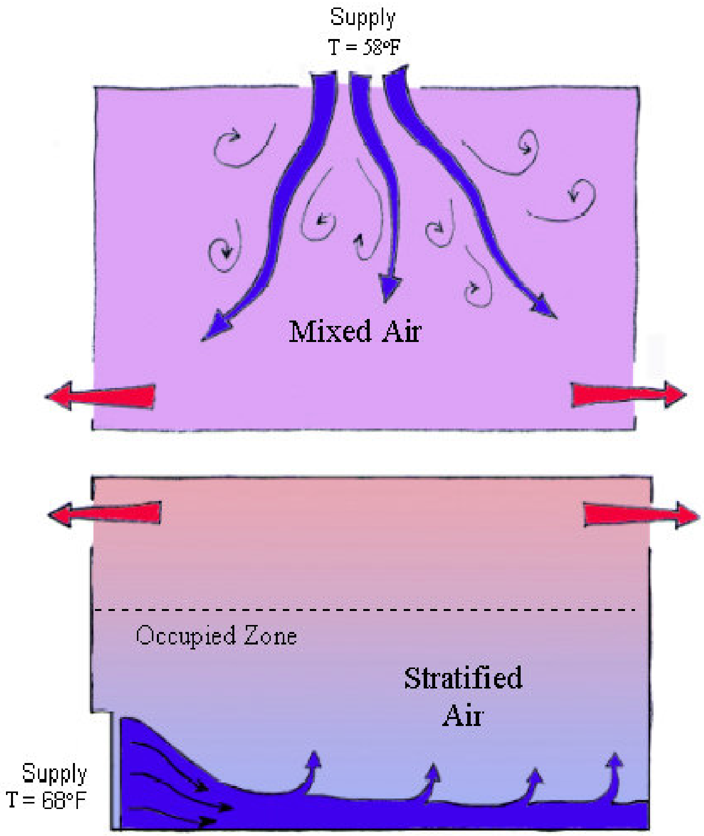

Figure 2.5: Illustrations of competing philosophies of design (conventional mixed method is on top and TDV method on the bottom); source: Roth et al, 2002

In the design of a data centre at Massachusetts Institute of Technology it was found that a TDV system offered a reduction in energy consumption by 22% as compared to the conventional method. This was attributed to the supply of air being approximately 3^{O} C warmer than the conventional system. It is also apparent that the TDV based system has a better opportunity to take advantage of the air-side economiser cycle, naturally cooling the building using outdoor air instead of mechanically cooled air (Massachusetts Institute of Technology, 1999).

However it is apparent that TDV HVAC systems are not a common market occurrence. This is because of the method remains largely unrefined and is not integrated with design practices and standards. Lunneburg (2003) concurs with this by arguing that most building simulation programs are based on conventional design and use heat balance methods for load calculation. This neglects the principle behind TDV that air will stratify according to temperature differences and will not mix. Accordingly this ensures that simulations do not take into account the reduced air supply and cooling load when TDV is employed, leading to oversized HVAC systems (Lunneburg, 2003).

Power Density

The success of HVAC system design is highly dependent on the accurate prediction of design load. A design load prediction exercise may be cumbersome when done manually. As a result, several simulation programs have been developed to simplify and quicken the load prediction process. The hallmark of a good simulation program is its ability to run easily on a personal computer and to accurately predict the load situations while being reasonably affordable (Walsh *et al.*, 2003).

Huang *et al.*, (2006) further insists that the program must be capable of dynamic use for energy management control. This is exemplified in the use of real-time control set points to regulate energy management functions such as outside air economiser, programmed start and stop lead time, load reset and occupied time adaptive strategy which led to energy savings of 14% to 17%. In South Africa the use of the QUICKcontrol programme developed by TEMM International(Pty) Ltd been touted as one of the most relevant in the local building industry (Buys, 2002).

However Kavanaugh *et al.*, (2006) observes that in most cases the simulation process is very complicated, time consuming and inaccessible. Their study suggests the use of a power density approach as an alternative in HVAC sizing and appraisal (Kavanaugh *et al.*, 2006). The power density approach involves calculating the heating load or cooling loads of a system as required by the American Society of Heating Refrigeration and Air Condition Engineers (ASHRAE) Standard 90.1-2004, after which respective specific design loads for energy-efficient buildings are divided by the system energy-efficiency ratio (BTu/Wh or COP) for cooling and the thermal efficiency (η_t) for heating to arrive at the respective power densities.

Types of HVAC equipment

Energy efficiency measures must be purpose-made to suit the specific HVAC equipment operated. Categories of equipments reviewed here include room conditioning units, radiators, under-floor heaters, centralised HVAC systems combining heating and cooling operation, propeller fans and roof-top units.

Room conditioning units

Room conditioning units offer personalised control systems and are therefore a natural choice for spaces like offices and reading rooms (Wulfinghoff, 1999). As such, these systems could prove ideal for energy efficiency strategies based on minimisation of hours of operations and spaces conditioned.

Radiators

Energy efficiency strategies in radiators must centre on hitch free operations of thermostats and heat fins. It is for this reason that Wulfinghoff (1999) advises on overhauls of the thermostatic controls and heat trapping against the exterior walls or curtains be avoided.

Under-floor Heaters

Lin *et al.*, (2005) compares the efficiency of under-floor heating systems with space heating system showing that it saves living and working space since it is integrated into the building envelope. Unlike space heating it is not dependant on the mean effective temperature which is a function of the ambient air and the radiant surface temperatures and therefore achieves comfortable conditions with a cooler air temperature by a large floor-heating surface. In addition it minimises indoor air pollution by the simple fact that it eliminates forced air movement.

Centralised HVAC systems

The main issues arising from centralised HVAC systems are avoidance of constant speed motors, use of variable volume systems, adoption of adjustable speed drives and adoption of suitable power transmission systems. The use of variable air volume (VAV) systems in HVAC units is preferred over constant volume systems for the simple reason that they minimise the reheat energy waste and in the process lead to increased energy savings (Wendes, 1994; Krarti, 2000). A study by Xu (2005) observed that a reduction in the air change rate by 10% could result in a power reduction of approximately 27%. This implies that adoption of variable speed motors would offer a window of opportunity towards great energy savings in these HVAC systems.

Wendes (1994) asserts that Adjustable speed drives could lead to up to 50% energy savings. Wendes (1994) goes on to apportion energy savings as derived from fan operations in variable air volume systems as 25% to 75%, depending on operational capacity and weather data during operations and for cooling and heating equipments in VAV systems as 5% to 30%, depending on prevailing weather conditions (Wendes, 1994).

The use of different volume control methods further influences the amount of energy savings achievable in VAV systems. Table 2.5a on the next page illustrates this in detail.

Table 2.5 a: Limits of Energy Savings due to use of various fan volume control methods in VAV systems at an average of 60% peak air flow (Source: Wendes, 1994)

Item	Description	Maximum % Energy Savings
1	Backward inclined fans with discharge dampers	13%
2	Airfoil or BI fans with Inlet vanes	36%
3	Forward curve fans with discharge dampers located 3 fan diameters from the fan	48%
4	Adjustable speed drive	50%
5	Forward curve fans with inlet vanes	57%
6	Adjustable frequency AC motor control	78%

In air handlers the use of fans is a central element in the operation and hence fan energy use provides the key to energy efficiency in these systems. In addition, modes of power transmission systems greatly determine the energy efficiency of HVAC systems. With good maintenance 5% to 10% energy savings could be achieved if synchronous belts with soft-start motor systems were retrofitted as observed by Oman (2006).

Rooftop units

Rooftop units are often preferred over other types of HVAC equipment for their relatively low costs, ease in installation, economy of floor space. They eliminate the plant room requirement and are applicable for several tenants to own and operate without involving the landlord in purchasing and paying for the system. It is however asserted that these systems have a relatively lower Coefficient of Operation (ASHRAE Press, 2007). As a result their use must be only recommended where space requirement is an issue, or where the installation of HVAC system was an afterthought and skilled labour for the required maintenance and installation is lacking.

Variable Speed Drives

The use of variable speed control for fans, pumps, chillers and HVAC systems is advocated for by many an energy saving criteria. Equation 2.5a gives a theoretical relationship between fan power and air supply (Energy Innovators Initiative, 2002):

$$W2=W1\times (Q2/Q1)^3 \qquad (2.5a)$$

(Where: W1=Power at 100% airflow (Q1). When the flow is reduced to 80 percent, the new Power (W2) will be $W1 \times (0.8)^3 = 0.51$ or 51 percent).

In Variable Frequency Drives, the motor and fan speed are reduced and the losses are ideally much smaller. The adoption of variable inlet vanes technology further enhances the probable energy savings due to its ability to maintain advantageous pressure levels while operating.

In a case study in Vancouver, Canada a building had its HVAC system retrofitted. The initial system was composed of 75 HP supply fan motor and 40 HP return fan motor which provided air for variable and constant volume mixing and heating boxes (Energy Innovators Initiative, 2002). The retrofit replaced the old motors with 50 HP supply and 25 HP return motors. The return motors were fitted with variable inlet vanes to maintain the pressure in the system. Based on a 24-hour duty cycle of operation, the new system realised an annual saving of approximately $6,294 per year (using 1997 rates) with a simple payback period of three years (Energy Innovators Initiative, 2002).

Xu (2005) urge the adoption of variable speeds methods for improving energy efficiency in HVAC systems by asserting that fan power is proportional to the cube of airflow rate or airflow speed and thus a reduction in the air change rate by 10% may result in a power reduction of approximately 27% (Xu, 2005). Accordingly, Xu (2005) explains that the energy efficiency of fan filter unit systems depends on the size and layout of the overall recirculation systems, the efficiency of individual fans and fan-filter units, the filter media, the controllability of the airflows, and pressures in the air systems. Thus the maximisation of energy efficiency for the fan filter units depends on the use of units with a higher efficiency and an optimisation of the operation and control units. It is therefore understandable that Variable Speed drives (VSDs) are used in fan filter units to improve energy efficiency by operating at higher airflow speeds. This according to Xu (2005), allows for flexibility during operation (Xu, 2005).

V-Belts versus Synchronous Belts

The choice of belt drives for air handlers also hase an effect on energy efficiency in HVAC system. Oman (2006) observes that whereas most air handlers in HVAC systems use V-belt drives for power transmission, the use of synchronous belts offers several advantages over V-belts, these are (Oman, 2006):

i. **Energy efficiency:** When well maintained, the operational efficiency of V-belts is 95% to 98%. During operations this reduces by approximately 5% to 10% depending on maintenance level. In comparison, synchronous belts retain an energy efficiency of approximately 98 percent throughout the life cycle. This is because V-belts have thicker cross-sections than synchronous belts, and require more energy to bend around sheaves due to friction caused by the wedging action, whereas synchronous belts rely on toothed grip.

ii. **Maintenance and tuning:** The optimum belt tension is maintained at all times for synchronous belts whereas V-belts require regular tensioning to maintain this.

However Oman (2006) recommends that synchronous belts should only be used in air handlers that have a soft start and those driven by an AC inverter because of the high start up loads and structurally rigid centres which may lead to failure of the belts and their replacement costs.

2.5.3 Operations

A schedule of operations and occupancy is highly important for energy efficiency in HVAC systems. The turning off of HVAC systems when not in use eliminates or reduces the use of energy through unnecessary conditioning, reheat losses and fan/pump operations. It therefore follows that HVAC systems should only be operated when necessary. In this regard it is advisable that for buildings with a regular schedule of operations, timers should be used to stop and start components (Wulfinghoff, 1999). Wulfinghoff (1999) further advises on the use of placards at controls, and the assignment of the task or responsibility for switching a unit on and off to space administrators or security personnel, and the use of automatic controls in personalised spaces.

This brings to the fore the issue of ensuring that HVAC systems are not operational when they are not needed and also that the operational capacity of the HVAC system is matched to the level of occupancy or the number of occupants in the room. In this regard it would seem prudent to use personal sensors to activate switches on entry into rooms, use controls connected with the lighting systems to ensure operations only when lights are on and use of timed turn-off switches to limit the conditioning to selected periods of time or a combination of these (Wulfinghoff, 1999).

2.5.4 Controls

Wulfinghoff (1999) argues that automatic controls are often better than manual controls and stresses that whenever the former are installed care should be taken to inform occupants of the working modalities of the systems. In addition flexibility should be allowed for where occupancy patterns fluctuate. It should however be noted that the idea of energy efficient control system is now more advanced as evidenced by the use of fuzzy-control logic systems. Fuzzy control logic systems create instructions which are converted by algorithms into a series of control functions. A study conducted in the

USA concluded that fuzzy control systems can lead to realisation of an average 5% energy saving in HVAC systems (Roth *et al.*, 2002).

These control systems achieve energy savings through several approaches including: firstly, by providing the stability of a control system, secondly by offering a fine turned operation of controllers, thirdly by real-time optimisation of operating parameters, fourthly by operationalising the strategies which would otherwise not be possible with classic control systems and lastly by enabling the system to optimise delivery of heating and cooling based on occupancy patterns (Roth *et al.*, 2002).

2.5.5 Maintenance

Maintenance is the process of ensuring that physical assets continue to fulfil their intended functions in a cost effective and sustainable manner (Lam, 2007). As such it is a process which is highly controlled by considerations of total life costs, simplicity or complexity of designs, technology used in construction, flexibility in operations and reliability of the building service equipment.

The sustainable maintenance of HVAC systems should therefore not only be focused on the traditional goal of trouble-free operation but must also embrace the need for energy efficiency in operations. A study done in 1999 in California State of the United States of America reported that major problems of HVAC installation and maintenance are over-sizing, inadequate airflow and improper refrigerant charge, and the frequencies of unwanted occurrences (CEE, 2000).

Figure 2.5a illustrates the major findings espoused by this study. Sometimes serious maintenance and energy costs results from an incomplete or poor installation procedure. This normally leads to improper equipment, improper air supply and the use of improper refrigerants.

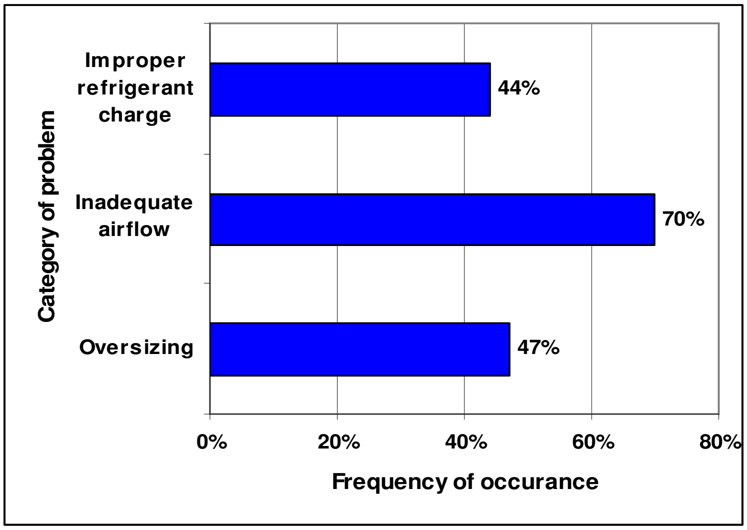

Figure 2.5a: Frequencies of major problem occurrences in HVAC systems (Source: Neme *et al.*, 1999; as reported by CEE, 2000).

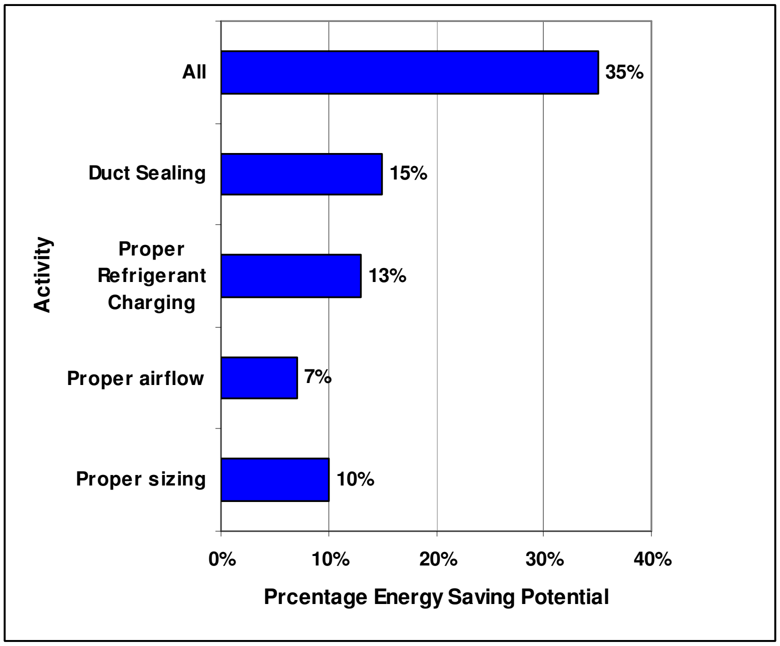

Figure 2.5b: Energy saving potential in HVAC residential units (Source: Neme *et al.*, 1999; as reported by CEE, 2000)

The CEE (2000) goes on to report that in most HVAC systems in the United States of America great energy savings can be made with proper sizing, proper airflow and proper refrigerant charging and that the total potential energy savings is approximately 35%. This is illustrated in Figure 2.5b.

Price (2006) gives several attributes of energy efficient maintenance of HVAC systems. These include the ability to be building-specific and system-focused, as such standardised and minimal interventions can be discarded for total solutions which address distinct internal environmental requirements of the building. Secondly the involvement of management is important in the monitoring and reporting process to ensure effective tracking of individual components' and system's performances via established records and trends while making sure that early signs of reduced efficiencies are noted and dealt with effectively. Thirdly, continuous tuning should be incorporated with maintenance and operation processes to ensure optimisation at all times and lastly replacement and upgrade policies should be implemented to give the systems the benefit of improved technology (Price, 2006). The main theme dominating the idea of energy efficient maintenance is specificity to systems, measurement and feedback processes in maintenance with monitoring and dynamic response to malfunctioning of systems. These specific issues are discussed below.

Monitoring and Measurement

A crucial task in energy saving, or conservation or efficiency practices for Facility Managers and Engineers is normally the measurement of the amount of energy consumed by building equipment. It is only after measurement of the actual consumption that a benchmark and a reasonable budget can be established to allow for a focussed energy efficiency programme. Van Gorp (2004) reports that modern measurements systems now play key roles including the use of Enterprise Energy Management (EEM) systems to first provide accurate energy metering and sub metering which is highly crucial in ensuring reliability. Secondly the EEM system can be used to conduct energy audits in the systems and lastly the measured data can be used for load profiling which is a necessity in scheduling and planning (Van Gorp, 2004).

Maintenance Planning

The key objective of energy efficient maintenance is sustainable continuous, trouble-free, cost-effective and functional operation of physical assets (Price, 2006; Lam, 2007). Trouble-free operations are however quite challenging where there is only little or inadequate funds earmarked for maintenances. This would imply eventual collapse of systems or a marked reduction in its functional efficiency. It is on this basis that Maisely and Beverly (2007) assert that all HVAC systems must have an Energy Master Plan that has clearly articulated goals aimed at minimal energy use, optimum occupancy, optimum comfort and optimum maintenance over its life cycle.

As such Tsang (1999) writes of reactive maintenance and describes it as following in the traditional perception of maintenance's role as fixing broken items. This must be avoided as it leads to generally efficiency. However Tsang (1999) and later Reeves (2008) note that many property managers go for reduced maintenance expenditure because the effects are long-term and may not be noticeable during their management term. This is because the primary reason for non-allocation of maintenance funds is the need to operate on a minimum budget.

Horner *et al.* (1997) and De Groote (1995) all advocate maintenance performance audits as ways of ensuring functional improvements. This is only possible in a planned maintenance system which is currently shunned by the Facility Managers in the buildings. Reactive maintenance leads to energy inefficient operations. An example to point out is the fact that the most common power transmission drive in centralised air systems is v-belt and pulley connection. According to Oman (2006) this means that regular belt adjustment and maintenance is mandatory as during operations their efficiency of transmission reduces by approximately 5% to 10% depending on the maintenance level.

As facilities managers become more informed of energy efficient maintenance it will be necessary to go a notch higher by instead practicing Risk Based Engineering (RBE). This according to Khan and Haddara (2003) would entail using a plan that ensures early correction of anticipated problems and conservation, recovery and use of refrigerants. For HVAC systems, RBE would entail a risk estimation which involves functional analysis of the components and probable failure scenarios. A consequent analysis of the failure would entail calculation on energy efficiency or cost, based the consequences of a failure and a probabilistic failure analysis which is often carried out by custom designed software (Khan and Haddara, 2003). The results of these are then used to plan for maintenance such that limited resources are allocated to where it is most needed and to ensure optimal operation.

Age of systems

The age of HVAC systems become crucial due to the elaborate maintenance requirement needed. Indeed, Adnot *et al.* (2006) clearly state that age is not a problem *per se* where performance and maintenance is good but note that performance of aged equipment cannot be guaranteed because most professionals are unfamiliar with old technology.

On the other hand Maisely and Beverly (2007) clearly capture the emerging theme in maintenance which ties it to the life cycle context and assert that optimisation of maintenance must ensure that the maintenance requirement is reduced by the elimination of aged components amongst other things.

According to Reeves (2008), key issues considered while assessing the maintenance specifications in existing buildings are the fact that their elements were not designed to be used for longer hours, increased occupant density and possible redundancy in technology. This complicates matters further taken that age reduces performance and is related to obsolescence (Canadian Housing and Housing Corporation, Undated). In the last 10 years new and more efficient technologies have been introduced which are more energy efficient than old technologies. An example of this is highlighted by the synchronous belt drives versus V-belt drives or Variable Speed Motors versus constant speed motors and TDV systems versus convectional mixing methods.

2.5.6 Installation and Commissioning

The ASHRAE guideline 0-2005 defines the *commissioning process* as a quality-focussed process involving verification and documentation of facilities and systems to check for compliance with the owner's project requirements with regards to installation, planning, testing, operations and maintenance (American Society of Heating, Refrigeration and Air Conditioning Engineers, 2005). Subsequently, *continuous commissioning* is defined by this document as the continuation of the commissioning process during occupancy and operation of the building, while *re-commissioning* is the application of the commissioning process requirements to a project that has been delivered using the commissioning process. While stressing the importance of commissioning process, CIBSE (1998) acknowledges that it is crucial if functionality of equipment according to design purpose and feedback during the initial phase is to be ensured.

Retro-commissioning is defined by ASHARE as the application of the commissioning process to an existing facility that was not previously commissioned (ASHRAE guideline 0-2005). It is recommended that buildings having HVAC systems classified as not properly commissioned should be re-commissioned or retro-commission. This would enable the buildings to enjoy improved indoor environmental quality and comfort, improved controls and zoning, reduced operations and maintenance costs and lastly improved energy savings as a result of optimisation associated with the exercise (Piette and Nordman, 1996; Portland energy Conservation, 2007).

2.5.7 Ducts and Ductwork

Duct and ductwork form an integral part of the HVAC energy efficiency agenda and their design and maintenance is of great importance. Whether via the optimisation method or a conventional method, the duct design methods entail the calculation of the cross sectional dimensions of the duct sections and working out the duct layout system, duct shapes, duct materials and duct construction methods including equipment and fittings for this purpose (Classen, 2003).

In a study at Leokoloa mine, Classen (2003) deduced that the use of optimisation techniques over conventional ones in duct design could realise savings in the range of 5% to 20% in life cycle cost. Studies have however failed to categorically ground optimisation techniques of design with the right design theory due to problems in ductwork pressure balancing the complexity of the combined supply and return flow analysis**.** This particular research (Optimisation of HVAC systems for energy efficiency in public buildings) did not touch on duct design but instead examined it in relation to maintenance.

2.5.8 Energy Efficiency and Life-Cycle Cost Analysis

Like any other project, the economic benefits of HVAC systems must be effectively examined before commencement of works. In this respect Gruman (1991) asserts that selling energy conservation to the owner of a building requires a good sense of economic logical argument.

Buys (2002) observes that decisions having the biggest impact on the cost of HVAC system are taken during the preliminary phase and hence economic analysis must be taken at this stage (Buys, 2002). Life-Cycle Cost (LCC) analysis is becoming increasingly popular among professionals in the built environment as the preferred tool for economic evaluation. Through LCC analysis, all factors that influence the total system cost in the lifetime are identified and quantified. Subjective factors such as fuel cost adjustments, component reliability, and maintenance costs are also included. LCC analysis can be used to assess the economic consequences of any decision by comparing two or more alternatives (Lacey, 1993; Matson, 1990).

For HVAC systems, the key issues for LCC are annual cost comparison based on analysis of energy costs, capital costs and maintenance costs. According to Schicht (1991) the contributions to total cost can be broken down as energy costs, contributing 65 to 75 percent; capital costs, that is, interest plus depreciation, contributing 15 to 25 percent and maintenance costs, contributing 10 percent (Schicht, 1991).

2.6 ENERGY EFFICIENT STANDARDS FOR BUILDINGS IN SOUTH AFRICA

Two categories of standards feature prominently with regards to HVAC systems. These are the standards that provide guidelines on the design load prediction and those that deal with energy efficiency issues. The International standards for HVAC systems are mainly guided by ASHRAE standard 62.1-2 and ASHRAE standard 90.1-2 and, the EN15243 and EN13779 (ANSI/ASHRAE, 2001: EN Standard, 2007a and EN Standard, 2007b).

In South Africa, the preparation of national standards to regulate energy efficiency practice in buildings was expected to end in 2007 (Reynolds, 2007). This did not materialise. However a draft standard for energy efficiency in buildings was published for public comments in mid 2008. This was the Energy Efficiency in Buildings Part 1, 2 and 3 Edition 1-SANS204-1, 2, 3:2008 which are available in draft copies (Standards South Africa, 2008a; Standards South Africa, 2008b and Standards South Africa, 2008c). Part 1 explains the general requirements of the standards. Part 2 discusses Energy Efficiency in naturally ventilated buildings. Part 3 is applicable to Energy Efficiency for artificially ventilated buildings. Sections below separately review the key issues tackled by parts 1 and 2 of the first edition energy efficiency standard in buildings.

The main criticism that has been labelled about the first edition of the energy efficiency standard in building is the fact that it does not make any provision for existing buildings but focuses on new buildings instead. This is despite the fact that available literature suggests that existing building stock contributes 85% of the expenditure in the building and construction industry (Holness, 2008)

2.6.1 Energy Efficiency in Buildings Part 1: General Requirements (SANS 204-1:2008 Edition 1, Standards South Africa, 2008)

SANS 204-1:2008 edition 1 specifies the general requirements for design and operation of energy efficient buildings with artificial environmental control and subsystems. It outlines the maximum energy demand and maximum annual consumption in accordance with several classifications of occupancies of buildings and prevailing climatic conditions. There are 31 main building classifications and each is assigned a specific design occupancy period that outlines hours per day of occupancy and days per week of occupancy that is to be used for the design of the HVAC system.

The standard states that the building envelope needs to be designed to use thermal loads (that is the need to have acceptable thermal elements in the building's fabric for reasonable heat gains and heat loss) for effective HVAC systems energy consumption and stresses the use of life-cycle costing and occupancy schedules as key parameters that should be taken into account during design and specification.

The need to have only energy-rated appliances fitted in new buildings is also emphasised in addition to ensure compliance with the requirements of SANS 10400-O and the design of systems to limit heat loss and heat gains from pipes, and ducts in the HVAC systems.

With regards to operation and maintenance, the standard aims for purpose-driven planned maintenance based on the operation of the mechanical/electrical components, and economic energy efficiency. It also emphasises the need to use standardised parts and upgrading of plants to increase the efficiencies of the components.

2.6.2 Energy Efficiency in Buildings Part 3: General Requirements (SANS 204-3:2008 Edition 1, Standards South Africa, 2008)

Part 3 of the standards asserts the use of general green building design principles, insulation and appropriate building materials and techniques to minimise heat loss and heat gain by buildings. It further specifies minimum thermal resistance values (R values) for different climatic zones.

Concerning air-side system-design criteria it outlines the supplementary controls that should be provided for special zones as long as the total supply to the comfort zones is not more than 25% of the overall system supply and that the total conditioned floor area is smaller than 100 m^2. The fan motor power is required to satisfy CAV or VAV fan systems except where the system total fan motor power is less than 5 kW or the system with only fan-coil units has individual motor power less than 5 kW.

Cooling and heating efficiencies for equipment are recommended to be according to ASHRAE 90.1. The standard also makes it mandatory for air conditioning systems to have temperature controls with set points ranging from 20^o C - 25^o C and dead band of at least 2 ^{o}C. It is also mandatory to have humidity control capable of preventing the use of energy to increase relative humidity above 30% during humidification or to decrease relative humidity below 60% during dehumidification. Zone based controls are outlined as requirements for both heating and cooling operations.

For unitary systems and packaged air conditioning equipment, minimum coefficients of performance (COP) figures are prescribed. These are as detailed in table 2.6.

Table 2.6: Minimum coefficient of performance of Unitary and Packaged Air Conditioning Equipment

1	2	3
Equipment type	**Capacity range**	**Minimum COP**
Unitary and Split type	<7	2.5
Packaged and split air conditioning	7<19	2.6
	10<40	2.96
	40<70	2.72
	>70	2.64
Water-cooled package	<20	3.2
NOTE 1: COP should be as determined under summer design condensing conditions of 35 ^{0}C dry bulb ambient for air cooled systems and summer design wet bulb for water-cooled systems		
NOTE 2: If a resistance heating is used, heating power consumption may not exceed cooling power consumption except in the case of equipment of <10 kW		
NOTE 3: COP should include airside fan power but exclude waterside cooling system power		

2.7 CONCLUSIONS

The twin issues of scarcity of electricity supply[2] and the high carbon intensity[3] nature emerge as key concerns in South Africa. This reinforces the importance of energy

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[2] ESKOM (2007) firmly warns that the 8% electricity production reserve is lower than the practiced norm of 15% which is needed for un-interrupted power supply in electricity distribution.

[3] The United Nations Development Programme (2007) indicates that 70% of carbon dioxide emissions in South Africa are generated by electricity generation activities.

efficiency as a way of reducing emissions of carbon dioxide to the atmosphere while also improving access to electricity via demand reduction. Towards this end it is worth noting that despite the fact that energy efficiency efforts has been frustrated by the perceived low price, institutional barriers, resistance to change and lack of overall investors' confidence due to lengthy payback period, South Africa's energy efficiency strategy underlies its commitment to reduce demand reduction by 12% by 2014 (Department of Minerals and Energy, 2005). Energy efficiency studies therefore become of strategic importance in South Africa's drive towards achieving energy security; this provides motivation for this research.

The building sector consumes 30-40% of world's energy and is therefore a natural focus in energy efficiency (UNEP, 2007). It is however notable that most of the building's energy consumption is during construction and later during it operations and occupation period (Jumila, 2004). It is therefore logical that any energy and by extension electricity demand reduction in building must lay emphasis on the operations and occupation period. In South Africa, energy efficiency studies in HVAC systems is particularly justified by the fact that a large portion of energy is used towards this end, Buys (2002) estimates this figure as 65% in the commercial sector. The focus of this study in existing buildings is further supported by Holness (2008) who asserts that this category of buildings forms the bulk of expenditure in the building industry.

The optimisation of HVAC systems in buildings could lead to large energy savings. Much research has been done but none has so far presented conclusively the exact savings potentials that can be offered by the optimisation of HVAC systems. Buys (2002) estimates the general energy savings potential in HVAC systems as ranging from 30% to 70%.

The optimisation of HVAC systems for energy efficiency in existing buildings is supported by research claims that link energy savings to retrofitting of several components. This is demonstrated by assertions by Wendes (1994) that use of various fan volume control methods at an average of 60% peak air flow in VAV systems leads to energy savings of 13% to 78%. Further on, Oman (2006) estimates that the uses of synchronous drive systems with soft-start motor types achieves a nominal saving of 5% to 10%.

In South Africa, the focus of energy efficiency research in buildings has mainly been in the area of labelling and green building implementation as evidenced by Reinink (2007) and Ntsoane (2005). In addition HVAC energy efficiency research has often been simulation based and geared towards heavy commercial uses as evidenced by Mathews *et al.*(2002), Buys (2002) and Claasen (2003). Research in energy efficiency of HVAC systems in buildings in South Africa therefore remains untouched, leading to a gap in knowledge. In addressing this issue this research focuses on existing public buildings in South Africa.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the research procedures, methods and tools used in the study and explain reasons for selection of the framework.

This study was conducted in 2008. A total of twenty two buildings were studied with buildings in the Ekurhuleni Metropolitan Municipality accounting for 16 of the total. The University of the Witwatersrand accounted for five buildings and at CSIR only one building was selected for study. It must be noted that all the buildings studied were partially or fully used as libraries, with unlimited access to visitors during the time of operation. This research was guided by the main question 'to what extents are the HVAC systems in these selected existing public buildings in Greater Johannesburg currently optimised for energy efficiency and what would be the effects of their optimisation?' To conduct the study the research question was thematically divided into three questions.

The first sub question was 'What is the current state of HVAC systems in selected existing public buildings in Greater Johannesburg? This question sought descriptive knowledge of HVAC systems installed in the facilities visited. The approach towards answering it was thus via observation and interview.

The second question was 'To what extent are the practices, techniques and standards associated with HVAC systems energy-efficient in the selected existing public buildings in Greater Johannesburg?' In answering the second question, document review and observation were used.

The third sub question was 'What are the possible optimisation practices, techniques and standards applicable for energy efficiency improvement of HVAC systems in the selected existing public buildings in Greater Johannesburg?'

Table 3.1a: Approaches to answering questions (Source: Author's Construction)

Sub Question	Details of Data Required	Data Collecting Instrument	Data Source	Method of analysis
Q1. What is the current state of HVAC systems in the selected existing public buildings in Greater Johannesburg	A1. Description of Current standards, practices and techniques and types of HVAC systems in the selected existing public buildings in Greater Johannesburg.(It is envisaged that one has to proceed from known to unknown hence the establishment of current practices, techniques etc. forms the initial point of research.	B1. Building survey during which the following will be used: Direct observation, Interview Questionnaire and Documents	C1. Buildings Building Operators Building Occupants Documents e.g. SANS 208, SANS10400	D1. Narrative Analysis based on theoretical framework; Descriptive statistics using weighted mean
Q2 To what extent are the practices, techniques and standards associated with HVAC systems energy efficient in the selected existing public buildings in Greater Johannesburg?	A2. Involves definition of optimisation, followed by comparative analysis of A1 above on the one hand and the best practices, standards and techniques shown by literature and international norm	B2. Literature review and against the background of establishments derived from A2	C2. Buildings Building Operators, Documents e.g. SANS 208, SANS10400; Journals, Books, Reports, Memoranda	D2. Narrative Analysis based on theoretical framework, Descriptive statistics using weighted mean
Q3. What are the possible optimisation practices, techniques and standards applicable for energy efficiency improvement of HVAC systems in the selected existing public buildings in Greater Johannesburg?	A3. Involves the formulation of recommendations on the most suitable way to optimise HVAC systems studied based on available options from the literature.	B3. Literature review on options available for energy efficiency for different types of HVAC systems	C3. Documents e.g. Standards and codes of practice, Journals, Books and Reports.	D3. Narrative Analysis based on theoretical framework

Though related to the second question this question differed in the context that its answer entailed formulation of recommendations on the most suitable way to optimise HVAC systems studied. The approach towards answering this question was thus totally reliant on literature review.

Table 3.1a on illustrates the approach taken to answer the research question. Further details concerning methodological issues are exhaustively discussed in sections 3.2 to 3.5 of the dissertation. This research initially established the base performance of HVAC systems in terms of energy utilisation in selected existing public buildings then analysed opportunities for their optimisation. The study thus looked at attributes shown on Table 3.1b. These attributes formed the basis for describing HVAC systems, judging whether they were energy-efficient or not. Further details follow.

3.2 STRATEGY

This section describes the approach used in the study and contextually places it in paradigmatic framework. The philosophical orientation and the link with methods selected are thus discussed in this section.

3.2.1 Research Description

The research is described hereunder in terms of purpose, framework, possible outcomes, and process chosen.

Exploratory, descriptive or explanatory research

Research may be termed as exploratory, or descriptive or explanatory depending on the type of objectives set (Durrheim, 1999). 'Exploratory studies' use open, flexible and inductive methods and are often geared towards preliminary investigations in ground breaking research areas. 'Descriptive studies' accurately describe, categorise or measure attributes of phenomena using methods which stress accuracy and reliability like sampling surveys. 'Explanatory studies' on the other hand are causal in nature and employ experimental or quasi-experimental methods (Durrheim, 1999). This study was combined aspects which were both 'exploratory' and 'descriptive' in nature. It was exploratory and descriptive in that it respectively sought to establish the trends while categorising and measuring aspects of optimisation possibilities in energy efficiency in HVAC systems in existing public buildings in Johannesburg.

Table 3.1b: Attribute details

Description of attribute	**Comments**
Ownership details	Preliminary information
Public conversance with HVAC operation	More than 50% conversance indicate energy efficiency practice
Availability of placard	Availability indicates energy efficiency
Use of building	Preliminary information
Responsibility assignment/accountability for energy management	Practice indicates energy efficiency adherence
Energy consumption budget	Practice indicates energy efficiency adherence
Energy conservation program	Practice indicates energy efficiency adherence
Design philosophy (TDV or Conventional mixing)	TDV indicates higher energy efficiency
Type of equipment operated	Preliminary information
HVAC power density	Preliminary information
Schedule of operation	Synchronised schedule of operation and controls indicates energy efficiency adherence
Occupancy levels	
Control Type	Fuzzy-Logic controls indicate higher energy efficiency
Controls condition	Good condition indicate energy efficiency adherence
Occupants conversance with HVAC controls	More than 50% conversance indicates energy efficiency practice
Energy measurements/monitoring systems	Practice indicates energy efficiency adherence
Maintenance planning	Practice indicates energy efficiency adherence
Response time in correcting faults	Practice indicates energy efficiency adherence
Contact details for reporting faults	Practice indicates energy efficiency adherence
Leakage in ducting	Presence indicates poor energy efficiency practice
Maintenance responsibility	Preliminary information
Age of equipment/retrofits	Equipment over 20 years illustrates inefficient energy use
Improper installation	Indicates poor energy efficiency practice
Due commissioning	Indicates energy efficiency

Source: Author's construction

Inductive or deductive

Deductive logic in research entails setting theory and confirming it via a series of observations in a process which is hypothesis driven and procedures which are reproducible (O'Leary, 2004). Inductive research logic on the other hand commences with a series of observations from which theories are constructed, amended or grounded (Durrheim, 1999). Though considered as using a mixed logical framework, this research was more inductive than deductive. This is in consideration of the fact that despite the setting of theories in the beginning, its methodological processes generated findings which helped ground the theoretical framework. Thus in order to answer the second and third research questions the best practices in optimisation of HVAC systems were described in the literature review section and observation made were then used to refine them in the discussion section.

Qualitative vs. Quantitative

Research can be qualified as either qualitative or quantitative according to the methods of data presentation, analysis of collected data (O'Leary, 2004) and use of theory Creswell (2003). O'Leary explains that quantitative data will be presented as numbers and analysed using statistics whereas qualitative data will be represented as narratives (with use of pictures, icons, words) and analysed via thematic explorations. With regards to the use of theory, quantitative approach often uses theory to provide explanations for constructs. On the other hand in qualitative research, theory may generate theory using an inductive process[4] or it may apply existing theory as guidelines for the research procedure (Creswell, 2003). In this particular study sets of theories in energy efficiency provided guidelines for investigating the optimisation of HVAC systems for energy efficiency in selected existing buildings in Greater Johannesburg. Thus, the literature review section was used to give a theoretical orientation to the study. The research

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[4] Inductive process in this case is explained by Creswell (2003) as emanating from collection of data via interviews, questionnaires amongst others, then analysing the data to form broad patterns or themes, the researcher then examines the themes to form theories which are then put across as findings.

instruments developed were therefore within the confines of the theories emanating from the literature review. Despite the strong arguments put across to support categorisation of research as either qualitative or quantitative it should be noted similarities exist in paradigms followed, methods, logic of inference and approaches to analysis in both domains (Bryman, 2001: 19; Silverman, 2000:11 and Grix, 2004:116). This study does not qualify as entirely a qualitative study as quantitative techniques[5] were used in collecting, analysis, and presentation of the data.

3.2.2 Paradigmatic Framework

The four main schools of thought that guide research works are positivism/postpositivism, constructivism/interpretativism, advocacy/participatory, and pragmatism (Creswell, 2003; Blanche and Durrheim 1999:16). The schools of thought are defined along rigid paradigms. Punch (2005) describes paradigms as systems that include interrelated practice, thinking and assumptions that define the nature of the research enquiry along the three dimensions of ontology, epistemology and methodology; further on 'ontology' is used to specify the nature of reality that is to be studied and what can be known about it whereas 'epistemology' specifies the nature of relationship between the researcher and what can be known and 'methodology' how a researcher may go about practically studying whatever he or believes can be known. Interlink between paradigms and the research design is best captured by Creswell (2003) in the statement that "new claims to knowledge must follow a clearly defined pattern in which methods, strategies and instruments are closely intertwined" (refer to Figure 3.1).

Thus, it is expected that objectives of research or nature of the problem would lead to the adoption of specific methods, strategies and instruments. Table 3.2 outlines the

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[5] The quantitative methods referred to here include stratified sampling for questionnaire administration, use of charts and graphs to present findings.

schools of thoughts and associated characteristics. The methods and tools chosen must correspond to the school of thought adopted by research.

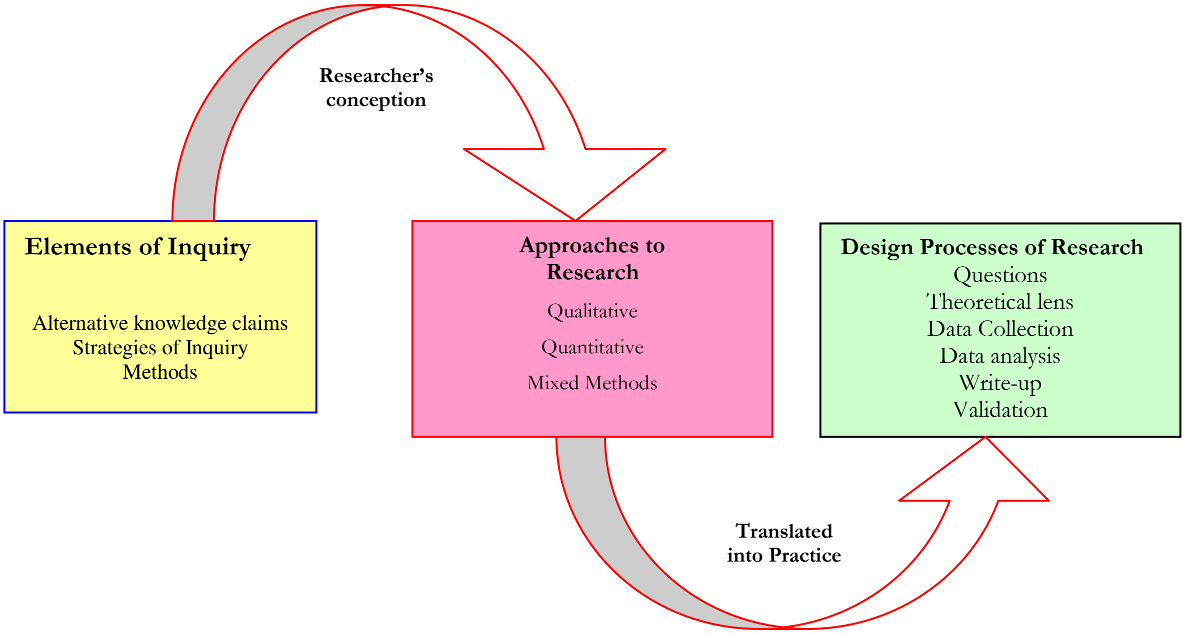

Figure 3.1 Knowledge Claims, Strategies of Inquiry, and Methods Leading to Approaches and Design Process (Source: Creswell, 2003)

This particular study could be categorised as either informed by positivist/postpositivist or constructivist/interpretativist. A convenient sample was adopted in the research after high non response rate from a number of 'Facilities Managers' contacted to participate in the study. Use of multiple methods and approaches as employed in the study is supported by the need for "triangulation of methods". This is supported by Bryman (1984), who argues that multiple methodologies imply better overall view of reality.

Table 3.2: Schools of thoughts guiding research (Source: Creswell, 2003)

School of thought	Characteristics
A1. Positivism/Postpositivism • Determinism • Reductionism • Empirical Observation and Measurement • Theory verification	B1. Positivism/Postpositivism a. Causes probably determine effects or outcomes b. Intent on reducing ideas to variables that constitute hypotheses and research questions c. Knowledge developed is based on careful observation and measurements of reality d. Theory is tested by data collection followed by analysis then revised in line with the tests
A2. Constructivism/Interpretivism • Understanding • Multiple participant meanings • Social and historical construction • Theory generation	B2. Constructivism a. Individuals seek to understand the world in which they live and work b. Inquirers inductively develop a theory or pattern of meaning c. Participants' view very much part of the research d. Researcher is to make sense of the meanings of observations and role players
A3. Advocacy/participatory • Political • Empowerment issue-oriented • Collaborative • Change-oriented	B3. Advocacy/participatory a. Research must be action oriented to help marginalized peoples b. Research must contain action agenda for reform c. Inquiries must be completed with others and not on or to others
A4. Pragmatism • Consequences of actions • Problem-centred • Pluralistic • Real-world practice	B4. Pragmatism a. Knowledge claims arise out of actions, situations and consequences b. Concern should be on what works c. Truth is what works at the time d. Researchers have freedom of choice on research approaches

The positivist/postpositivist characteristics of the study include:

a. The study was motivated by the fact that management practices in buildings affects the overall energy efficiency of HVAC systems. This concurs in with the determinist aspect of the theory that causes probably determine effects or outcomes.

b. The main research question was reduced into 3 sub questions which were then divided into variables to be tested. Thus, a reductionist approach is manifested in the process.

c. Using structured observation, the study was able to identify practices and technologies affecting energy efficiency in HVAC systems in buildings. This approach is empiricist. The other positivist methods[6] applied were sampling and questionnaires. The main sampling method used was snowballing[7].

d. The data collected was transformed to ordinal measures which were then analysed using descriptive statistics to support theories in energy efficiency measures for HVAC systems in buildings.

Two main interpretativist aspects of the study were evident, these were:

a. The need to holistically understand the practices associated with HVAC systems in public buildings. Qualitative methods (interview and document review) were applied to gather data on management, maintenance and operation of the HVAC systems in public buildings.

b. The interview respondents' opinions and narration on management and operation procedures in the building informed the analysis, conclusions and recommendations of the study.

3.3 METHODS AND TOOLS

This section discusses several methods and tools that were available for use and also provides a rationale. O' Leary (2004) defines methods as techniques used to collect data and tools as being used to help in data collection procedure. The specific methods discussed include sampling, observation, documentary research, questionnaire use, energy audit and interview.

Two reasons are provided for the use of multiple methods in this study. The first one was the desire to triangulate findings so that reliability and validity is increased. This is supported by Yin (1994) while arguing for convergence in lines of inquiry as of

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[6] Interpretative methods included documentary research, observation and interview were largely qualitative.

[7] Snowball sampling relies on referrals from colleagues and friends details are available in section 3.3.1

paramount importance to validation of findings. The second reason was the fact that naturally different methods often complement each other. In this particular study observation method was used to gather data relating to trends/practices identified in theory in the literature review (this included type of equipment operated, availability or lack of availability of placards among others).

Interviews on the other hand were used in this study to collect data pertaining to maintenance, management practices and plans including energy conservation programmes and energy planning. Questionnaires targeted information about cultural issues, dressing mode, conversance with the equipment and awareness to policy issues. The document review only targeted the appropriateness of key public policy papers on energy efficiency and how energy efficiency impacted on the HVAC systems in buildings.

3.3.1 Sampling

Sampling is the selection of a part of whole population for study whereas a *census* is the study of the whole population (Rao, 2000). O'Leary (2004) further underlines the importance attached to proper definition of population being studied. In this particular study the population being studied was public library buildings in Gauteng area. In the context of this study public buildings allowed relatively unrestricted access and these could include educational and research facilities, car parks, entertainment halls and offices. However due to lack of access and the need to maintain uniformity of data the study opted for library based buildings. A total of 22 buildings had their HVAC systems studied. In addition to this, questionnaires were sent to 40 respondents.

With regards to the population size (the number of buildings), the number may not be the minimum of thirty recommended for statistical analysis by O'Leary (2004). Representativeness was however achieved by the fact that the population sample captures all the various elements/characteristics of the population under study and that in the case of government owned buildings the whole segment of libraries in a region were studied[8], in addition 5 library buildings out of a total 9 at the University of the Witwatersrand were studied. To provide further diversity into energy management strategies one building at the CSIR complex in Pretoria was included in the sample. The field study commenced in mid October 2008 and ended in mid November 2008. The focus was on management, design, controls, operations, maintenance and installations/commissioning that have continued to influence HVAC systems over the years, hence its relevance and setting was not bound by dates.

Sampling methods

Random sampling method was not used in selection of buildings for study. Forms of random sampling include simple random sampling, systematic sampling, stratified random sampling. The study employed non random sampling techniques (purposive). Table 3.3 reviews the various sampling techniques available in the context of this study.

Rao (2000) identifies *non probability/Non random sampling* as including *handpicked*, *snowball*, *voluntary* and *convenience* sampling. In the selection of buildings for the study snowball sampling was the main method after the failure of facilities managers to respond to requests to use their buildings. Despite the fact that sometimes non probability sampling is dismissed, this study was laid on the premise advanced by O'Leary (2004) that as long as case selection is done with representativeness in mind non-random samples will credibly represent the population.

As the names suggest, handpicked sampling select cases purposively while snowball sampling uses referrals to select cases. Volunteer sampling on the other hand relies on the volunteers to study as cases, while convenience sampling select cases in a manner convenient to the researcher (O'Leary, 2004). The buildings in Braamfontein (at the

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[8] All the library buildings in Southern Ekurhuleni Metropolitan Municipality were studied, these were 15 in total.

University of the Witwatersrand) were *conveniently selected* because of existing linkage and ease of accessibility. The CSIR building was handpicked to highlight certain aspects of energy management of HVAC systems in public buildings; this ensured fodder for argument development during the research.

It must be emphasised that representativeness was maintained in this research despite the use of non random sampling methods. This was achieved through *firstly* ensuring that the buildings studied were clearly defined thus only library buildings were selected, this ensured uniformity and consistency. *Secondly*, all the library buildings at the two study clusters (Braamfontein-Wits and Ekurhuleni) were studied, hence eliminating the possibility of sampling bias. Finally, the inclusion of the office building from a third cluster (CSIR, Pretoria) ensured diversity which ensured that additional aspects in the optimisation of HVAC systems for energy efficiency in buildings were captured in the study. These aspects included budgeting, use of occupant-customised control systems, accountability for energy management and zone-based HVAC system units.

Table 3.3 gives a summary the various sampling techniques and their relative strengths and weaknesses.

3.3.2 Interviewing

Interviewing is the act of collection or gathering information for research purposes via verbal interaction or conversation (Pedhazur and Schmelkin, 1991; Punch, 2005). Fontana and Frey (1994) list types of interviews as being individual-face to face, group-face to face, or telephone interviews on one hand and structured, semi-structured or unstructured interviews on the other hand. The main types of interview options and their applicability are reviewed hereunder.

Table 3.3: Sampling methodologies

Category	Description	Comments in relation to the study
Random sampling	Simple random sampling	The process demands full identification of the population. It is cumbersome and was not used in the process due to limitation in resources.
	Stratified sampling	Was used in the selection of respondents to questionnaires due to its ability to improve representation while remaining cost effective.
	Systematic sampling	It was not used in the study due to the fact that it does not work well where accessibility is a problem as the n$^{th.}$ case may decline to take part in the study.
	Cluster sampling	It was not used in the study due to the fact that it does not work well where accessibility is a problem and cost reduction is a necessity.
Non-random sampling	Voluntary sampling	Was not used for the simple fact that it may lead to bias as the voluntary cases are always in the extreme group which is biased.
	Handpicked sampling	One case was handpicked to ensure that certain aspects of the subject were discussed in the study.
	Snowball sampling	Due to accessibility and non response problem the study relied heavily on referrals hence it qualified as the perfect sampling method for the buildings study
	Purposive sampling	The University of Witwatersrand facilities (Braamfontein cluster) were studied due to the convenience in terms of network, costs and time to do the research.

Source: Author’s construction

In structured interview the respondent is queried on preset interview and response is in preset categories; this is what is often short and stimulating and could sometimes qualify as a questionnaire (Punch, 2005). Its applicability is indeed similar to the questionnaires and it is also preferred for its elimination of bias. It is however not applicable where there is need to evaluate the interviewee response (Pedhazur and Schmelkin, 1991). This method was not used in the study.

Punch (2005) describes unstructured interviews as often non-standardised, open-ended and sometimes in-depth or ethnographic in nature. It is advantageous in the sense that the response is not limited to specified categories and interactions are increased for the interviewee and the interviewer. Most importantly however the interviewer has an opportunity to exact more control in presentation and thus eliminate possible ambiguities in the framing of questions (Pedhazur and Schmelkin, 1991). This method was used to gather information from the Facilities Managers at the University of the Witwatersrand and at the Ekurhuleni Metropolitan Municipality. The Liaison in-charges during the study opportunity were available during the building survey period. Thus, information like use of budget for energy consumption, energy management plans, maintenance planning and response time to correct malfunctioning systems were obtained via unstructured interviews.

3.3.3 Observation

O' Leary (2004) describes *observation* as systematic way of gathering data while relying fully on the researcher's visual senses. However, researchers are warned that observation as a data collection tool may be hampered by several disadvantages. These include *firstly* their inherent bias which may impact greatly on the observation made, *secondly* the fact that personal history, experiences and expectations often influence perceptions and thus pose a credibility challenge to observed data and *lastly,* replication of the observation when made informally may be difficult, thus reducing the confidence level (O' Leary, 2004).

Several types of observation methods exist, these include structured, semi-structured and unstructured observation methods. O' Leary (2004) defines *unstructured observation* as involving observers' attempts to collect data without predetermined criteria then moving on to make deductions concerning emergent themes. *Structured observation* techniques on the other hand use predetermined criteria related to people, events, practices, issues, behaviour, actions, situations and phenomena being observed while *semi-structured* observations use guidelines (schedules and checklists) to organise already made observations (O' Leary, 2004). This study used structured observation in the form of energy audit inspection sheets and observation checklists to collect data concerning the condition of the building fabric, dress of the building occupants, types of HVAC systems in use, positioning and type of control systems used, signs of possible leakages on ducts and installation positions of the fans. Details of the checklists and building energy survey sheet can be found in Appendix D. It must however be noted that observed features were triangulated with questionnaire results and interviews to ensure consistency and reliability. This removed any bias that could have been introduced in either of the methods.

3.3.4 Documentary Research

Scott and Marlene (2006) describe documentary research as review of already existing materials to arrive at desired conclusion. The documents providing feedstock to the research are named by Yin (1994) as including external *communiqués* (examples are letters, memoranda), reports detailing events (including agendas, minutes, proposals, memoranda), formal statements of the same case and media clippings). This research used documentary research to collect data on standards and government polices with regards to energy efficiency in HVAC systems in buildings. In the case study use was made of memorandum[9] to staff on energy conservation measures and past reports detailing aspects of the same case study[10].

Whilst using the existing documents it was noted that specific care had to be taken to avoid the pitfalls of using the documents as standalone sources of truth. Thus effort was made to use them to corroborate evidence from observation as well as questionnaires. Failure to do this would results in what Yin (1994: 82) refers to as 'potential over-reliance on documents in case study research'. The following documents were among those studied:

Draft energy efficiency standards for South Africa (Standards South Africa, 2008)

All the parts of this document are considered relevant to this research. The document is still considered to be a draft paper but is the first attempt to legislate and make a standard on energy efficiency in buildings. As such it forms the backbone for analysis on building standards with regards to this study. The document appears as SANS 204-1:2008 Edition 1, SANS 204-2:2008 Edition 1 and SANS 204-3:2008 Edition 1 (Standards South Africa, 2008a; Standards South Africa, 2008b and Standards South Africa, 2008c)

Energy Efficiency Strategy for South Africa (Department of Energy, 2005)

In the energy optimisation of HVAC systems in public buildings, review was made of general government policy on energy efficiency. This then narrowed down to the implementation of the policy to commercial and public buildings with use of HVAC systems in existing and new buildings.

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[9] This was a memorandum from the General Manager-Electricity written to staff at Ekurhuleni urging them to adopt various conservation measures.

[10] These included property management reports giving details of floor area sizes for the sites visited.

3.3.5 Questionnaire

Pedhazur and Schmelkin (1991) describe interviews as information gathering tools which are to a large extent self administered and which have the advantage of being less susceptible to bias as interviewer effects and deviations from the instructions are eliminated. The use of questionnaires was used because it enjoys several advantages. Pedhazur and Schmelkin (1991) lists the advantages over interviews: *firstly* their relatively low cost of administration as it demands less selection, training, and supervision of staff, *secondly* they reduce the chances of a bias and *finally* they lead to greater confidentiality and anonymity. As this study was limited in resources (time and money) in addition to the need to protect the confidentiality of sources it was therefore decided to use questionnaires for gathering data.

A total of 40 questionnaires were administered to building operators and occupants. Questionnaires were administered to one occupant and one operator per building studied. This ensured representativeness for all the sites visited.

The questionnaires were used to investigate of issues relating to management, operations, control, maintenance and installation and commissioning. A summary of key issues interrogated by the questionnaires are discussed below and the questionnaire used for the study is in the Appendix E.

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Management: Questions in this category explored issues concerning ownership and use of buildings, accountability for energy management, energy consumption budget and energy conservation measures in place.

Operations: Schedule of operations- The questionnaire sought to establish the building's and HVAC system's schedule of operations in hours per day and days per week. In addition it was asked whether the operation of the HVAC systems was in any way linked to the operation of the whole building. Concerning occupancy levels, the occupants were asked how often they visited the library and also whether their visit pattern to the facility was constant throughout the year or whether it depended on the season.

Controls: Building occupants and operators were asked if they were familiar with the control settings/operation of the HVAC system and if any training had been conducted in respect to this.

Maintenance: The building operators were asked if here were energy consumption meters in place for the building, further inquiries were made as to whether these included sub meters for different installations in the building. Questionnaires sought to determine details of maintenance planning and what informed the type of maintenance arrangement used in the facility. The response time needed to correct faulty HVAC systems was also investigated by the questionnaire. Issues such as age of equipment or retrofit and whether the maintenance management was done in-house or outsourced were asked in the questionnaire.

Installation and commissioning: The questionnaires sought to establish whether the HVAC systems had maintenance manuals, commissioning hand-over notes and as-built drawings.

3.4 CASE STUDY

Punch (2005) describe *case study* as involving the examination of one case or a small number of cases in details(in-depth) using appropriate methods in its natural setting whilst recognising its complexity and acknowledging its context. Case studies may be categorised as *intrinsic* where the study is undertaken to improve understanding of the case or *instrumental* where key emphasis is on giving insight into an issue or refining theory or *collective* where the instrumental case study is extended to cover several cases and the focus is on learning about a phenomenon or population or general condition (Punch, 2005; O'Leary, 2004).

This research used the approach of a collective case study where the issue was the 'Optimisation of HVAC systems for energy efficiency' in existing public building. To gain a good understanding of the case it was decided to use several government owned and research institution buildings which acted as independent cases and chose several important attributes in the optimisation of procedures in management, operations, controls, maintenance, installation and commissioning of HVAC systems with to achieve energy efficiency. Thus, the cases can be loosely categorised as government owned buildings (which included the library buildings in Alberton, Germiston, Boksburg, Elsburg, Dinwiddie, Leondale, Katlehong, Isaac Mokoena, Thokoza, Edenpark, Palm Ridge, Zonkizizwe, Vosloorus, Spruitview, Brackenhurst and Reigerspark) and Research Institution owned buildings (which included John Moffat, William Cullen, Wartenweiller, Edu-com and Albert Wessels at the University of the Witwatersrand and Building 2 at the CSIR complex).

A case study approach was chosen for several reasons. This included the fact that it allowed an opportunity for new ideas and hypotheses to emerge from the collective study, as described by Pedhazur and Schmelkin (1991).

Another reason for the adoption of the case study approach was its detailed nature which Lindegger (1999) refers to as “richly ideographic” and often leads to critical reflection on existing theories. Even though only one case could have been studied, the choice was made to study several buildings built at different historical periods, shaped by different social norms and fitted with different HVAC systems. The ability to study HVAC systems in buildings in rich suburbs, townships, government owned and research-institution owned all at the same time led to rich findings. This is what O’Leary (2004) refers to as increased authenticity that is not possible with use of other survey instruments in his statement below:

> ‘The goal (of case study) is authenticity and richness and in-depth understanding that goes beyond what is generally possible in large scale survey research’ (O’Leary, 2004: 116)

3.4.1 Generalisation of Cases

Traditionally a case study approach is often criticised due to difficulties in generalising their findings (Punch, 2005). However, this is not applicable in this study because a collection of cases was used rather than a single case approach. Furthermore, Punch (2005) dismisses this argument on several aspects, *firstly* each case may deserve to be studied as a stand-alone domain to investigate its intrinsic nature; *secondly* the study of negative cases is also as important as the general ones; lastly, the use of conceptualisation methods in the study of cases ensures that several aspects are explained which may lead to new prepositions and hypotheses.

3.4.2 Case Study Methods

Yin (1994) names the underlying principles of data collection for a high quality case study as firstly, the use of multiple sources of evidence; secondly the formulation of a case study database which assembles distinctive evidence and lastly maintains evidence that is explicitly linked to the research questions. Case study as a research strategy employs several methods which are named by Yin (2004) and O’ Leary (2004) as including documentation, archival records, interviews, direct observation, participant observation and physical artefacts.

This study used documentation to triangulate the findings emanating from observations made during the building survey. In addition, an analysis of documents concerning the new energy efficiency standards for buildings in and green building ratings in South Africa were done. Further, details on the documentary research as applied by this study were discussed in section 3.3.4. Direct observation was the main method applied in the building survey. The observation mode was basically structured with priority being given to HVAC systems in place at the buildings visited. Further details on observation in this study appeared in section 3.3.3.

This study employed self distributed questionnaires in addition to personal interviews. Questionnaires were distributed to building occupants and operators in a bid to gather pertinent information concerning management, scheduling, controls, operations and maintenance of the HVAC systems. Details of these were discussed in sections 3.3.2 and 3.3.5. Table 3.4 summarises the methods and used in the case study.

Table 3.4: Summary of methods used in the case study

Method	Data details	Data sources
Direct Observation	*Building & Equipment:* Building fabric, HVAC systems types Date of installation' types of HVAC systems in use, positioning and type of control systems used signs of possible leakages on ducts and installation positions of the fans. *Occupants & Operations:* Dressing & attitude of the building occupants,	Observations during building survey conducted in the 22 buildings visited
Interview	Operation schedule Attitude of operators and occupants Management policies Maintenance planning Historical background of equipment Energy conservation and management	Respondents Facility Managers and Technicians at the visited buildings
Questionnaire	Operation schedule Attitude of operators and occupants Management policies Maintenance planning Historical background of equipment Energy conservation and management	Respondents Building operators (1 per building) Building Occupants (1 per building)
Documents	Historical background of equipment Energy conservation and management	Memos; Energy Efficiency Strategy(2005) Standards and Codes of practice (SANS204; SANS 10400 etc)

Source: Author's construction

3.4.3 Validity and Reliability

The use of multiple sources of evidence specifically direct observation, interviews, and questionnaire entrenched the construct validity and reliability in this study and ensured a triangulation of findings and an eventual high level of accuracy. This is referred to as '*convergence of lines of inquiry'* by Yin (1994: 92). who argues that the use of multiple sources of evidence implies the equal measures of similar phenomenon under study and in the process this adequately addresses 'construct validity' issues. The development of a case distinctive database using case study notes (prepared during field study), narratives (gleaned from interviews) and case study documents ensured that reliability concerns were addressed.

3.5 ANALYSIS FOR EFFICIENCY/OPTIMISATION

In presenting the results, sight has not been lost that the key theme of this study is optimisation and energy efficiency. In this aspect the study defined its minimum requirements and considerations for HVAC systems to as energy-efficient then went ahead to lay down the equivalent considerations for optimisation. It is on this basis that the HVAC systems were judged as energy-efficient, energy-inefficient and optimised for energy efficiency or not. This evaluation is of paramount importance, taking into account that the research gravitates around the three key points: *firstly* the need to establish the current state of HVAC systems in public buildings, *secondly* to establish the extent of energy efficiency in HVAC systems in public buildings and *lastly,* identify possible energy based optimisation practices applicable to HVAC systems in public buildings.

The first point was established by survey followed by general description of key themes around management, design, operations, control, maintenance, installation and commissioning. The last issues were investigated using a points based evaluation developed with the aid of theories discussed in chapter two and the principles adopted from the Hong Kong Buildings Environmental Assessment Method System commonly referred to as 'HK-BEAM' (Centre of Environmental Technology, 1999). The key evaluation items were seventeen in number. These were public conversance with HVAC operation, availability of placard, responsibility assignment for energy management, energy consumption budget, design philosophy (TDV or Conventional mixing), schedule of operation, control type, occupants conversance with HVAC controls, energy measurements and monitoring systems, maintenance planning, response time in correcting faults, contact details for reporting faults, maintenance responsibility, age of equipment/retrofits and installation and commissioning.

A point was awarded for every item evaluated as energy-efficient whereas energy inefficiency earned zero for every item judged. Items evaluated as optimised energy efficiency or as achieving best practice were awarded two points. These points were then weighted under the categories of management, design, operations, control, maintenance and installation and commissioning. The maximum points attainable were thus twelve for best practice achievement, whereas the minimum points needed to achieve a base energy efficiency was seventeen. Table 3.6 (Appendix B) illustrates the evaluation criteria in greater detail.

3.6 CONCLUSIONS

To effectively answer the question *'What is the effect of optimisation of HVAC systems for energy efficiency in existing selected public buildings in Johannesburg?'* the research employed a case study approach in which a set of twenty two cases were purposively sampled. The criterion for case selection was the use of building as a library, accessibility to be public, and management to be either by a research institution or government. The cases selected were distributed between Ekurhuleni Metropolitan Municipality-Southern zone library buildings (16 buildings in total), University of the Witwatersrand buildings (5 buildings in total) and CSIR (1 building). The cases at Ekurhuleni Metropolitan Municipality were selected using snowball sampling, whereas those at the University of the Witwatersrand and the CSIR were selected based on convenience/purposive sampling. Accessibility difficulties, limited time and finance dictated the use of snowball sampling and convenience/purposive sampling techniques in the study.

The dominant methodological procedures were qualitative though the research could be effectively described as employing mixed methods. The methods and tools used in the study included questionnaires, interviews, structured observation and documentary research. Questionnaires were distributed to 40 respondents (building operators and occupants) who were selected on the basis of stratified sampling with 2 respondents being selected per building studied. Interviews with the Liaison Officers in the study facilitated the build up of case-distinctive notes which enabled case-specific details to be established. Structured observation on the facilities visited helped in establishing details like types, conditions and practices of HVAC systems in the studied buildings. Documentary evidence was used to establish practices and techniques in the installations.

In general it can be said that the studied was largely interpretative in nature with aspects of positivists' methods being applied in the investigation. The interpretative nature allowed the benefits of contextualising the findings while the positivists' method enabled the study to maintain additional reliability and validity due to the replicable nature.

CHAPTER 4: PRESENTATION OF FINDINGS

4.1 INTRODUCTION

This section attempts to answer the research questions posed earlier on. The results were obtained after energy audits on 22 buildings. The audits mainly focused on HVAC systems operated in the buildings. In addition questionnaires on operations and management of HVAC systems were distributed to building operators/tenants and occupants/building users.

The results are categorised and presented under the headings management, design, operations, controls, maintenance and installation and commissioning. In addition, efficiency and optimisation evaluation results are presented later in section 4.8. Further details about this chapter are discussed in the sections below.

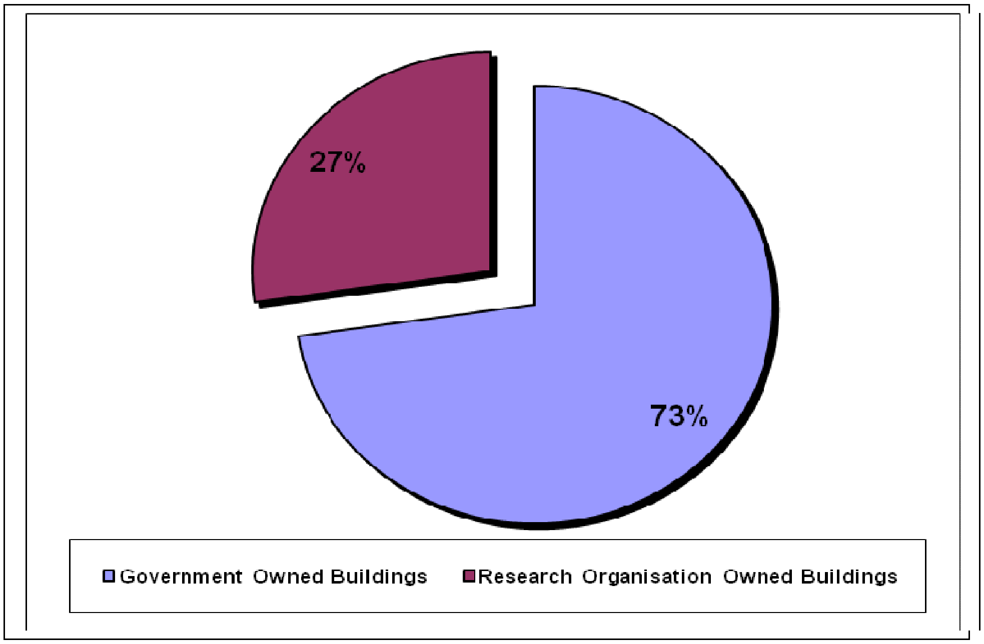
4.2 MANAGEMENT

This section presents results about ownership, details of buildings, use to which the building is put, accountability, budgeting and energy conservation programmes in place in the buildings.

4.2.1 Ownership of buildings

A total of 22 buildings were studied in the research. Of these, 6 buildings belonged to research institutions whereas 16 buildings belonged to the government through the Ekurhuleni Metropolitan Municipality. Ownership details of the building are of prime importance because it influences the type of energy efficiency programmes pursued. Figure 4.2a illustrates the percentage details of the building ownership categories.

Figure 4.2a Ownership details of buildings

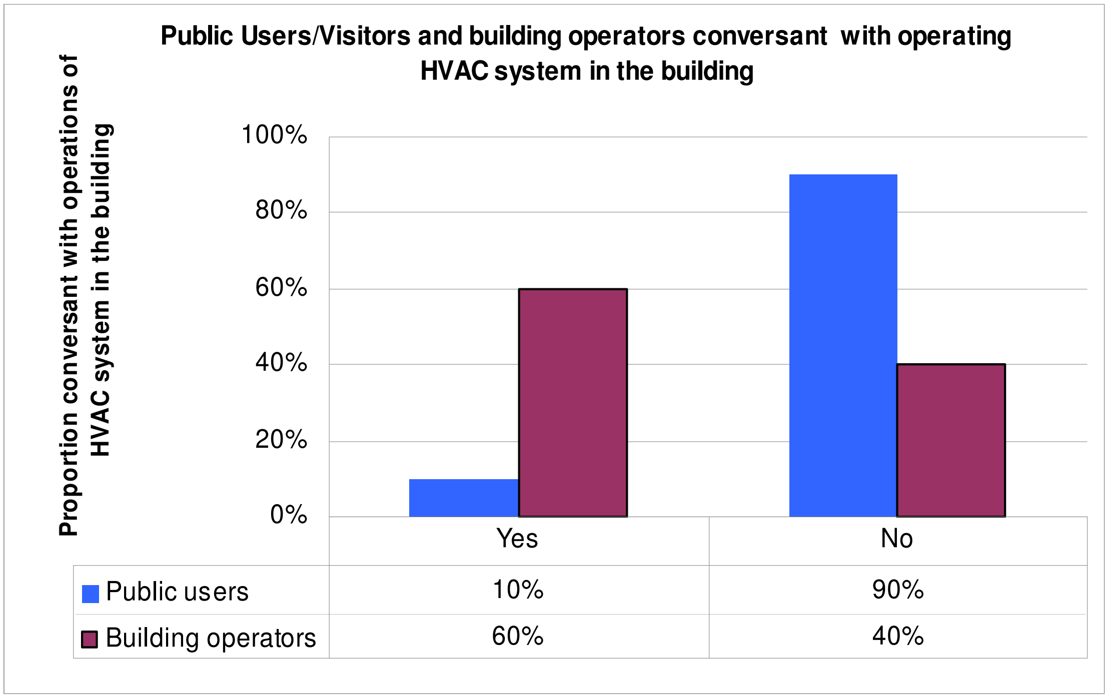


Source: Field interview, 2008

All the buildings studied were those accessible to a large number of people as the general public, as students or as researchers. Due to this large number of users the issue of conversance with HVAC systems operations was considered of prime importance. When asked whether they were conversant with the HVAC systems operation, the majority of the building occupants and also operators responded negatively. (Refer to Figure 4.2b.)

The terms 'building occupants' was used to refer to the general public or students/researchers visiting the building whereas 'building operators' referred to employees tasked with managing the building facility. This issue was investigated because a lack of knowledge may result in a high susceptibility to abuse of systems which could lead to energy inefficiency (Wulfinghoff, 1999).

Figure 4.2b: Public Users/Visitors Conversance with HVAC systems operations



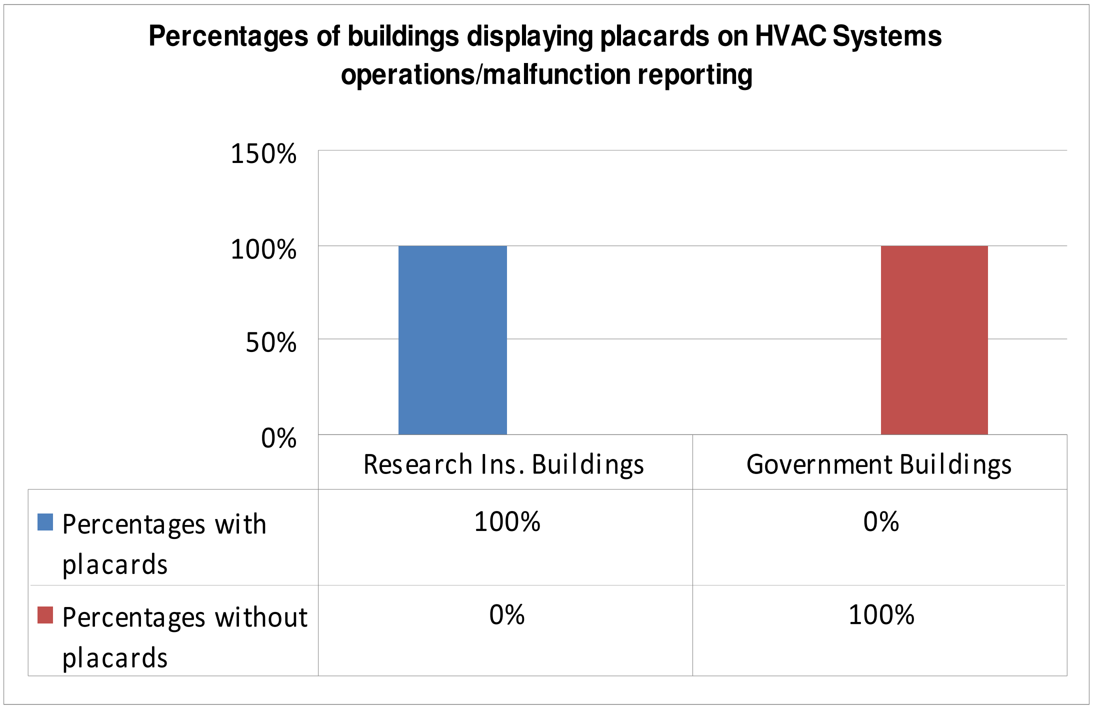
	Yes	No
🟦 Public users	10%	90%
🟪 Building operators	60%	40%

Source: Field interview, 2008

Another issue investigated was the method of communicating operations procedure or enforcing familiarity with HVAC systems; Wulfinghoff (1999) advocates the use of placards in this regards, arguing that they are cheap and to the point.

Observations revealed that all the buildings managed by Research Institutions (Wits University and CSIR) had placards giving contacts to report general malfunctioning and operations instructions in place. This is as shown in Figure 4.2c. The positioning of the placards were however not suitable as most occupants could hardly even recall having seen them.

Figure 4.2c: Percentages of buildings displaying placards on HVAC systems operations/malfunction reporting

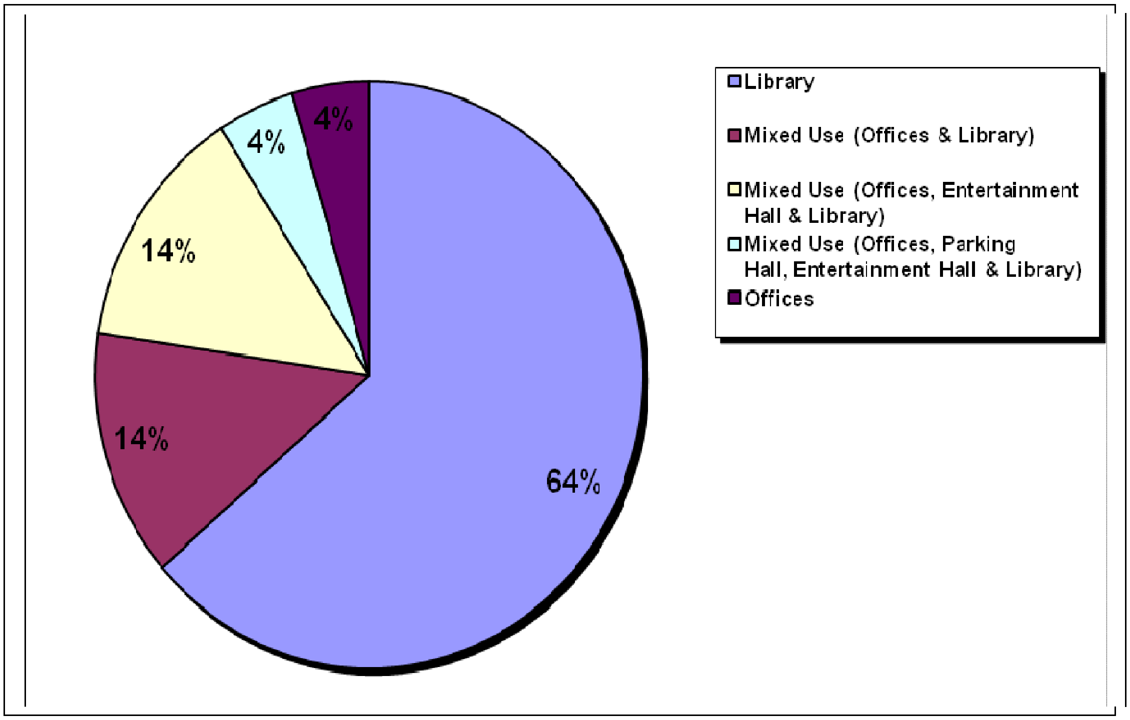


Source: Field interview, 2008

4.2.2 Use of Building

Issues investigated under the heading "use of building" included the purpose for which the building was constructed and the period during which the building was put to use. The buildings studied were overwhelmingly for library use. Of all the buildings studied 64% were entirely for library use only whereas the remainder were for mixed usage (Office and Library) 14%, mixed usage (Office, Library and Entertainment Hall) 14% and, mixed usage (Office, Library, Car Parking and Entertainment Hall) with Office only accounting for 4%.

Fig 4.2d: Use of building



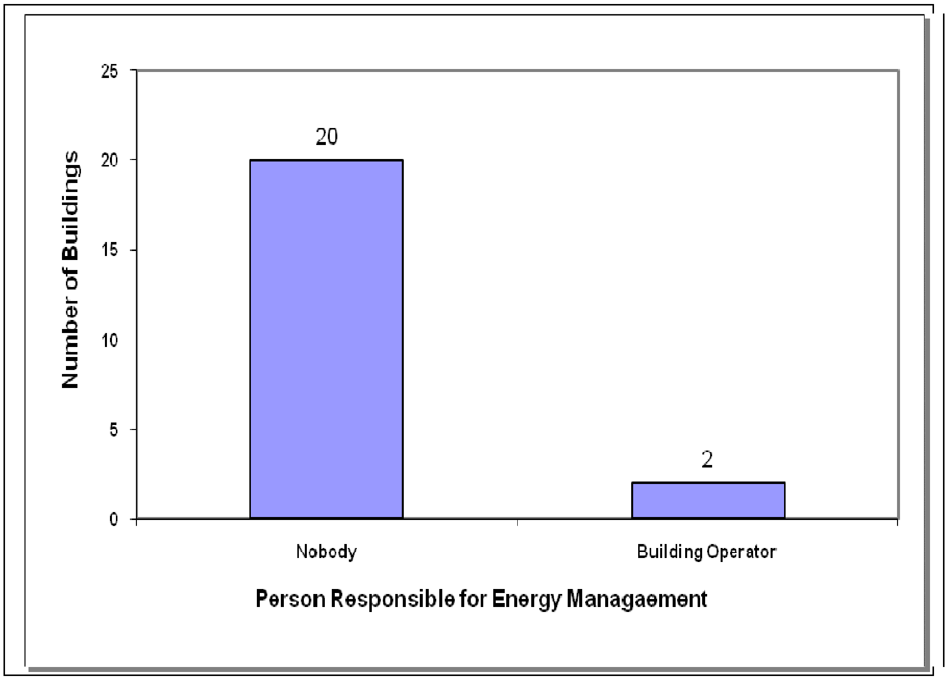
Source: Field interview, 2008

4.2.3 Accountability

It is normally important to have specific task assignment for any management actions to succeed. This study revealed that there was nobody specifically tasked with energy management in 20 of the buildings visited (refer Figure 4.2e). Only 2 buildings had operators tasked with energy management.

This implied a lack of planning for energy management and further highlighted the fact that for most buildings the use of energy by the building equipment and by extension the HVAC systems was not a consideration.

Fig. 4.2e: Assignment of responsibility for energy management



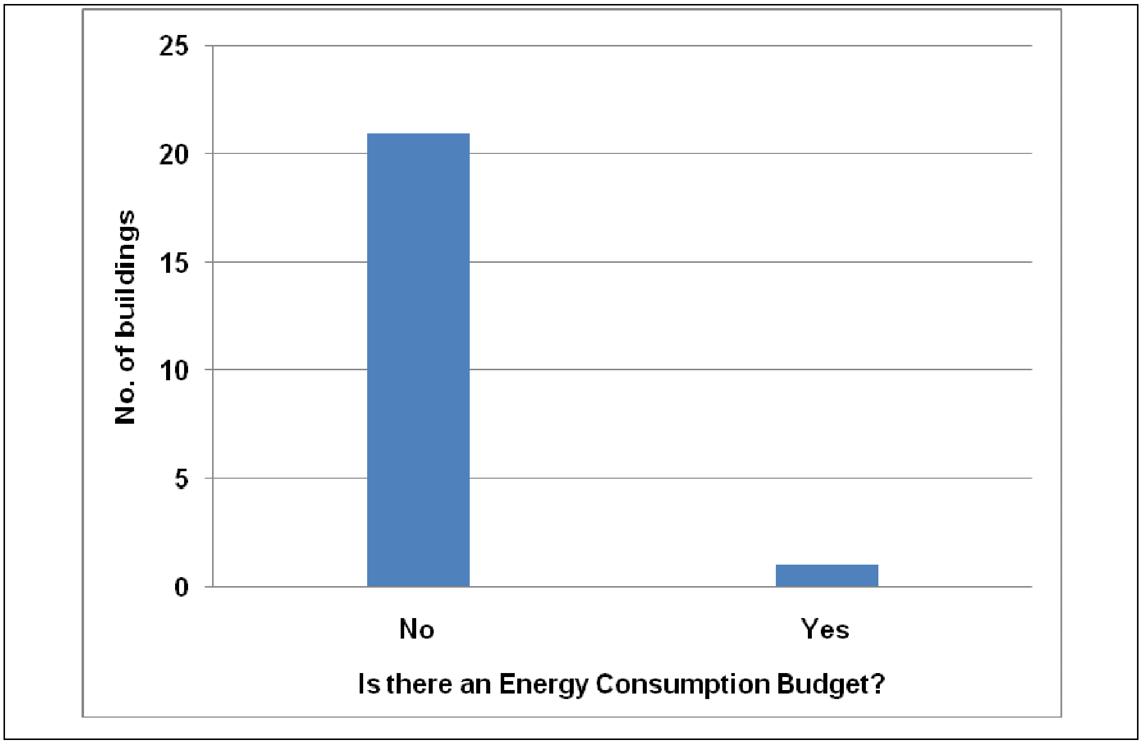
Source: Field results, 2008

4.2.4 Budgeting

Budgets are important in resource allocation because they put a ceiling on its use and in the process enforce savings. Energy use in HVAC systems must not be an exception; this study revealed that only one building visited had an annual energy budget with associated costs attached to it.

It should be noted that even this sole building (having an energy consumption budget) did not specifically have a defined allocation for HVAC system consumption but rather had a general amount allocated to water and electricity consumption.

Figure 4.2f: Energy consumption budget



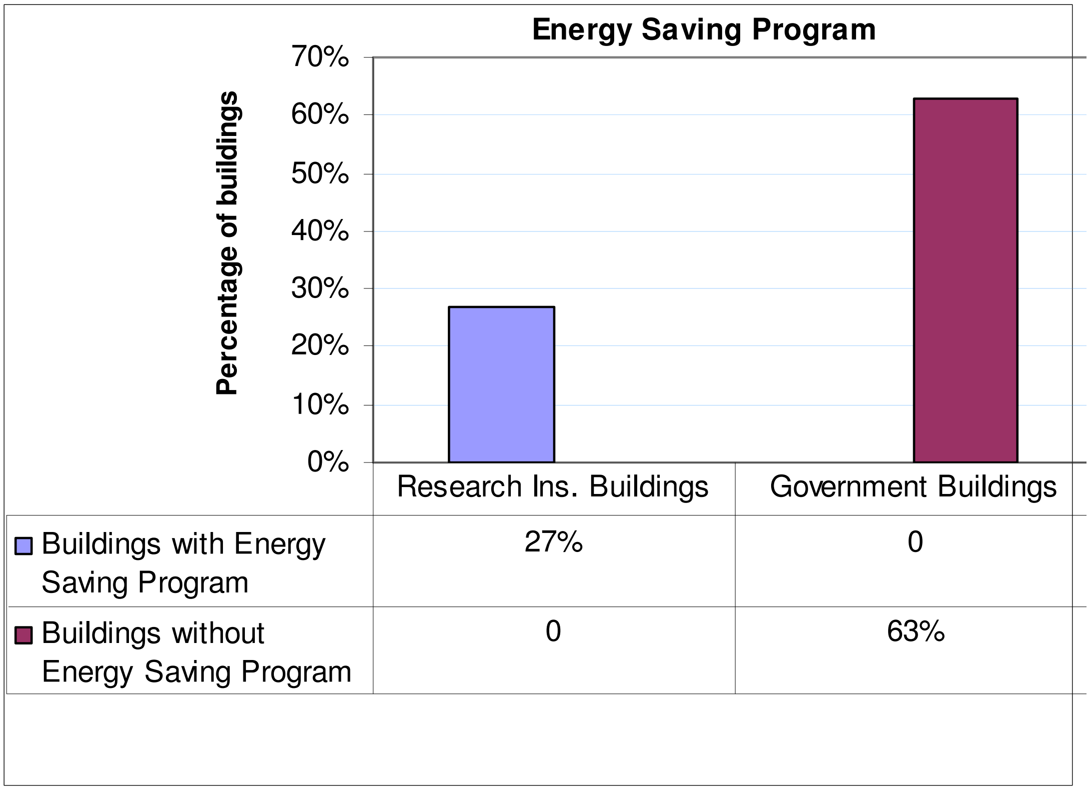
Source: Field results, 2008

4.2.5 Energy conservation

All the government-owned buildings studied did not have energy saving programmes in place to reduce/control consumption for HVAC systems. On the other hand, all research institutions visited practiced some measure of energy saving; at the CSIR departments were allocated utilities budget which had to be adhered to.

In addition, use was made of HVAC systems using variable frequency drive motors to limit consumption of electricity. At the University of the Witwatersrand sites special emphasis was made on closing doors on account of the weather, use of placards to urge faster reporting of abnormalities and centralised operations of systems.

Figure 4.2g: Energy conservation programme



	Research Ins. Buildings	Government Buildings
🟦 Buildings with Energy Saving Program	27%	0
🟪 Buildings without Energy Saving Program	0	63%

Source: Field interview, 2008

4.3 DESIGN

The approach taken was to investigate the design philosophy used in the analysis of the heating/cooling load and the types of equipment selected for the building. These are discussed in the sections 4.3.1 and 4.3.2.

4.3.1 Design Philosophy & methods of load analysis

The issue investigated under this heading was the use of conventional / mixing methods versus total displacement volume (TDV) method in the design process and the methods of load analysis employed during design process. All the buildings studied employed conventional /mixing technique in HVAC systems design. This is despite the fact that available literature suggest that approximately 20% energy saving may be realised using while using TDV method (Roth *et al.,* 2002; Lunneburg, 2003).

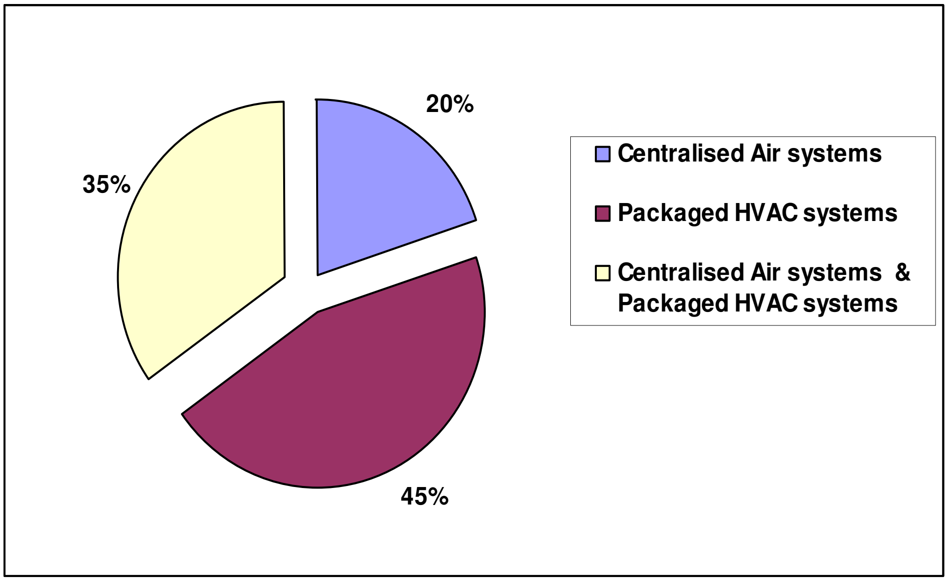
The method of load analysis is of great importance because the heating/cooling load estimation is the key determinant of equipment size. The precision of the heating /cooling load calculation is therefore highly crucial as over-estimation leads to selection of an oversized system and therefore unnecessary high amount of energy consumption. On the other hand, under-estimation of the heating /cooling load would lead to an under-sized equipment selection hence a likely HVAC system failure.

4.3.2 Types of Equipment/Equipment selection

In this research it was revealed that over 65% of the buildings visited used room conditioning units and self contained HVAC systems. Figure 4.2a and 4.2b outline the distribution and types of HVAC systems encountered in this study.

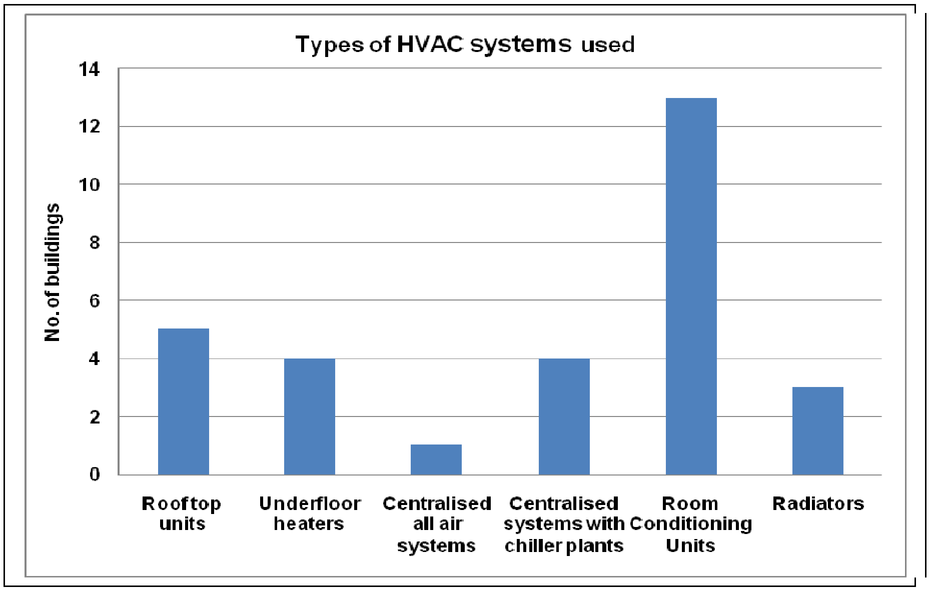
It was revealed that 45% of the buildings studied used packaged HVAC systems and that a further 35% used a mixture of packaged and centralised. Only 20% of the buildings studied used centralised HVAC systems. Further differentiations in the HVAC systems distribution appear in Figures 4.3 c and 4.3d

Figure 4.3a: Types of HVAC systems in use



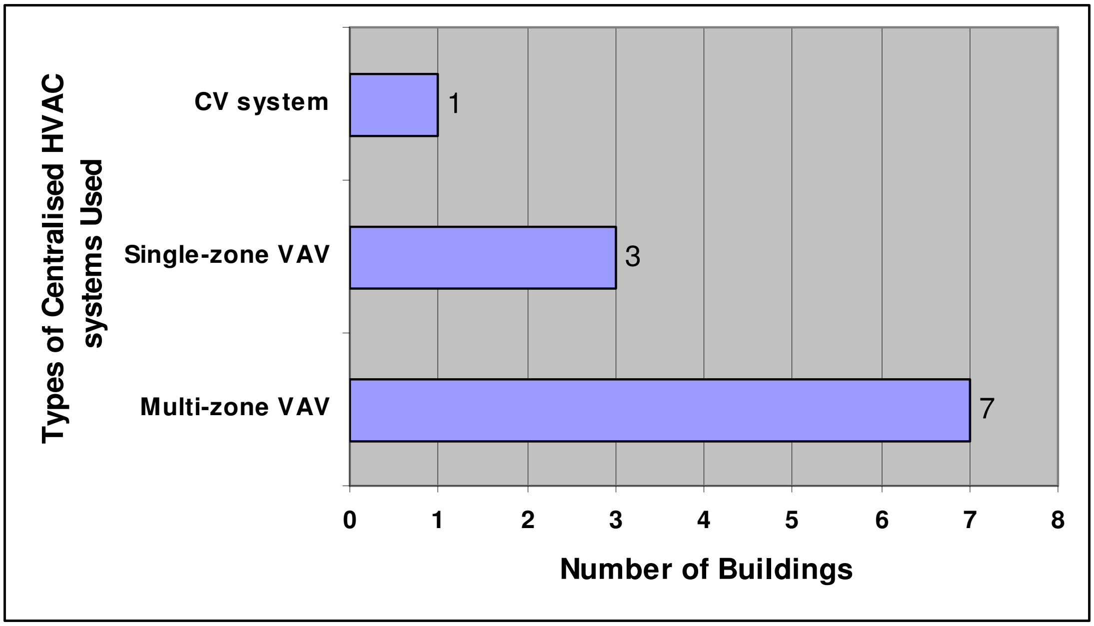
Source: Field interview, 2008

Figure 4.3b: Types of HVAC systems in use



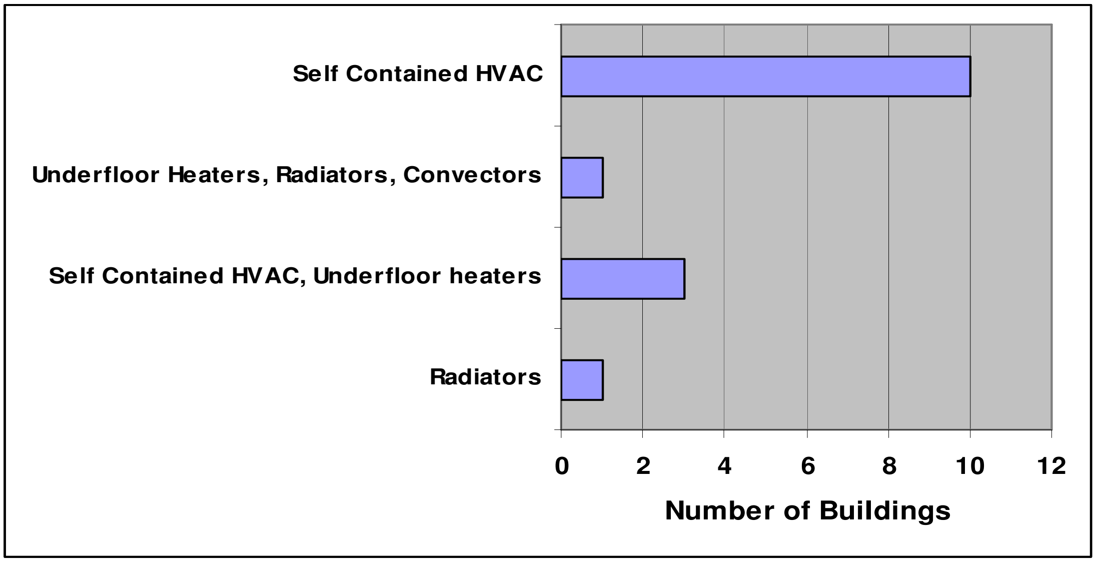
Source: Field results, 2008 (NB: There were multiple types of HVAC systems at some buildings)

Figure 4.3c: Types of Centralised HVAC system used



Source: Field interview, 2008

Figure 4 .3d Categories of Packaged HVAC systems



Source: Field interview, 2008

Details of HVAC systems observed during the study appear in Table 4.2 (Appendix B).

4.4 OPERATIONS

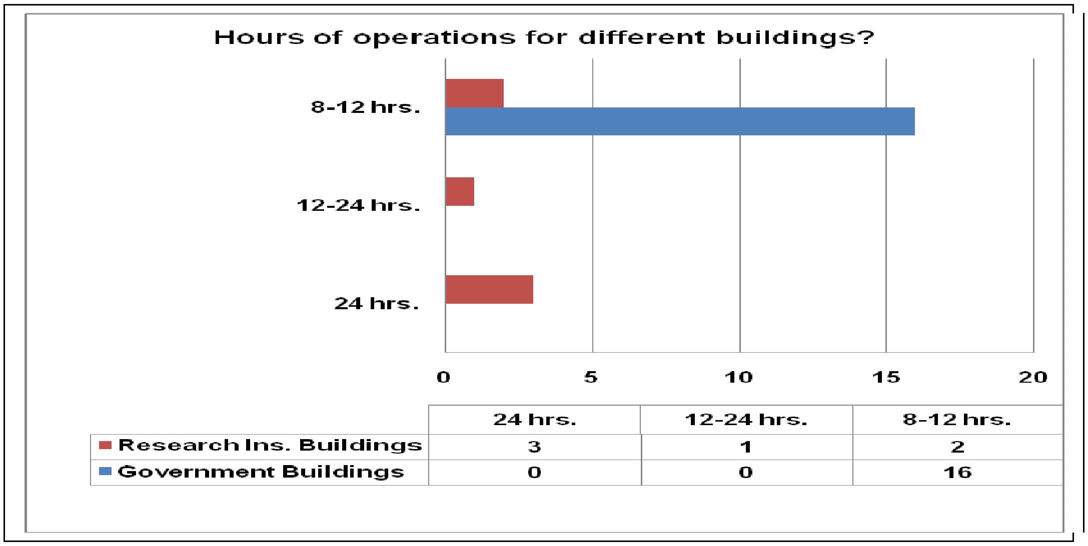
This section examines the level of occupancy and schedule of operations to find out if re-sequencing of these could improve the energy efficiency attribute of the HVAC systems studied.

4.4.1 Schedule of operations

The study revealed that in three of research buildings, HVAC systems operated 24 hours daily whereas in a further two, the HVAC systems operated for a period of between 8-12 hours daily. Only one research institution building studied had its HVAC system operating only when the occupants needed it. All the government owned buildings operated their HVAC systems 8-12 hours daily. It was also revealed that the HVAC systems in all the buildings except one were operated as long as buildings were operational. The CSIR building facility was the only one that had HVAC system operating only whenever the occupants needed it. The details of the operations schedules for the HVAC systems studied in this research are as summarised in Figure 4.4a and 4.4b.

The turning off of HVAC systems when not in use eliminates or reduces the use of energy through unnecessary conditioning, reheat losses and fan/pump operations. It therefore follows that HVAC systems should only be operated when necessary. In this regard it is advised that for buildings with regular schedule of operations, timers should be used to stop and start components (Wulfinghoff, 1999).

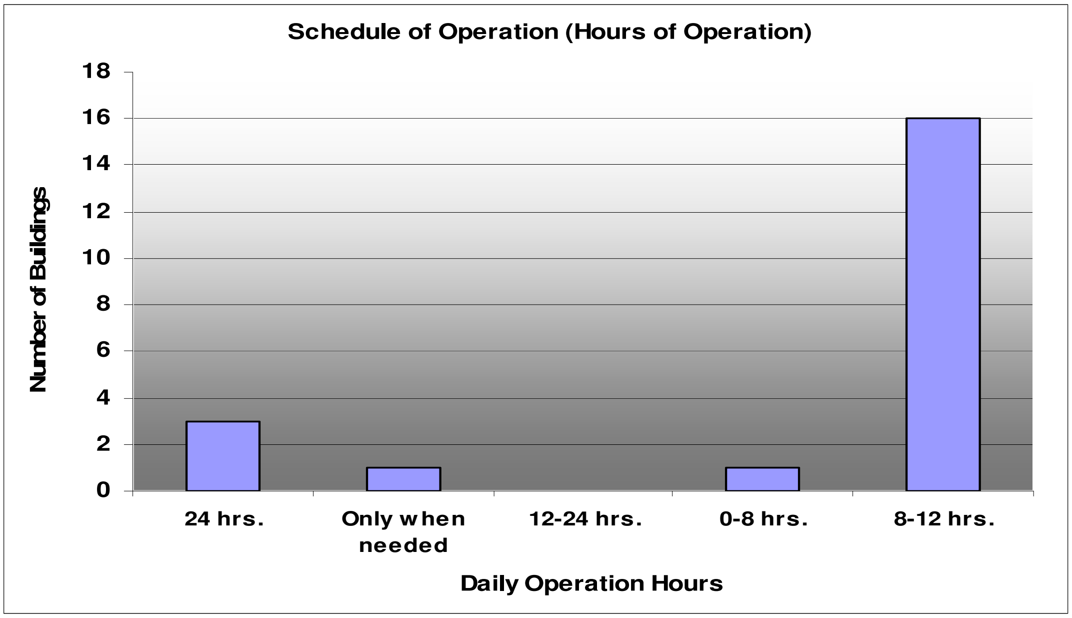
Figure 4.4a: Hours of operation & ownership details



	24 hrs.	12-24 hrs.	8-12 hrs.
🟥 Research Ins. Buildings	3	1	2
🟦 Government Buildings	0	0	16

Source: Field results, 2008

Figure 4.4b: Operation schedule

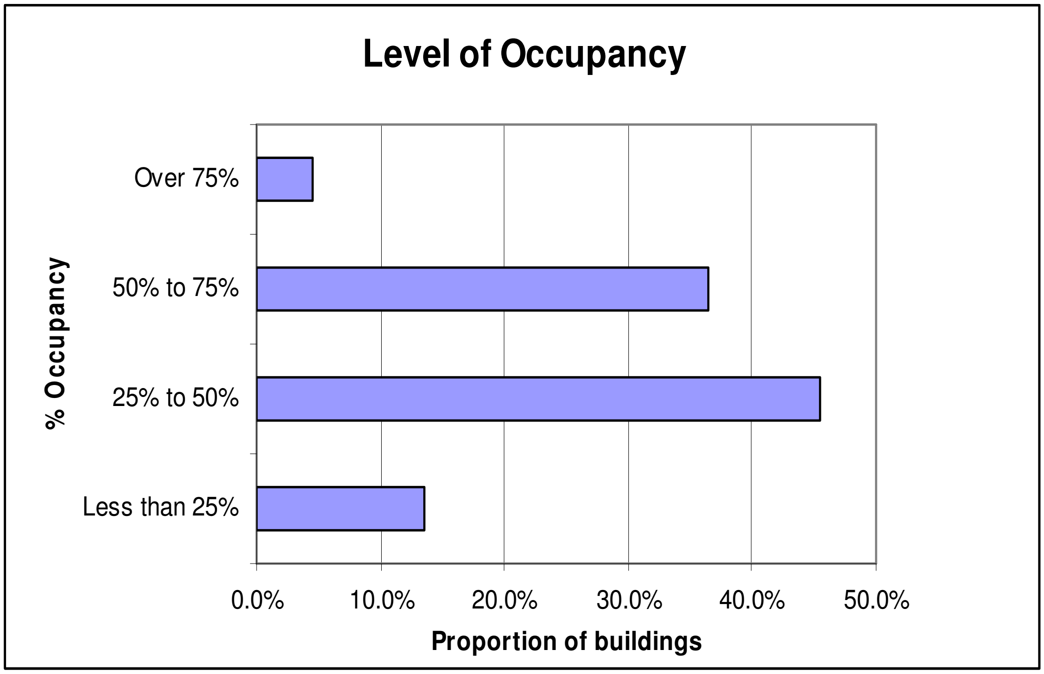


Source: Field results, 2008

4.4.2 Occupancy levels

Figures 4.4e and 4.4f illustrate the observed level of occupancy in the buildings visited. It was observed that in over half of the buildings the occupancy level was less than 50% of the optimum designed space (refer to Fig.4.4e).

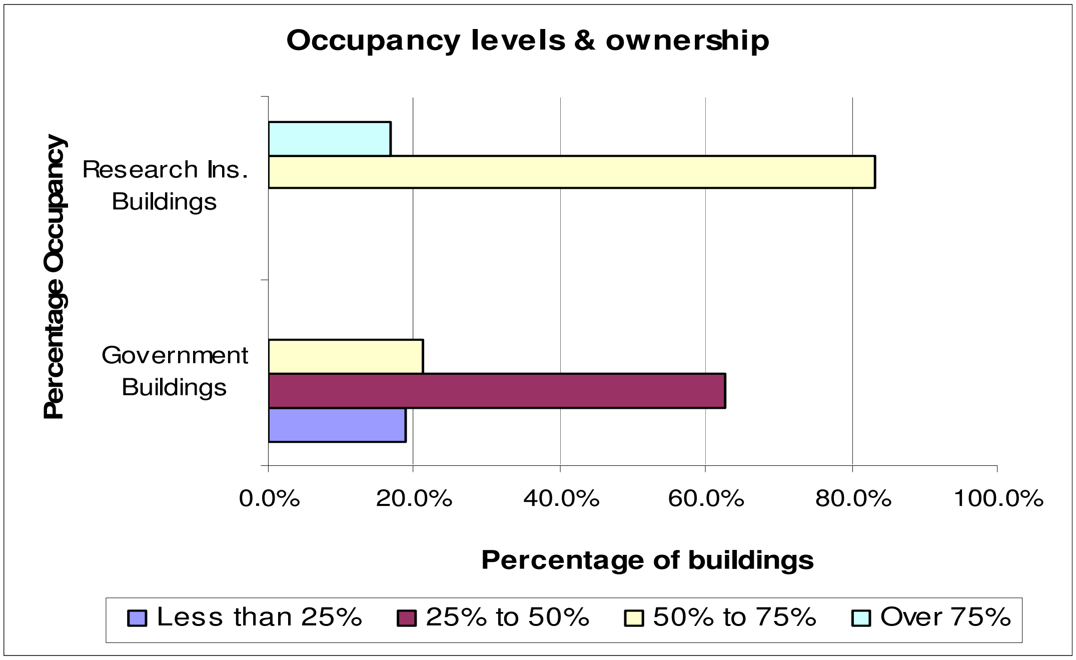
Figure 4.4 e: Occupancy levels in buildings



Source: Field results, 2008

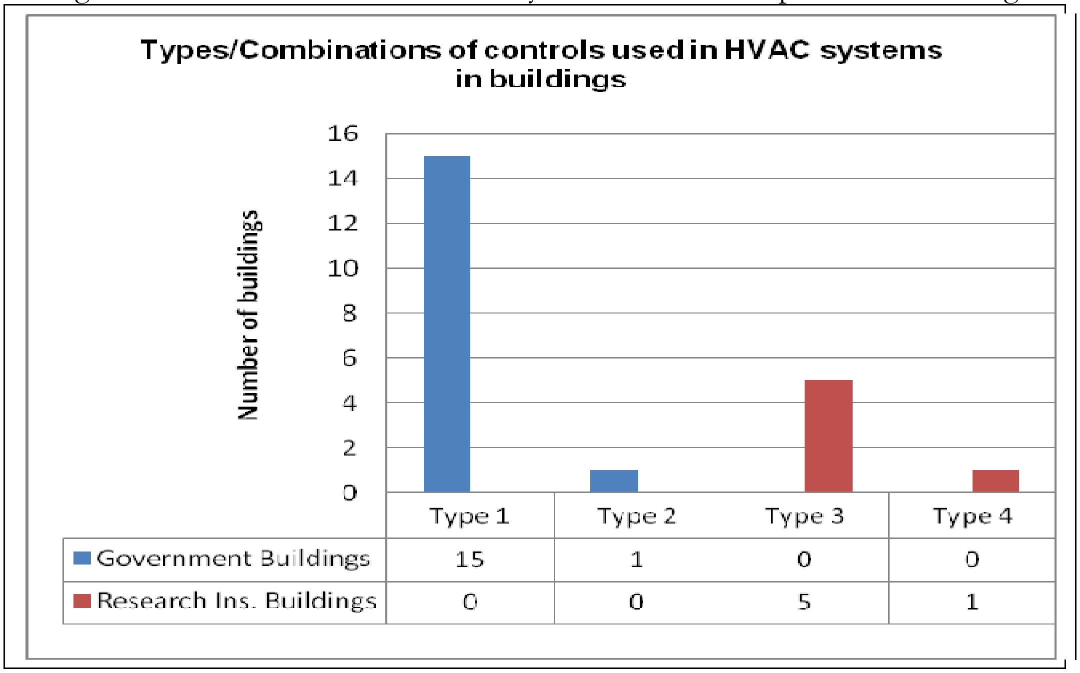
It was further revealed that occupancy level in Research Institution owned buildings were above 50% of the full capacity at all times (refer Figure 4.4g).

Fig. 4.4g: Occupancy levels & ownership category



Source: Field interview, 2008

Figure 4.5a: Combinations of HVAC systems Control components in buildings



	Type 1	Type 2	Type 3	Type 4
🟦 Government Buildings	15	1	0	0
🟥 Research Ins. Buildings	0	0	5	1

Source: Field results, 2008

4.5 CONTROLS

Fifteen government-operated buildings used classic control systems with the greatest proportion being the type 1 combination[11]. Details are as shown in Figure 4.5. Type 1 control combination allows for basic operation by manually switching the systems on and off while having a provision for operating the HVAC components on a timer based on occupancy schedules/pattern. Whereas this system is an energy saving opportunity, it allows little for personalised spaces and irregular occupancy patterns. A few government buildings used type 2[12] control combination which did not have a manual override system but which was zone-based to handle multiple room temperatures.

The research institution buildings used only type 3[13] and type 4[14] control combinations. The former allows for centralised operation of On/Off Isolator, Timer and Auto-Thermostat components whereas the later ensures individualised room operation via an On/Off Isolator, Timer, Fan Speed Controls, Temperature controls available via remote control set. This ensures not only customised room conditions but also greater opportunities for energy savings. Wulfinghoff (1999) argues that automatic controls are often better than manual controls and stresses that whenever the former are installed care should be taken to inform occupants of the working modalities of the systems. In addition flexibility should be allowed for where occupancy patterns fluctuate. This view is satisfied entirely in the type 4 control components combination which was only used in one building.

The lack of use of type 4 control component combinations is probably associated with the finesse and high costs that go with it. Another key issue investigated was familiarity of the building occupants and users with HVAC system controls. The study revealed

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[11] Type 1 control combination is composed of On/Off Isolator, Timer & Auto-Thermostat with manual over-ride

[12] Type 2 control combination is composed of On/Off Isolator, Timer & Auto-Thermostat, Zone Controls

[13] Type 3 control combination is composed of On/Off Isolator, Timer & Auto-Thermostat

[14] Type 4 control combination is Individualised system with On/Off Isolator, Timer, Fan Speed Controls, Temperature controls available via remote control set

that in all buildings visited the occupants were not fully conversant with the operations of the control systems (refer to Table 4.5). This flies in the face of the assertion that non familiarity with controls often lead to vandalism (Wulfinghoff, 1999). In this case no vandalism on the control knobs was reported in the buildings studied.

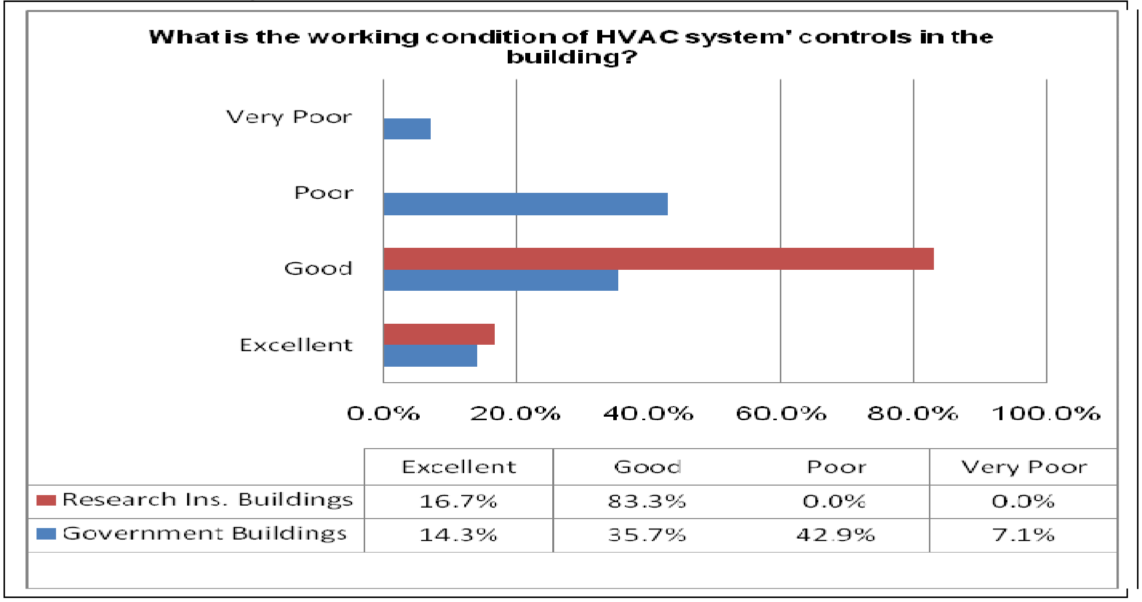
Table 4.5: Are the Occupants fully conversant or familiar with HVAC control system in the building?

Buildings Category	Response Category	
	No	Yes
Government Buildings	100%	0%
Research Ins. Buildings	100%	0%

Source: Field results, 2008

Nevertheless, it would be greatly advantageous if operators were given information on the operation of the control systems via the use of placards or office bulletins. In summary, the conditions of controls were good in the research institutions buildings but oscillated between good and poor for government buildings (refer Figure 4.5b).

Figure 4.5b: Conditions of controls in HVAC systems



	Excellent	Good	Poor	Very Poor
🟥 Research Ins. Buildings	16.7%	83.3%	0.0%	0.0%
🟦 Government Buildings	14.3%	35.7%	42.9%	7.1%

Source: Field results, 2008

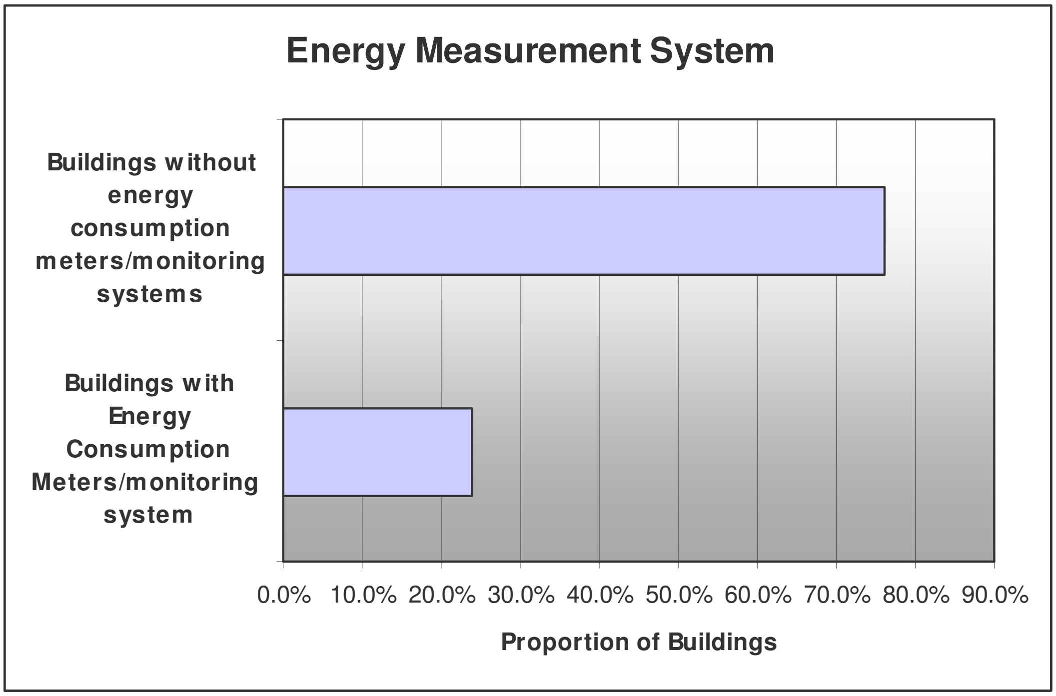
4.6 MAINTENANCE

The aspects of maintenance investigated in this section included telemetry, planning in maintenance and age of equipment or retrofits. The details follow in the next sections.

4.6.1 Measurement and Monitoring

A crucial task in energy saving, or conservation or efficiency practices for Facility Managers and Engineers is normally a measurement of the amount of energy consumed by building equipment. The study revealed that close to a quarter of the buildings had energy consumption measurement systems in place. Further inquiry established that even where the energy measurement system was in place, the meters were rarely read and the idea was as recent as the electricity supply crisis in the country. Figures 4.65a and 4.6b illustrates the results in details.

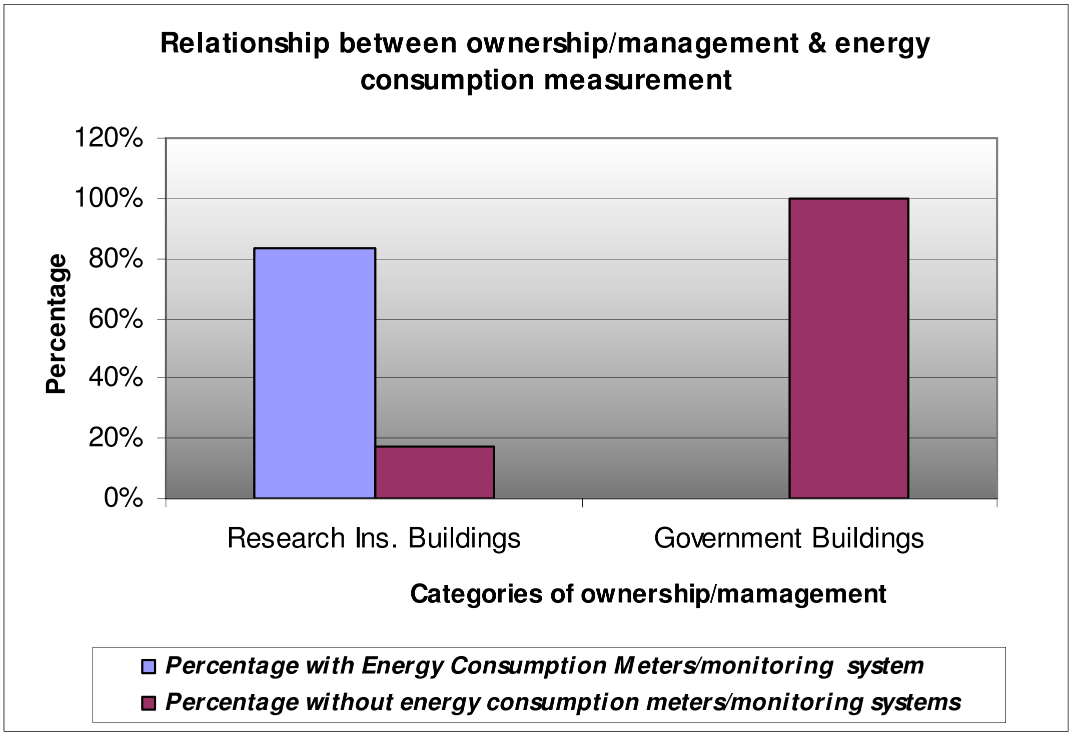
Figure 4.6a: Buildings with Energy Measurement Systems in Place



Source: Field results

It should also be noted that all the buildings with energy measurement systems in place were those managed by Research Institutions (Wits University). It was further noted that at the time of research the meters were barely 8 months old and the actual readings were unknown to the Facilities Managers in the institutions. Attempts to acquire the measured consumption was unsuccessful.

Figure 4.6b: Buildings with Energy Measurement Systems in Place Showing Ownership details

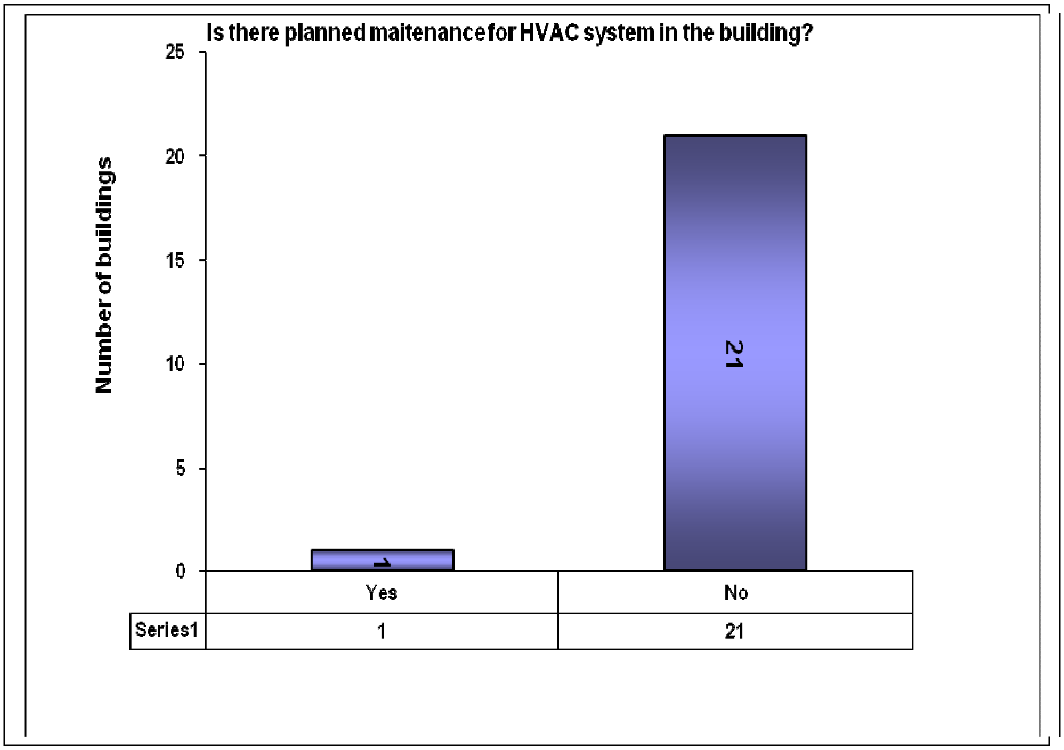


Source: Field interview, 2008

4.6.2 Maintenance Planning

The research revealed that there were no planned maintenance services for HVAC systems in any building except one (refer to Figure 4.6c). Further inquiry revealed that the reasons for lack of planned maintenance services for HVAC systems included lack of adequate financial allocation, insufficient manpower and ignorance. The HVAC systems in the buildings were only repaired when they became faulty or less efficient. In the buildings in the research institutions, maintenance and repair services were mainly outsourced and the skeletal staff available presided over the management aspect of the job. In government-owned buildings the repair and maintenance work were the responsibility of the staff provided by the government.

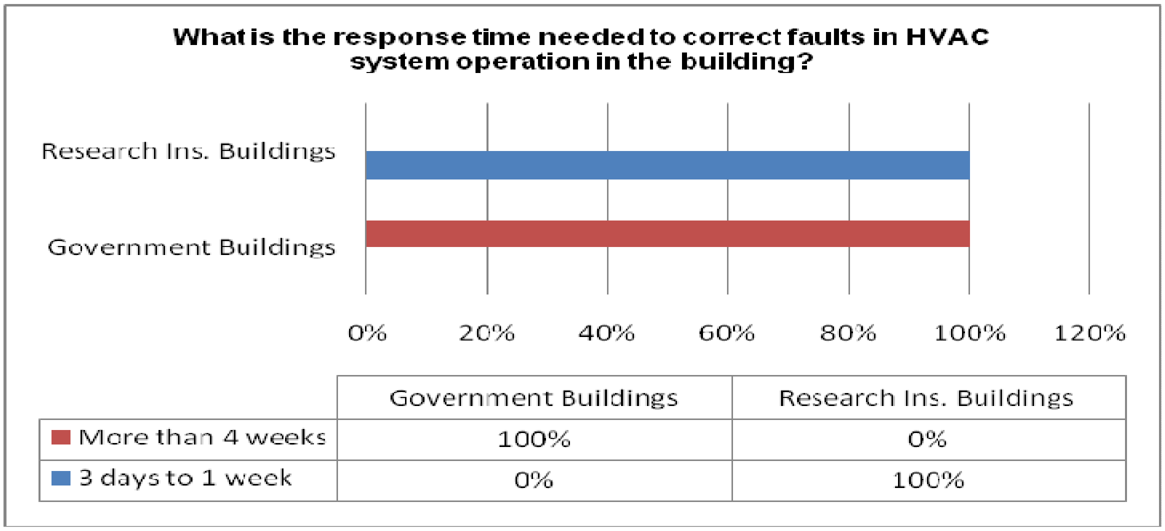
Figure 4.6c: Planned Maintenance service for HVAC systems in buildings



Source: Field results, 2008

Further evidence of interesting maintenance tendencies are in the fact that in all the centralised systems installations no duct cleaning had been undertaken since installation of the systems. Eighty percent of the centralised HVAC systems had duct works with possible leakage; this further underlined the prevailing poor maintenance practices in public buildings. The case for maintenance management is even worsened by the fact that the government buildings tend to have unreasonably long response time to correct defects in the systems (over 4 weeks) and that correction depended on availability of funds and was not automatic (refer to Figures 4.6d and 4.6e). This led to a situation whereby a number of buildings managed by government had their HVAC systems faulty.

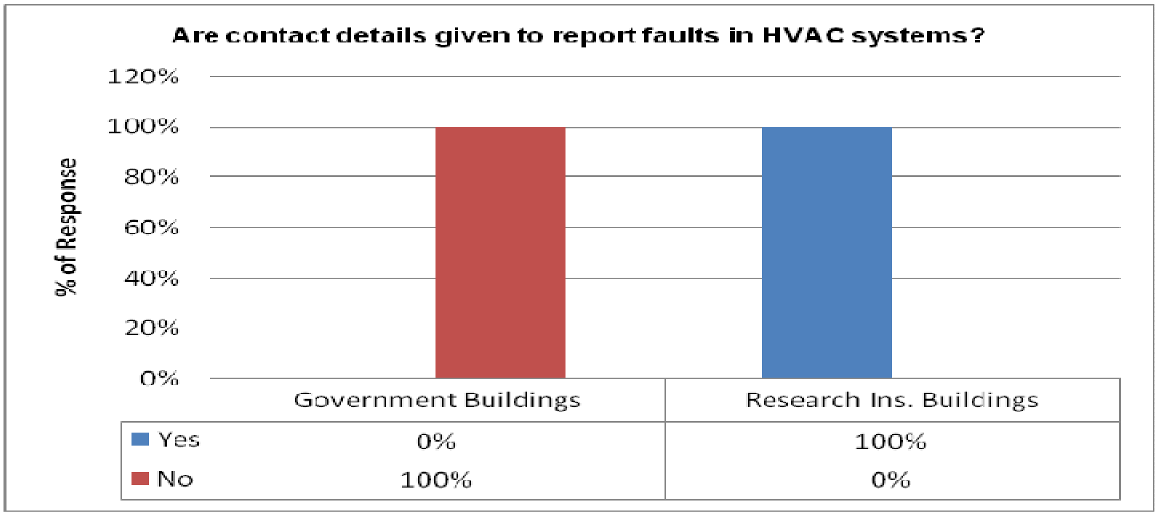
Figure 4.6d: Response time to correct faults



	Government Buildings	Research Ins. Buildings
🟥 More than 4 weeks	100%	0%
🟦 3 days to 1 week	0%	100%

Source: Field results, 2008

Figure 4.6e: contact details for reporting faults in systems



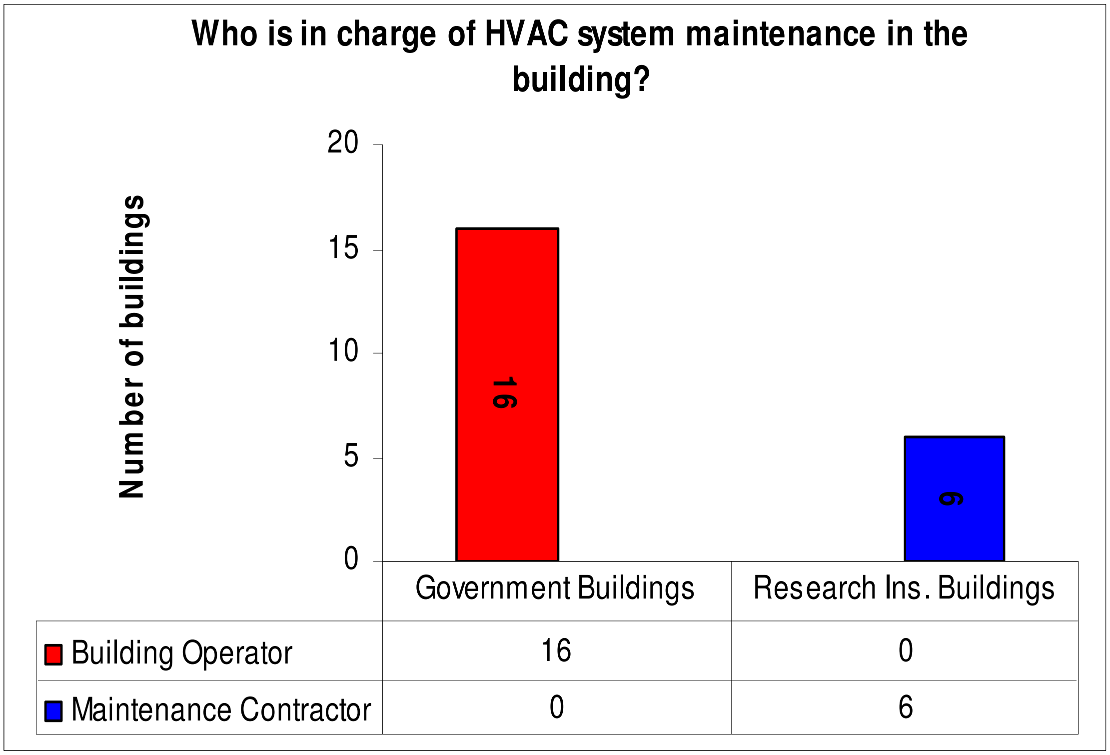
	Government Buildings	Research Ins. Buildings
🟦 Yes	0%	100%
🟥 No	100%	0%

Source: Field interview, 2008

Additionally, it was discovered that the government-owned buildings did not have publicly visible guidelines for users to report faults in the system. On the other hand, in the research institutions buildings placards were used to advise occupants to report malfunctions in the building elements. This ensured a reliable feedback mechanism necessary for successful maintenance.

It was also observed that the responsibility for the maintenance of HVAC systems in the research institution buildings was entirely outsourced to contractors with specific skilled staff being in-charge of works supervision (refer to Figure 4.6f). The contractors were on a list of institution-preferred vendors; these contractors were always called whenever required for reactive maintenance duty by the institutions.

Figure 4.6f: HVAC Maintenance Responsibility



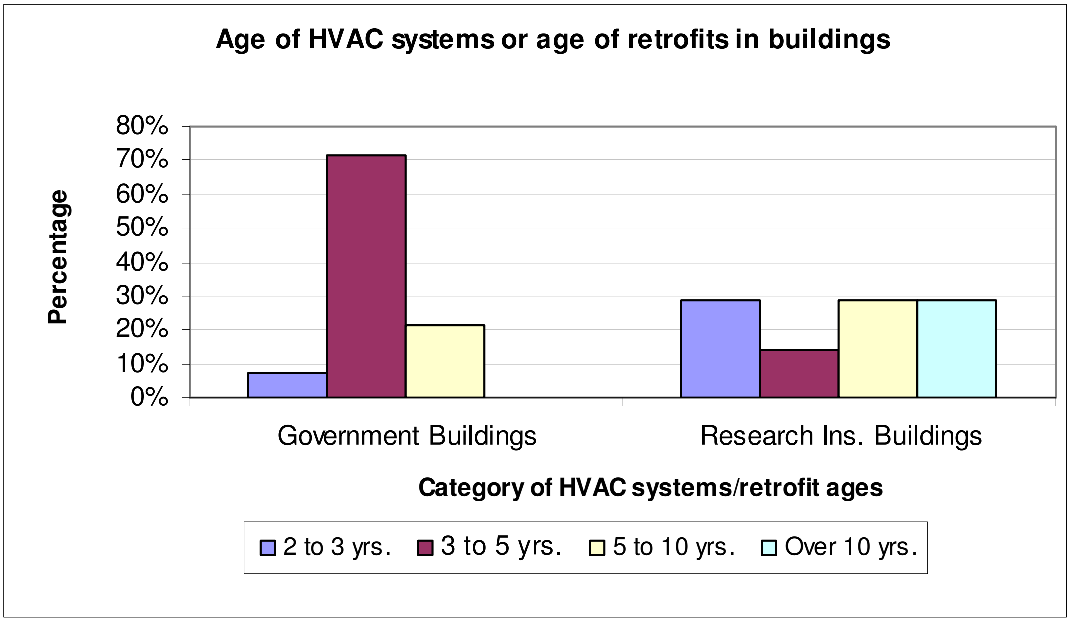
	Government Buildings	Research Ins. Buildings
🟥 Building Operator	16	0
🟦 Maintenance Contractor	0	6

Source: Field results, 2008

4.6.3 Age of equipment/retrofits

Figure 4.6i illustrates the age of categories for HVAC systems studied in this research. In cases where the HVAC systems had retrofits, the equipment age was taken as the age of the retrofits.

Figure 4.6i: Age of HVAC systems/age of retrofits



Source: Field Results

It was found that government buildings operated relatively new HVAC systems compared to the research institutions. This could be explained by the fact that in a number of government buildings visited. Most HVAC systems were installed as an afterthought or as later improvements in buildings (these include Vosloorus, Thokoza, Edenpark, Spruitview, Katlehong, Zonkizizwe and Reigerspark). Even government buildings with old HVAC systems had retrofits undertaken in them in the last 10 years.

4.7 INSTALLATION AND COMMISSIONING

The key issues examined in this section were improper installation and due commissioning. Discussions on this appear below.

Improper installation

Interview with the liaison in-charge at Ekurhuleni Metropolitan Library revealed that certain HVAC installations (in particular the HVAC systems at Isaac Mokoena, Spruitview, Zonkizizwe) were improperly installed and never operated for a long time after the handed over of the facilities. This forced the management to install the room conditioning units which are currently operational in the buildings.

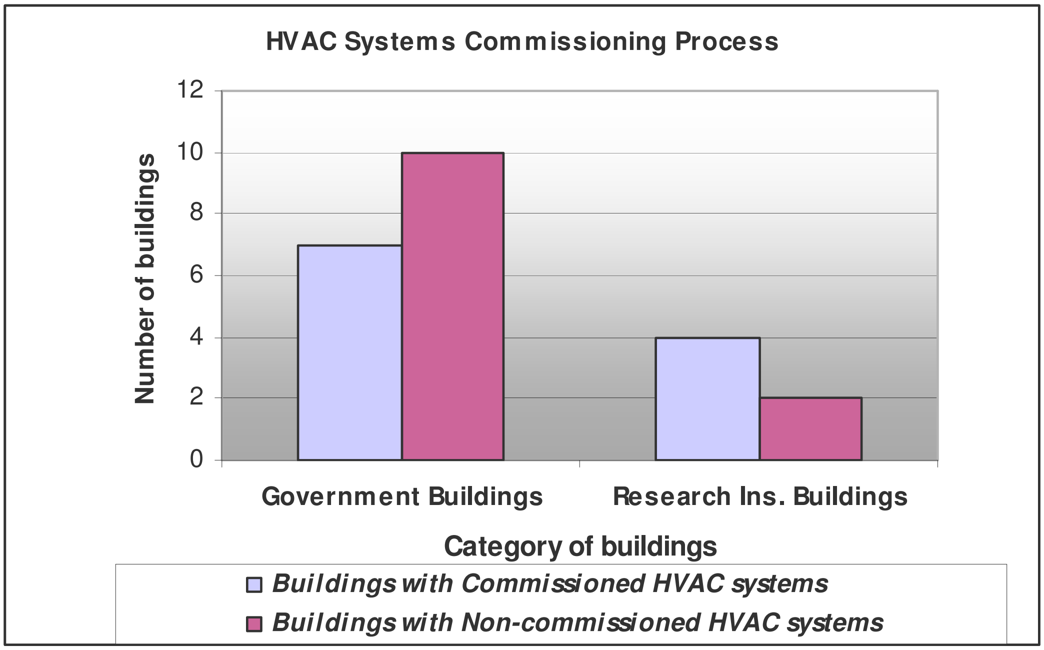
The Reigerspark facility (Ekurhuleni Metropolitan Library) however had a slightly different type of improper installation. In this case the room conditioning units were all installed on one side of the reading hall leading to the issue of poor positioning of equipment in facilities. Ideally the HVAC units would have been uniformly distributed in the building.

Concerning radiators/element heaters it was revealed that the installations at John Moffat building were often positioned below the curtains leading to a situation whereby the heated air was easily ventilated out of the window. Wulfinghoff (1999) articulates that where element heaters are used, the heated air must be away from the window and directed towards the centre of the room.

Commissioning

The study revealed that HVAC systems in a substantial number of buildings were not duly commissioned. These were 10 Government Buildings and 2 Research Buildings. The due commissioning process required proper documentation, maintenance manuals and hand over notes available to the building operators before the initial operation. Details of buildings with Commissioned HVAC systems are presented in Figure 4.7a.

Fig. 4.7a: Commissioning of HVAC systems



Source: Field interview, 2008

4.8 BASE EFFICIENCY AND OPTIMISATION FOR ENERGY

In an effort to classify the HVAC systems in buildings as either energy-inefficient, achieving base energy efficiency or optimally energy–efficient, the assessments were based on the criteria described in section 3.5. At the end of award of points, any HVAC system achieving a weighted score of 6 points was deemed as having attained the base energy efficiency, a weighted score of less than 6 was deemed inefficient whereas a weighted score of 7 to 12 was categorised as optimally energy-efficient. Tables 4.8a to 4.8f illustrate the scores resulting from evaluation of efficiency levels and optimisation possibilities in this study.

Table 4.8a: Evaluation details of management issues

Site/Building	Evaluation Points Awarded					
	PC	AP	EM	EB	EC	Wt. Mean
Leandale	0	0	0	0	0	0
Vosloorus	0	0	0	0	0	0
Edenpark	0	0	0	0	0	0
Thokoza	0	0	0	0	0	0
Spruitview	0	0	0	0	0	0
Elsburg	0	0	0	0	0	0
Boksburg	0	0	0	0	0	0
Germiston	0	0	0	0	0	0
Dinwiddie	0	0	0	0	0	0
Katlehong	0	0	0	0	0	0
Isaac Mokena	0	0	0	0	0	0
Zonkizizwe	0	0	0	0	0	0
Reigerpark	0	0	0	0	0	0
Brackenhurst	2	0	0	0	0	0.40
Alberton	0	0	0	0	0	0
Palm Ridge	0	0	0	0	0	0
CSIR Building 2	2	1	0	1	2	1.2
William Cullen	0	1	1	0	1	0.6
Wartenweiller	0	1	2	0	1	0.8
John Moffat	0	1	0	0	1	0.4
Edu-Com	0	1	0	0	1	0.4
Donald Gordon	0	1	0	0	1	0.4

Key

PC: Conversance of public with systems;

AP: Placards for operation/fault reporting

EM: Assignment of responsibility for energy management

EB: Energy Budget;

EC: Energy Conservation

Source: Field Results, 2008

Table 4.8b: Design philosophy evaluation

Site/Building	Design Philosophy Evaluation
Leandale	0
Vosloorus	0
Edenpark	0
Thokoza	0
Spruitview	0
Elsburg	0
Boksburg	0
Germiston	0
Dinwiddie	0
Katlehong	0
Isaac Mokena	0
Zonkizizwe	0
Reigerpark	0
Brackenhurst	0
Alberton	0
Palm Ridge	0
CSIR Building 2	0
William Cullen	0
Wartenweiller	0
John Moffat	0
Edu-Com	0
Donald Gordon	0

Source: Field Results, 2008

Table 4.8c: Evaluation details of operations schedule

Site/Building	Operations Schedule Evaluation
Leandale	0
Vosloorus	0
Edenpark	0
Thokoza	0
Spruitview	0
Elsburg	0
Boksburg	0
Germiston	0
Dinwiddie	0
Katlehong	0
Isaac Mokena	0
Zonkizizwe	0
Reigerpark	0
Brackenhurst	0
Alberton	0
Palm Ridge	0
CSIR Building 2	2
William Cullen	1
Wartenweiller	1
John Moffat	1
Edu-Com	1
Donald Gordon	1

Source: Field Results, 2008

Table 4.8d Evaluation Details for Controls

Site/Building	Evaluation Points		
	Control Type	Occupants' Conversance	Wt. Mean
Leandale	1	0	0.5
Vosloorus	1	0	0.5
Edenpark	1	0	0.5
Thokoza	0	0	0
Spruitview	1	0	0.5
Elsburg	1	0	0.5
Boksburg	1	0	0.5
Germiston	0	0	0
Dinwiddie	1	0	0.5
Katlehong	0	0	0
Isaac Mokena	0	0	0
Zonkizizwe	1	0	0.5
Reigerpark	1	0	0.5
Brackenhurst	1	0	0.5
Alberton	0	0	0
Palm Ridge	0	0	0
CSIR Building 2	2	0	1
William Cullen	1	0	0.5
Wartenweiller	1	0	0.5
John Moffat	1	0	0.5
Edu-Com	1	0	0.5
Donald Gordon	1	0	0.5

Source: Field Results, 2008

Table 4.8e: Evaluation details of maintenance

Site/Building	Evaluation Points						
	EMM	MP	RT	CD	MR	AG	Wt. Mean
Leandale	0	0	0	1	1	1	0.5
Vosloorus	0	0	0	1	1	2	0.67
Edenpark	0	0	0	1	1	2	0.67
Thokoza	0	0	0	1	1	2	0.67
Spruitview	0	0	0	1	1	2	0.67
Elsburg	0	0	0	1	1	2	0.67
Boksburg	0	0	0	1	1	1	0.50
Germiston	0	0	0	1	1	2	0.67
Dinwiddie	0	0	0	1	1	2	0.67
Katlehong	0	0	0	1	1	2	0.67
Isaac Mokena	0	0	0	1	1	2	0.67
Zonkizizwe	0	0	0	1	1	2	0.67
Reigerpark	0	0	0	1	1	2	0.67
Brackenhurst	0	0	0	1	1	2	0.67
Alberton	0	0	0	1	1	1	0.50
Palm Ridge	0	0	0	1	1	2	0.67
CSIR Building 2	0	2	2	1	2	2	1.50
William Cullen	1	1	2	2	2	1	1.50
Wartenweiller	1	1	2	2	2	2	1.67
John Moffat	1	1	2	2	2	1	1.5
Edu-Com	1	1	2	2	2	2	1.67
Donald Gordon	1	1	2	2	2	2	1.67

Key
EMM: Energy Measurement & Monitoring
MP: Maintenance Planning
RT: Response time in correcting faults;
CD: Contact Details for reporting faults
MR: Maintenance responsibility;
AG: Age of equipment

Source: Field Results, 2008

Table 4.8f: Evaluation details of installation and commissioning

Site/Building	Evaluation Points		
	Installation	Commissioning	Wt. Mean
Leandale	1	1	1
Vosloorus	1	0	0.50
Edenpark	1	1	1
Thokoza	1	0	0.50
Spruitview	0	0	0
Elsburg	1	0	0.50
Boksburg	1	1	1
Germiston	1	1	1
Dinwiddie	1	0	0.50
Katlehong	1	0	0.50
Isaac Mokena	0	0	0
Zonkizizwe	0	0	0
Reigerpark	0	0	0
Brackenhurst	1	1	1
Alberton	1	1	1
Palm Ridge	1	0	0.50
CSIR Building 2	2	2	2
William Cullen	1	0	1
Wartenweiller	1	1	1
John Moffat	0	0	0
Edu-Com	1	1	1
Donald Gordon	1	1	1

Source: Field Results, 2008

4.9 SUMMARY OF FINDINGS

Twenty two buildings were studied in this research. Of these sixteen were categorised as government-owned while the rest were considered research institution owned. The buildings studied were mainly used for library purposes; other uses also included entertainment, parking and office space. Findings generally revealed HVAC systems in selected existing public buildings to be hampered by practices which do not encourage energy efficiency in their management, design, operations, control systems, maintenance, installation and commissioning. The sections (4.9.1 to 4.9.8) present summarised findings for the study.

4.9.1 Management

Only two buildings studied had staff assigned with the task of energy management of all building systems (including HVAC). This implied that even if the management were aware of energy efficiency or conservation they were yet to get their act in order. In summary, it appeared that energy consumption planning was lacking at the facilities visited. Concerning budgeting, only one building had a cost-based energy consumption budget, revealing once more poor energy consumption planning and by extension, poor understanding of the urgent need for energy efficiency in buildings.

It is worth noting that even this building did not have a specific budget allocated to the energy consumption of HVAC systems. It should be noted that all government buildings studied as opposed to those owned by the research institutions did not have energy conservation programs in place. This could have been due to general lethargy associated with implementation policies by the government.

4.9.2 Design

Even though the TDV method is touted as most viable, there is persistent presence of the conventional/mixing method, possibly because of unfamiliarity with the former.

There was predominant use of room conditioning in facilities visited. This could be attributed to their economical use of space and ease of installation and operations, especially where HVAC system planning was not originally part of the building or where the main system has failed. This was demonstrated by its use in facilities at William Cullen (Wits University) and Reigerspark, Zonkizizwe, Spruitview, Vosloorus, Edenpark, Thokoza, Katlehong and Isaac Mokoena (Ekurhuleni Metropolitan Municipality).

4.9.3 Operations

It was revealed that even though the occupancy levels fluctuated in all instances, the operation of the HVAC systems were never sequenced to optimally operate with occupancy levels. This ensured the HVAC systems were always operated at peak capacity even when the function was not demanded.

4.9.4 Controls

Most control systems used in the HVAC systems in the facilities visited performed only the basic purpose of isolating them from electricity supply. This led to a situation whereby energy efficiency was not integrated into the HVAC control system.

4.9.5 Maintenance

Continuous monitoring and measurement of energy consumption and other performance based attributes of HVAC systems was generally lacking. Where available the systems were left unattended as was the case of the meters installed in facilities at the University of the Witwatersrand. This denied the Facility Managers the opportunity to fine-tune systems for continuous improvement in energy efficiency.

The maintenance system was generally reactive and unplanned, leading to a situation whereby HVAC systems could operate inefficiently and consume additional energy unnecessarily. In addition, the response time taken to repair faults or malfunctions in government facilities took longer in comparison with research institutions ones.

This again betrayed possible waste of energy while this equipment continued operation. It was also revealed that over 50% of the research institutions buildings operated HVAC systems which were over 5 years old (close to 30% of these were over 10 years old). This gave evidence of reduced energy efficiency in them, taken that the lifespan of HVAC systems is conventionally assumed to be 15 years.

4.9.6 Installation and Commissioning

Improper installation was noticed in isolated facilities[15] with regards to the positioning of HVAC equipment. In total twelve facilities had cases of improper commissioning.

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[15] These were at John Moffat and Reigerspark buildings

Table 4.9 Rating for optimisation of energy

Site/Building	Weighted Means for Energy Efficiency Attributes' Category						
	MGT	DSN	OPN	CON	MTN	I&C	Total
Leandale	0	0	0	0.50	0.50	1	2
Vosloorus	0	0	0	0.50	0.67	0.50	1.67
Edenpark	0	0	0	0.50	0.67	1	2.17
Thokoza	0	0	0	0	0.67	0.50	1.17
Spruitview	0	0	0	0.50	0.67	0	1.17
Elsburg	0	0	0	0.50	0.67	0.50	1.67
Boksburg	0	0	0	0.50	0.50	1	2
Germiston	0	0	0	0	0.67	1	1.67
Dinwiddie	0	0	0	0.50	0.67	0.50	1.67
Katlehong	0	0	0	0	0.67	0.50	1.17
Isaac Mokena	0	0	0	0	0.67	0	0.67
Zonkizizwe	0	0	0	0.50	0.67	0	1.17
Reigerpark	0	0	0	0.50	0.67	0	1.17
Brackenhurst	0.40	0	0	0.50	0.67	1	2.57
Alberton	0	0	0	0	0.50	1	1.50
Palm Ridge	0	0	0	0	0.67	0.50	1.17
CSIR Building 2	1.20	0	2	1	1.50	2	7.70
William Cullen	0.60	0	1	0.50	1.50	1	4.60
Wartenweiller	0.80	0	1	0.50	1.67	1	4.97
John Moffat	0.40	0	1	0.50	1.50	0	3.40
Edu-Com	0.40	0	1	0.50	1.67	1	4.57
Donald Gordon	0.40	0	1	0.50	1.67	1	4.57

Key

MGT: Management
DSN: Design
OPN: Operation
CON: Controls
MTN: Maintenance
I&C: Installation and Commissioning

Source: Field Results, 2008

4.9.7 Optimisation for Energy

Only HVAC system in one facility managed to surpass the base energy efficiency level (this was CSIR Building 2 which managed a weighted mean of 7.70 points out of a maximum of 12 points). The facility having the least energy efficiency rating was Isaac Mokoena at 0.67 weighted mean total followed by Thokoza, Spruitview, Katlehong, Zonkizizwe, and Palmridge at 1.17 point. None of the studied facilities could be rated as having achieved the base efficiency requirement. Details of these appear in Table 4.9 (ratings are for optimisation of energy).

Table 4.9 b: Percentiles

Percentile	Smallest Measure	Largest Measure
1%	0.67	0.67
5%	1.17	1.17
10%	1.17	1.17
25%	1.17	1.17
50%	1.67	-
75%	3.40	4.57
90%	4.60	4.60
95%	4.97	4.97
99%	7.70	7.70

Table 4.9c: Measures of variability

Description	Measure
Mean	2.47
Standard Deviation	1.76
Variance	3.11
Skewness	1.47
Kurtosis	4.54

Table 4.9b and 4.9c give the percentiles of the distribution and the measures of variability respectively.

Figure 4.8: Box Plot for the distribution

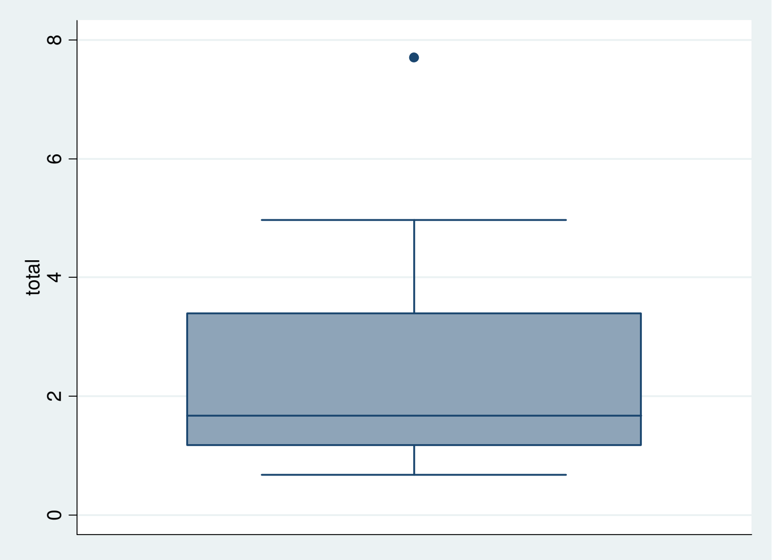
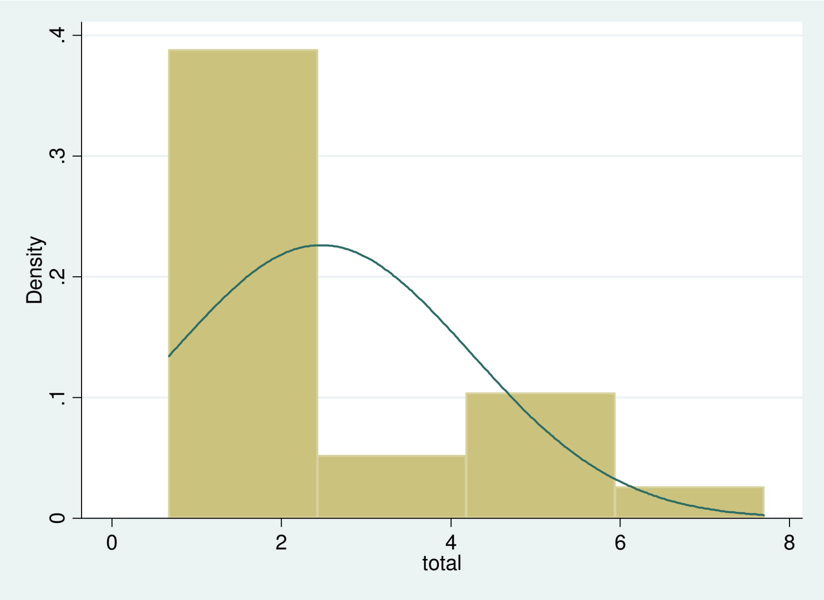


Figure 4.9: Histogram plot



Figures 4.8 and 4.9 give illustrative plots of box distribution and histogram for the weighted totals in study.

CHAPTER 5: ANALYSIS

5.1 INTRODUCTION

This chapter discusses the findings of the study. The sections are thematically structured under the headings management, design, operations, controls, maintenance, installation and commissioning.

Different types of HVAC systems available in the studied facilities and respective current states are described, followed by an analytical look at their optimisation for energy purposes. In general, this chapter explains the reason behind the low energy-efficiency of HVAC systems revealed in chapter 4, while also offering prescriptive insights on emerging themes.

5.2 MANAGEMENT

The main issues explored included ownership of buildings, use of buildings, and accountability for energy management, budgeting for energy consumption and conservation programmes. Details appear in the sections below.

5.2.1 Ownership of buildings

Earlier, literature showed that property owners and tenants play a key role in the implementation of energy efficiency measures as that they are the ones who pay utility bills and have the onus to decide on project investments (Wilkinson and Reed, 2006). In this regard, the government agencies and research institutions, as owners of the buildings, need to streamline their facilities management systems to ensure that energy efficiency issues are handled in a simplified and faster manner. This may be difficult considering that optimisation in HVAC systems could involve retrofits or equipment upgrades, hence high capital inputs. The standard procedure would be procurement and hence a long procurement process which is affected by initial cost of the bids, affirmative action and possible in-competence in energy-efficiency or projected savings presented in the bids (World Energy Council, 2008; Wiel, 1991). The concept of energy performance contracting (and hence selected bidding to prequalified companies) with emphasis on life-cycle costs and energy savings as suggested by World Energy Council (2008) and Sardianou (2008) may mean very high capital costs. However the silver lining is in the energy savings over the total life cycle of the building.

5.2.2 Use of Building

Taken that buildings, like any other engineered products, are purpose-made to fit the client's requirements, it automatically follows that those allowing public access or which are subjected to heavy usage must have HVAC systems that can cope with use and abuse. The government owned buildings studied had occupants who were illiterate and uninformed on HVAC systems operations. In addition, they had no idea on how to report system malfunctions. This is contrary to the best practice for energy efficiency that envisages clearly visible placards explaining the details of operations and giving contact details of the staff to report malfunctioning of the HVAC systems to (Wulfinghoff;1999).

5.2.3 Accountability for energy management

Lack of planning for energy management was evident in the buildings visited taking into account that only two of the buildings studied had operators held accountable for energy management. The optimisation of HVAC systems needs deft management of human behaviour and general administration of the programme. This service may either be outsourced or performed in-house as suggested by Bream (1986). Whichever method chosen, somebody must be appointed to be responsible for energy management. The key issue would be to formulate and implement an energy management programme. In the cases studied, the best option for the government-owned buildings may be to train the existing Building Operators (Custodian Librarians and Janitors and Parking

Attendants) to manage the buildings. For the Research Institution buildings studied it may be prudent to expand the scope of facilities management supervisors to include energy management.

5.2.4 Energy Consumption Budget

Bream (1986) is categorical that finance is the backbone of the successful implementation of an energy saving programme. As such, a firm budget for energy consumption is a sure way towards optimisation of HVAC systems. This is based on the premise that it allows for benchmarking the actual consumption. The fact that only one building had a vague budget in place effectively implies that the Facilities Managers in both research institutions and government-owned buildings are ill-informed and ill-prepared to tackle the issue of energy efficiency. Olofsson *et al.* (2004) underline the importance of budgeting, by assertion that whether negotiated, statistical-based or life-cycle based, the energy consumption budget forms a key role in the assessment of energy-efficiency performance of buildings. The cases studied would best be budgeted for by reaching a budget based on statistical comparisons with previous energy billings.

5.2.5 Energy conservation

Only six out of twenty two buildings had energy conservation measures in place (all the six buildings were those managed by research institutions). This trend is worrying, considering the electricity supply situation in South Africa. This could be due to the fact that government procedures are highly bureaucratic and "innovative" ideas in management take long to hatch into reality.

A typical energy conservation activity would involve capital investment, improvements in operation of the plant equipment, improvement in general housekeeping and an effective management of information (Talbot, 1986). In this study, all the elements of energy conservation activity were generally lacking in government buildings. It should be taken into account that energy conservation programmes may be a low-capital or high-capital venture. The former is however the most alluring for both research institutions owned and government buildings. Low-capital investment energy-conservation measures entail readjusting the operating conditions like space air-temperature, air-supply velocity, chilled-water temperatures among others, and the resetting of operating conditions to match seasonal changes and peak or off-peak situations and a reduction in operation time (Fong *et al.*, 2003). It is conceiveable that conservation practices may be best achieved by training and motivation of the building occupants and operators (Librarians and Attendants).

5.3 DESIGN

The realm of energy-efficiency of existing buildings HVAC system design is important as it affects the method of analysis/design philosophy and type of equipment used. These aspects are discussed below.

5.3.1 Design Philosophy & methods of load analysis

All the buildings studied employed conventional/mixing technique in their HVAC systems design. This could be attributed to the a number of factors including: *first* the buildings were designed and built when the TDV technique was still in its infancy, *second* even buildings which were refurbished or retrofitted in recent years did not use TDV technique because of the grey areas in modelling load capacity, and lastly engineering standards do not accommodate the TDV method (Lunneburg, 2003).

The non usage of TDV denies an opportunity to rake in an energy savings potential in the range of 22% to 45%, depending on the climate and type of equipment operated (Roth *et al.*, 2002; Lunneburg, 2003 and Massachusetts Institute of Technology, 1999). Considering that the TDV is not integrated in the design manuals and standards of the HVAC system, it is important that more refined studies be undertaken to ensure that the benefit of its use is harnessed.

5.3.2 Types of Equipment/Equipment selection

Room conditioning units

Room conditioning units are easy to install and operate where the building initially did not allow for mechanical ventilation, heating and air conditioning, so they were a natural choice for the most of the government buildings studied. Another reason explaining the use of room conditioning system was the fact that they tended to be easier to replace where aged equipment (mostly air handling system) had failed. In addition, room conditioning units offer personalised control systems and therefore are a natural choice for spaces like offices and reading rooms (Wulfinghoff, 1999).

It should be further noted that the building occupancy rate is very low and that as the design offers several clusters of reading rooms per facility, the Facility Manager could implement a system whereby the few visitors are hosted in particular rooms at full capacity while the HVAC system in the unused spaces is shut down. This would go a long way to ensuring that the HVAC systems are optimally operated by minimising on use/hours of operation.

Radiators

The method of space heating is disadvantaged by the fact that it is open to abuse as the personal manual thermostat allows the occupant to overheat the room, leading to unnecessary high energy consumption. This method encourages wastage of electricity and therefore non-optimal use of energy. Certain rooms in facilities may be heated with open windows, leading to continuous escape of heated air as the cold fresh air supply moves in. In addition, the poor maintenance track observed in the facilities visited goes contrary to the suggested best practices for energy efficiency advanced by Wulfinghoff (1999) who holds that annual overhauls of the thermostatic controls and heat trapping against the exterior walls or curtains must be avoided.

Under-floor Heaters

Lin *et al.* (2005) qualifies the efficiency of under-floor heating systems in comparison to space heating system by the simple fact that it saves living and working space. This is because it is integrated into the building envelope. Unlike space heating it is not dependant on the mean effective temperature which is a function of the ambient air and the radiant surface temperature (Lin *et al.*, 2005). This makes under-floor heating systems achieve comfortable conditions with a cooler air temperature by a large floor-heating surface. In addition it minimises indoor air pollution by the simple fact that it eliminates forced air movement. The main limitation of under-floor heaters was the fact that the installations were aged and the technology used was old wth some over 20 years old. This is with regards to the concerns raised by Adnot *et al.* (2005) on the unreliability of equipment over 20 years taking into account that most technicians are unfamiliar with them.

Centralised HVAC systems- Chiller Plants and Air handlers

The main issue arising from the HVAC systems studied is that they were all using constant speed motors which were over 10 years old. If we are to take into account the study by Xu (2005), a reduction in the air change rate by 10% may result in a power reduction of approximately 27%. Thus, adoption of variable speed motors would offer a window of opportunity towards great energy savings in these HVAC systems. Indeed Wendes (1994) asserts that Adjustable speed drives could lead to up to 50% energy savings.

The use of fans is the central element in the operation of air handlers. Thus the fan energy use provides the key to energy efficiency in these systems. The twin issues of the power transmission systems and the use of motor thus become highly important in pursuing of energy efficiency in air handlers. The use of V-belts in power transmission for air handlers predominates, at the expense of synchronous belts in the facilities visited. This denies them a chance to save 5% to 10% in energy consumption that could be achieved if soft-start motor systems were retrofitted as observed by Oman (2006).

Rooftop units

The Air-Conditioning System Design Manual attributes the preference for roof top units to their relatively low cost, ease in installation and economy of floor space (ASHRAE Press, 2007). By eliminating the plant room requirement and the possibility is opened up for several tenants owning and operating without involving the landlord in purchasing and paying for the system. It is however conceeded that these systems have a relatively lower Coefficient of Operation (ASHRAE Press, 2007).

5.4 OPERATIONS

For optimal energy efficiency, it is often important to ensure that HVAC systems are not operational when they are not needed. Most importantly, the operational capacity of the HVAC system must be matched to the level of occupancy or the number of occupants in the room. It must therefore be ensured that proper operational schedules and occupancy capacity and schedules are well known to ensure energy-efficient operations management of HVAC systems. This is what is described by Wulfinghoff, (1999) as "minimised duty time" HVAC systems. It is often accepted as being among best practices for energy-efficient HVAC systems as it reduces the use of energy through unnecessary conditioning, reheat losses and fan/pump operations. This is the reason behind assignment of the responsibility for unit switching on and off to space administrators and use of placards, automated controls and timers for buildings with regular schedule of operations. The buildings visited were in this category hence the use of the methods advised. However the use of placards was not as popular. Additionally the automated controls were not as advanced. This led to a situation where full energy savings potential was not achieved.

A key finding, worth commenting on was the fact that the operational capacities of the HVAC systems were not matched to the level of occupancy or the number of occupants in the room. This led to the operation of the HVAC systems at peak capacity, yet the situation demanded otherwise. In this regard, it would seem prudent to use people sensors to activate switches on entry into rooms, use of controls connected with lighting systems to ensure operation only when lights were on and use of timed turn-off switches to limit conditioning tot selected periods of time or a combination of these (Wulfinghoff, 1999). This would work best where there are multiple zones in the HVAC system or where room conditioning units and self contained HVAC systems are used. The underlying objective of optimal efficiency in this context would be matching the level of occupancy with required operation.

5.5 CONTROLS

Type 4 control components (which were only used in one scenario) exemplify the best flexibility to accommodate fluctuations in occupancy levels. This interfaces with the above opinion which articulates the matching of occupancy levels with operation. Little evidence of the use of type 4 control components may be speculated as being associated with the finesse and high costs that go with it against the background of cheap electricity at the time of construction of the buildings (Venter, 2006; Energy Research Institute, 2006).

It should however be noted that the idea of an energy-efficient control system is now more advanced as evidenced by the use of fuzzy control systems which allows for an average of 5% energy saving in HVAC systems (Roth *et al.*, 2002). This technology was however totally absent from the visited sites, probably because of its recent nature.

In all buildings visited, the occupants were not fully conversant with the operations of the control systems yet vandalism of the control knobs was not an observed issue (refer to Figure 4.5c). This flies in the face of Wulfinghoff's assertion that non-familiarity with controls often lead to vandalism (Wulfinghoff, 1999). In this case no vandalism of the control knobs was reported in the buildings studied. Nevertheless, it would be greatly advantageous if operators were given information on the operation of the control systems via the use of placards or office bulletins.

5.6 MAINTENANCE

Only 27% of the total buildings studied achieved a mean score warranting classification of the base energy efficiency. At the same time none of the government-owned buildings attained a rating of the base efficiency. This denied the facilities opportunities for cost control, taken in to account that good maintenance practices may lead up to 30% energy savings. Discussion on maintenance is presented in sections 5.6.1 to 5.6.3.

5.6.1 Measurement and Monitoring

Energy efficiency practices for Facility Managers and Engineers demands measurement of the amount of energy consumed by the building equipment (Van Gorp, 2004). It is only after measurement of the actual consumption that a benchmark and a reasonable budget can be established to allow for a focussed energy-efficiency programme. Contrary to this, the study found that the only buildings with energy-measurement systems in place were those managed by research institutions. None of the government-owned buildings had any measurement and monitoring system in place. It was also observed that a portion of the buildings with measurement and monitoring systems in place did not have their readings uploaded for analysis, leading to the deduction that the installation of the meters was a knee-jack reaction to the electricity supply crisis or that when the energy measurement system was in place, the benefits of the programme were not clearly understood by the staff involved in the implementation as it was a prescriptive measure designed by top management.

5.6.2 Maintenance Planning

The key objectives of energy-efficient maintenance is sustainable, continuous, trouble-free, cost-effective and functional operation of the physical assets (Price, 2006; Lam, 2007). However, trouble-free operations are challenging where there are only little or inadequate funds earmarked for maintenance. This would imply eventual collapse of the systems or a marked reduction in its functional efficiency. The research revealed that there were no planned maintenance services for HVAC systems in any building except one. This goes against the grain of the energy efficiency principle that all HVAC systems must have an Energy Master Plan (EMP) that has clearly articulated goals aimed at minimal energy use, optimum occupancy, optimum comfort and optimum maintenance over its life cycle (Maisely and Beverly, 2007).

The HVAC systems in the buildings were only repaired when they became faulty or less efficient. This is what Tsang (1999) succinctly refers to as "reactive maintenance" and describes it as following in the traditional perception of maintenance's role as fixing broken items. Tsang (1999) and later Reeves (2008) are proved right on the assertion that most managers would rather advocate for reduced maintenance expenditure because the effects are long-term and may not be noticeable during their management term. This is because the primary reason for non-allocation of maintenance funds is the need to operate on minimum budget cuts over a whole range of items.

Reactive maintenance leads to energy inefficient operations. An example is the fact that the most common power transmission drive in centralised air systems in the study was the V-belt and pulley connection. According to Oman (2006) this means that regular belt adjustment and maintenance is mandatory as during operations their efficiency of transmission reduces by approximately 5% to 10%.

Regarding the allocation of funds for maintenance, the inadequacy is explained by the fact that the exercise is general for the whole building and non-specific neither for the building equipment nor for any particular building element. Thus, only a limited amount is allocated to repair and maintenance fund. In most cases this only caters for civil works (including painting and re-plastering), electrical maintenances as well as equipment repair.

Further evidence of worrying maintenance tendencies lie in the fact that in all the centralised system installations, no duct cleaning had been undertaken since installation of the systems. 80% of the centralised HVAC systems had duct works with possible leakage; this further underlined the prevailing poor maintenance practices in public buildings.

The case for maintenance management is worsened by the fact that the government buildings tend to have unreasonably long response times to correct defects in the systems (over 4 weeks) and that such correction depends on the availability of funds and was not automatic (refer to Figures 4.6c and 4.6d). This led to a danger that malfunction or maladjustment in HVAC systems could take unnecessarily long to correct, leading to possible waste of energy in unproductive operation. The use of placards to urge users to report any malfunctions at the research institutions facilities was successful in ensuring the reliable feedback mechanism for successful maintenance. This was instrumental in ensuring functional efficiency, and by extension, optimisation for energy purposes.

Even though the system of outsourcing for reactive maintenance appeared cheap when considered on short-term basis, it is only suited for use in small and non-critical equipment. Indeed, on a long-term basis, it is most expensive due to the potential for secondary damage to other components and associated increased energy usage for components such as line fans (Reeves, 2008). However this is contradicted by the situation in the research institution buildings which achieved ratings above base efficiency, yet they were fully reliant on this policy. As a result Facilities Managers must not over-emphasize it while planning for maintenance.

5.6.3 Age of systems

HVAC systems in 3 buildings studied used equipment which were slightly over 20 years old, forcing Facilities Managers to rely on the services of personnel who worked on them during the installation period. This may prove expensive and unreliable on a long-term basis. In the words of Maisely and Beverly (2007) and Reeves (2008), optimisation of maintenance for energy purposes must ensure that the maintenance requirement is reduced through the elimination of aged components among other things. However it is encouraging to note that most government-owned buildings were operating newly fitted or retrofitted HVAC systems (less than 5 years). This contributes highly to energy efficiency levels.

5.7 INSTALLATION AND COMMISSIONING

The study revealed that the HVAC systems in a substantial number of buildings studied were not duly commissioned. Building that were not duly commissioned were 10 Government Buildings and 2 Research Buildings. Due commissioning processes were those with proper documentation, maintenance manuals and hand-over notes available to the building operators before the initial operation. Successful commissioning often leads to functional efficiency hence energy efficiency.

It is thus not surprising that while emphasising the importance of the commissioning process CIBSE (1998) acknowledge that it is crucial if functionality of equipment is to be ensured. It is in this light that improperly commissioned HVAC systems in buildings should be re-commissioned or retro-commissioned in order to enjoy improved indoor environmental quality and comfort, improved control and zoning, reduced operation costs, maintenance costs and optimised energy savings (Piette and Nordman, 1996; Portland energy Conservation, 2007).

5.7 CONCLUSION

This chapter successfully highlighted key considerations in the optimisation of HVAC systems for energy. The main issues that came out strongly are that the energy efficiency levels in research institutions could be increased from efficiency rating of 3.40 points to 4.97 points out of a maximum of 12. On the other hand, the government-owned buildings had a much lower efficiency rating of 0.67 points to 2.57 points out of a maximum of 12 points. This explains the skewness to the left (refer to Figure 4.9). A lot of effort is needed in all areas. However, energy efficiency could be improved to the base level (6 points rating) largely by low-capital efforts. These ratings are below the base efficiency but could be improved by laying more emphasis particularly in the adoption of new technologies in design and control for energy efficiency (TDV and fuzzy logic controls), training of occupants, re-commissioning and use of placards for communications. Specific recommendations are available in the next chapter.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

This research was undertaken against the backdrop of two main issues of electricity supply deficit and the high carbon intense nature of electricity in South Africa. The main motivation for the study was the postulate that energy efficiency increases access to electricity through demand reduction. The eventual results would be a reduction in carbon dioxide emission as a result of diminished electricity generation activities. The building sector was chosen due to estimates that it consumes 30%-40% of the world's energy (UNEP, 2007). In addition, the study was narrowed down to HVAC systems in recognition that in South Africa over 65% of energy is used by HVAC systems in the commercial sector (Buys, 2002).

The main objective of the study was to investigate the extents and possible effects of optimisation of HVAC systems for energy-efficiency in selected, existing public buildings in Greater Johannesburg. To realise this objective, the research was guided by the main question:

> 'To what extents are the HVAC systems in selected, existing public buildings in Greater Johannesburg currently optimised for energy efficiency and what are the effects of their optimisation?'

To answer this question, emerging themes in the optimisation of HVAC systems for energy efficiency in buildings were categorised as management, design, operation, control, maintenance, and installation and commissioning. These are discussed in section 6.2. The sections below give the conclusions reached and recommendations proposed.

6.2 CONCLUSIONS

It is concluded that the public buildings studied were largely energy-inefficient and need efforts to minimally achieve base efficiency. This is explained by the skewed nature of the distribution curve (skewness of 1.47). Details appear below.

6.2.1 Management

The single agency ownership of the buildings studied eliminates the difficulty posed in implementing high capital improvements associated with energy efficiency programmes in HVAC systems. This is however a challenge to government-owned facilities due to the long and highly bureaucratic procurement processes. As a result, energy performance contracting seems a highly viable option for energy efficiency improvement.

The use of placards showing operational details of controls and key personnel contacts for reporting faults placed at strategic positions may go a long way to ensuring minimal energy is used in HVAC systems in public buildings. This could lead to optimal operations and hence increased efficiency. In addition, the assignment of staff for management of energy programmes could help strengthen the human intervention required for improvement of energy efficiency levels.

Close on the heels is the idea of energy budgeting, which when implemented, could enhance energy efficiency of HVAC systems. It is recognised that a low-capital venture type of energy conservation measure[16] should be encouraged for the selected public buildings as availability of finance may handicap programmes.

6.2.2 Design

It is particularly disturbing to note that the use of TDV to design buildings has not caught on in South Africa, despite the proven success in reducing energy consumption

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[16] The low capital energy conservation measures identified by Fong *et al.*(2003) are readjustments of operating conditions like space air-temperature, air-supply velocity, chilled-water temperatures among others to match peak conditions or seasonal changes.

no existing public building using it in retrofits. Additionally, most buildings used constant volume systems, while it is common knowledge that greater energy efficiency levels could be achieved in variable volumes systems.

6.2.3 Operations

The main issue arising in operations is the lack of tracking with occupancy levels. Hence most systems operate at peak capacity while occupancy remains low.

6.2.4 Controls

Control systems are generally at the base efficiency levels. However, improvements to attain optimal efficiency could be easily achieved by upgrades.

6.2.5 Maintenance

Maintenance is generally poor, unplanned and a high contributor to energy inefficiency in HVAC systems in government-operated public buildings. However, this is not the case for HVAC systems in the research institution buildings. This is attested by the ratings of 0.5 to 0.67 points gained by government buildings and 1.50 to 1.67 for research institution buildings.

6.2.6 Re-commissioning and Retro-commissioning

Close to fifty five percent of the buildings needed re-commissioning, having failed to achieve a duly commissioned status. On the other hand, cases of poor installation were comparatively few.

6.3 RECOMMENDATIONS

Recommendations for this study are categorised as either low-capital investment efforts or high-capital investment efforts or future research. These recommendations follow.

6.3.1 Low capital investment efforts

Low capital investment efforts are relatively lost cost remedies proposed to ensure benefits resulting from the optimisation of the HVAC systems for energy efficiency in the buildings.

Management

To address the lack of energy efficiency planning that pervaded the buildings, it is proposed that an 'Energy Master Plan' (EMP) be drawn up for the HVAC systems. The concept of an EMP as articulated by Maisely and Beverly (2007), when applied to the research context, would *first* mean determination of the energy consumption of the HVAC systems and hence the installation of energy measuring meters. This would set the initial benchmark needed to pioneer the planning activities. *Second*, an energy consumption budget would be put in place for the HVAC systems. Energy consumption levels would then be analysed periodically against the set budget for the HVAC systems.

To successfully implement the EMP concept it is necessary to assign staff to be in charge of the energy management activities in each building. It is this staff that Bream (1986) refers to as the Energy Manager. It is emphasised that Energy Managers for all the government-owned buildings be appointed from the pool of available Centre Librarians or Janitors. This would ensure that there is continuity in the programmes initiated as they would be supported within the established management structure. The appointed Energy Managers would have to undergo basic training in energy issues. This would ensure that the Energy Manager dealt with behaviourally related issues that affect the energy use of the HVAC systems. Behavioural issues include attitude to energy conservation measures, appropriate dressing as demanded by weather conditions, the act of 'switching off' HVAC systems when conditioned or heated spaces are not in use and dissemination of periodic information concerning energy efficiency.

The use of placards in buildings should be particularly emphasised as one of the low capital investment drives. Placards and memos can be used first to advise building operators to close doors and windows to conditioned spaces on account of the weather or when the HVAC systems are operational, and second to ask occupants to dress appropriately to the weather patterns.

Controls

Placards, memos and letters may be used to first clearly define spaces covered by the controls of the HVAC systems. Second, placards could be used to inform building occupants where automatic controls are used. Because HVAC systems are used for improvement of thermal comfort and general indoor air quality, perceived lack of these could lead to vandalism of controls. Consequently the HVAC systems would not operate optimally. The use of placards is particularly encouraged in the government-owned buildings as none of the buildings visited had them.

Operations

It is advised that to match occupancy with the operation of equipment, rooms should only be opened one at a time, according to instantaneous capacity demand of the occupants. This would ensure that equipment is operated in response to demand.

6.3.2 High capital investment efforts

High capital investment efforts involve high capital expenditures and are generally considered high cost with longer payback periods. Details of mitigated actions are discussed below.

Management

The use of an 'Energy Management System' is recommended for buildings in cluster units. This would allow better interaction between different room conditions and atmospheric condition like humidity, air temperature and air velocity. The required set optimal conditions would then be used to trigger the operation of HVAC systems.

Design

The use of TDV in design of HVAC systems needs refining in addition to integration with existing standards or manuals of design. This would make it be possible to enjoy the energy savings potentials associated with this method (Lunnenburg, 2003; Massachusetts, 1999 and Roth *et al.*, 2002).

Installation of room conditioning units should continue to be encouraged in smaller libraries with several rooms that are used for reading. This would ensure multiple zones and ease in control. In addition, occupancy can be matched with operation schedule by using only one room at a time until it is fully occupied, before opening up other spaces for occupation.

Several measures are advised for different HVAC units. These are annual overhauls for thermostats in Radiators and element heaters in the control to improve efficiency, disposal of units which are old and obsolete and use of variable speed drives in centralised systems and the application of synchronous belts for soft-start motors (Oman, 2006; Xu, 2005; Adnot *et al.*, 2005; and Wulfinghoff, 1999).

Operation and Controls

For isolated buildings with centralised HVAC systems, automatic control systems are advised. Automatic control systems would be in the form of demand controlled ventilation system that would be operated by carbon dioxide sensors or movement sensors that trigger the operation of the HVAC systems. This would ensure that multi-zone VAV systems are operated in accordance with demanded ventilation or thermal comfort in addition to switching off systems when sections of the buildings are not in use.

Another proposal would be to adopt fuzzy control strategies to suit variable use of existing HVAC systems in buildings. Roth *et al.* (2002) acknowledge that the use of this method may incorporate adjustment of controls to reflect parameters like weather prediction or desired operation patterns and in the process lead to energy savings pegged at 5% potential. It is noted that centralised systems including roof top units would be ideal for implementation of fuzzy control strategies.

Maintenance

All the HVAC systems should be metered to determine consumption levels and create load profiles (Van Gorp, 2004). This would enable easy energy audits and target setting in energy efficiency. Planned maintenance is recommended as it not only ensures energy efficiency operation but also trouble-free operation. The use of old equipment must not be encouraged as up to 50% energy difference may be experienced through use of technology over 10 years old and that no guarantee can be made on continued use of old machines as the equipment may be unfamiliar to technicians (Adnot *et al.*, 2006).

Re-commissioning and retro-commissioning

Systematic retro-commissioning and re-commissioning of all buildings would ensure the availability of HVAC system details like operational notes, maintenance logs, as-built specifications, drawings and maintenance manuals. In addition, HVAC systems would get retested and due recommendations would be made for redress where necessary. This would eventually lead to regular energy audits and the principal of continuous commissioning.

6.3.3 Future Research

It is recommended that future research to use observed characteristics and the actual practice of HVAC systems should integrate data on costs and actual energy consumptions. This would entail the use of meters throughout the year and should end up providing key data needed for simulation studies.

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APPENDICES

APPENDIX A: RATINGS AND TYPES OF HVAC SYSTEMS

Table 4.2: HVAC systems used in buildings

Site Details	Equipment Type	No. of units	Equipment Power Rating in kW
Leandale Facility	Propeller fans	10	0.07
Vosloorus Facility	Propeller fans	14	0.07
	Room Conditioning Unit -(2 Fan Type)	5	5
	Room Conditioning Unit -(1 Fan Type)	6	4.1
Edenpark	Propeller fans	14	0.07
	Room Conditioning Unit -(2 Fan Type)	5	3.3
	Room Conditioning Unit -(2 Fan Type)	3	5
	Room Conditioning Unit -(1Fan Type)	1	4.1
Thokoza	Room Conditioning Unit -(2 Fan Type)	8	5
Spruitview	Roof top unit	1	6.6
	Room Conditioning Unit -2 Fan Type)	2	3.3
	Room Conditioning Unit -(1 Fan Type)	5	1.65
	10” Extractor fan	1	0.05

Source: Field data, 2008

Table 4.2: HVAC systems used in buildings-Continued

Site Details	Equipment Type	No. of units	Equipment Power Rating in kW
Elsburg	Propeller fans	7	0.07
	Room Conditioning Unit -(2 Fan Type)	6	3.3
	Room Conditioning Unit -(1 Fan Type)	1	1.65
Boksburg	Centralised A/C HVAC Unit –Air Handler-2 Fan capacity	1	7.8
	Centralised A/C HVAC Unit –Air Handler-(3 Fan Type)	3	37.5
	Chiller pumps	2	19
	Chiller pumps	2	2.5
	Under-floor heaters	1	23
Germiston	Centralised A/C HVAC Unit –AHU	1	
	Chiller pumps	4	19
Dinwiddie	Propeller fans	7	
	Room Conditioning Unit -(1 Fan Type)	6	1.65
	Underfloor Heater	7	5

Source: Field data, 2008

Table 4.2: HVAC systems used in buildings-Continued

Site Details	Equipment Type	No. of units	Equipment Power Rating in kW
Katlehong	Propeller fans	10	0.07
	Room Conditioning Unit -(1 Fan Type)	8	1.65
Isaac Mokena	Roof top unit	1	6.6
	Room Conditioning Unit - (2 Fan Type)	6	3.3
Zonkizizwe	Rooftop unit	1	6.6
	Room Conditioning Unit -(2 Fan Type)	6	3.3
	Room Conditioning Unit -(1 Fan Type)	1	1.65
	Propeller Fan	2	0.07
	Extractor Fan	2	0.05
Reigerpark	Heaters	3	6.6
	Propeller fan	12	0.07
	Room Conditioning Unit-(2 Fan Type)	8	9.5
	Room Conditioning Unit-(1 Fan Type)	1	1.65

Source: Field data, 2008

Table 4.2: HVAC systems used in buildings-Continued

Site Details	Equipment Type	No. of units	Equipment Power Rating in kW
Brackenhurst	Room Conditioning Unit - (2 Fan Type)	9	3.3
	Heaters	2	5
Alberton	Centralised A/C Unit-AHU with chiller	1	
CSIR Building 2A, 2B & 2C	Room Conditioning Unit-1 Fan	320	1.65
William Cullen	Central A/C system: AHU	1	13.5
	Room Conditioning Unit-1Fan	3	1.65
	Room Conditioning Unit-2 fan	2	3.3
	Under-floor Heaters	18	8.5
Wartenweiller	Central A/C system: AHU with Chiller Plant	1	285.6
	Under-floor Heaters	9	11.4
	Under-floor Heaters	3	2.5

Source: Field data, 2008

Table 4.2: HVAC systems used in buildings –Continued

Site Details	Equipment Type	No. of units	Equipment Power Rating in kW
Edu-Com	Roof Top Units, 4 fan	1	22.5
	Roof Top Units, 4 fan	1	34.7
	Roof Top Units, 1 fan	1	6.45
	Roof Top Units, 2 fan	1	27.3
	Roof Top Units, 2 fan	1	12.9
	Room Conditioning Unit-(1 Fan Type)	1	1.65
	Room Conditioning Unit - (2 Fan Type)	1	3.3
Donald Gordon	Roof Top Unit	1	82
John Moffat	Central A/C system: AHU with Chiller Plant	1	5
	Under-floor Heaters	9	11.4
	Under-floor Heaters	3	2.5
	Convector / Radiator Element Heaters	40	1.5

Source: Field data, 2008

APPENDIX B: ENERGY EFFICIENCY INDICATORS

Table 3.6; Energy Efficiency Indicators for HVAC systems

Description of Indicator	**Indicators of Energy Efficiency Levels**		
	Lack of Energy Efficiency	**Minimum Requirement (Base Energy Efficiency)**	**Best Practice Requirement (Optimised Energy Efficiency)**
Public conversance with HVAC operation	Less than 50% of public conversant with HVAC operation	50% of public conversant with the operation with HVAC operation	More than 50% conversant with HVAC operation
Availability of placard	No placards available	Placards available but not clearly visible nor articulate	Clearly visible and articulate placards available
Responsibility assignment/accountability for energy management	No staff assigned to be responsible for energy management	Staff is assigned to be responsible for energy management	Well trained staff assigned to be responsible for energy management
Energy Consumption Budget	No energy consumption budget	Basic energy consumption budget is available	Detailed Energy Consumption Budget Available
Energy conservation program	Lack of energy conservation program in place	Basic Energy conservation program in place	Detailed Energy conservation program in place
Design philosophy (TDV or Conventional mixing)	Conventional Mixing used	Conventional Mixing used	TDV used
Schedule of operation	Discordant operations of HVAC systems without regards to occupancy. Unregulated operations schedule	Minimised and regulated operational schedule time for HVAC systems	Minimised and regulated operational schedule time & ability to synchronise HVAC schedule of operation and controls with occupancy

Source: Author's construction

Table 3.6 Energy Efficiency Indicators for HVAC systems (continued)

Description of Indicator	**Indicators of Energy Efficiency Levels**		
	Lack of Energy Efficiency	**Minimum Requirement (Base Energy Efficiency)**	**Best Practice Requirement (Optimised Energy Efficiency)**
Control Type	Faulty operation of controls. Isolator as the only control mode	Availability of Isolator, timer, and thermostat (i.e. type 1 and type 2, type 3 controls); Good working condition for controls	Availability of Isolator, timer, fan speed control via remote control and thermostat (i.e. type 4), Use of Fuzzy-Logic controls; Good working condition for controls
Occupants conversance with HVAC controls	Less than 50% public conversant with HVAC controls	50% of public conversant with the operation with HVAC controls	More than 50% conversant with HVAC controls
Energy Measurements/monitoring systems	Lack of energy consumption measurement or monitoring system	Basic energy consumption measurement system allowing for overall consumption tracking	Elaborate energy measurement and monitoring system complete with ability to give feedback and prompt for corrective measures
Maintenance planning	Reactive maintenance	Budget restricted regular maintenance	Performance based regular/planned maintenance
Response time in correcting faults	Over 28 days	7 to 28 days	Less than 7 days

Source: Author's construction

Table 3.6 Energy Efficiency Indicators for HVAC systems (continued)

Description of Indicator	**Indicators of Energy Efficiency Levels**		
	Lack of Energy Efficiency	**Minimum Requirement (Base Energy Efficiency)**	**Best Practice Requirement (Optimised Energy Efficiency)**
Contact Details for reporting faults	Lack of established protocol in reporting faults	Established protocol in reporting faults with contact details available at a desk/office	Established protocol in reporting faults with visible contact details available in placard
Maintenance Responsibility	Staff assigned to be responsible for maintenance	Staff assigned to be responsible for maintenance	Well trained staff or contractor is assigned to be responsible for maintenance
Age of equipment/retrofits	Equipment over 15 years in age with no recent retrofit	Equipment/Retrofits from 5 years to 15 years in age	Equipment/Retrofits less than 5 years in age
Installation	Improper installation practices	Installation averagely done	Installation according to best norms of practice
Commissioning	No documentation nor handover notes available	Documentation available, no handover notes are available	All documentation details are available, handover notes are available

Source: Author's construction

APPENDIX C: DATA COLLECTION SHEET

RESEARCH TOPIC: OPTIMISATION OF HVAC SYSTEMS FOR ENERGY EFFICIENCY IN PUBLIC BUILDINGS

DATA SHEET FOR BUILDING AUDIT

a. Date of survey………………………………………………………………………………………………
b. Site Liaison
c. Details……………………………………………………………………………………
d. Sample No……………………………………………………………………………………………………
e. Physical & Postal Addresses

……………………………………………………………………………

………

………………………………………………………………………………

i. Who owns the building?
   a. Government (Central or local) ☐
   b. Commercial Private ☐
   c. Public Trust (university, colleges, public societies, government trusts) ☐
   d. Private Individual & Trust ☐

ii. What is the building currently used for?

Ref.	**Current Building use**	**Marking**
a	Entertainment & Assembly Hall	
b	Lodging Facility	
c	Library	
d	Storage & Warehouse	
e	Office & Banking	
f	Public Order & Security/Detention centre	

iii. When was the building constructed or last refurbished with regards to HVAC systems?

0-5 years ☐ 5-10 years ☐ 10-15 years ☐ Over 15 years ☐

iv. What was the building originally used or designed for? (mark in the box)

Ref.	**Original Building use**	**Marking**
a	Entertainment & Assembly Hall	
b	Lodging Facility	
c	Library	
d	Storage & Warehouse	
e	Office & Banking	
f	Public Order & Security/Detention centre	

v. Are the architectural blueprints available?

Yes ☐ No ☐

vi. Are operational logs including repair, maintenance summary available?

Yes ☐ No ☐

vii. Are HVAC Manuals available?

Yes ☐ No ☐

viii. How many days is the building used per week? (mark in the box)

Ref.	**No. of days in a week**	**Marking**
a	Daily	
b	6 Days	
c	5 Days	
d	4 Days	
e	3 Days	
f	Less than 3 days	

ix. How long is the building used on any single day of operation?(mark in the box)

Ref.	**No. hours of use**	**Marking**
a	24	
b	12-24	
c	8-12	
d	0-8	

x. Are electricity bills for the building available?
If yes, a copy must be made or details noted

xi. What is the floor area and volume of the space requiring HVAC use?

……

xii. Does the building have a specific staff assigned to management of energy or plant operation?

Yes ☐ No ☐

xiii. What type of HVAC system is in use the building?

Centralised air systems ☐

Room Conditioning Units/packaged HVAC equipment ☐

xiv. If (a) in (ix) above what categories below further accommodate the type of HVAC system in the building?

a- Single zone system ☐ b- Multi-zone system ☐

c- Constant Volume system ☐ d- Variable Volume system ☐

e- Single Duct with reheat system ☐ f- Single Duct system ☐

g- Dual Duct system ☐ h-Induction system ☐

xv. If (b) in (ix) above what categories below

☐ a- Radiators/Convectors ☐ b- Roof Top Units

☐ c-Self Contained Air Conditioners & Thro' wall Heat pumps

☐ d-Remotely Cooled Contained Air Conditioners & Heat pumps

☐ e- Heat Pump Loop Systems ☐ f- Direct Fired Heating Units

xvi. Who is responsible for energy management in the building?

a-Building Operator ☐ b-Maintenance Contractor ☐ c-Nobody ☐

xvii. Is there an energy consumption budget?

Yes ☐ No ☐ Not sure ☐

xviii. What fraction of (xiii) is constituted by HVAC System consumption?

☐ Less than ¼ ☐ ¼ to ½ ☐ ½ to ¾ ☐ Over ¾

xix. Does the building management review or carry out analysis of energy consumption?

Yes ☐ No ☐ Not sure ☐

xx. If yes above (xv) at what time intervals are the energy consumption reviews carried out?

0 to 6 months ☐ 6 to 12 months ☐ 12 to 18 months ☐ over 18 months ☐

xxi. Is there planned maintenance for HVAC systems in the building?

Yes ☐ No ☐ Not sure ☐

xxii. What are the schedules for planned maintenance?

0 to 6 months ☐ 6 to 12 months ☐ 12 to 18 months ☐ over 18 months ☐

xxiii. Who is in charge of HVAC system service maintenance in the building?

a-Building Operator ☐ b-Maintenance Contractor ☐ c-Nobody ☐

xxiv. If (b) in (xix) is there is a maintenance or service contract?

Yes ☐ No ☐ Not sure ☐

xxv. If yes briefly tick from choices below the elements covered by the maintenance or service contract?

a-Service or maintenance duration ☐ b-Filter Replacement or clean up ☐

c-Duct Clean up ☐ d- Replacement of faulty units/parts ☐

e-Refrigerant recharge/change ☐ f-Purging of system ☐

g-Review of HVAC system performance and operational/energy efficiencies ☐

xxvi. Is there an energy saving program in operation or under review?

a- Yes ☐ No ☐ Not sure ☐

xxvii. If yes in (xxii) what are the focuses of the energy saving program with regards to HVAC system?

☐ a-Demand reduction by minimum operation of system

☐ b-Introduction of an energy management system

☐ c-Demand scheduling

☐ d-HVAC system retrofit

☐ e-Energy efficient maintenance program

☐ f-Duct cleaning

xxviii. Tick the control types/strategies used for HVAC systems operation in the building?

- ☐ On/Off Isolator
- ☐ Automatic thermostat based control
- ☐ Automatic thermostat based control with manual over-ride
- ☐ Variable Fan speed adjuster
- ☐ Air intake control
- ☐ Carbon dioxide sensors
- ☐ Variable motor speed adjuster
- ☐ Timers
- ☐ Zone base control systems

xxix. Are the controls in good working conditions?

Yes ☐ No ☐

xxx. If (a) in above what are the observable faults?

- ☐ Control settings are very low
- ☐ Control settings are higher than desired
- ☐ Adjusters are faulty
- Control Knobs are broken ☐
- Control sensors faulty ☐

xxxi. On percentage basis (100% being full capacity occupancy) rate the occupancy level?

....

xxxii. Are the occupants conversant with or informed on operations of controls?

Yes ☐ No ☐

xxxiii. Are there contact(s) given for persons to get in touch with in case the HVAC system is faulty?

Yes ☐ No ☐

xxxiv. How long does it take the management to act on the reports of faulty items?

☐ <3 days ☐ 3days to 1 week ☐ 1 to 4 weeks >4 weeks ☐

xxxv. Are there signs of vandalism of the control knobs and switches?

Yes ☐ No ☐

xxxvi. Are the occupants informed about the importance of energy conservation and specific implications of to HVAC systems?

☐ Yes No ☐

xxxvii. Is there a Building Management Systems?

☐ Yes No ☐

xxxviii. Is there an occupant assigned to monitor the operation of xxi above?

☐ Yes No ☐

xxxix. Are the occupants dressed appropriately for the weather?

☐ Majority are not ☐ Majority are

☐ None are ☐ All are

Components, equipments & measure values

xl. What is the age of the HVAC system?

☐ 0 to 1 years ☐ 1 to 2 years 2 to 3 years ☐

☐ 3 to 5 years ☐ 5 to 10 years Over 10 years ☐

xli. What is the power rating of the equipment & associated components?

....

....

xlii. What are the model types of the equipment and components?

....

....

xliii. What is the year of manufacture of the equipment?

....

xliv. What is the stated air change rate of the HVAC system?

……………………………………………………………………………………………………

xlv. When is the HVAC system operated?

(Tick in the box)

Ref.	**Operation schedule for HVAC system**	**Marking**
a	All the time(24 hrs)	
b	As long as the building is occupied	
c	Only when conditions warrant use	
d	When the sensor switches on	
e	When thermostat trips on	
f	When occupants feel like it	

xlvi. How often is the duct cleaned?

(Tick in the box)

Ref.	**Frequency of duct clean up**	**Marking**
a	Every 0-6 months	
b	Every 6-12 months	
c	Every 12-18 months	
d	Every 18-24 months	
e	Irregularly/Unplanned	
f	Never	

xlvii. Is there any visible leakage in the duct work?

Yes ☐ No☐

APPENDIX D: INTERVIEW GUIDELINE WITH LIASON OFFICERS

Preliminary details

1. What is your name?
2. What is your occupation?
3. In what capacity are you in the organisation?
4. How long have you been with the organisation?
5. What are your duties?

Site details

1. What is the brief history of the building?
2. When was the HVAC system retrofitted or installed?
3. What are the common maintenance problems experienced by the HVAC systems?
4. Who is in charge of HVAC system maintenance?
5. Are energy efficiency issues taken into consideration?
6. What are the obstacles to implementing energy efficiency in buildings?
7. Is there any documentation available for operation of HVAC systems, as-built specifications and drawings, maintenance logs, maintenance manuals and commissioning details?

APPENDIX E: QUESTIONNAIRE

This questionnaire is administered as part of a research entitled "optimisation of Heating, Ventilation and Air Conditioning (HVAC) Systems for energy efficiency in buildings in Johannesburg. It is the researcher's hope that this work will contribute to increase energy and overall cost savings in the use of buildings in South Africa.

Particulars

Name:	
Telephone No.	
Address:	

Instruction: You are requested to kindly mark against your answer.

1 Are you conversant with HVAC system operations?

Yes	
No	

2 What greatly dictates your dressing mode?

Weather patterns(in response to weather)	
I do not know	
Fashion	

3 Are you aware of energy efficiency/energy conservation or energy savings and importance?

Yes	
No	

4 Is there any staff specifically tasked with energy management for the building equipment? (Ignore for public building users, only applicable to building operators)

Yes	
No	

5 Does this building have an energy budget? (Ignore for public building users, only applicable to building operators)

Yes	
No	

6 Are there any energy conservation programs in place for this building? (Ignore for public building users, only applicable to building operators)

Yes	
No	

7 Are you familiar with the operation procedure of the HVAC system installed in this building?

Yes	
No	

8 Have you come across any placard explaining operations or any other issues concerning the HVAC systems in this building?

Yes	
No	

9 How is the maintenance of this building organised?

Whenever there is faulty operation	
On regular basis	
Whenever funds allow	

10 What is the waiting period taken to repair reported faults in this building?

Less than 3 days	
3 days to 1 week	
1 week to 2 weeks	
2 weeks to 3 weeks	
4 weeks	
Over 4 weeks	

11 Who undertakes maintenance in this building?

Outsourced Service provider/contractor	
Building Operator	