# Estimation of Standby Power and Energy Losses in South African Homes

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# Declaration

I declare that this thesis is my own, unaided work, except where otherwise acknowledged. It is being submitted for the degree of Doctor of Philosophy to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.

Signed this ___ day of ___________ 20___

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Mercy Violet Shuma-Iwisi.

# Abstract

In this thesis, research work on appliance standby power and energy losses is presented and discussed. The research had three components: Household survey, appliance power consumption measurement campaign, and mathematical estimation of the standby power and energy losses.

The household survey was implemented on 555 households in 11 suburbs of Greater Johannesburg in South Africa. Survey results indicate that the estimation parameters: Appliance saturation ($s$) rates, appliance penetration ($p$) rates, time spent in standby mode ($t_{sb}$) as well as appliance efficient use index ($AEUI$) are clustered across the household sample. A household cluster is defined to be a group of households with similar estimation parameters. Five clusters were identified in the household sample. *Universal* appliances are identified and defined to be appliances that are common in all clusters and have saturation rates of 50% or more.

Measurements were conducted in 30 households drawn from all clusters in the household sample. Measurements on new appliances were done in three large appliance retail stores. Measurement results indicate wide variations in power consumption levels in appliances with same capabilities and functionalities. In some appliances, very small margins in power consumption levels exist between standby and full operational modes. Poor power factors are evident in most appliances in both standby and full operational modes. Consequently, relatively large components of apparent and reactive power are measured. *Significant* appliances are identified and defined to be appliances with the largest standby power consumption levels.

Estimation was based on a mathematical model developed. The estimated standby power losses per household based on sample parameters is 73.5 W and the energy losses amount to 561.8 kWh per year. The standby power losses per household estimated using cluster parameters range from 28.2 W to 111.7 W and the respective energy losses per household per year range between 181.6 kWh to 862.1 kWh.

*This work is dedicated to the memory of my dear parents*
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*Your desire and example in serving God and Man*
*lingers on forever*

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# Chapter 1

# Introduction

The question of Energy Supply and sustainable development has become of great importance to all economies in the world, both small and large. The effects of climate change and environmental degradation are directly linked to the utilisation of energy into economic activities. Energy supply and sustainability is central to world policies because of dwindling reserves of fossil fuels. The Kyoto Agreement [1] is the umbrella under which sustainability is propagated. It has become imperative to all economies that there is a need to take bold steps in the generation and utilisation of electrical energy for sustainability. Actions that have been taken include demand side management, energy efficiency, and renewable energy technologies.

The South African economy is energy intensive [2, 3]. Energy demand in South Africa can be classified into the following groups [4]: Industry (36.2%), Transport (25.7%), Residential (17.9%), Agriculture (2.9%), Commerce (6.7%), Mining (7.0%), and others uses (3.6%). Coal is the dominant primary energy source in South Africa. The total national primary energy supply by fuel in 2004 was a total of 5,240,908 TJ accounted as follows: 68.2% coal, 2.8% Nuclear, 19.4% crude oil, 8% Renewables, 1.6% Gas and 0.1% Hydro [3, 4]. There is a mix of energy sources in South African households such as coal, electricity, liquid petroleum gas (LPG), natural gas, paraffin, solar, vegetable waste and wood. In this energy mix, electricity accounts for 37.3% and the residential sector consumes 17% of the total electricity supply in South Africa making this sector the second largest in electricity consumption [2, 3, 4].

The South African Department of Minerals and Energy (DME) released the White paper on energy policy in December 1998, which was approved by Cabinet as the government policy on energy [5]. Energy efficiency is one of the issues in the policy which cuts across disciplines. The policy acknowledges that significant scope exists in the industrial, commercial, domestic and transport sectors for improved energy efficiencies. The policy states [5]:

*Energy efficiency needs to be promoted, especially in households where such measures will increase both disposable income and disposable energy.*

There has been recognition by government of South Africa of the benefits that would accrue from the introduction of energy efficiency standards and measures in South Africa. As a step forward the government released the Energy Efficiency (EE) strategy for South Africa in March 2005 [2]. The strategy is the first consolidated document by the government of South Africa geared toward the development and implementation of energy efficiency programs in the South Africa. The strategy states [2]:

*In recent years energy efficiency has significantly gained stature and has become recognised as one of the most cost effective ways of meeting the demands of sustainable development.*

The EE Strategy sets a national target for energy efficiency improvement of 12% by 2015 and a final energy demand reduction of 10% is anticipated in the residential sector [2]. It is expected that the 10% reduction will be obtained through thermal insulation of new houses, appliance efficiency, mass education and awareness campaigns.

Energy efficiency is one effective way of increasing energy security due to the reduction of overall demand for energy consumption. As stated in the United Kingdom energy policy [6]:

*Using energy more efficiently is the fastest and most cost effective way of cutting carbon dioxide emissions. Improving energy efficiency has already made a significant contribution to our energy and climate change goals.*

Energy efficiency can be implemented both at the supply side and in the end-uses. The supply side efficiencies in general look into efficiencies in extraction, conversion, transportation and distribution of energy. Efficiencies in end-uses are primarily to do with efficient utilization of energy which gears at reducing total energy consumption. In electrical energy end-use efficiencies have to do with real power consumed by electrical end-use machinery, equipment or appliances.

Electricity supply to South African residences can be said to supply four distinct loads namely:

- Household appliances
- Lighting
- Water heating
- Space heating

Household appliances can be further divided into the following groups [7] :

- Major appliances
- Information Technology
- Entertainment
- Small appliances

Major appliances include clothes washing machines and dryers, dish washing machines, air conditioners, water heaters, space heaters, electric cookers/ovens, refrigerators and freezers. Information technology appliances are appliances such as personal computers (pc), pc monitors, photocopiers, printers, scanners, laptop computers, modems, pc speakers with separate power supplies and multi function equipment i.e. printers/copiers/fax/scanners. Entertainment appliances are: Analogue televisions (TV's), digital TV's, Video cassette Recoders (VCR's), Digital Versatile Disks (DVD's), Digital TV set top boxes and converters, pay TV set top boxes, integrated and portable stereo systems, separate sound systems components (receivers, amplifiers, tuners, compact disk (CD) players, and tape decks.) Small appliances include external power supplies, smoke detectors, microwave ovens, bread makers, coffee machines, security systems, automatic garage doors, automatic gates, motion detectors and networked smart home products.

The electricity consumption due to the use of some of major household appliances as well as the lighting and heating loads have been studied and documented by energy researchers in South Africa [8, 9, 10, 11]. However, these research studies do not reflect the whole spectrum of South African households because they were directed to "First World Houses in South Africa". The electricity utility company in South Africa, Eskom, has and still is implementing an efficient lighting initiative, as an input toward energy efficient households. A recent energy efficient lighting initiative was implemented in 2006 in Cape Town after technical problems led to the shut down of one of the generators at Koeberg power station resulting in power shortages. Global research on the rest of household entertainment, information technology, small appliances, and some of the major appliances such as air conditioners is fairly recent and no extensive and detailed research has been conducted in South Africa. These appliances account for 12% of total residential energy in South Africa indicating a significant end-use [3].

Energy efficiency of the household appliances is characterized by efficiencies in consumption of power in both full operational and in standby power modes. Standby power is an essential part of appliance efficiency and its importance is evidenced in the following statements. In the report for project Eureco, it is stated that [12]:

*It is not possible anymore to deal with domestic electricity consumption without an in depth analysis of the standby power issue.*

In a report by Sustainable Energy Policy Concepts (Sepco), it is stated [13]:

*Household appliances is an area where large potentials of efficiency improvements are possible by replacing cheaper old and inefficient appliances with the best available efficient appliances.*

## 1.1 What is appliance standby power?

Standby power is associated with the operational mode of an appliance [14]. There are several different operational modes of an electrical/electronic appliance [14, 15]. These operational modes are illustrated in Figure 1.1.

Any electrical/electronic appliance can be either connected (plugged) or disconnected (unplugged) from the mains. When disconnected, the appliance is drawing zero electrical power. If an appliance is connected to the mains, then it can be ON or OFF as determined by the state of the electrical switch. If an appliance is connected to a power source and the power source switch is off then the appliance is in 'OFF' state and draws zero power.

An appliance switched off at its power button and connected to a switched on power source can be in one of two modes: hard-off or soft-off. The placement of the power switch in an appliance determines if a switched off appliance has a hard-off or soft-off mode. If a mechanical power switch is placed between the power source and the internal power supply circuit, the appliance has a hard-off mode and in this mode an appliance does not consume power. However if a mechanical power switch in an

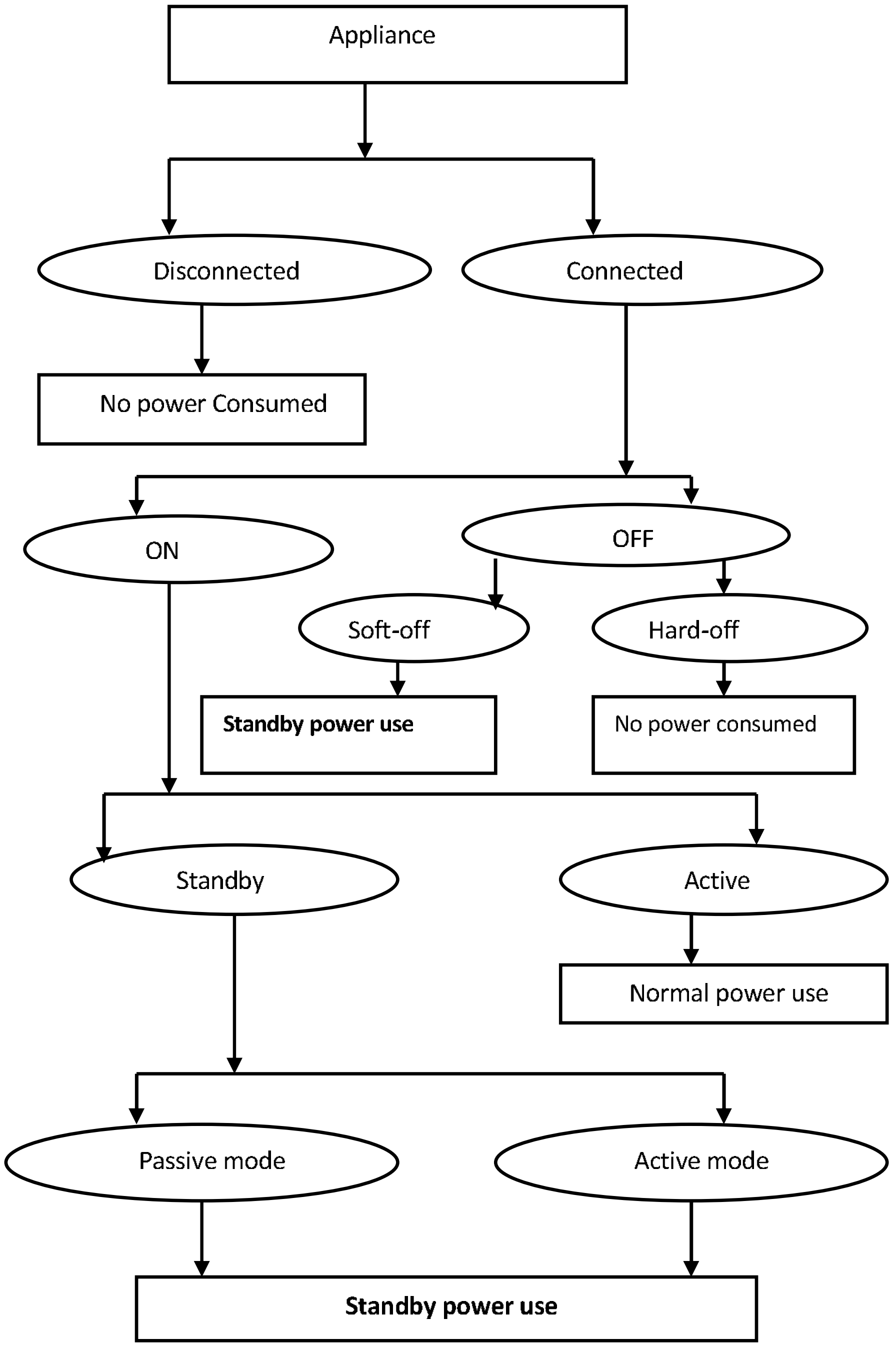


Figure 1.1: Appliance operational Modes

appliance is placed between the internal power supply circuit and the rest of the electronic/electrical circuits that make up the appliance, then the appliance has a soft-off mode. An appliance with a soft-off mode consumes power even when the appliance is switched off, at its power button, because of the current flowing into the appliance power supply from the mains.

A switched 'ON' appliance can be in active or standby mode. In active mode, the appliance is said to be in normal use, performing its primary function, and can be expected to draw up to the maximum power specified by the manufacturer. In standby mode, an appliance can either be in standby passive or standby active mode [15]. An example of standby passive mode is an appliance waiting to be switched on by a remote control or waiting to receive information thus maintaining device memory function, or displaying of time. If an appliance is performing an additional support function that is not its primary function such as the downloading of software updates in the case of digital satellite decoders, then it is in standby active mode.

Standby mode is defined as the lowest power consuming mode which cannot be switched off (influenced) by the user and that may persist for an indefinite time when the appliance is connected to the main electricity supply and used in accordance with manufacturer's instructions [16]. Standby power is the average power in standby mode [16]. In this work, the power that appliances consume while in soft-off, standby passive or standby active mode is considered *standby power* as also defined by Meier et al [17]. The advancement in electronic technology has resulted in standby modes being found in all the four categories of household appliances i.e. major appliances, information technology, small appliances and entertainment appliances. Technology Quaterly of March 9th 2006 writes in an article "Pulling the Plug on Standby Power" [18]:

*We are moving from an electromechanical world that is on and off to an electronic world that's never off.*

Equipment responsible for standby power load is present in residential, commercial, industrial, and agriculture demand sectors. In some appliances standby power serves no useful function and in others where there is useful function, the levels of power consumed are excessive compared to the necessary function being performed [19]. Individually standby power is very small but collectively especially due to high saturation and penetration levels of these appliances, the amount of power consumed is significant. These concerns are what led to research activities in Standby Power in Australia, European Union, USA, Japan, Canada, and China [15, 20, 21, 22, 23, 24, 25, 26].

## 1.2 Standby Power Research

Standby power became a concern in the 1990's. This is a time when the consumer market saw the introduction of electrical/electronic appliances with the capability of drawing continuous low levels of power consumption [19] while not performing their primary function. There was also the occurrence of electronic appliances such as smoke detectors, security systems, networked equipment which are designed to operate in a continuous basis while drawing low levels of power. There was another category of appliances that was introduced that requires to maintain a certain low level functionality at low power consumption levels for the purpose of sensing communication or monitoring. Standby power consumption can be a direct result of or a combination of the following [14, 27]:

- Poor power supply design
- Memory retention function
- Internal clocks
- Displays (LED's/LCD)
- Battery charging
- Instant on or remote control capability

Standby power consumption measurements have been conducted in the following countries [14, 22]: Australia, Canada, China, Denmark, Greece, Italy, Portugal, United Kingdom, Sweden, Japan, New Zealand, and USA. Bottom-Up estimates of standby power use as well as in-store measurements have been done and documented [22].

The results obtained from the household studies indicate a wide variation of the percentage fraction that is standby power consumption. Standby power consumption ranged from as high as 100 Watts in New Zealand to 32 Watts in United Kingdom [22]. Standby power was found to contribute up to to 12% of total household consumption in Australia and the lowest was 3% in Switzerland [22]. The results of these studies are not fully comparable because each study differed in the details and although relatively low numbers of households were involved in most of the studies it is still possible to draw concrete conclusions on the impacts of standby power in households [14, 20, 22, 23, 26, 27].

In Australia, standby power is one of the largest individual electrical end-users in the residential sector at 10% [21]. Estimates of residential standby power indicate the following percentages of standby power as a fraction of total elecctricity use in a household [12, 14]: France 7%, Germany 10%, Japan 9.4%, Netherlands 10%, New Zealand 11%, Switzerland 3%, United Kingdom 8%, United States 5%, 14.4% in Denmark, 13.3% in Greece, 15% for Italy and 13.7 % for Portugal. According to International Energy Agency (IEA) by 2030, 15% of total appliance electricity consumption in Europe could be for standby power functionality which is currently unregulated [28]. It is stated in the National Appliance and equipment Energy Efficiency Program in Australia that [7]:

*In the absence of action Standby Power in Australia is projected to exceed the combined in-use power of televisions, VCR's, clothes dryers, washing machines, freezers in households by 2010.*

It should be noted that there are no available statistics on many developing countries, a group in which South Africa belongs. As *Meier* writes [22]: *But three large regions have essentially no information about standby power. South Asia (India, Pakistan etc.), South America and Africa.*

## 1.3 Research question

The main research question is:

- What is the estimated magnitude of the domestic standby power and energy consumption in South African households?

To answer the main research question the following sub-questions were answered:

- What are the saturation and penetration rates of appliances with standby power capabilities in South African households?
- What are the appliance standby power consumption levels of appliances found in South African households?
- What are the specific characteristics of standby power and energy consumption in South African households?
- What is the appropriate model for the estimation of standby power and energy losses for South Africa?

## 1.4 Research Objectives

The objectives of the research are to:

- Identify major appliances contributing to standby power load
- Establish appliance saturation and penetration levels
- Establish initial data on standby consumption measurements in South Africa
- Quantify and characterise standby energy and power consumption in South African households

## 1.5 Significance of the research

The following indicate the significance of investigating standby power load in South Africa.

### 1.5.1 The global need to find measures to reduce $CO_2$ emissions

In South Africa 71% of the total primary energy supply comes from coal [3]. Ninety percent of South Africa's electricity is generated from coal [29] and coal is a highly carbon intensive fossil fuel. In Eskom annual report for 2007 it is stated that [30]:

*Emissions have been increasing over the last decade due to the dominance of coal in our energy mix and increasing demand for electricity.*

South Africa is one of the highest emitters per capita of Greenhouse gas $CO_2$ in the world due to the energy intensive economy and high dependence on coal for primary energy. Actually, South African per capita emissions are higher than those of many European countries, and almost on par with the Organization for Economic Co-operation and Development (OECD) countries average [2, 31]. The residential sector of the OECD contributes 0.6% to the total $CO_2$ emissions [14].

The high carbon emission intensity compels South Africa to seriously consider mechanisms that could help move the country onto a lower emission intensity path. Energy Efficiency programs have a direct impact in green gas emission levels. Greater efficiencies, results in less energy requirement, in return this means less coal burnt and consequently less emissions. Lowering of the electricity demand will have a direct effect on $CO_2$ levels because of the high reliance on coal for electricity generation. Energy efficiency can also delay the need to invest in new power generation capacity as less power is utilized by the end-users creating virtual power stations. Weber argues that global action to reduce standby power could result in the reduction of global $CO_2$ emissions by about 27 megatons per year [32].

The strategy to reduce standby power in order to cut $CO_2$ emissions could be a viable option for South Africa. However, the magnitude of domestic standby power load in South Africa is not yet known hence the impact of reducing the standby load on $CO_2$ emissions cannot be evaluated.

### 1.5.2 The need to equip policy makers and energy analysts with data

The energy policy paper states, *Good data is fundamental to the implementation of an Integrated Energy Policy* [5]. The energy white paper also states *The lack of good data is a major weakness in the energy policy-making process in South Africa* [5]. Indeed, formulations of good and coherent policy rely on how well policy makers are informed on the specific issues underlying the policy. Energy analysts rely on quality data to be able to create accurate tools to predict energy trends. Research on the standby power load will create data and a body of knowledge, which are crucial for both the energy policy makers and energy analysts.

### 1.5.3 The Need to Include South African Data in Global Estimates

Lebot et al states [33]: *A global estimate of standby power should, ideally, include estimates for less developed countries. We believe that situations in developed countries are significantly different from those in less developed countries; moreover, the data on stocks of appliances in those (less developed) countries is particularly poor and changing rapidly.*

It is evident that there is a need to fill in the void due to an absence of data from individual countries in Africa. Measurement of standby power load in South Africa will improve global estimates by providing data from a major electricity consumer in Africa, as South Africa consumes half of Africa's electricity [31].

### 1.5.4 Dwindling National Electricity Supply

In 2006 Cape Town experienced major power failures and, more recently, there have been generalized power failures in the whole country that have suddenly alerted generators/suppliers and consumers alike to the fact that electrical power is a limited resource which should be efficiently managed. At present, the electricity reserve margin is at 8% to 10% and this should be seen in light of the accepted global margin of a minimum of 15% [34]. Therefore, the fears that the peak winter demand will be hard to meet have come to be a reality. In view of the fact that new generating capacity is expected to come online only in 2012, energy efficiency remains a major coping option. This therefore brings in the question of energy efficient appliances and demand side management to which standby power losses are firmly linked.

### 1.5.5 The Need to Inform Consumers of Possible Savings on Energy

*Information and education to raise consumer awareness are often an important part of a package of measures to improve energy efficiency. Information, education and training measures generally target behaviour* [14].

Consumer's can be part of an energy saving initiative if only they are aware of the possible benefits to be garnered. Energy saving is a direct result of consumer energy efficient behaviour which is acquired through information, education and training on energy utilisation. Energy saving benefits must be quantifiable and tangible to the consumer either individually or collectively. Correct and credible information to consumers of possible savings on Energy can only be obtained from accurate and reliable data. Programs to raise consumer awareness should be backed by concrete data that validate possible savings for the consumers from their energy saving behaviuor. To formulate and carry out such educational campaigns it is also necessary to have reliable data to support any scientific/technical claims to be made.

### 1.5.6 Presence of Specific Indicators

Standby power research is important especially now because of the possibility of large growth of standby power load in South African households indicated by the following:

- Increase in the number of electrified households

- Introduction of new appliances with standby power capability in South African homes

### Increase in the number of electrified households

South Africa embarked on a vigorous electrification process driven mainly by Eskom the national electricity utility company from 1994. The electrification is mainly geared toward's the raising of the standard of living as well as stimulation of economic activities within low income households. It was reported in the Eskom 2006 annual report that 106,968 new customers were connected [35]. This brought the total of new household connections to 3.3 million. This trend of new connections is expected to continue because the South African government is aiming to provide electricity for every South African by the year 2012!

The data obtained from South African Advertising Research Foundation (SAARF) indicate that ownership of all domestic appliances has steadily increased over the past years i.e. from 1996 onwards [36]. This increase in ownership suggests an increase in the use of these appliances. It is therefore plausible to assume that the increase in electrification has a direct effect on ownership and hence the increase in use of appliances with standby power.

### The Introduction of New Appliances with Standby Power Capability

The South African consumer market has experienced an influx of three new appliances [36]. These are personal computers (PCs) for home use, cell phones, and analogue M-Net television decoders and digital satellite television (DSTV) decoders. Of these three, the ownership of cell phones is higher than ownership of PCs or M-Net/DSTV decoders. To allow for continuous software upgrades a requirement from the service provider is for DSTV decoders to remain switched on all day long all year long. This requirement result in the appliance being in standby mode for considerable amount of time, which can offset the lower ownership figures for the total standby power consumed. Ownership of these appliances is expected to grow with time, hence increasing the number of appliances in use and consequently the magnitude of the standby load. In general, the use of other new standby appliances such as DVD, home theater equipment, WEB-TV, and networked appliances will increase in the future, influencing standby load heavily [36].

The move to digital TV and broadband communication is also witnessed in South

Africa. The South African Cabinet approved the time table for migration of television services to digital and digital migration is expected to commence in November 2008. The change from analogue to digital TV broadcasting requires that viewers obtain set top boxes for decoding the digital to analogue signal for compatibility with analogue TV or buy television screens that have inbuilt digital tuners. This implies that between November 2008 and 2011 when the analogue signal would be finally switched off, there will be a gradual increase of set top boxes and digital television screens in South African homes until saturation levels are reached. The introduction of set top boxes will see a massive increase in appliances with standby power capabilities in South African homes. The migration to digital TV is also expected to accelerate the increase of high power consumption LCD, and plasma TV technologies in households where these appliances can be afforded.

## 1.6 Review of current methods and research

Estimation of standby power load has been done in three separate ways [22].

### 1.6.1 Whole house measurements

Whole-house measurements have been done in: Australia, Canada, China, Denmark, France, Germany, Greece, Italy, Japan, New Zealand, Netherlands, Switzerland, Island, United Kingdom and USA [14, 22]. According to Meier [22], whole-house measurements involve visiting a home and measuring the standby power use of every device consuming standby power. By monitoring a representative sample of homes a survey can establish a reasonably accurate and credible estimate of standby power use. Whole-house measurements, provide important perspectives on variation of standby power consumption in individual homes, an attribute not found in bottom-up or new-product measurements. In whole-house measurements, uncertainty lies in:

- The number of hours that an appliance is actually consuming standby power [23]
- Obtaining a representative sample of homes [21, 23, 24]

It is therefore important to investigate ways of improving the measurement technique so as to minimize uncertainties due to number of hours an appliance is actually consuming standby power. This can be achieved by looking into ways of actually measuring the time a specific appliance is in standby mode. A representative sample can be obtained by using appropriate sampling techniques [37].

### 1.6.2 Bottom-up estimates

Meier writes *Bottom-up estimates of standby power consumption are used to estimate either average standby per home or national standby power consumption. The estimate is based on measurements of standby power in specific appliances and then multiplied by the average saturations of those appliances. This approach is suited for common appliances where there are typically large numbers of measurements and saturations are well known, but fails for minor appliances. Therefore bottom-up estimates tend to underestimate actual standby power use* [22]. Bottom-up estimates have been conducted in among others Argentina, Australia, Canada, France, Germany, Netherlands, Switzerland, and USA [22].

### 1.6.3 New product measurements

New product measurements involve visiting a store or factory and measuring the standby power use of new products. This is a favourable method of quickly assessing levels of standby power but the results do not match in-house measurements [22]. The difference in results is due to the fact that normally the stock of appliances in the stores is not necessarily the same as the stock of appliances found in households. In-store measurements provide results for rough estimation only.

## 1.7 Research Methodology

The research methodology is made up of the following components:

- Appliance survey
- Measurement of individual appliance standby power consumption
- Load estimation.

### 1.7.1 Appliances ownership survey

By using the survey, it was possible to obtain data that was used for the estimation of household saturation and the penetration levels of standby appliances. The survey was also be used to: Estimate appliance use times, gain an insight into user appliance operational behaviour, and gather some demographic data.

### 1.7.2 Measurement of appliance standby power

Measurement of individual appliance standby and full mode power consumption were carried out in households and retail stores. The measurements were carried out in households that were part of the household appliance survey. A suitable power meter that measured very low power levels where current waveform distortions were present was used for reliable results.

### 1.7.3 Load estimation and prediction

The results of measurements and appliance ownership survey are used as basic input data for estimating the household standby real power and energy consumption. The estimated household standby energy and power consumption be obtained by using an appropriate model. Different approaches have been used in estimation of individual electrical end-uses in a household and these include mathematical or engineering, econometric and artificial neural network (ANN) techniques [38, 39, 40, 41, 42, 43]. In most standby power estimation studies, the bottom-up approach which is essentially a mathematical model has been employed to evaluate the average household real power and energy losses due to appliances in standby mode [14].

## 1.8 Criteria of validation of research findings

There is no standby data for South Africa or any other African country. Validation of the data from appliance measurements is done by comparing our results with research findings of other studies on similar appliances. Data from appliance measurements for various studies exists [14, 26, 44].

## 1.9 Contribution from the research

The contribution of the research is in :

- Establishment of the first estimates of standby power and energy losses in South African households
- Characterization of standby power and energy losses in household clusters across the household population
- Creating appliance use efficient index ($AEUI$) a parameter to account for user operational behaviour
- Establishment of appliance saturation and penetration clusters
- Establishment of *significant* and *universal* appliances to standby power and energy losses
- Creation of South African data for global estimation and prediction of standby energy and power consumption
- Availability of credible data to inform the National development of appropriate policies and standards
- Creation of appliance saturation, penetration and standby power consumption data
- Stimulation of standby research in other electricity demand sectors in South Africa
- Stimulation of consumer awareness campaigns on appliance standby energy and power consumption

## 1.10 Conclusion

There is no available data on household standby power and energy consumption in South Africa. The literature review has substantiated the need for standby power research in South Africa especially now that our National electricity reserves are dwindling to be driven by:

- The global need to find measures to reduce carbon dioxide emissions

- The need to equip policy makers and energy analysts with credible data
- The need to include South African data in Global estimates
- Dwindling National Electricity supply
- The need to inform Consumers of possible energy savings source
- The presence of specific indicators

Furthermore, the contribution of the research to South Africa in particular and the world at large underscores the importance of the research.

The rest of the thesis is organised as follows: Chapter 2 discusses the survey sample and implementation, the survey results are presented in chapter 3. The detail of the measurement equipment, measurement sample and the measurement results are presented in chapter 4. The power and energy estimation model and the estimation results are discussed in chapter 5. Chapter 6 is the conclusion and recommendations are in chapter 7.

# Chapter 2

# Household Appliance Survey

Estimation of the standby power load is informed by appliance penetration and saturation levels, user behavior, and the estimated time spent in standby mode by a particular appliance. Appliance saturation data for households in South Africa is available for some but not all appliances of interest [36]. Data on appliance penetration levels, and the estimated time spent in standby mode, as well as user appliance operational behaviour are not available. It was therefore necessary to conduct a survey on a representative sample of South African Households with the following objectives:

- Determine the most commonly found electrical appliances with standby power capabilities in South African homes
- Determine saturation levels of appliances with standby power features
- Determine the penetration levels of appliances with standby power capabilities in South African homes
- Establish the approximate age of the appliances with standby power mode found in South African homes
- Establish consumer appliance user habits
- Establish the level of consumer awareness on appliance standby power and energy losses
- Establish estimated appliance use times

Table 2.1: Household Grid Electricity Consumption by Province for 2001

| Province | Consumers | Electricity(MWh) |
|---|---|---|
| Eastern Cape | 555 325 | 1 590 230 |
| Free State | 385 361 | 1 098 813 |
| Gauteng | 1 492 829 | 10 878 769 |
| Kwa Zulu Natal | 915 723 | 4 468 885 |
| Limpopo | 458 269 | 1 238 740 |
| Mpumalanga | 519 990 | 1 153 591 |
| Northern Cape | 174 578 | 349 958 |
| North West | 246 423 | 708 273 |
| Western Cape | 895 884 | 3 689 112 |

## 2.1 Target Population

There are nine provinces in South Africa namely: Western Cape, Eastern Cape, Kwazulu Natal, Limpopo, Mpumalanga, Free State, North West, Northern Cape and Gauteng. The most recent available data on total number of household grid electricity consumers and power consumption figures for the nine regions are given in Table 2.1 [29].

From Table 2.1 it is evident that the largest number of household grid electricity consumers and the highest electrical energy consumption is found in Gauteng. Therefore Gauteng province formed the survey target population.

## 2.2 Sample Size

The size of the sample is determined by the following factors:

- Availability of time and funds
- Necessary degree of precision

### 2.2.1 Availability of Time and Funds

Only fifteen working days were allocated and budgeted for data collection. This was advised by the utility provider so as to avoid unwanted linkages to the survey process by criminals. The budget was restricted in terms of number of budgeted research assistants, the cost of developing the questionnaire and processing the results. This implied that the survey had to be administered to the sample size within the constraints of time, human and monetary resources.

### 2.2.2 Degree of Precision

The degree of precision is determined by two factors namely:

- Confidence interval
- Confidence level

Confidence interval is used to express the uncertainty in a quantity being estimated. The width of a confidence interval, determines the certainty of a whole population being within a specified particular range. Confidence intervals are affected by: Sample size ($s$), Percentage ($p$), and population size. The larger the sample size the surer one can be that the responses truly reflect the population. However for a given confidence level the larger the size the smaller the confidence interval and the relationship is not linear [37].

The worst case percentage i.e. 50% is used when determining the sample size needed for a given level of accuracy [37]. According to [37], unless the sample size exceeds a few percent of the total population, then the size of the population is irrelevant. The target population for the survey was very large; which implied that the target population had no consequence to the sample size. A 95% confidence level was used in the survey.

### 2.2.3 Sample Size Calculation

Equation 1 was used for sample size calculation [37].

$$SS = Z^2 \times p \times 1 - p \div C^2 \quad (2.1)$$

Where: Z = the Z value for 95% confidence level = 1.96
p = worst case percentage expressed as decimal (0.5)
C = Confidence interval expressed as decimal

For a confidence interval of 5 the sample size was calculated to be 384. A round figure of at least 385 households was adopted for the survey.

### 2.2.4 The Survey Sample

In South African large cities and towns, security systems, automated entrance gates, and closed circuit TV systems are found in many suburbs. These measures have become necessary because of high crime rates. Suburbs are cordoned off by boom gates and homes are hidden behind high walls. These security features are used to deter/restrict the movement of people into and within a specific area. The success of the survey was highly dependent on easy accessibility into homes. To this effect, the utility provider City Power was instrumental in the selection of the eleven suburbs so as to maximize accessibility. An unbiased sample was achieved by randomly picking up households within a suburb. The survey was conducted in eleven different suburbs in the greater Johannesburg namely:

- Devland
- Lenasia Extension 1
- Lenasia Extension 3
- Lenasia extension 7
- Lenasia Extension 8
- Florida
- Florida Park
- Gressworld
- Kew
- Waverley
- Alexandra East Bank

Devland, Lenasia Extensions 1, 3, 7 and 8 are suburbs in the south of Johannesburg. Florida and Florida park are found in the western suburbs, while Gressworld, Kew, Waverley and Alexandra East Bank are situated in the northern suburbs. In total 555 households participated in the survey way above the calculated sample size of 385. Table 2.2 provides the detail of the number of households that participated in the survey in each suburb [45].

Table 2.2: Household Sample

| Suburb | Number of Households |
|---|---|
| Devland | 36 |
| Lenasia Extension 1 | 126 |
| Lenasia Extension 3 | 72 |
| Lenasia Extension 7 | 46 |
| Lenasia Extension 8 | 61 |
| Florida | 76 |
| Florida Park | 30 |
| Gressworld | 18 |
| Kew | 28 |
| Waverley | 30 |
| Alexandra East Bank | 32 |

## 2.3 Survey Sample and ULSM Groups

The South African Advertising Research Foundation (SAARF) Universal Living Standard Measure (ULSM) is a [46]:

- multivariate market segmentation index
- wealth measure based on standard of living

The ULSM employs 29 household variables, as a set of descriptors to bring together groupings of people out of the total population continuum into contiguous and sometimes slightly overlapping groups [46]. The set of descriptors form multivariate differentiators which group the total population into 10 groups. The ULSM moves away from segmentation based on demographics and is developed to minimize bias due to:

- Income
- Education
- Occupation

Each province is divided into the 10 ULSM groups and the proportion of the population belonging to each group is known [46].

### 2.3.1 Where does the Survey Sample fit in the ULSM Groups?

Using the ULSM group definitions it can be concluded that the households that participated in the survey were not from ULSM groups 1 to 3 because [47]:

- 99% of the population in ULSM group 1 are rural dwellers and are concentrated in KwaZulu-Natal and the Eastern Cape
- 87% of ULSM group 2 population is in rural areas mainly in KwaZulu-Natal, Limpopo, and Eastern Cape provinces
- ULSM group 3 population is found mainly in Limpopo and in KwaZulu-Natal
- About 64% of group 3 ULSM population are rural dwellers
- 21% of ULSM group 3 population live in small towns and only 15% lives in metropoles
- ULSM group 3 has a high proportion of squatter camp dwellers and compound hostel dwellers
- Dwellings in ULSM group 3 are predominantly houses in informal settlements or conventional houses
- Most of the population in ULSM groups 4 to 10 live in Gauteng Province
- Most of the population lives in large towns, cities and metropolitan areas
- In ULSM groups 5 to 10 rural population is no longer significant
- Conventional houses, townhouses, cluster homes and flats dominate in ULSM groups 4 to 10

The households in the sample were drawn from the Greater Johannesburg. ULSM Group 1, 2, and 3 populations are found in KwaZulu-Natal, Eastern Cape and Limpopo provinces and forms 37.3% of the population. The dwellings in the survey did not include squatter camp areas or hostel compounds or homes in informal settlements. Therefore, the household sample used in the survey can be said to be representing the ULSM groups 4 to 10 which constitutes 62.7% of the total population [47].

## 2.4 Data Collection Method

There are several methods of data collection each with its merits and demerits [37]. In the questionnaire used, some questions required the respondents to physically inspect the status of an appliance. This meant the interviews could take considerable time to complete depending on the number of appliances in the household. The costs of land line and/or mobile phones in South Africa are not low, which implies that telephonic interviews would result in high research costs. A problem encountered in the Australian appliance ownership survey [21] was low telephonic success rates due to the length of time it took to complete an interview. Therefore, the use of telephonic interviews as a data collection method was excluded mainly due to costs and anticipated low success rates.

Mail surveys have long response times and low responses rates because of the reliance on the respondent's goodwill to complete and mail back the questionnaire. Electronic surveys are becoming popular but because of the low incidence in computer and internet services in households [48], computer direct interviews, e-mail surveys, scanning and internet surveys could not be used.

Personal interviews were the preferred data collection method used for the survey because of the time and budgetary constraints as well as expected high success rates.

## 2.5 The Questionnaire

The questionnaire presented in the Appendix A was used to gather the following:

- Demographic data
- Appliance ownership
- Appliance use time
- Appliance operational behaviour
- User awareness

Two types of questions were used in the questionnaire:

- Open format

- Closed format

The questionnaire had five main sections A, B, C, D, and E. Section A was geared toward the establishment of appliance age and appliance saturation and penetration levels. Section B looked into user appliance operational behavior in order to establish if user behavior that lends itself to standby power losses was present amongst the households. Section C was included to establish user lifestyles and be able to estimate time spent in standby mode by appliance and in the deduction of the probabilities of appliances being in use in different days and seasons. Section D was on user awareness level on energy losses due to standby power and section E was on demographic data.

Day one was used to test the questionnaire. At the end of day one it was observed that most respondents did not give responses to some questions in Section C and some respondents refused to continue with the interviews upon being asked questions in section C of the questionnaire. These questions in Section C probed in great detail about the activities of the members of the household. In particular, respondents were questioned on how they spent their leisure time and the type of leisure activities they participate in. As a result of the extremely poor response to these questions in Section C, the questions were omitted in the subsequent interviews.

## 2.6 Survey Implementation

Homes in Johannesburg are hidden behind high walls, automated gates, electric fences and security boom gates due to high levels of criminal activities. Households in clusters were not included in the survey mainly because of tight levels of security implemented by private security companies. The physical presence of security personnel in a residential area at entrance points results in an even more diminished direct access to the homes.

Before entering a specific suburb, the research team introduced themselves to the households by means of a letter written in conjunction with City Power the utility service provider in the suburbs where the survey was conducted. The introductory letter was used as a tool to allay fears from the respondents on the presence and activities of the researchers. However, sometimes the interviewing process was abruptly terminated because either the police or the security company would have advised us to do so, as a direct response to the security concerns of the residents. Gladly, no intimidation or acts of violence were experienced during the survey period only expressions of mistrust mainly due to high crime levels.

Participation in the survey was voluntary and homes were chosen randomly within a specified suburb. Respondents were at liberty not to respond to any part of the questionnaire if they felt uncomfortable in giving responses. It is therefore assumed that all responses were willfully given and no respondent was coerced into giving a response. All respondents remained anonymous and the only identification of a household was a questionnaire number, suburb and the date of the interview. Again because of fear of crime, respondents were skeptical to answer some of the questions that probed deeper into their lifestyles. This part of the questionnaire could be executed using telephonic interviews. This possibility should be taken into consideration in future studies.

The research assistants who conducted the interviews were fully familiarized with the questionnaire so that they fully understood what the questions were set out to obtain. This was important because in some instances during the survey the research assistants communicated the questions to the respondents in other languages apart from English, the language of the questionnaire. This was expected because South Africa has 11 official languages namely, English, Afrikaans, Zulu, Xhosa, Sotho, Venda, Sepedi, Tswana, Seswati, Ndebele and Tsonga therefore the general population can be expected to be confident in expressing themselves in any of the eleven languages.

## 2.7 Limitations of the Survey

The survey was implemented successfully in 555 households in eleven different suburbs of greater Johannesburg. The following can be stated as the limitations of the survey:

- Absence of ULSM groups 1 to 3 in the survey sample
- Omission of less accessible areas from the survey

The fact that the sample was mainly drawn from ULSM groups 4 to 10 and the omissions of groups 1 to 3 was not by design but rather by default since the survey was conducted in Johannesburg. Only 11% of homes in ULSM 1 are electrified making the contribution from these homes very small especially when appliance saturation levels are considered [47]. In ULSM group 1 TV saturation is 4%, Hi-fi is 9%, cellphone is 1% and radio is at 70%. Most of these appliances can be safely assumed to not be powered by electricity because of the low levels of grid electricity connections in ULSM 1 [47].

Grid electricity connections increase to 55% in ULSM 2 and 85% in ULSM group 3 and it is also evident that the saturation of the TV, Hi-Fi, Cellphones and Radio increase significantly [47]. These increases are still relatively low compared to the upper groups 4 to 10 with the exception of radios. The absence of saturation levels of VCR's, microwave ovens, M-net connections, DVD's and DSTV connections in ULSM groups 1 to 3 further underlines the diminished presence of standby power appliances in these groups [47]. This raises the question of how significant is the contribution from ULSM group 1 to standby power load. However, it can be argued that for completeness data from ULSM 2 and 3 should be included by sampling in relevant areas. This is substantiated by the level of grid electricity connections as well as saturation levels of some appliances in ULSM groups 2 and 3.

The question of inaccessibility to some residential areas can not be easily dealt with because of its sensitive nature. Above all, it is attached to individual liberties and matters of personal judgment. However, inaccessibility to some suburbs did not imply exclusion of any ULSM group because of random distribution of the groups within a random household population sample.

## 2.8 Conclusion

Gauteng, the province in which Johannesburg is located, is the largest electricity consumer as well as the province with the highest number of consumers connected to grid electricity in South Africa. The survey was successfully conducted in eleven suburbs of greater Johannesburg. Level of accessibility was the main factor that determined the choice of a particular suburb as an implementation area for the survey. A sample size of 385 households was calculated as sufficient to give 95% confidence interval. The calculated sample size was considered the minimum number of households that were required and in total 555 households participated in the survey. The households that participated in the survey can be assumed to dominantly represent a population in ULSM groups 4 to 10 as characterized by SAARF [46].

# Chapter 3

# Survey Results, Analysis and Discussions

The survey results are presented and discussed under the following five major areas:

- Sample Demographics
- Appliance saturation and penetration levels
- Appliance age
- Consumer appliance operational behaviour
- Appliance use time

## 3.1 Sample Demographics

Demographic information on the respondents was sought to establish sample characteristics pertinent in the assessment of the extent of standby losses in the households. These characteristics are:

- Type of dwelling
- Family organization

### 3.1.1 Types of Dwellings

From the questionnaire responses it was established that 86% of the respondents live in conventional houses, 4% in flats and 1% in town houses or clusters. The high

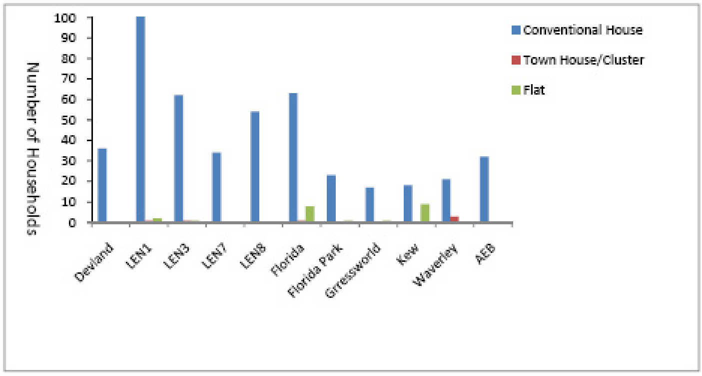


Figure 3.1: Type of Dwellings in Suburbs

incidence of conventional houses was observed across all eleven suburbs as shown in figure 3.1. The dominant incidence of conventional houses and the low incidence of respondents living in town houses and property clusters is a direct result of the sampling criteria used to ensure high accessibility to households in the sample. Most town houses and clustered properties are not easy to access due to security manned entrance gates. The high figures of conventional homes confirm our initial conclusion that the sample was mostly made up of ULSM groups 4 to 10. The type of dwelling has an influence on the appliances that can be found in a particular household. The possibility of finding a wide range of appliance types is higher in conventional houses than in flats mainly due to space available. The larger the space available the higher the possibility that the space will be taken up by appliances.

### 3.1.2 Family Organisation

Two characteristics were determine namely the number of people in the household and the family structure.

### 3.1.3 Number of People in the Household

The number of people in a particular household was considered important in explaining the estimated appliance use times. If we consider small family size, for example a family made up of only two people or a single person, then it can be assumed that appliance use times in such households are much lower than in households with larger family sizes. Furthermore, households with low number of occupants would signal relatively longer appliance standby mode periods as compared to households with high number of occupants. This is because the low number of people available to operate the appliances. In households with high number of occupants the assumption is longer appliance full operational modes because of the high number of people available to operate the appliances.

The results indicating the family sizes in the survey sample are presented in table 3.1.

Table 3.1: Number of People in Surveyed Households

| Number of People | % Number of Households |
|---|---:|
| One | 1% |
| Two | 10% |
| Three | 16% |
| Four | 24% |
| Five | 22% |
| Six or more | 27% |

From table 3.1 the total percentage of households with more than 2 members is 89% and in particular 73% of the households are made up of four or more members. Figure 3.2 represents the corresponding number of households in each suburb for each category of family size.

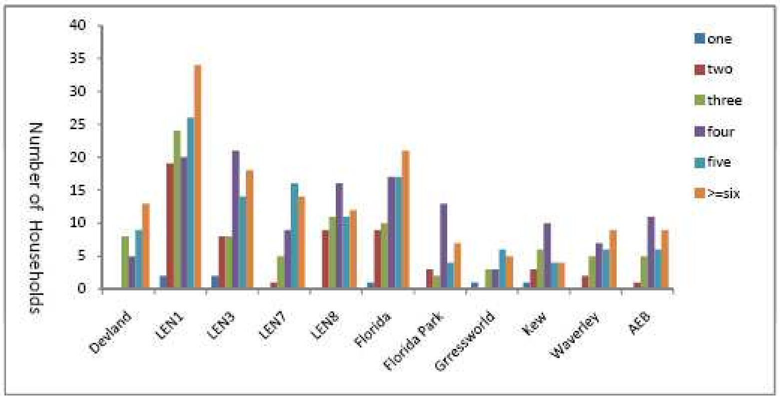


Figure 3.2: Number of people in Households

1% of households are single member households and these households are spread in all suburbs except in Devland as shown in figure 3.2. Ten percent of the households have two members and the households are spread in small numbers in all suburbs except in Gressworld and in Devland as shown in figure 3.2. These figures indicate that most of the households can be considered to be medium to large sized families. From figure 3.2, it is evident that in each suburb, the number of households with three, four, five, and six or more members dominate. It is no surprise that in Devland, there are no households that consist of one or two members and in Alexandra east bank, there are no single member households. This is expected because these two suburbs are predominantly Black African and it is common in the African culture to take care of members of the extended families. This implies that the nuclear familiy is almost always living with other extended family members.

### 3.1.4 Family Constitution

The objective in finding out how the families were constituted in the surveyed households was to be able to associate appliance usage and family structure. The extent of the usage of appliances in a household can be linked to the structure of the family. For example if one family is constituted by a single couple and another family is made up of a group of family members then it can be assumed that the usage of appliances in the single couple household is less compared to the household with a group of several members.

In the survey sample 73% of the households were made of families of four or more members implying high possibility of higher appliance usage levels. Figure 3.3 represents the different family categories found in the sample in percentages.

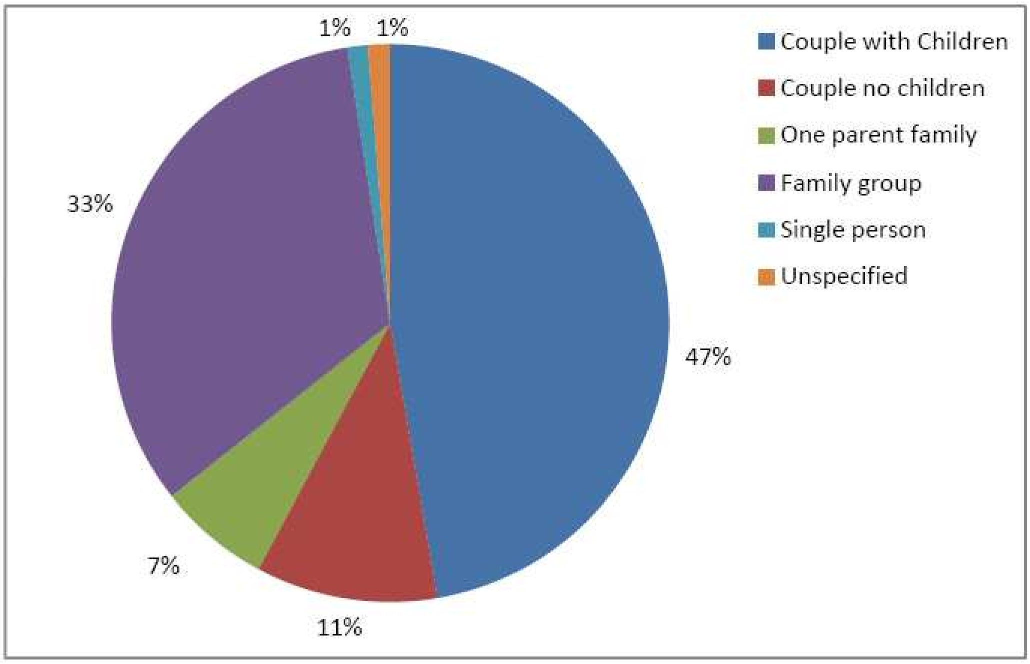


Figure 3.3: Family Structure

The categories one parent family, couple with children and group of family members account for 87% of the households. Single and no children couples form 8% of the sample. This further confirms that the family sizes are medium to large and we expect that appliance use times to be high. Figure 3.4 presents the detail of the different family structures in each of the 11 suburbs.

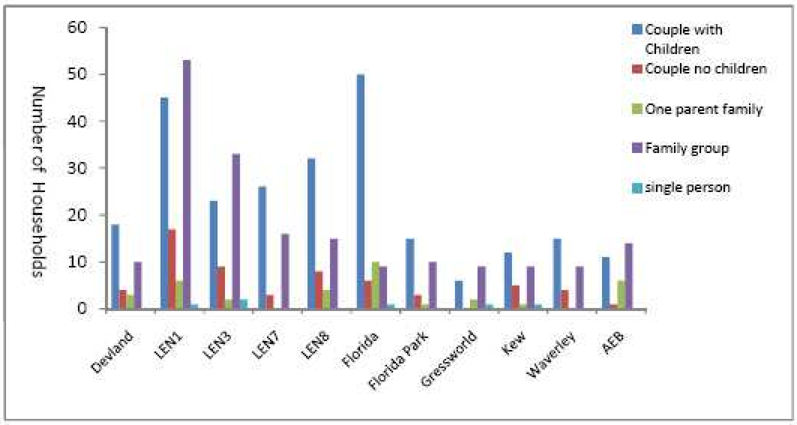


Figure 3.4: Family Structure in Suburbs

In all suburbs as seen in figure 3.4, the classifications couple with children, and family group dominate and this finding is supported by the fact that most dwellings in the household sample were conventional houses. This underscores an earlier argument that the households in the survey sample constituted of medium to large size families.

## 3.2 Appliance Saturation and Penetration Rates

Appliance saturation rate is a percentage that indicates the number of households in a given geographical area that own a specific appliance [45]. Saturation levels reflect the ownership intensity of a specific appliance within a given geographical area. Where every household owns a specific appliance saturation levels are said to be 100%. Appliance penetration rate is defined as the incidence of occurance of an appliance within a given geographical area. In an area where there are more than one appliance per household, the penetration rate may exceed 100% [49]. Reports from different countries in the world indicate that saturation and penetration rates of electronic appliances is growing rapidly [49, 50, 51, 52]. In South africa saturation rates of common household appliances are reported in the SAARF 2007 AMPS report but the list does not include all appliances of interest to the study and furthermore data for penetration rates is available for television sets only [48].

The specific case of saturation and penetration rates of appliances with standby power capabilities has not been widely reported for developing countries. Mohanty states [27]:

> *No detailed field surveys are currently available for developing countries in Asia and Pacific region.*

The lack of data for developing countries has also been reported by Meier [14]. Mohanty speculates on penetration rates in developing countries and he states [27]:

> *In developing countries, there is lower penetration of electronic products in homes and offices.*

One of the objectives of the appliance survey was to establish saturation and penetration rates of appliances of interest to the study to make data available for the estimation of standby power and energy losses.

### 3.2.1 Appliance's Included in Ownership Survey

The appliances included in the ownership survey to determine saturation and penetration rates are: Television sets, mobile phones, microwave ovens, DVD's, Hi-Fi systems, personal computers, printers, radio/cd alarm clocks, VCR's, Digital satellite TV (DSTV) decoders, fax machines, and printer/fax/copier machines. In general the appliances of interest fall in three major appliance groups entertainment appliances (TV, DSTV decoders, Hi-Fi, DVD's, and VCR's) office equipment (Personal computers, fax machine, printers/fax/copiers) and small appliances (mobile phones, radio/cd/alarm clocks) [21]. The list of appliances is very similar to appliances listed in other surveys and measurements campaigns [23, 24, 53, 54, 55]. This line of thought was pursued so that meaningful comparisons could me made on the data obtained.

In South Africa, security is a major concern. Security systems such as alarm systems, automated garage and entrance gates, closed circuit TV and intercom systems are considered essential for monitoring and controlling access into households. These systems are on all the time in readiness for operation. The systems are not considered to be on standby mode in any time of the day but instead they are in full operational mode. Therefore, security systems are not considered to be contributing to standby and they were not included in the study. Moreover, because the suburbs used for the survey were those where high accessibility was possible, the survey sample does not reflect the reality on the ground in the case of security systems [45]. This study differs from the Australian Appliance Ownership survey where security systems were considered to contribute to household standby power losses.

## 3.3 Saturation Rates

Appliance saturation rates were determined for the sample as well as for each suburb.

### 3.3.1 Sample Appliance Saturation Rates

Table 3.2 presents the sample appliance saturation levels [45].

Table 3.2: Sample Appliance Saturation Rates

| Appliance | Total Number in the Sample | Sample% Saturation |
|---|---|---|
| Television | 532 | 96 |
| Cellphone | 488 | 88 |
| Microwave | 484 | 87 |
| DVD | 371 | 67 |
| VCR | 334 | 60 |
| Hi-Fi | 332 | 60 |
| PC/Monitor | 301 | 54 |
| DSTV Decoders | 227 | 41 |
| Printer | 196 | 35 |
| Clock radio | 196 | 35 |
| Printer/fax/copier | 75 | 14 |
| Fax | 61 | 11 |

As observed in Table 3.2 television sets, mobile phones, microwave ovens, digital video decoders (DVD), Video Cassette recoders (VCR), HiFi systems, and personal computers all have saturation rates higher than 40%. Ownership of personal computer implied ownership of a monitor and ownership of a mobile phone implied the presence of an external power supply for the phone.

In Europe, as reported by de Almeida [28], audio devices represent an almost saturated market and the number of mobile phones are reaching almost saturation levels which is also the case in the sample. In Australia, the following appliance saturation rates were recorded in 2005 [44]: Television sets (100%), DVD's (72%), portable stereo (48%), VCR ( 84%), and stereo's (65%), microwave oven (83%),set top boxes (32%), Home theatre systems (13%), personal computers and monitors (68%), printers (100%), answering machines (17%), and (48%) for printers/scanners/copiers/fax/answering machines what is commonly known as multifunction devices (MFD). In California the reported saturation rates for audio and video appliances in 2002 are [51]: CD players (57%), Compact audio system (49%), portable stereo (68%), analog colour television sets (98%), personal computers (75%)and DVD players (25%).

The following observations are made if the saturation rates from the survey are compared to available saturation figures for Europe, Australia and California:

- Saturation rates for television sets and microwave ovens are the same across all the regions
- As in Europe and Australia cellphones are almost reaching 100% saturation rates in the South African sample
- Saturation rates for other appliances are within 10% except for answering machines and multifunction devices

These results show that the saturation rates of appliances with standby power capabilities in the survey household sample compares favorably with other countries. The suburb appliance saturation rates further substantiates this conclusion.

### 3.3.2 Suburb Appliance Saturation Rates

The suburb saturation rates are presented in Tables 3.3 and Table 3.4 [45].

In most suburbs saturation rates for TV's are above 95% and the lowest saturation rate is at 87% figures matching others from developed countries. Saturation rates for cellphones indicate cellphone battery chargers are over 80% in all suburbs. Because cellphones are a recent technological development, this proves how quickly a technology can penetrate a population if it meets a crical need of the society. This is the case elsewhere in the world as documented in [28, 56].

Table 3.3: Suburb Appliance Saturation Rates

| Appliance | Devland | Len Ext1 | Len Ext3 | Len Ext7 | Len Ext8 |
|---|---|---|---|---|---|
| Television | 94 | 95 | 90 | 98 | 87 |
| Cellphone | 81 | 82 | 74 | 96 | 84 |
| Microwave Oven | 64 | 89 | 83 | 89 | 82 |
| DVD | 50 | 69 | 56 | 87 | 61 |
| VCR | 28 | 63 | 53 | 72 | 57 |
| Hi-Fi | 53 | 48 | 58 | 48 | 64 |
| PC/Monitor | 11 | 50 | 47 | 67 | 38 |
| DSTV Decoder | 3 | 37 | 43 | 63 | 36 |
| Printer | 6 | 33 | 42 | 50 | 25 |
| Clock radio | 8 | 32 | 38 | 39 | 31 |
| Printer/Fax/Copier | 3 | 7 | 8 | 22 | 7 |
| Fax Machine | 3 | 10 | 18 | 0 | 5 |

Table 3.4: Suburb Appliance Saturation Rates

| Appliance | Florida | FP | GW | Kew | Waverley | AEB |
|---|---|---|---|---|---|---|
| Television | 96 | 100 | 100 | 100 | 100 | 100 |
| Cellphone | 93 | 97 | 94 | 96 | 100 | 94 |
| Microwave Oven | 95 | 97 | 89 | 82 | 90 | 87 |
| DVD | 72 | 69 | 67 | 61 | 80 | 53 |
| VCR | 66 | 76 | 67 | 61 | 73 | 38 |
| Hi-Fi | 71 | 72 | 67 | 71 | 77 | 53 |
| PC/Monitor | 75 | 72 | 44 | 50 | 90 | 44 |
| DSTV Decoder | 50 | 48 | 28 | 46 | 70 | 28 |
| Printer | 40 | 38 | 33 | 32 | 63 | 31 |
| Clock radio | 47 | 48 | 33 | 36 | 37 | 28 |
| Printer/Fax/Copier | 26 | 31 | 0 | 11 | 33 | 6 |
| Fax Machine | 12 | 7 | 17 | 21 | 33 | 6 |

### 3.3.3 Saturation Clusters

In this study we define and coin the term *appliance saturation rate differentiators* to be appliances whose saturation rates set apart the ownership levels in the sample. Tables 3.3 and 3.4 reveals that the saturation rates for PC/Monitor, and DSTV decoders set apart the different suburbs. The saturation differences due to PC/monitor and DSTV saturation rates are further clarified in Figure 3.5.

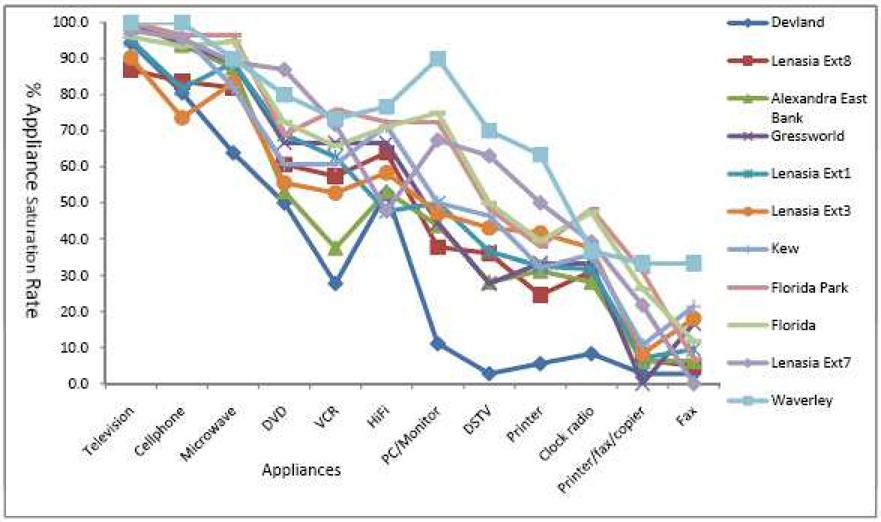


Figure 3.5: Saturation rates across all suburbs

Normalized saturation rates of the differentiator appliances are used to further show the resulting saturation clusters. The normalized saturation rates for DSTV decoders and PC/monitors are shown figure 3.6 and figure 3.7 respectively.

As seen in figure 3.6 and figure 3.7, five distinct appliance saturation clusters emerge. We define and coin the term *saturation cluster* to be a group or collection of suburbs whose saturation rates for the differentiator appliance(s) can be considered to be of the same measure of magnitude. Table 3.5 present the five suburb saturation clusters in the survey sample.

Table 3.5: Appliance Saturation Clusters

| Cluster number | Suburb(s) in Cluster |
|---|---|
| Cluster 1 | Devland |
| Cluster 2 | Lenasia Ext8, Alexandra East Bank, Gressworld |
| Cluster 3 | Lenasia Ext1, Lenasia Ext3, Kew |
| Cluster 4 | Lenasia Ext.7, Florida Park, Florida |
| Cluster 5 | Waverley |

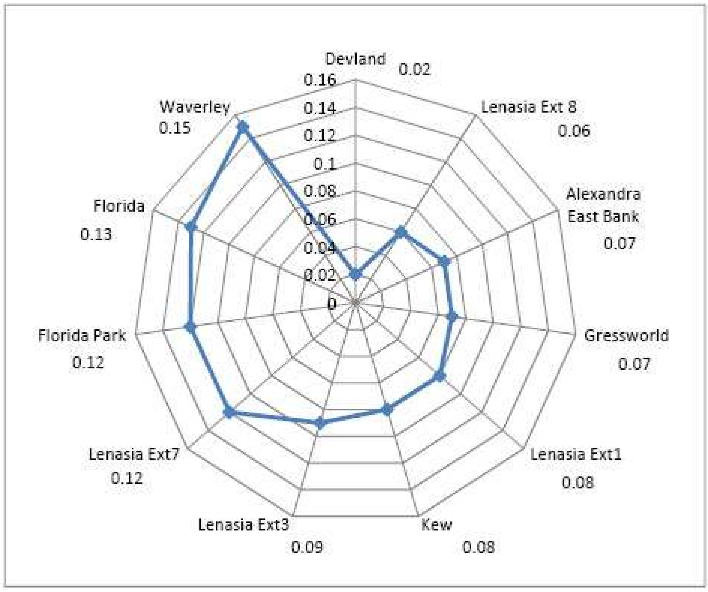


Figure 3.6: Normalized Saturation rates for PC's

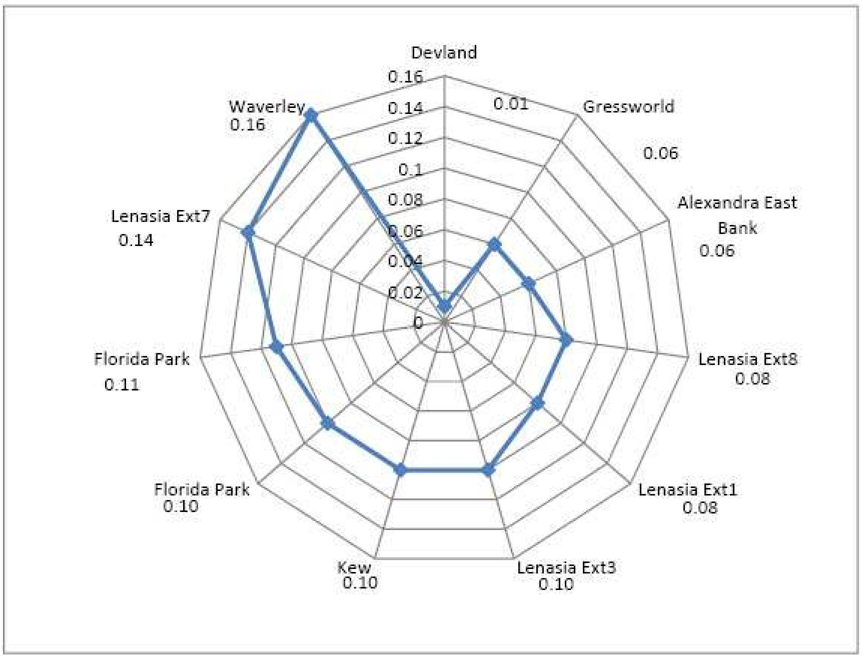


Figure 3.7: Normalized Saturation rates for DSTV Decoders

The saturation rates of the differentiator appliances are lowest in cluster 1 and highest in cluster 5. Saturation rates of the differentiator appliances in suburb clusters 2, 3, and 4 are bounded by the saturation rates in the first and fifth cluster. Therefore appliance saturation rates of the differentiator appliances increase gradually across the five clusters.

## 3.4 Appliance Saturation rates in Suburb Clusters

We define and coin the term *copious* appliances to standby power losses in a saturation cluster to be appliances for which saturation rates are equal to or above 50%. These appliances are vital because of the the pool of appliances they represent especially when one considers the total number of households in South Africa is estimated to be 17 million [57]. *Copious* appliances in each cluster are detailed in table 3.6.

Table 3.6: Copious Appliances

| Cluster 1 | Cluster 2 | Cluster 3 | Cluster 4 | Cluster 5 |
|---|---|---|---|---|
| TV's | TV's | TV's | TV's | TV's |
| Cellphone | Cellphone | Cellphone | Cellphone | Cellphone |
| Microwave | Microwave | Microwave | Microwave | Microwave |
| DVD | DVD | DVD | DVD | DVD |
| Hi-Fi | Hi-Fi | Hi-Fi | Hi-Fi | Hi-Fi |
| | VCR | VCR | VCR | VCR |
| | | PC/Monitor | PC/Monitor | PC/Monitor |
| | | | DSTV | DSTV |
| | | | | Printer |

We observe that the number of *copious* appliances in the different clusters is not the same. Cluster 5 has the most *copious* appliances and the least number of *copious* appliances are found in Cluster 1. The *copious* appliances in cluster 1 are also found in all the other clusters but in higher percentages. These appliances are television sets, cellphones, microwave ovens, DVD's and Hi-Fi systems. These five *copious* appliances common to all clusters is what we have termed and coined as *universal* appliances. The saturation rates of the *universal* appliances are observed to be the highest in all clusters as seen in figure 3.8.

From figure 3.8 it can be observed that there is a variation in saturation rates

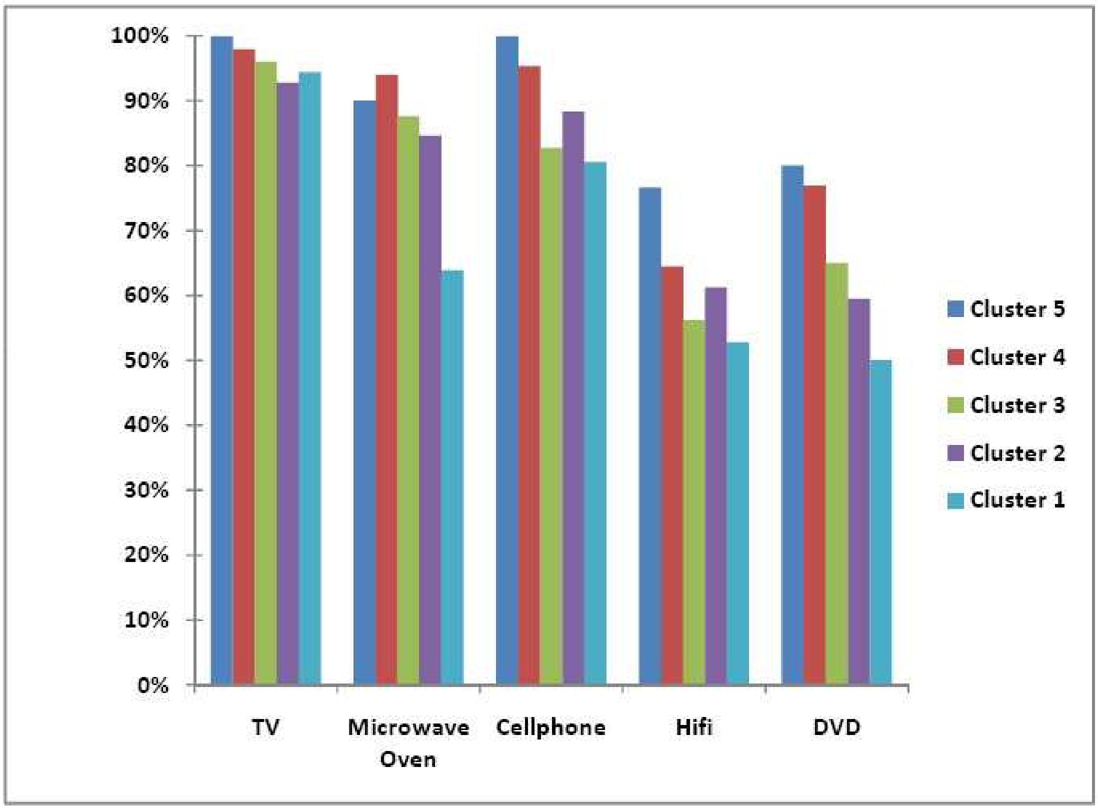


Figure 3.8: Universal Appliance Saturation Rates in Suburb Clusters

of universal appliances across the clusters and it is more pronounced in microwave ovens, cellphones, Hi-fi systems and DVD's. This observation, supports an earlier finding that the number of *copious* appliances across the clusters is not equal. The presence of appliance saturation clusters indicate that the contribution of the different clusters to standby power load is not equal. If all other variables of the standby power load equation remain constant it is expected that there is a diminishing contribution to standby power losses across the clusters. Cluster 5 is expected to have the largest contribution and Cluster 1 will have the least contribution. The higher contribution to standby power load from cluster 5 will be due to the higher number of *copious* appliances as well as higher appliance saturation levels. Cluster 1 has the lowest number of *copious* appliances and saturation levels are lower than in cluster 5. The non-universal appliances are presented in figure 3.9.

The non-universal *copious* appliances in the suburb clusters are VCR's, personal computers and monitors, DSTV decoders and Printers. The saturation rates of these appliances in the different clusters is clearly observed in figure 3.9 where the highest rates are indicated for cluster 5 and lowest for cluster 1. The orders of magnitude of the saturation rates increases as you move from cluster 1 to cluster 5. In the case of DSTV decoders and printers the saturation rates in cluster 1

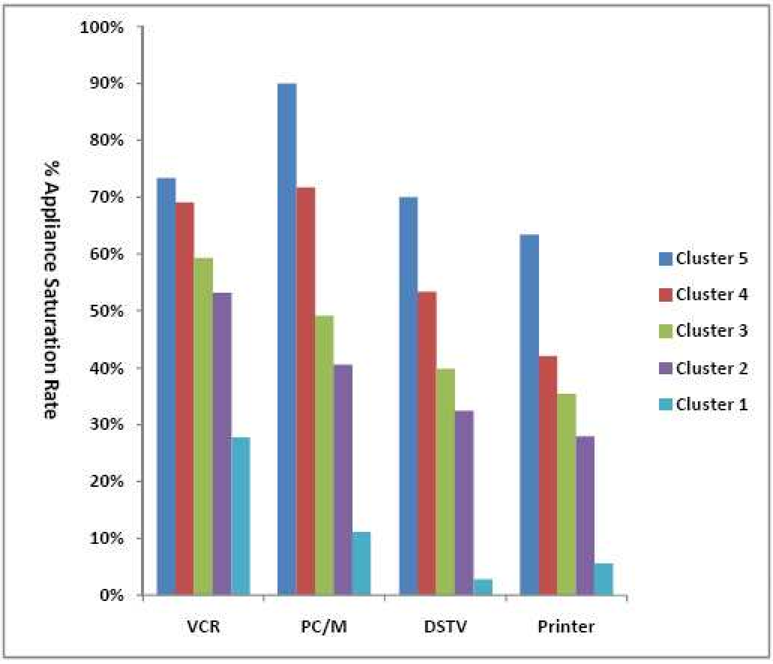


Figure 3.9: Non-Universal Appliances Saturation Rates in Suburb Clusters

decrease to below 10%. A detail illustration of the cluster saturation rates of all the appliances included in the survey sample is presented in table 3.7

Table 3.7: Appliance % Saturation Rates in Clusters

| Appliance | Cluster 5 | Cluster 4 | Cluster 3 | Cluster 2 | Cluster 1 |
|---|---|---|---|---|---|
| TV's | 100 | 98 | 96 | 93 | 94 |
| Cellphone | 100 | 95 | 83 | 88 | 81 |
| Microwave | 90 | 94 | 88 | 85 | 64 |
| DVD | 80 | 77 | 65 | 59 | 50 |
| Hi-Fi | 77 | 64 | 56 | 61 | 53 |
| VCR | 73 | 69 | 59 | 53 | 28 |
| PC/Monitor | 90 | 72 | 49 | 41 | 11 |
| DSTV | 70 | 53 | 40 | 32 | 3 |
| Printer | 63 | 42 | 35 | 28 | 6 |
| Alarm CD/Radio | 37 | 45 | 34 | 31 | 8 |
| Multifunction Devices | 33 | 26 | 8 | 5 | 3 |
| Fax | 33 | 7 | 14 | 7 | 3 |

Alarm CD/radios, Printers/Fax/Copier machines (multifunction devices), and fax machines all have cluster appliance saturation levels of less than 50% in all clusters. This does not imply that these appliances have little or insignificant contributions to standby power losses especially because the total number of households in South Africa is approximately 17 millions [57].

We define and coin the term *middling* appliances to be appliances whose saturation rates are lower than 50% but greater than or equal to 10%. We further define and coin the term *scanty* appliances to be appliances with saturation rates less than 10%. From Table 3.7, five tables 3.8, 3.9, 3.10, 3.11 and 3.12 are derived. These tables present the appliances in each of the three groups: *copious*, *middling* and *scanty* as defined earlier for each saturation cluster.

The appliances in the different classification groups are not the same across the clusters. Cluster 5 does not have any *scanty* appliances and most of the appliances are *copious* appliances while in Cluster 1 most appliances are *scanty* appliances. *Copious* appliances in Cluster 1 are what we have termed *universal* appliances and these as expected are common in all the five clusters. It can be observed that an appliance can be classified differently depending on the cluster being considered. For example DSTV decoders are classified as *copious* appliances in Clusters 4 and 5 but the same appliance is a *middling* appliance in clusters 2 and 3 and *scanty* appliance in Cluster 1. This augers well with the concept of saturation clusters.

## 3.5 Appliance Penetration Rates

Appliance penetration rates are used to indicate the total number of an appliance found in a specified population of households [45]. Appliance penetration rates may exceed 1 in cases where there is more than one of each appliance per household. Appliance penetration rates can be equal to appliance saturation rates in the case where each household owns one of the appliance in question. Otherwise it is always possible that penetration rates are higher than saturation rates indicating that a single household owns more than one of the appliance in question. Results on penetration rates are presented for:

- Sample
- Suburbs
- Clusters

Table 3.8: Appliance Classification in Clusters 1

| | Copious | Middling | Scanty |
|---|---|---|---|
| Cluster 1 | TV | VCR | DSTV |
| | Microwave | PC/Monitors | Printers |
| | Cellphones | | Fax machine |
| | Hi-Fi | | Multifunction Device |
| | DVD | | Alarm CD/Radio |

Table 3.9: Appliance Classification in Clusters 2

| | Copious | Middling | Scanty |
|---|---|---|---|
| Cluster 2 | TV | PC/Monitors | Fax machine |
| | Microwave | Printers | Multifunction devices |
| | Cellphones | DSTV | |
| | Hi-Fi | Alarm CD/Radio | |
| | DVD | | |
| | VCR | | |

Table 3.10: Appliance Classification in Clusters 3

| | Copious | Middling | Scanty |
|---|---|---|---|
| Cluster 3 | TV | PC/Monitors | Multifunction devices |
| | Microwave | Printers | |
| | Cellphones | DSTV | |
| | Hi-Fi | Alarm CD/Radio | |
| | DVD | | |
| | VCR | | |

Table 3.11: Appliance Classification in Clusters 4

| | Copious | Middling | Scanty |
|---|---|---|---|
| Cluster 4 | TV | Multifunction devices | Fax machine |
| | Microwave | Alarm CD/Radio | |
| | Cellphones | Printers | |
| | Hi-Fi | | |
| | DVD | | |
| | VCR | | |
| | PC/Monitors | | |
| | DSTV | | |

Table 3.12: Appliance Classification in Clusters 5

| | Copious | Middling | Scanty |
|---|---|---|---|
| Cluster 5 | TV | Multifunction devices | |
| | Microwave | Alarm CD/Radio | |
| | Cellphones | Fax machine | |
| | Hi-Fi | | |
| | DVD | | |
| | VCR | | |
| | PC/Monitors | | |
| | DSTV | | |
| | Printers | | |

### 3.5.1 Sample Penetration Rates

The appliance penetration rates are presented for television sets, cellphones, microwave ovens, DVD's, Hi-Fi's, VCR's, DSTV decoders, PC's, computer monitors, printers and alarm clocks. The sample penetration rates are presented in Figure 3.10.

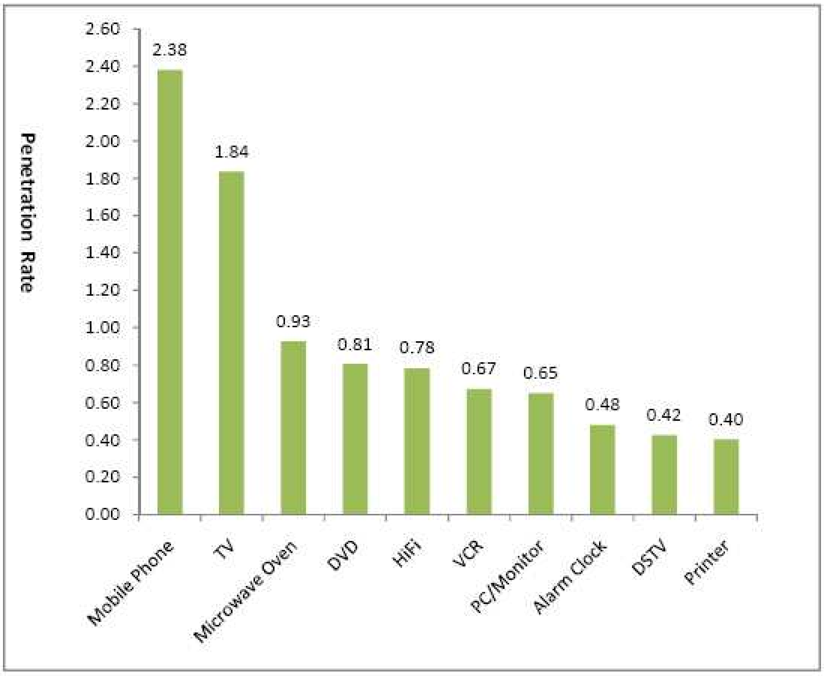


Figure 3.10: Sample Appliance Penetration Rates

In the house survey sample, mobile phones have the highest sample penetration rate at 2.38 followed by television sets at 1.84. These figures indicate the incidence of these two appliances in the household within the sample to be more than one appliance in some of the households. The sample penetration rates for TV's, mobile phones, microwave ovens, DVD's, and Hi-Fi's are between 0.78 for Hi-Fi's and 2.38 for mobile phones i.e above 0.5 for all appliances. These sample penetration rates figures further validate the concept of universal appliances. The numbers signify that in the survey sample more than 50% of households own one or more of the universal appliances.

### Comparisons with Other Countries

The appliance penetration rates reported for Australia for 2001 and 2006 are presented in Table 3.13 [21, 44].

Table 3.13: Appliance Penetration Rates Recorded for Australia

| Year | Mobile Phone | TV | DVD | Hi-Fi |
|---|---|---|---|---|
| 2001 | 1.05 | 1.9 | 0.089 | 1.19 |
| 2006 | - | 2.07 | 0.82 | - |
| Year | Microwave Oven | STB | PC | VCR |
| 2001 | 0.93 | - | 0.73 | 1.21 |
| 2006 | - | 0.32 | 1.25 | 1.1 |

From table 3.13 it can be seen that the appliance penetration rates for Australia in 2006 are much higher than the sample penetration rates obtained in 2006 from the eleven suburbs. However the penetration rates for mobile phones and DSTV decoders in the sample of households in South Africa are higher than the rates reported for Australia for Set Top Boxes (STB's) and mobile phones in 2006. DVD's in Australia are reported to have penetration rates of 0.089 (2001) and 0.82 (2006). In the household sample for South Africa, the penetration rate for DVD is 0.81 (2006). The penetration rates for DVD in 2006 are the same for Australia and South Africa.

As seen in table 3.13, there are large differences in the penetration rates for TV's, PC's and DVD's between 2001 and 2006 for Australia while the penetration rates for VCR's stays constant between 2001 and 2006. The large differences indicates increased assimilation of the technology within the sample, in the case of TV's, PC's and DVD's. VCR's technology is slowly being replaced by DVD's and this is evidenced by the almost constant numbers in the sample over a six year period. Such trends are expected to be also true for South Africa as new technologies enter the household market. Such technologies are DVD's, PC's, Laptops, mobile phones, and new television screen technologies such as LCD and Plasma. In general the rates reported for Australia in 2001 for TV's, VCR's, PC's and microwave ovens are comparable to the sample penetration rates of the corresponding appliances in South Africa. The reported penetration rate for TV's in the European Union in 2007 is 1.3 and this is lower than the 1.84 for the survey sample of 11 suburbs in South Africa [50].

The penetration rates obtained for the universal appliances in the household sample for South Africa are comparable to the figures reported for Australia and Europe. This necessitates that the statement *in developing countries there is lower penetration of electronic products in homes and offices* [27] be qualified.

### 3.5.2 Suburb Appliance Penetration Rates

The suburb saturation rates indicate that the ownership of appliances is aggregated across the suburbs within the sample. It is expected that the appliance penetration rates would follow the same trend. Figure 3.11 presents the penetration rates of the different appliances in the each suburb. In each suburb, mobile phones have the

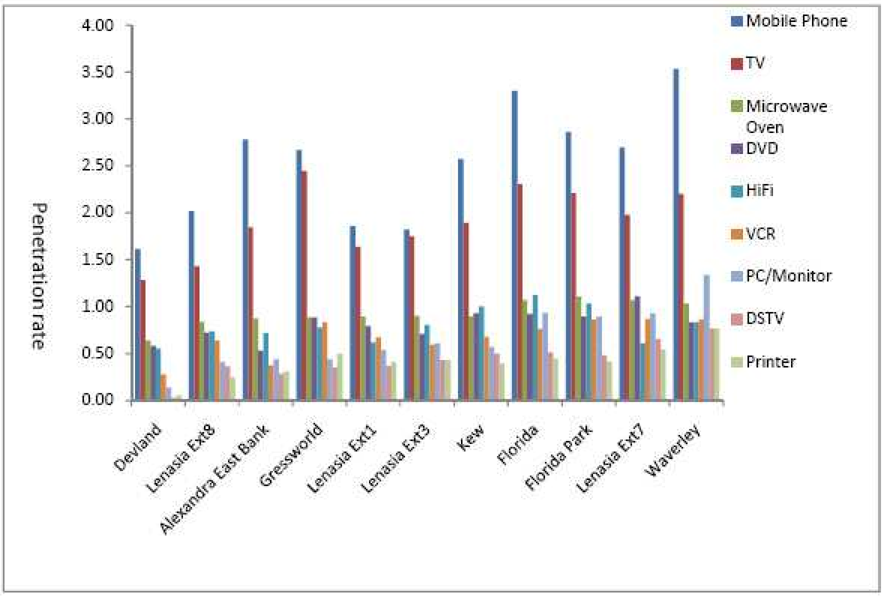


Figure 3.11: Suburb Appliance Penetration Rates

highest penetration rates with highest rate of 3.53 indicated for Waverley and the lowest 1.61 indicated for Devland. In the rest of the suburbs mobile phone penetration rates are bounded by those of Devland and Waverley. The high penetration rates observed across all suburbs are evidence of how quickly the mobile phone technology has been embraced by the general population and it is an indication of the importance of the communication service it provides to the greater population.

Table 3.14 presents the penetration rates of the *universal* appliances in each of the eleven suburbs. The penetration rates of all the *universal* appliances across all the eleven suburbs are greater than 0.5 with the lowest rate being 0.53 for DVD's in Alexandra East Bank.

Table 3.14: Universal Appliances Penetration Rates in Suburbs

| Suburb | Mobile Phone | TV | Microwave Oven | DVD | Hi-Fi |
|---|---|---|---|---|---|
| Devland | 1.61 | 1.28 | 0.64 | 0.58 | 0.56 |
| Lenasia Ext.8 | 2.02 | 1.43 | 0.84 | 0.72 | 0.74 |
| Alexandra East Bank | 2.78 | 1.84 | 0.88 | 0.53 | 0.72 |
| Gressworld | 2.67 | 2.44 | 0.89 | 0.89 | 0.78 |
| Lenasia Ext.1 | 1.86 | 1.63 | 0.9 | 0.79 | 0.62 |
| Kew | 2.57 | 1.89 | 0.89 | 0.93 | 1.00 |
| Lenasia Ext.3 | 1.83 | 1.75 | 0.9 | 0.71 | 0.83 |
| Florida Park | 2.77 | 2.13 | 1.07 | 0.87 | 1.00 |
| Florida | 3.30 | 2.30 | 1.07 | 0.92 | 1.12 |
| Lenasia Ext.7 | 2.70 | 1.98 | 1.07 | 1.11 | 0.61 |
| Waverley | 3.53 | 2.20 | 1.03 | 0.83 | 0.87 |

The penetration rates observed in table 3.14 once again validates the concept of universal appliances.

As seen in in figure 3.11 the appliance penetration rates seems to be clustered in groups. Personal computers penetration rates are used to differentiate the suburbs into different clusters. The result is presented in Figure 3.12.

### 3.5.3 Appliance Penetration Clusters

Figure 3.12 portrays the existence of what we have termed and coined as *appliance penetration clusters*. Penetration clusters are defined as groups of households for which the significant appliances have almost equal magnitudes of appliance penetration rates. From figure 3.12 five cluster groups are evident. The five clusters emerging from figure 3.12 are portrayed in figure 3.13 which presents the penetration details for the differentiator appliance in each suburb.

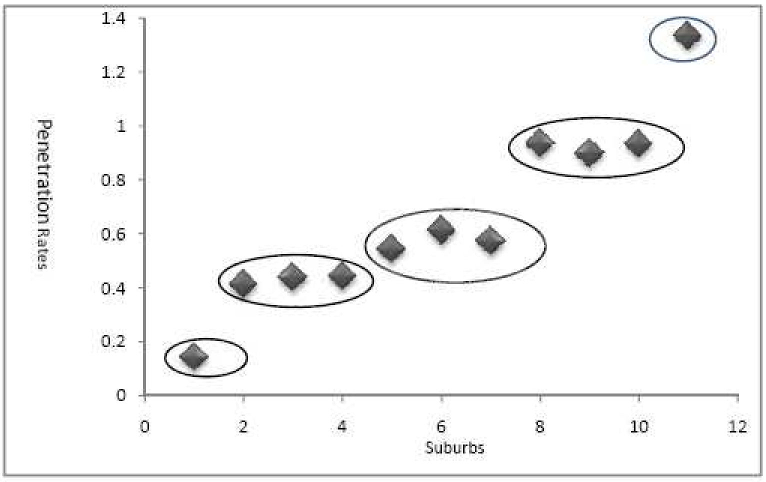


Figure 3.12: Penetration Rates for Differentiator Appliance: PC's

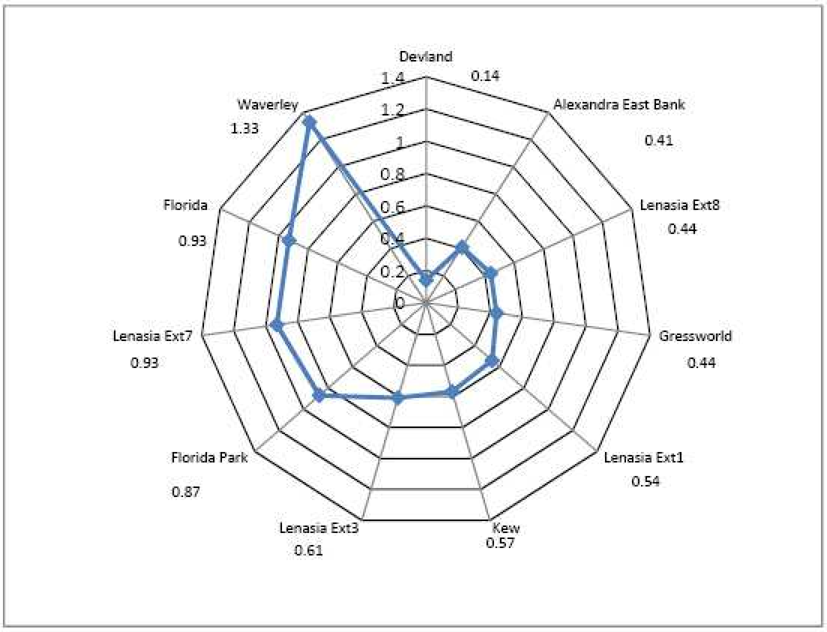


Figure 3.13: Suburb Penetration Rates for Differentiator Appliance

The five clusters identified from figure 3.13 and as indicated by figure 3.12 are:

- Cluster 1: Devland
- Cluster 2: Lenasia Ext.8, Gressworld and Alexandra East Bank
- Cluster 3: Lenasia Ext1, Kew and Lenasia Ext.3
- Cluster 4: Florida Park, Florida, Lenasia EXt.7
- Cluster 5: Waverley

The suburb(s) that form the five appliance penetration clusters are the same as the suburbs in the five appliance saturation clusters. This indicates that the clusters established by appliance saturation rates are indicators of the appliance penetration rates in the sample. The saturation clusters correspond to the penetration clusters i.e. high saturation rates implies high penetration rates and low saturation rates implies low penetration rates. If there was no correspondence there would be a contradiction nullifying the survey results. Where saturation rates are high, the concentration of those particular appliances are expected to also be high. Table 3.15 present the appliance penetration rates of the *copious* appliances in the five penetration clusters.

Table 3.15: Copious Appliances Penetration Rates in Clusters

| Appliance | Cluster 5 | Cluster 4 | Cluster 3 | Cluster 2 | Cluster 1 |
|---|---|---|---|---|---|
| Mobile Phone | 3.53 | 3.01 | 1.93 | 2.34 | 1.61 |
| Television | 2.02 | 2.17 | 1.70 | 1.71 | 1.28 |
| Microwave Oven | 1.03 | 1.07 | 0.90 | 0.86 | 0.64 |
| DVD | 0.83 | 0.97 | 0.78 | 0.69 | 0.58 |
| Hi-Fi | 0.83 | 0.94 | 0.73 | 0.74 | 0.56 |
| VCR | 0.87 | 0.81 | 0.65 | 0.59 | 0.28 |
| PC/Monitor | 1.33 | 0.92 | 0.57 | 0.47 | 0.14 |
| DSTV | 0.77 | 0.55 | 0.40 | 0.33 | 0.03 |
| Printer | 0.77 | 0.47 | 0.42 | 0.31 | 0.06 |

Appliance penetration rates is another variable that is required for the estimation and prediction of standby power load. The finding that penetration rates are clustered in five distinct groups across the survey sample implies that standby power and energy losses are differentiated by penetration rates across the clusters in the household sample.

## 3.6 Appliance Age

Figure 3.14 represents the year of purchase for different appliances in the survey sample. Oldest appliances found in the household sample were purchased between

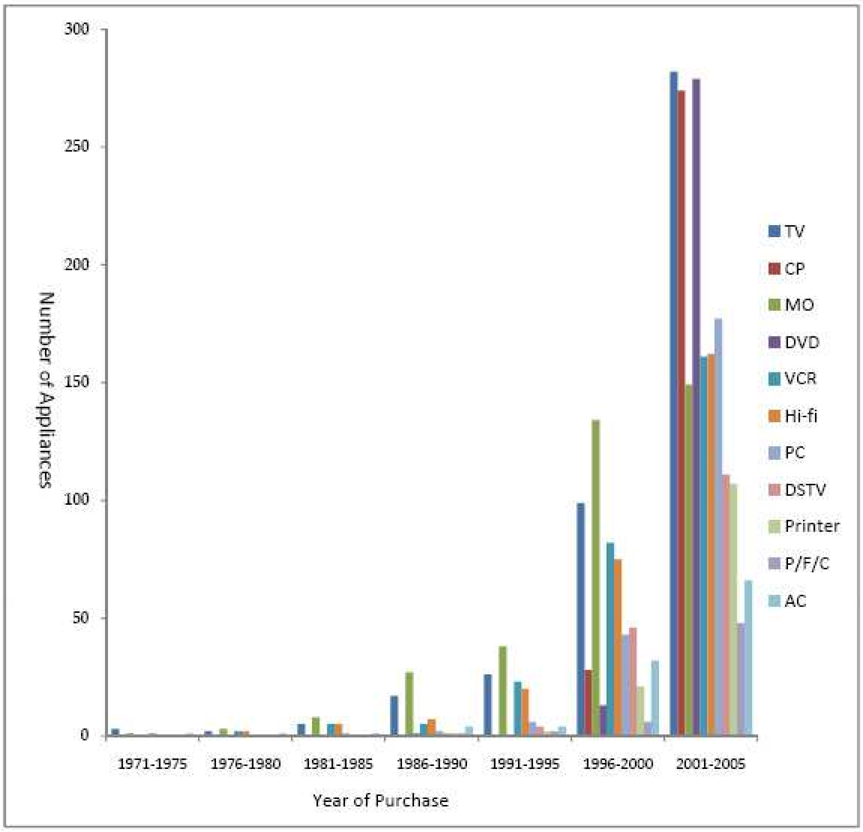


Figure 3.14: Appliance Age

1971 and 1975. In these years of purchase we find only six appliances 3 television sets, and one each of microwave oven, alarm clock and Hi-Fi system. In the years of purchase between 1976 and 1985 again only 26 appliances were recorded indicating small numbers. Between the years, 1986-1990 the recorded appliances more than double those of 1976-1985 to 66. In the years 1991-1995, again the numbers almost double to 126 and the largest number of appliance are recorded to have been purchased between 1996 to 2005 altogether a total of 2395 far much larger than any other period before. From the analysis of figure 3.14 it is clear that most appliances found in the sample were purchased in the last ten years i.e. between 1996 and 2005.

The age of appliances found in the survey sample can be used to determine the appliance turn over rates. The appliance turn over rates can be used in the prediction of the standby power load. High turnover rates would imply that the standby power load will change over short periods of time as complete new appliances or advancement on old appliance technologies enter the households. Long appliance turnover rates would mean that the determined load can be assumed to be constant over a longer period of time without a significant change unless there is a step change in the market.

The change from analogue to digital television broadcasting in South Africa is an example of an impulse or step change in the market. The markets will have to respond to the change by introducing new television screen technologies as well as set top boxes for receiving digital signals. In such cases, the new technologies brings in new types of domestic loads with different power characteristics which completely changes an initial profile of household power consumption.

### 3.6.1 New Technologies

The term new technologies in this work is considered to mean advancement in older technologies or complete new appliances that enter the market for the first time. Advancement of older technologies results in new appliance with new appliance performance parameters, efficiencies, and added functionalities. All these results in new power consumption parameters that redefine an established load. Complete new technologies imply an added load to the already existing loads in the household, resulting in increased total load. Therefore both technology advancement and complete new appliance technologies have an impact on the prediction of the load. Figure 3.15 illustrates the incidence of new appliance technologies in the households sample.

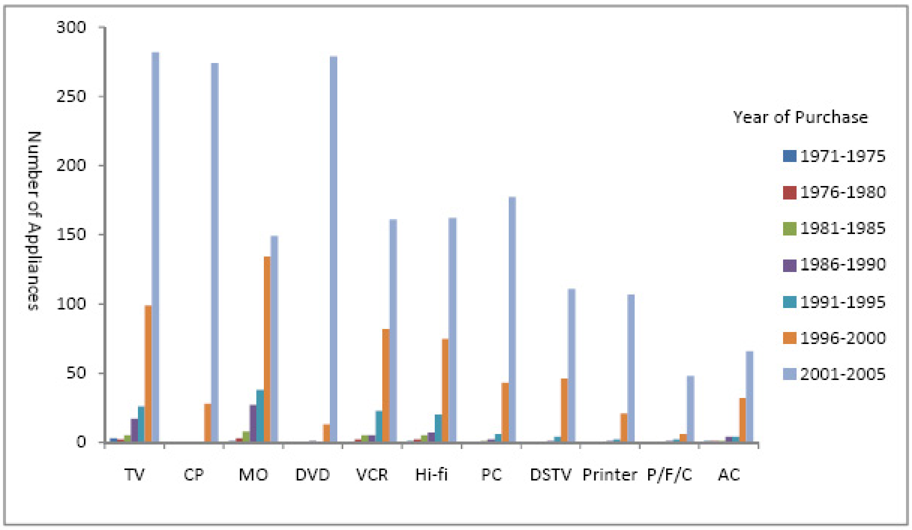


Figure 3.15: Appliance Age

The purchase of a PC is recorded for the first time in the period 1976-1980. DSTV decoders, Printers, and multifunction devices appear for the first time in the purchase period 1981-1985. DVD's appear in the purchase period 1986-1990 and cellphones are recorded only from 1991 onwards. Figure 3.15 signifies the gradual introduction of new technologies in South African households. The effect of new technologies is zero until the technologies are assimilated in the households. A decision to purchase an appliance locks-in specific power consumption levels for different operational modes for the life of that appliance.

In figure 3.15 it is clear that DVD's, cellphones and personal computers have gained significant shares of ownership in the households. An opportunity exists of introducing energy efficient appliances in early/new models because these new products will not be replaced for many years making there power consumption footprint static for the whole period of use. At present the South African household is seeing the introduction of new appliance technologies in digital television sets as well as new technologies in set top boxes to support the envisaged change from analogue television to digital television broadcasting. This change is expected to bring a step change in the household standby power load. An opportunity to introduce a new energy efficient technology exists. If not taken, an important energy efficiency opportunity will be lost and the inefficient products could remain in the households for many years to come.

## 3.7 Consumer Appliance Operational Behaviour

One of the factors that determine the energy use in a specific household is the behaviour of the residents [58]. An energy efficient behaviour manifests itself in appliance use behaviour and appliance purchasing criteria. This is supported by the work of Raaij and Verhallen, who discussed three types of energy related behaviours namely purchase, usage and maintenance [59]. When a consumer takes into consideration the energy attribute of an appliance at the time of purchase the behaviour exhibited is what is reffered to as purchase related behaviour [59]. Usage related behaviour is governed by the day to day energy conscious behaviour exhibited in operating appliances and it is generally harder to change [59].

The size of an appliance standby power load is linked to the appliance technical attributes [27]. Appliance technical attributes are the appliance power consumption levels in different operational modes as well as operational functionalities available to the user. Appliance operational functionalities influences user operational behaviour to some large degree. If for example an appliance has a remote controller, the availability of the remote controller to the user influences the user on how he/she operates the appliance. Likewise if an appliance does not have a power off switch then it implies that when not in use the appliance is either switched off at the wall or in standby mode. In both cases, the user appliance operational behaviour is influenced by the technical attributes of the appliance and its functionality.

The usage or what we have termed operational behaviour distinguishes between one user who exhibits an energy efficient behaviour and another user with no energy efficient behaviour. These two users contribute differently to household standby power and energy losses.

In the survey the aim was to establish how the consumers operated their appliances and be able to determine if the appliance operational behaviour of consumers lend itself to standby power and energy losses. This is a variable that has not yet been used before in determining appliance standby power and energy losses in previous studies [12, 21, 23, 33, 53, 55].

The questions in the survey were grouped in two major groups, appliances with and without remote controllers as seen in Appendix A.0.2. Remote controlled appliances included television sets, DVD's, Hi-Fi's, DSTV's decoders, and VCR's. Microwave ovens, mobile phone chargers, personal computer, computer monitors, printers and printers/fax/copier machines are the appliances without remote controllers. The questions for the two appliance groups were different. The question for remote controlled appliances read as follows:

When not in use the following appliances are normally:

- Switched off with the remote controller (SORC)
- Switched off at the appliance power switch (SOAPS)
- Switched off at the wall switch (SOAWS)

The question for the appliances without remote controllers was: The following appliances are normally:

- Left on all the time (LOAT)
- Switched on only when required for use (SOOWR)

Most remote controlled appliances do not have hard off switches provided on the appliances. This is supported by data obtained during measurement campaign where for each appliance measured the technical attribute 'soft off' was recorded as true or false. Table 3.16 represents the number of appliances with remote controllers with 'soft off' attribute recorded as 'true'. In soft-off state, an appliance consumes very low levels of power and in a hard-off state an appliance power consumption is zero as illustrated in figure 1.1.

Table 3.16: Measured Remote Controlled Appliances with Soft-Off Capability

| Appliance | 'Soft Off' | Measured Appliances |
|---|---|---|
| Television | 3 | 145 |
| VCR | 0 | 49 |
| DVD | 1 | 84 |
| Hi-Fi | 0 | 40 |
| Mini Hi-Fi | 2 | 37 |
| DSTV decoder | 0 | 36 |

From table 3.16 it is evident that the number of appliance with soft-off attribute is very small within the sample of measured appliances. Therefore, in most of appliances the state of the appliance is the same for the two responses 'switched off using the remote controller' and 'switched off at the appliance power switch'. These two responses results in an appliance in 'standby state' while the 'switched off at the wall' results in 'hard off' state. Table 3.16 further confirms that very few appliances with remote controllers have the soft-off attribute implying that when switched off at the wall, the appliances power consumption is zero for most of the appliances.

### 3.7.1 Operational Behaviour: Remote Controlled Appliances

The remote controlled appliances are: Television sets, VCR's, DVD's Hi-Fi's, and DSTV decoders. Table 3.17 presents the responses from the households in the survey sample to the question of how remote controlled appliances are switched off when not in use.

Since almost all remote controlled appliances do not have the soft off attribute then from table 3.17 it is clear that for all the appliances at least 85% (VCR) of the households in the sample and at most 96% (DSTV) of the households in the sample normally leave the appliances in standby mode when the appliances are not in use. The user operational behaviour of these appliances lends itself heavily to the presence

Table 3.17: User Operational Behavior: Remote controlled Appliances

| Appliance | SORC (%) | SOAPS (%) | SOAWS |
|---|---|---|---|
| Television | 55 | 34 | 11 |
| VCR | 53 | 32 | 15 |
| DVD | 55 | 33 | 12 |
| Hi-Fi | 49 | 38 | 13 |
| DSTV decoder | 83 | 13 | 4 |

of standby power losses. This is seen in table 3.18 which represents the sum total of the responses SORC asnd SOAPS.

Table 3.18: Standby mode behaviour in Sample (%)

| Appliance | Standby Mode (%) | Non-Standby Mode (%) |
|---|---|---|
| Television | 89 | 11 |
| VCR | 85 | 15 |
| DVD | 88 | 12 |
| Hi-Fi | 87 | 13 |
| DSTV decoder | 96 | 4 |

### 3.7.2 Operational Behaviour: Non-Remote Controlled Appliances

As stated earlier the non-remote controlled appliances includes PC and monitors, Printers, Printers/Fax/Copier machines, microwave ovens and mobile phone chargers. Table 3.19 presents the % responses on the state of non-remote controlled appliances when they are not in use from the sample of households. The response

Table 3.19: Appliance Operational Behaviour: Non-remote Controlled Appliances

| Appliance | SOOWR (%) | LOATT (%) |
|---|---|---|
| PC/Monitors | 76 | 24 |
| Printers/Fax/Copiers | 30 | 70 |
| Printers | 66 | 34 |
| Microwave Ovens | 31 | 69 |
| Mobile phone Chargers | 74 | 26 |

'Left On All the time' (LOAAT) represents an appliance operational behaviour that lends itself to standby power losses. The response 'Switched on only when required'

(SOOWR) implies an energy efficient behaviour. An appliance considered to be in 'off' state could further be in either 'soft' or 'hard-off' mode.

From table 3.19 the response LOAAT for Printers/Fax/Copier machines (multifunction devices) is 70%. This high incidence can be linked to the fax receiving function of the appliance. The fax receiving function can take place anytime of the day hence it is logical to leave the appliance on all the time. PC/Monitors, printers and mobile phone battery chargers have higher rates for SOOWR indicating and energy efficient behaviour. It was found out during the measurements campaign that none of the microwave ovens and mobile phone batterry chargers continued to consume power at very low levels when switched off at the wall i.e none had soft off capabilities. Out of 13 printers measured one was found to have soft off capabilities this is also the case in the 19 multifunction devices. Out of 91 personal computer and monitors measured, 18 were found to have soft off capabilities. Table 3.20 presents the detail of the total number of measured appliances and the corresponding number of appliances with soft-off capabilities.

Table 3.20: Measured Non-Remote Controlled Appliances with Soft-Off Capability

| Appliance | 'Soft Off' | Measured Appliances |
|---|---|---|
| PC/Monitors | 18 | 91 |
| Multifunction Devices | 1 | 19 |
| Printers | 1 | 19 |
| Microwave Ovens | 0 | 45 |
| Mobile Phone Battery Charger | 0 | 63 |

### 3.7.3 Appliance Operational Behaviour in Suburbs

In this section the operational behaviour of the 11 different suburbs included in the sample are discussed. The three responses 'SORC', 'SOPS' and 'SOAWS' for remote controlled appliances and the two responses 'LOATT' ans 'SOOWR' for non-remote controlled appliances are presented in percentages and discussed.

#### Switched Off with Remote Controller (SORC)

Table 3.21 presents the responses on SORC in each suburb.

The response SORC lends itself to appliances left in standby mode. In general

Table 3.21: Suburb % Responses for SORC

| Suburb | TV | VCR | DVD | Hi-Fi | DSTV |
|---|---|---|---|---|---|
| Devland | 41 | 44 | 38 | 56 | 100 |
| Lenasia Ext.8 | 45 | 45 | 51 | 34 | 80 |
| Gressworld | 47 | 50 | 75 | 31 | 100 |
| Alexandra East Bank | 81 | 75 | 76 | 65 | 100 |
| Lenasia Ext.1 | 45 | 42 | 45 | 48 | 74 |
| Lenasia Ext.3 | 50 | 47 | 55 | 58 | 74 |
| Kew | 57 | 59 | 53 | 26 | 100 |
| Florida | 62 | 65 | 66 | 59 | 83 |
| Florida Park | 66 | 57 | 64 | 42 | 100 |
| Lenasia Ext.7 | 52 | 46 | 41 | 44 | 75 |
| Waverley | 83 | 81 | 78 | 52 | 100 |

households in Waverley exhibit the highest percentages of the response SORC for all remote controlled appliances. Households in Devland exhibit the lowest percentages in responses for SORC. The other households in the remaining suburbs exhibit percentage responses bounded by those of Waverley at the top and Devland at the bottom except for households in Alexandra East Bank. The responses for households in Alexandra East Bank are comparable to those in Waverley and this cannot be explained on the basis of the household location, income or race. However the case of lower percentage responses for Devland can be based on technological interventions.

In Devland all household with electricity have installed prepaid meters. The prepaid meter is a technological intervention which aids the user to directly observe and become aware of their electricity usage. Where the electricity usage cannot be explained the cause of the losses is determined and eliminated. The prepaid meter induces actions which result in an energy efficient behaviour.

It can also be observed that the percentage responses for SORC for all appliances in all suburbs increases gradually as you move from Devland to Waverley. This tendency supports the clustering phenomena that has been observed for saturation and penetration rates in the suburbs.

The percentage responses for DSTV are 100% in Devland, Gressworld, Alexandra East Bank, Lenasia Extension 1, Kew, Florida Park and Waverley. This implies that in these suburbs if DSTV decoders are not in full operational mode then they are in standby mode. From table 3.16 out of 36 DSTV decoders comprising different decoder models none had soft off capability. Therefore if a DSTV decoder is switched off at the appliance power switch (SOAPS), the decoder is left in standby mode. If the DSTV percentage response values for SORC and SOAPS are added then the percentage number of households in each suburb in which the DSTV decoder is left in standby mode ranges from 93% in Lenasia Extension 1 to 100%. The very low percentages to the the response 'Switched of at the Wall Switch' (SOAWS) in table 3.23 confirms the high incidences of DSTV decoders left in standby mode when not in use. These high numbers can be attributed to the unavailability of the off switch (technical attribute) as well as the service provider's operational requirement that clients keep their decoders in standby mode when not in use.

### Switched Off at Appliance Power Switch (SOAPS)

In general, for the response SOAPS the percentages are lowest for Waverley followed by Alexandra East Bank and highest for Lenasia Extension 7, if all appliances with remote controllers are considered as seen in table 3.22.

Table 3.22: Suburb % Responses for SOAPS

| Suburb | TV | VCR | DVD | Hi-Fi | DSTV |
|---|---|---|---|---|---|
| Devland | 38 | 22 | 44 | 44 | 0 |
| Lenasia Ext.8 | 47 | 39 | 38 | 44 | 15 |
| Gressworld | 29 | 17 | 0 | 15 | 0 |
| Alexandra East Bank | 19 | 17 | 18 | 35 | 0 |
| Lenasia Ext.1 | 41 | 42 | 38 | 39 | 19 |
| Lenasia Ext.3 | 34 | 32 | 31 | 23 | 22 |
| Kew | 36 | 41 | 41 | 58 | 0 |
| Florida | 27 | 19 | 27 | 36 | 11 |
| Florida Park | 24 | 29 | 18 | 53 | 0 |
| Lenasia Ext.7 | 46 | 49 | 54 | 44 | 21 |
| Waverley | 14 | 14 | 17 | 43 | 0 |

In the case of Waverley and Alexandra East Bank this is the opposite of what was observed for the response SORC. The gradual general increase in percentages for all appliances from Waverley to Devland once again points to the suburb clusters that has been already observed and discussed.

To interpret the response SOAPS correctly in terms of its consequences to power losses the function of the appliance switch is vital. If an appliance has a power switch that when operated it switches the appliance to a standby mode then in such appliances SOAPS implies that the appliance is in standby mode. If an appliance has an appliance switch that can be operated and the appliance is switched off then the response SOAPS implies either a hard off or a soft off state. In hard off state, the appliance draws no power but in a soft off state the appliance continues to draw but very little power. From table 3.16 it is evident that soft off capabilities is present in some appliances though in small numbers. These appliances are television sets, DVD, and Mini-Hi-Fi systems. In these appliances the variable user behaviour can result in three possible appliance modes namely: full, standby or soft off. No soft off capabilities were found on DSTV decoders, VCR's and Hi-Fi sets as seen in table 3.16. Therefore for these appliances only two operational states are possible either full or standby mode.

#### Switched of at Wall Switch (SOAWS)

The response SOAWS lends itself to a behaviour that does not result in standby power losses. The percentage responses for the remote controlled appliances in all suburbs are presented in table 3.23.

Table 3.23: Suburb % Responses for SOAWS

| Suburb | TV | VCR | DVD | Hi-Fi | DSTV |
|---|---|---|---|---|---|
| Devland | 22 | 33 | 19 | 0 | 0 |
| Lenasia Ext.8 | 8 | 16 | 11 | 22 | 5 |
| Gressworld | 24 | 33 | 25 | 54 | 0 |
| Alexandra East Bank | 0 | 8 | 6 | 0 | 0 |
| Lenasia Ext.1 | 14 | 16 | 17 | 13 | 7 |
| Lenasia Ext.3 | 16 | 21 | 14 | 20 | 4 |
| Kew | 7 | 0 | 6 | 16 | 0 |
| Florida | 11 | 17 | 7 | 5 | 0 |
| Florida Park | 10 | 14 | 18 | 5 | 0 |
| Lenasia Ext.7 | 2 | 6 | 5 | 11 | 4 |
| Waverley | 3 | 5 | 4 | 4 | 0 |

Alexandra East Bank is the suburb in which SOAWS scores are the least with 0% for three appliances TV, Hi-Fi's, and DSTV decoders. This implies that the suburb Alexandra East Bank lends itself highly to standby power losses and energy efficient behaviour levels are the lowest. The figures for Gressworld and Devland indicate that in these two suburbs the levels of energy efficient behaviour are higher than in the other suburbs.

In six suburbs namely Devland, Gressworld, Alexandra East Bank, Kew, Florida Park and Waverley the percentages are 0% for DSTV decoders. In the remaining suburbs the percentages range between 4% and and 7%. Therefore all the households in six suburbs in the sample leave the DSTV decoder in standby mode and in the remaining suburbs between 93% and 96% of the households leave the DSTV decoder in the standby mode. These figures start to reveal the extent of the power losses. Table 3.23 indicates that energy efficient behaviour is at low levels in all the suburbs and across all the appliances and this hints on the levels of power losses due to appliances in standby mode.

### Left On All the Time (LOATT)

The response LOATT is related to the function of the appliance. Some appliances like multifunction devices and fax machines have continuous functions over time that require the function to be available all the time. From table 3.24 it is evident that the percentage of the response LOATT for multifunction devices and faxes are higher compared to the the other appliances.

Table 3.24: Suburb Responses for LOATT (%)

| Suburb | PC/Monitor | MFD | Printer | Fax | Microwave | MPBC |
|---|---|---|---|---|---|---|
| Devland | 25 | 0 | 0 | 100 | 36 | 17 |
| Lenasia Ext.8 | 14 | 67 | 42 | 50 | 57 | 27 |
| Gressworld | 63 | - | 60 | 100 | 80 | 25 |
| Alexandra East Bank | 21 | 50 | 44 | 50 | 75 | 23 |
| Lenasia Ext.1 | 17 | 33 | 12 | 31 | 63 | 22 |
| Lenasia Ext.3 | 25 | 50 | 32 | 60 | 48 | 17 |
| Kew | 29 | 100 | 22 | 71 | 77 | 22 |
| Florida | 33 | 92 | 55 | 75 | 83 | 35 |
| Florida Park | 32 | 88 | 33 | 100 | 89 | 29 |
| Lenasia Ext.7 | 20 | 63 | 20 | - | 83 | 20 |
| Waverley | 19 | 73 | 60 | 63 | 96 | 64 |

These figures can be attributed to the functional requirement of the appliances in question. The entries for multifunction devices and printers are 0% for Devland and this is because of the absence of these appliances in households in Devland. The case for personal computers and monitors, printers and mobile phone charges is different.

In these appliances, the percentage responses are lower indicating an energy efficient behaviour in the operation of these appliances, again this behaviour can be driven by the functional requirement of these appliances. In all suburbs except in Gressworld a trend is observed in the responses for microwave ovens in which the percentages increase gradually from 30% for Devland to 96% for Waverley hinting that energy efficient behaviour is clusterd.

The response LOATT for mobile phone battery chargers ranges from 17% for Devland and Lenasia Extension 3 and 35% for Florida except in Waverley where the response is 64%. This indicates energy efficient behaviour that is exhibited by 65% to 83% of the households but not in Waverley where the opposite is true that only about one third of the households exhibit an energy efficient behaviour. Therefore, because in most households the appliance operational behaviour indicate that mobile phone chargers are not left in standby mode, then standby power losses due to mobile phone chargers in these households are expected to be critically diminished. However, the case of Waverley is different and its contribution to the total standby load due to mobile phone chargers can not be ignored.

The observed different tendencies in appliance operational behaviour by different suburbs, further solidifies the argument made earlier that standby power losses are clustered across the household population. Appliance operational behaviour divides the household population into different levels of contribution to the total standby power load. In conclusion, saturation and penetration levels set the total number of appliances in the household population but appliance operational behaviour determines the number of appliances that actually contribute to the losses.

### Switched On only when Required (SOOWR)

The response SOOWR indicates an energy efficient behaviour. In its own very nature is was used to examine the consistency for the response LOATT. It is expected that the responses for SOOWR are opposite of LOATT. Table 3.25 presents the percentage response for SOOWR in the eleven suburbs.

As expected Table 3.25 responses are opposite of those in Table 3.24 proving consistency in the respondents. In general most of the households switch on personal computers, monitors, printers and mobile phone chargers only when required. Therefore, the contribution to total standby power load of these appliances is limited by the user operational behaviour. The fax receiving function of multifunction devices and fax machines require that the appliances be left on all the time. Therefore, these

Table 3.25: Suburb Responses for SOOWR (%)

| Suburb | PC/Monitor | MFD | Printer | Fax | Microwave | MPBC |
|---|---|---|---|---|---|---|
| Devland | 75 | 100 | 100 | 0 | 64 | 83 |
| Lenasia Ext.8 | 86 | 33 | 58 | 50 | 43 | 73 |
| Gressworld | 37 | - | 40 | 0 | 20 | 75 |
| Alexandra East Bank | 79 | 50 | 56 | 50 | 25 | 77 |
| Lenasia Ext.1 | 83 | 67 | 88 | 69 | 37 | 78 |
| Lenasia Ext.3 | 75 | 50 | 68 | 40 | 52 | 83 |
| Kew | 71 | 0 | 78 | 29 | 23 | 78 |
| Florida | 67 | 8 | 45 | 25 | 17 | 65 |
| Florida Park | 68 | 12 | 67 | 0 | 11 | 71 |
| Lenasia Ext.7 | 80 | 37 | 80 | - | 18 | 80 |
| Waverley | 81 | 27 | 40 | 38 | 4 | 36 |

appliances contribution to the total standby load is based on the saturation and penetration rates because they are left on all the time mostly in Florida, Waverley and Gressworld. The contribution of microwave wave ovens to the total standby load is clustered across the suburbs with the largest contribution being from Waverley and the least from Devland.

#### Appliance Efficient Use Index (AEUI)

Appliance operational behaviour determines the actual number of appliances contributing to standby power and energy losses from the total number of appliances present in the households. The operational mode of an appliance when not in use determines if the appliance contributes to standby power and energy losses. It can be argued that, if in a specific household appliances are always switched off at the wall switch, then these appliances are in hard off mode and they do not contribute to standby power and energy losses. However, if appliances are either switched off by a remote controller or are left on all the time, then the appliances are in standby mode and contribute to standby power and energy losses.

For the purpose of this research, we have coined and defined the term *Appliance Efficient Use Index (AEUI)* of a household appliance. The appliance efficient use index is a measure of energy efficiency behaviour exhibited by a particular household in appliance operation. $AEUI$ is defined for every appliance in the household because from section 3.7 we have established that appliance operational behaviour can not be generalized across the household appliances. The measure of $AEUI$ is directly linked to the appliance functionality and the various technical attributes made possible by the manufacturer for switching off the appliance. For example, multifunction devices and fax machines are left on all the time because of their fax receiving function. DSTV decoders on the other hand, are mostly switched off using a remote controller resulting in a standby mode. User appliance operational behaviour is a variable that accounts for the randomness of standby power and energy losses.

To a large extent as seen in section 3.7 the users propensity to save energy distinguish between households in which appliances do and do not contribute to standby power and energy losses. In defining $AEUI$ we are advocating that ownership of an appliance does not necessarily imply that the appliance contributes to standby power losses. An appliance contributes to standby power losses if and only if the household $AEUI$ is nonzero for that particular appliance.

### The measure of $AEUI$

$AEUI$ varies between 0 and 1. An index of 1 indicates total inefficient behaviour i.e. a guarantee that the appliance is in standby mode resulting in standby power and energy losses. An index of 0 represents a highly efficient use behaviour i.e certainty that the appliance is not in standby mode and therefore does not contribute to standby power and energy losses. The results from this research indicate that technology that informs the user on household energy usage has an impact on the operational behaviour as is the case of households in Devland where prepaid electricity meters are installed. The results of this research also indicate that index trends can be established within the sample.

From the individual household appliance operational behaviour data an index for a group of households can be obtained. The cluster groups that have been established in the household sample are used to determine the index for each specific appliance. From the measurement campaign, it was found out that DVD's, VCR's, Hi-Fi's and DSTV decoders were always in standby mode independent of the way they are switched off. This implies that in these appliances, the responses SORC and SOAPS both indicate an appliance in standby mode. Therefore, for these appliances the responses SORC and SOAPS are combined to determine the corresponding $AEUI$ for each appliance. Appliance Efficient Use Index $AEUI$is the fraction made up of SORC and SOAPS responses in the total number of households in a particular cluster.

In television sets, the response SORC determines the AOBI for TV sets because there are some television sets that when switched off at the appliance power switch resulting in a non-standby power mode. This is a source of uncertainty in determining the measure of *AEUI* for television sets. The response LOATT for non-remote controlled appliances i.e. PC and monitors, printers, multifunction devices, microwave ovens and mobile phone battery chargers,is a direct measure of *AEUI* in these appliances.

The measures of *AEUI* for the different appliances are given in figures 3.16, 3.17, 3.18, 3.19, 3.20 for remote controlled appliances and figures 3.21, 3.22, 3.23, 3.24 and 3.25 for non-remote controlled appliances.

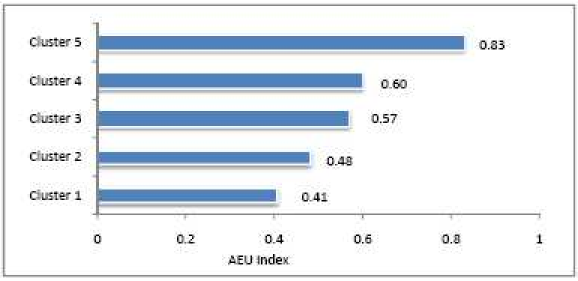


Figure 3.16: Appliance Efficient Use Index for TV's

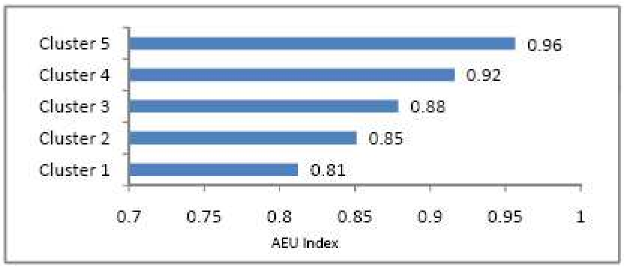


Figure 3.17: Appliance Efficient Use Index for DVD's

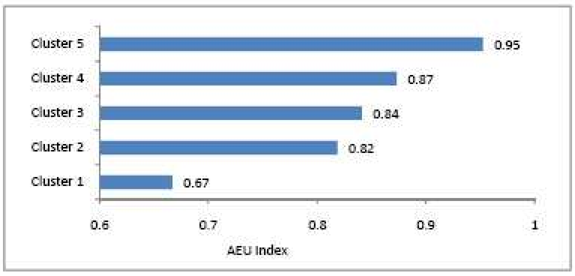


Figure 3.18: Appliance Efficient Use Index for VCR's

The Appliance Efficient Use indexes for the remote controlled appliances indicate that the indexes increase gradually as you move from cluster 1 to cluster 5. Cluster

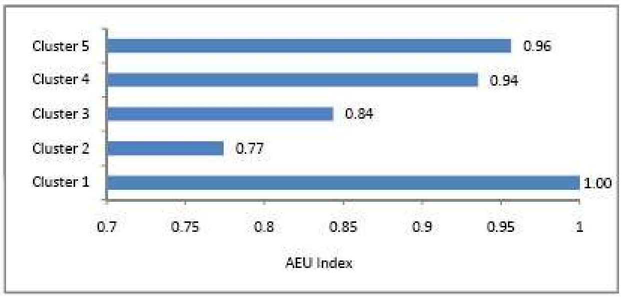


Figure 3.19: Appliance Efficient Use Index for Hi-Fi's

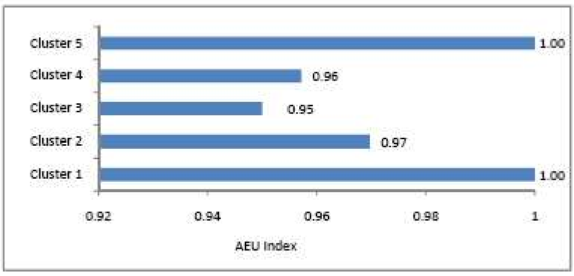


Figure 3.20: Appliance Efficient Use Index for DSTV Decoders

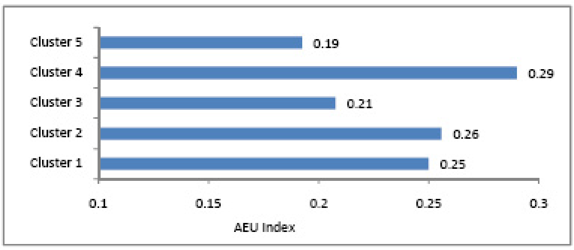


Figure 3.21: Appliance Efficient Use Index for PC's and Monitors

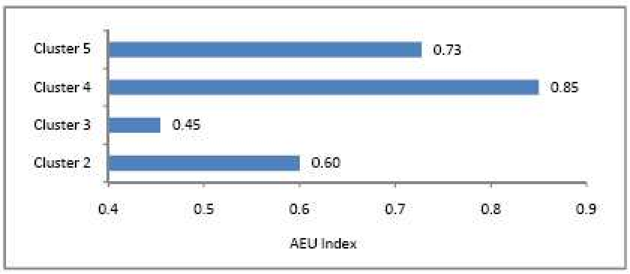


Figure 3.22: Appliance Efficient Use Index for Multifunction Devices

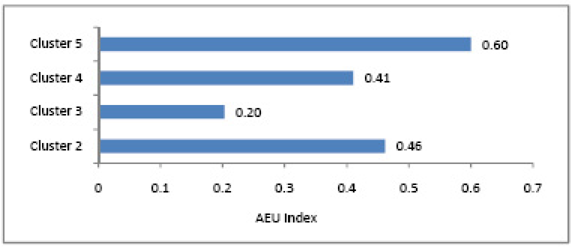


Figure 3.23: Appliance Efficient Use Index for Printers

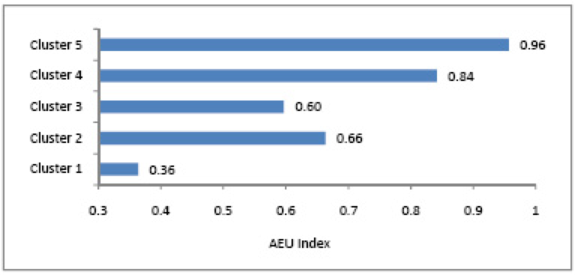


Figure 3.24: Appliance Efficient Use Index for Microwave Ovens

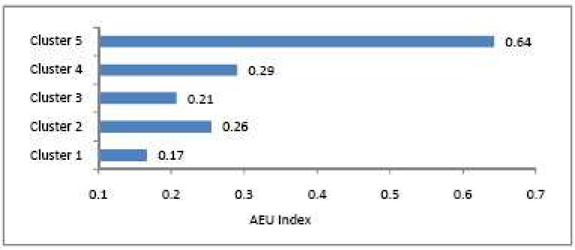


Figure 3.25: Appliance Efficient Use Index for Mobile Phone Battery Chargers

1 exhibits the lowest indexes whilst cluster 5 exhibits the highest indexes. The final number of appliances that contribute to standby power and energy losses is governed by *AEUI* we can therefore conclude that:

- Clusters with high indexes will have large number of appliances contributing to standby power losses
- Clusters with low indexes will result in lower number of appliances contributing to standby power losses
- An appliance index of 1, implies certainty on contribution to standby power and energy losses
- An appliance index of 0, implies certainty on no contribution to standby power and energy losses
- Cluster 1 has the least number of appliances contributing to standby power losses
- The largest number of appliances contributing to standby power losses are in cluster 5

The indexes for non-remote controlled appliances are much lower than those of the remote controlled appliances except for those of microwave ovens. There are no indexes for printers and multifunction devices indicated for Cluster 1 because the established saturation rates were 0. The indexes for PC's and mobile phone battery chargers are the lowest. The indexes for multifunction devices are also comparatively high and as suggested before, this could be linked to the fax receiving function of the appliance. Personal computers, monitors, Printers and multifunction devices have significant saturation rates only in clusters 5. The low indexes registered in the other clusters could be a reflection of the number of appliances found in the clusters.

Mobile phone battery chargers saturation rates are high in all clusters but the *AEUI* for this appliance indicate that numbers contributing to standby power losses in clusters 1, 2, 3, and 4 are low. This is due to the fact that most households in the sample switched off mobile phone battery charges at the wall switch when not in use. The case made earlier that the presence of an appliance in a household does not necessarily mean contribution to standby power losses is clearly made and the importance of the Appliance Efficient Use index is underscored.

### 3.7.4 Accuracy in Determination of *AEUI*

An accurate determination of *AEUI* require a through knowledge of all the appliance operational modes and the operational events that take the appliance into each of its valid operational modes. Secondly it requires that the respondent to the question be someone who has a deep knowledge in the operational details of the appliance and he or she is an appliance operator. The greatest challenge is the accuracy in established *AEUI* values obtained from interviews because within a single household there are a number of individuals who are possible appliances operators who do not exhibit the same appliance operational behavior. We will call this the Multiple Operator Factor (*MOF*) in the determination of *AEUI* values for different appliances in a household.

The *MOF* brings in a number of individuals in a household who can directly determine the *AEUI* for a particular appliance. Differences in appliance operational behaviour by different operators could be driven by: Acquired/internalised appliance operational behaviour, or existing circumstance at the time of operation, or some other unknown variables. We need to find out what drives the different appliance operational behaviour's of different operators. Uncertainty in the *AEUI* figures obtained is also due to the fact that there is no guarantee that a specific operator will always operate the same appliance in exactly the same manner every time. We call this the uncertainty in repeated operations.

The uncertainties due to multiple appliance operators as well as in repeated operations by the same operator need to be taken into consideration in the measure of *AEUI*. These sources of uncertainty highlight the difficulty in obtaining high accuracy in the determination of *AEUI* by using a questionnaire. An accurate way of obtaining *AEUI* can be through continuous monitoring of appliances over a specified period of time. What is indicated and ascertained by results of this research is firstly that the *AEUI* figures are different for different appliances in different clusters because different households operate each of their appliances differently. Secondly, the impact of appliance functionality and switch-off technical attributes on the measure of *AEUI* is apparent in the results obtained.

## 3.8 Appliance use times

Appliance use time is the amount of time an appliance is in full operational mode. Use time is another variable required to be established in order to be able to evaluate the total energy losses due to standby power losses. Standby energy losses depends on how long an appliance spends in the standby mode. The average daily hours of usage is the main determinant factor of an appliance standby power consumption especially because the actual measured power levels are not very high for most appliances. In the study done in Australia, a simplistic assumption was taken that the hours that an appliance is in full operational mode for most appliances are relatively small, with the exception of television viewing [21].

In the survey the respondents were requested to estimate the use time of the different appliances in the household on a weekday, weekend day and during holiday time. This is not a very accurate methodology of establishing actual appliance use times but it is considered sufficient in estimation of the energy losses. Estimated use times from household survey were also employed in USA, United Kingdom, and China [23, 55]. Accurate appliance use times can be established by continuous real time monitoring of the appliances as was the case in the EURECO study, but this is a costly exercise as it requires a monitoring instrument be attached to each appliance of interest in each household [12, 44].

The results obtained from this survey are presented as averages under three sections namely:

- Sample
- Suburbs
- Cluster

### 3.8.1 Sample Average Appliance Use Times

The average use times obtained from the sample are presented in table 3.26

The sample average use time indicate that DSTV decoders are the appliances that are most used. It was expected that television sets would have the highest use times because they are used in conjunction with DSTV decoders, VCR's or DVD's and TV games but this is not the case. This can be explained by the possibility that because in most cases the TV screen goes blank after a few seconds when the decoder is in audio function some households do not consider the TV to be in use because there are no images displayed. The reported television viewing hours by AC Nielsen for South Africa are 4.5 hours excluding viewing linked to DSTV decoder use [60].

In 2005 television usage in America per household was reported to be 8.2 hours and

Table 3.26: Sample Average Appliance Use Times (Hours)

| Appliance | Weekday | Weekend Day | Holiday |
|---|---|---|---|
| Television sets | 6.7/day | 7.5/day | 7.9/day |
| DSTV Decoders | 5.1/day | 7.1/day | 7.9/day |
| Hi-Fi | 3.8/day | 4.5/day | 4.2/day |
| DVD | 2.5/week | 3.8/weekend | 3.7/day |
| VCR | 2.1/week | 2.6/weekend | 2.7/day |
| MPBC | 1.1/day | 1.1/day | 1.1/day |
| Microwave Oven | 0.5/day | 0.5/weekend | 0.5/day |
| PC/Monitors | 3.2/week | 3.2/weekend | 3.2/week |
| MFD | 0.6/week | 0.4/weekend | 0.3/week |
| Printers | 0.4/week | 0.3/weekend | 0.2/week |

it rose to 8.4 hours in 2007 [61]. The usage of DVD's in America, was observed to increase on weekends as indicated by a study done by the Ball State University, a trend that is also witnessed in table 3.26. Data for Australia indicates that television viewing hours range from 20 to 40 hours a week [44]. These figures translate to 2.8 to 5.7 viewing hours a day and compare well with the results obtained from the survey.

Television average daily viewing time for Italy was reported to be three hours and fifty minutes, United Kingdom three hours and forty three minutes, France three hours and thirteen minutes, and the Netherlands two hours and forty three minutes [50]. These figures translates to 3.8 hrs for Italy being the highest and 2.7 hours for the Netherlands indicating a wide range of viewing hours across different countries especially when figures for Japan (4.0 hrs) and South Korea (2.5 hrs) are included [50]. Television viewing hours in Europe have been reported to have increased from 3.4 hrs in 1995 to 3.8 hrs in 2005 hinting a global increase across nations [50]. If these figures are compared to the results obtained from the survey, it can be concluded that TV viewing hours are much longer in the household sample in South Africa. The long television viewing hours in South African households can be linked to the results on family size and structure that indicate medium to large family sizes in the household sample.

The average use times during weekends and holidays for the sample are almost the same with very small variations. This suggests that there is not much differentiation in the usage of appliances during these two distinct times. However, in all appliances except battery chargers, printers and multifunction devices the weekend appliance use times are higher than for weekdays. This is expected because the presence of more people in the households during weekends and holidays times results in more usage. The average usage times for mobile phone battery chargers is the same across the three categories. This indicates a systematic use pattern where the phone is charged daily for approximately the same amount of time to keep the mobile phone in operation.

The sample average appliance use time suggests that microwave wave ovens, printers and multifunction devices are used for less than an hour in any day of the week. This indicates very limited use of these appliances in full operational mode and suggests that the appliances spend about 98% of the time in any day in standby mode. This concurs well with the simplistic approach to 'use time' adopted in the Australian survey [21]. The number of hours that Hi-Fi sets are in use are much higher than reported for other countries. This can be explained by the structure and size of the families in the survey sample, in that most of the households were a group of family members and the dominant number of people in a household was found to be more than four.

### 3.8.2 Average Appliance Use Times in the Suburbs

Average appliance use times were considered for each appliance in each suburb. The average usage times for the different appliances are discussed under low, medium and high usage. The classification into low, medium and high is determined for each appliance using the highest average usage time on a weekday as a reference. The highest usage takes place in weekdays because there are a total of 5 week days and only two weekend days in a week. Three range markers are defined to differentiate between the three usage groups. The range markers are relative to the highest weekday average use time. The suburbs in a specific usage group were obtained from the weekday usage times as follows:

Suppose X is the highest average usage time for a specific appliance. Then the upper marker for the High group is X, the upper marker for Medium group is $X - X/3$, and the upper marker for the Low group is $X/3$. The average use time values Y in each of the three usage groups High, Medium and Low are then defined by Equations 3.1, 3.2 and 3.3 respectively.

$$X - X/3 < Y_{high} \leq X \tag{3.1}$$

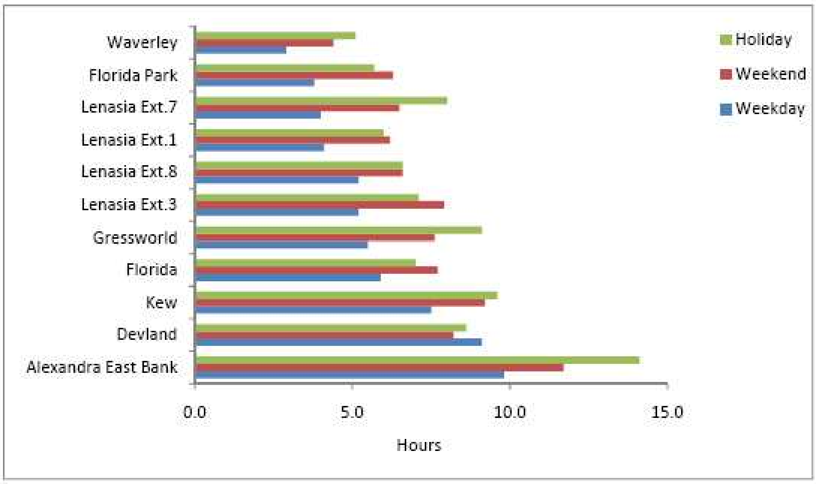


Figure 3.26: Average Use Time for TV's in Suburbs

$$X/3 < Y_{medium} \leq X - X/3 \tag{3.2}$$

$$Y_{low} \leq X/3 \tag{3.3}$$

**Television Sets**

Figure 3.26 presents the average use times for television sets in each of the eleven suburbs.

Using the criteria for determining the membership into the three usage groups the following are the results for television sets. In the high use group the use time ranges from 7.5 hours to 9.8 hours for week days, 8.2 hours to 11 hours for weekends and 8.6 hours to 14.1 hours in holidays. Three suburbs fall in the high use category and these are Alexandra East Bank, Devland and Kew. Seven suburbs are in the medium television usage group. These suburbs are Lenasia Ext.7, Lenasia Ext.1, Lenasia Ext.8, Lenasia Ext.3, Gressworld Florida and Florida Park. The average television use time recorded for a weekday in the medium usage group range from 3.8 hours to 5.9 hours, weekend hours range from 6.2 to 7.9 and holiday hours average use time ranges from 5.7 to 9.1 hours. Waverley is the only suburb in the low usage time group for televisions. In the low usage group, the average use times are 2.9 hours in a weekday, 4.4 in a weekend day and 5.1 hours on holiday days.

In all usage groups the general tendency is that the usage times in weekends and holidays are higher than is for a weekday mainly because it is logical to assume that more household members are present at home and appliance use times are expected to increase.

**DVD's**

The average DVD use times for each of the suburbs in the survey sample is presented in Figure 3.27.

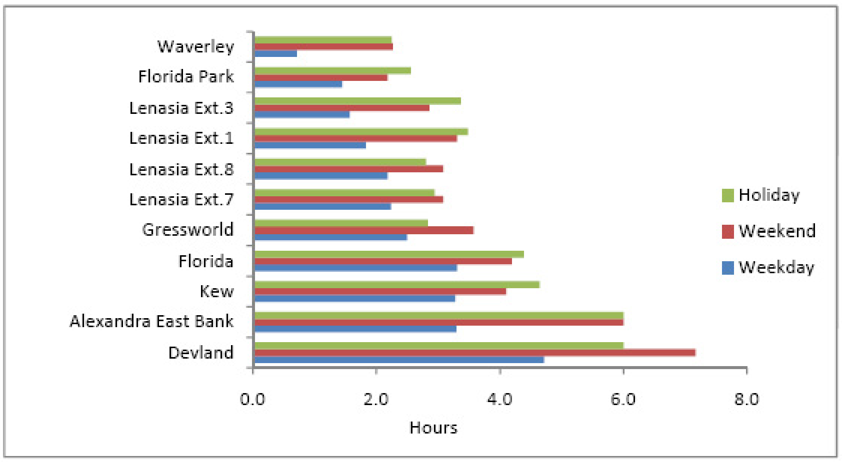


Figure 3.27: Average Use Time for DVD's in Suburbs

Devland, Florida, Kew and Alexandra East Bank are the suburbs in the high usage group for DVD's. The average use time are 3.3 hours to 4.7 hours on weekdays, 4.1 hours to 7.2 on weekends and 4.4 hours to 6 hours on holiday days. Medium usage hours that range from 1.6 to 2.5 hours in weekdays, 3.1 to 3.6 hours on weekend days and 2.8 to 3.5 hours on holiday days are recorded for Gressworld, Lenasia Ext.7, Lenasia Ext.8. Lenasia Ext.1, and Lenasia Ext.7. Two suburbs namely, Florida Park and Waverley form the low usage group. In this group the average DVD usage times ranges between 0.7 hours to 1.5 hours on a weekday, 2.2 hours to 2.3 hours on a weekend day and 2.3 hours to 2.6 hours on a holiday day. Again as was for average usage times for televisions the general tendency is increase on average use times on weekend and holiday days when compared to weekdays.

**VCR's**

The average use times obtained for VCR's are presented in Figure 3.28. The highest VCR average use time of 6.4 hours in weekdays. 5.6 hours in weekend days and 5.8

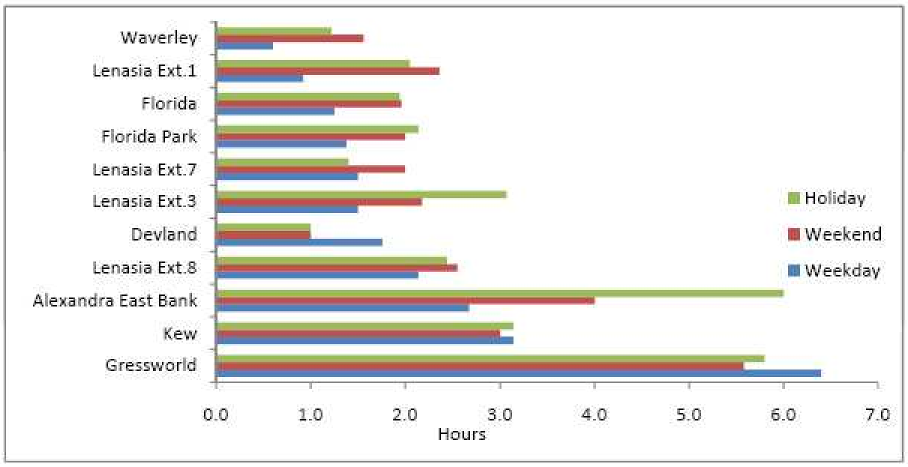


Figure 3.28: Average Use Time for VCR's in Suburbs

hours on holidays are recorded in Gressworld the only suburb in the high usage group. These average usage hours are exceptionally high when compared to the rest of the suburbs. Medium average usage hours are recorded in Kew, Alexandra East Bank and Lenasia Ext.8. The average usage hours in these three suburbs range from 2.1 to 3.1 hours on a weekday, 2.6 to 4 hours on a weekend day and 2.4 to 6 hours on holidays.

In the remaining six suburbs average usage times range from 0.6 hours to 1.8 hours on weekdays, 1 to 1.6 hours on weekends and 1.2 hours to 1 hour on holidays. These six suburbs are Devland, Lenasia Ext.3, Lenasia Ext.7, Florida Park, Florida, Lenasia Ext.1, and Waverley. In these six suburbs VCR usage time is considered low compared to the other suburbs. The large number of suburbs in the low usage group for VCR's could be explained by the use of DVD's instead of VCR's as a result of technology change. As for television sets and DVD's, The average use hours for television sets and DVD's are higher in weekends and holidays than on weekdays.

**Hi-Fi's**

Presented in Figure 3.29 are the average use times for Hi-Fi's in the eleven suburbs in the survey sample. Devland is the only suburb in the high usage group. The average use times recorded for Devland are much higher when compared to the use times in the rest of the suburbs. The Hi-Fi average use time in Devland on weekdays is 8 hours, on weekends 8.6 hours and 6.4 hours for holiday days. Suburbs in the medium usage group are Alexandra East Bank, Florida, Kew, Lenasia Ext.3, Lenasia Ext.7, Lenasia Ext.8, Lenasia Ext.1 and Florida Park. In this group average

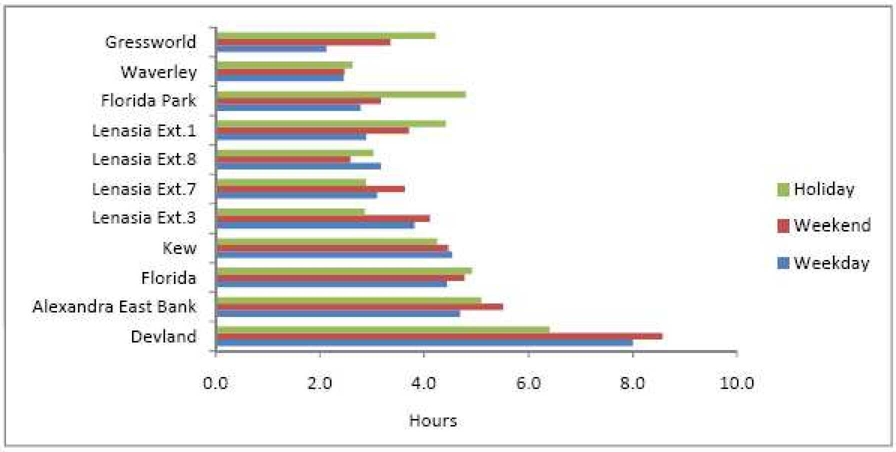


Figure 3.29: Average Use Time for Hi-Fi's in Suburbs

use time ranges from 2.8 hours to 4.7 hours on weekdays, 2.6 hours to 5.5 hours on weekends and 2.9 to 5.1 hours on holidays. Two suburbs Waverley and Gressworld form the low usage group in the case of Hi-Fi's. The average use times in this group ranges from 2.1 hours to 2.5 hours on a weekday, 2.5 hours to 3.4 hours on weekend days and on holidays 2.6 hours to 4.2 hours.

### DSTV Decoders

The average use times of DSTV decoders in the different suburbs that formed in the survey sample are presented in Figure 3.30. The highest average use times of 10.8

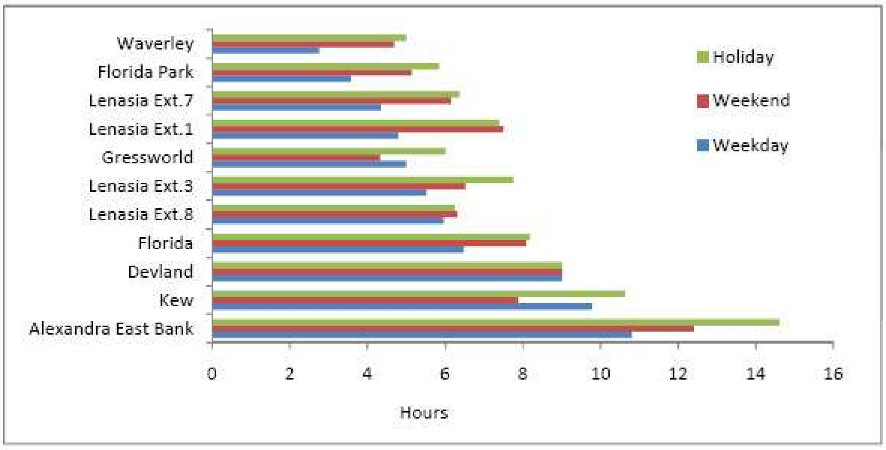


Figure 3.30: DSTV Decoders Average Use Time in Suburbs

hours, 12.4 hours and 14.6 hours respectively for a weekday, weekend and holiday day are recorded in Alexandra East Bank. These high use times can be attributed to the total number of people in the households in Alexandra East Bank suburb.

Suburbs in which high usage times are observed are Alexandra East Bank, Kew, and Devland. The average use times in these three suburbs, range between 9 hours to 10.8 hours on a weekday, 7.9 hours to 12.4 hours on a weekend day and 9 hours to 14,6 hours during holidays. These figures are generally high hinting to high usage of television sets in these suburbs a tendency observed for the in Figure 3.26.

Medium DSTV decoder usage ranges between 4.8 hours to 6.5 hours on weekdays, 4.3 hours to 8.1 hours on weekends and 6.0 hours to 8.2 hours on holidays. The suburbs in this group are: Florida, Lenasia Ext.8, Lenasia Ext.3, Gressworld, and Lenasia Ext.1. Low average usage times are observed in Lenasia Ext.7, Florida Park and Waverley. The usage times are between 2.8 hours and 4.4 hours on weekdays, 4.7 hours and 6.1 hours on weekends and in holidays the average use time ranges between 5 hours and 6.4 hours.

If figure 3.30 is compared to figure 3.26, what emerges is a very high correlation between the suburbs in the three different usage groups. Since the usage of DSTV decoders is directly linked to the use of television sets then the high correlation of the suburbs in the different usage groups is an expected result otherwise a contradiction would have arisen.

### PC's and Monitors

The average use time of personal computers and monitors in the different suburbs are presented in Figure 3.31.

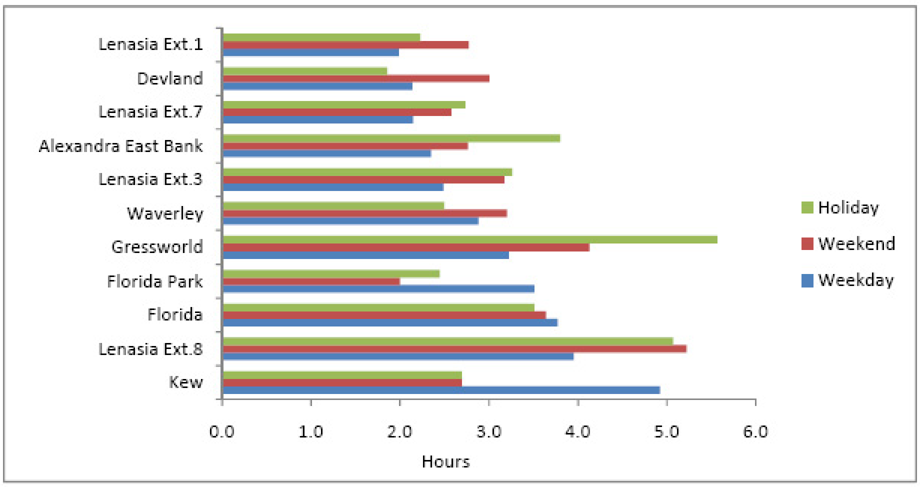


Figure 3.31: Average Use Time for PC's and Monitors in Suburbs

Kew, Lenasia Ext.8, Florida and Florida Park are the suburb classified in the high usage group. The average use times in this group are 3.5 hours to 4.9 hours on weekdays, 2.0 hours to 5.2 hours on weekends and 2.5 hours to 5.1 hours during holidays. The calculated lower range marker for the low usage group for PC's and monitors is 1.6 hours. Therefore, there are no suburbs in the low usage group for PC's and monitors. The remaining 7 suburbs i.e. Gressworld, Waverley, Lenasia Ext.3, Alexandra East Bank, Lenasia Ext.7, Devland and Lenasia Ext.1 form the medium usage group. In this group, the average use times ranges from 2.0 hours to 3.2 hours on weekdays, 2.6 hours to 4.1 hours in weekend days and 1.9 to 5.6 during holidays. The fact that there are no suburbs in the low usage group can be an indicator of the extent of personal computers general use in South African households. It can be safely assumed that in the future growth in numbers and use can be expected.

### Mobile Phone Battery Chargers

Figure 3.32 presents the mobile phone battery charger's average use times in suburbs. In nine out of eleven suburbs usage time for mobile phone battery charger's

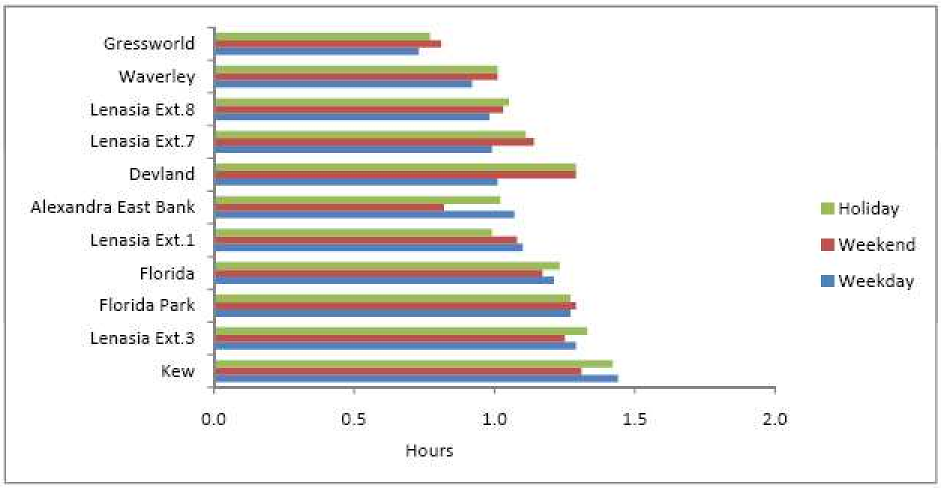


Figure 3.32: Average Use Time for Mobile Phone Battery Charger's

is a minimum of one hour and a maximum of 1.4 hours on weekdays. The weekend and holiday average usage hours are almost equal underlining the fact that there is no differentiation in the use of mobile phone chargers across the households in the sample. These nine suburbs Kew, Lenasia Ext.3, Florida Park, Florida, Lenasia Ext.1, Alexandra East Bank, Devland, Lenasia Ext.7, and Lenasia Ext.8 form the high usage group for mobile phone battery charger's. The average use times for the high usage group range between 1.0 and 1.4 hours on weekdays, 0.8 to 1.3 hours on weekends and 1.0 hours to 1.4 hours during holidays. Waverley and Gressworld form the medium usage group with average usage time of 0.7 hours to 0.9 hours on weekdays, 0.8 to 1.1 hours on weekends and 0.8 to 1.2 hours during holidays.

In general across all suburbs there is no marked differences in the average usage times on weekdays, weekends and holiday days. This non-variation is expected because the amount of time used in charging a phone battery is determined only by the level to which the battery power has fallen to. The results here suggest that in most households it takes about an hour to charge the mobile phone battery adequately. This survey however could not explicitly distinguish the amount of time a mobile phone charger is left in maintenance mode after a charging process is complete.

### Multifunction Devices

In most suburbs and in any day as indicated in figure 3.33 multifunction devices are in use for less than an hour in 8 suburbs. High usage group is made up of Lenasia

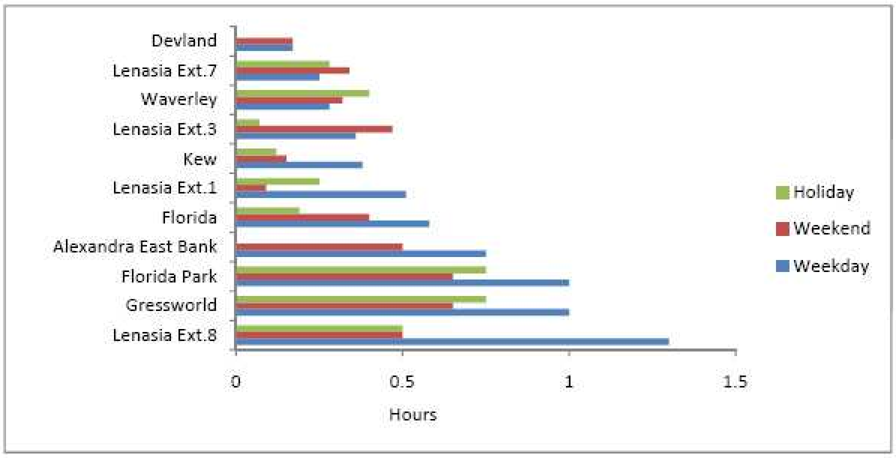


Figure 3.33: Average Use Time for Multi Function Devices

Ext.8, Gressworld and Florida Park. The average usage times range from 1 to 1.3 hours on weekdays and drops to between 0.7 and 0.5 hours on weekends and 0.5 hours to 0.8 hours on holidays. The amount of time it takes to print/copy/fax a single page is in order of seconds and depends on the technology in use. Therefore, an hour of use results in considerable printing/copying/faxing job sizes even when the jobs are mixed as is allowed by the functionality of the appliance. Although the fax receiving and transmitting function take longer to complete, in home use the average use times of 1 hour to 1.3 hours could be considered very high. The extensive use can be explained by the possibility of the presence of home offices that utilizes the multifunction device intensely. From the survey the use of MFD was not examined in detail and therefore the long hours obtained can not be fully explained.

It would have been helpful to obtain information on if the MFD are used in a home office environment or not.

In the medium usage group three suburbs are found. These are: Alexandra East Bank, Florida and Lenasia Ext.1. The low usage group is made up of Waverley, Lenasia Ext.7, Kew, Lenasia Ext.3, and Devland. In general the average use times in these usage groups are still quite high when printing speeds are considered to be in the order of seconds. The usage times in medium group range between 0.5 hours and 0.8 hours on weekdays, 0.1 to 0.5 hours on weekends and 0.0 to 0.3 hours on holidays. In the low usage group average use time on weekdays range between 0.2 and 0.4 hours, 0.2 to 0.5 on weekends and 0.0 to 0.3 on holidays. In the high and medium usage groups average use times for weekends and holidays are lower than for weekdays. This observation could be a further hint on the use of these devices in home office environment.

**Printers**

Figure 3.34 present the average use times for printers in the suburbs. In the house-

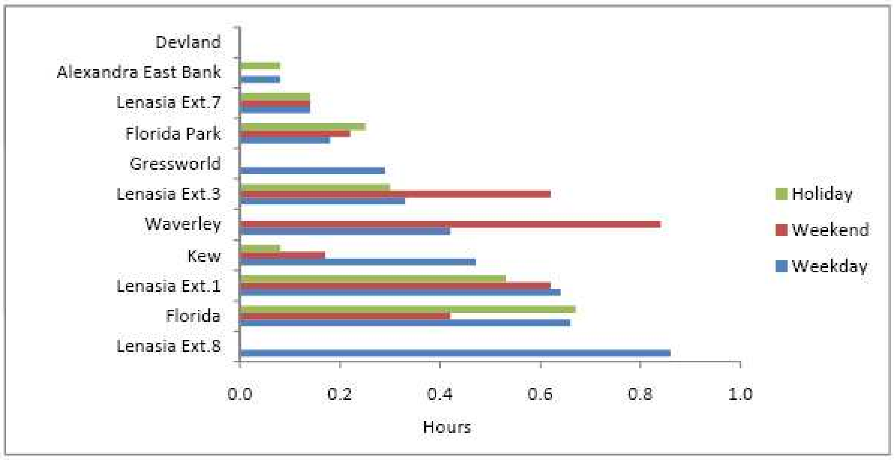


Figure 3.34: Printers Average Use Times

hold survey no printers were found in Devland and therefore no use times are presented. The average use times in the suburbs range from 0.1 to 0.9 hours on a weekday, 0.0 to 0.8 hours on weekends and 0.0 to 0.7 on holidays. The high usage group made up of Lenasia Ext.8 and Florida have average use time of 0.7 to 0.9 on weekdays, 0.0 to 0.4 hours on weekends and 0.0to 0.7 hours on holidays. The high figures as was for MFD seem to be on the high side and cannot be explained.

Medium usage is observed in Lenasia Ext.1, Kew, and Waverley with average use times of 0.4 to 0.6 on weekdays, 0.2 to 0.8 on weekends and 0.0 to 0.5 on holidays. The figures also seem to be on the high side when home use is considered to be the ultimate use of the appliance. The low usage group has five suburbs namely; Lenasia Ext.3, Gressworld, Florida Park, Lenasia Ext.7, and Alexandra East Bank. In these suburbs lower average use times are observed. Of interest are the very low usage times of 0.1 recorded for all days in Lenasia Ext.7 and Alexandra East Bank. This translates to six minutes of use a day and can be considered to be a more realistic projection of the average use of printers in a non-office environment.

#### Average Use Times for Microwave Ovens

Microwave ovens are the least used appliances in all households in the survey sample with highest average use time recorded being 0.7, 0.5, 0.5 hours respectively for weekdays, weekends and holidays. The detail on microwave average use times are presented in figure 3.35. With reference to the highest average of 0.7 hours for a

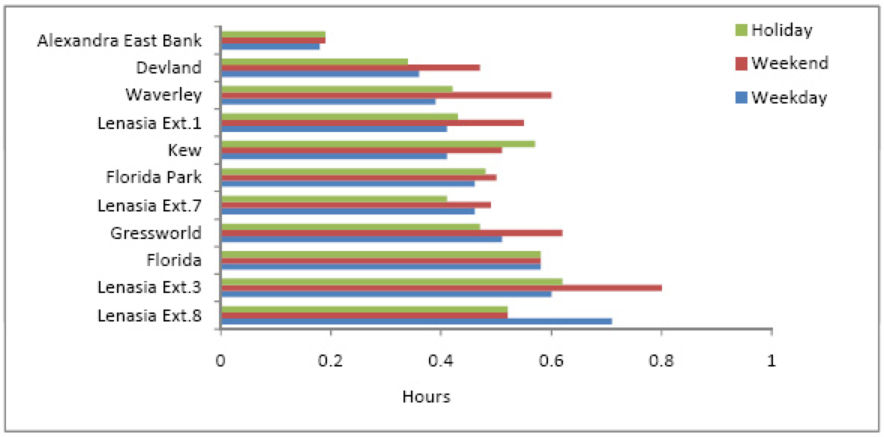


Figure 3.35: Average Use Times for Microwave Ovens

weekday, the high usage group is made up of Lenasia Ext.8, Lenasia Ext.3, Florida, and Gressworld. In this group the average use times range from 0.5 to 0.7 hours on a weekday, 0.5 to 0.8 hours on a weekend day and 0.5 to 0.6 hours on holidays. The medium usage group comprises of the suburbs Lenasia Ext.7, Florida Park, Kew, Lenasia Ext.1, Waverley and Devland. In this group the lowest use time of 0.3 hours is recorded on a holiday as well as the highest average usage time of 0.6 hours. Alexandra East Bank falls in the low usage group and the average use times are 0.2 hours for weekday, weekend and holiday day.

Microwave ovens are mainly used in cooking, reheating and thawing food. Normally the time used in these functions are very much shortened when compared to conventional methods of food preparation. The average use times obtained for microwaves when translated to minutes indicate that microwave ovens are used for all three major functions in the high usage group, some cooking and mainly reheating and thawing in the medium usage group and only reheating or thawing in the low usage group.

## 3.9 Appliance Average Use Times in Clusters

The clusters established for the saturation, and penetration rates within the suburbs are used in determining the appliance average time spent in standby mode. It should be noted that by using Appliance Efficiency Use Indexes for the different appliances it is possible to obtain the numbers of appliances which contribute to standby power losses in each particular cluster. In this section the time appliances spend in standby mode in each cluster is determined. Using the established five clusters in the sample the corresponding appliance average times for each cluster are determined. Time spent in standby mode in a day is the difference between 24 hours and the average usage time.

Three different scenarios emerge for time spent in standby mode for the different appliances in the five clusters. There are appliances for which there is:

- Change in time spent in standby mode across clusters
- No change in time spent in standby mode across clusters

### 3.9.1 Variability in Time Spent in Standby Mode Across Clusters

Appliances in which there is change in the amount of time spent in standby mode across the clusters are television sets, DVD's, DSTV decoders, and Hi-Fi systems. Figures 3.36, 3.37, 3.38, and 3.39 present the time spent in standby mode by TV's, DVD's, DSTV decoders and Hi-Fi systems respectively.

From figures 3.36, 3.37, 3.38, and 3.39 it can be seen that there is gradual increase in the time spent in standby mode as you move from cluster 1 to cluster 5 in all days i.e. weekdays, weekends and holiday days. All the appliances for which time spent in standby mode is clustered are remote controlled appliances. It was in these appliances where efficiency use index was observed to have marked differences across

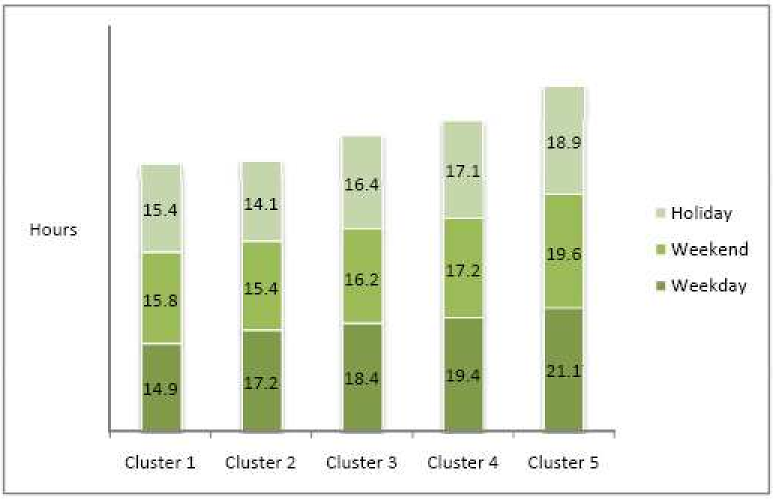


Figure 3.36: Time in Standby Mode: TV's

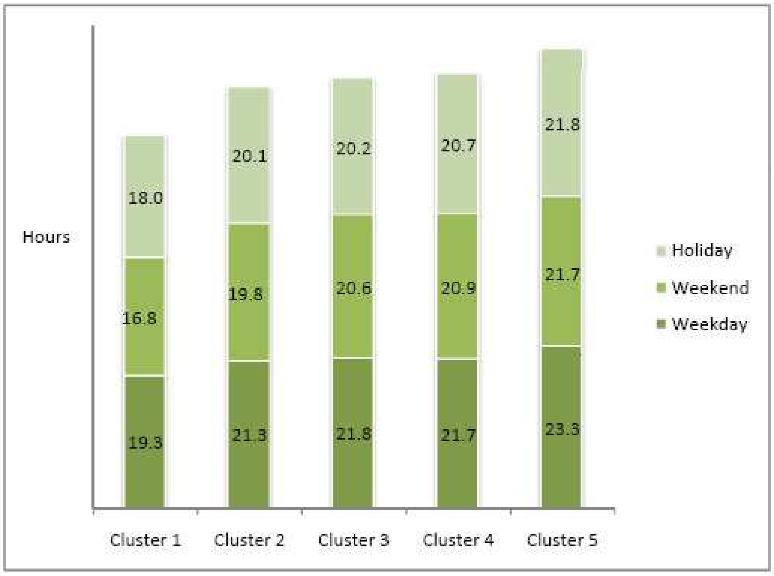


Figure 3.37: Time in Standby Mode: DVD's


Figure 3.38: Time Spent in Standby Mode: DSTV Decoders

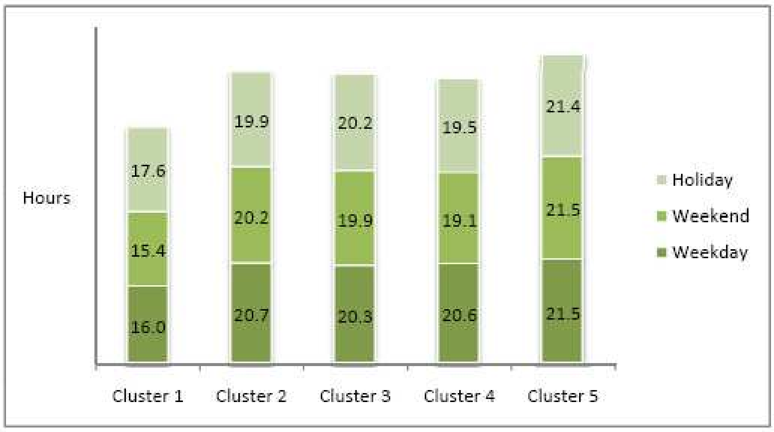


Figure 3.39: Time Spent in Standby Mode: Hi-Fi's

the suburbs mainly because of the availability of the remote controller for switching off the appliances when not in use. Furthermore, it was observed that there are no hard switch-off capabilities in these appliances a fact that results in the appliance remaining in standby mode even when it is switched off at the appliance power switch. For these appliances, the *AEU* indexes rely heavily on the user propensity to save energy because the appliance technical attributes work against energy saving. Households in cluster 1 in which prepaid meters are installed, household members are continuously aware of the energy usage and in general their *AEU* indexes are low translating to low average time spent in standby mode.

The gradual changes in time spent in standby mode observed across the clusters in these appliances can be attributed to the changes in appliance efficient use indexes across the suburbs. Where the operational behaviour lends itself to low efficient use indexes, time spend in standby mode is low as seen in the first cluster. In cases where operational behaviour lends itself to high efficient use indexes, time spent in standby mode is long as is the case of Cluster 5. The remaining clusters 2,3 and 4 are bounded in between cluster 1 and cluster 5.

The finding that time spent in standby is clustered for remote controlled appliances, supports an observation made earlier on that appliance contributions to standby energy losses are clustered not only due to clustering in penetration and saturation levels but also due to the clustering in time spent in standby mode. Households in the cluster 5 will have higher contribution to energy losses when compared to households in cluster 1.

The time spent in standby mode by VCR machines is different across the clusters as shown in Figure 3.40.

For clusters 1, 3, and 4 the time spent in standby mode is of similar magnitudes i.e about 22 hours a day on weekdays and 21 to 23 hours on weekends and holidays. In cluster 5 the amount of time is slightly longer than is for clusters 1, 3, and 4. In cluster 2, the time spent in standby mode is averagely 20 hours on any day. These observed trends in time spent in standby mode by VCR's can be attributed to the fact that VCR's are no longer the preferred appliance, instead DVD's have taken over. Therefore it would be plausible to conclude that the use of VCR's in household has diminished across all households and the decrease in usage time is pronounced more in some clusters such as cluster 5, to a lesser extent in clusters 1, 3, and 4, while in cluster 2 it can be concluded that VCR's are still in considerable use.

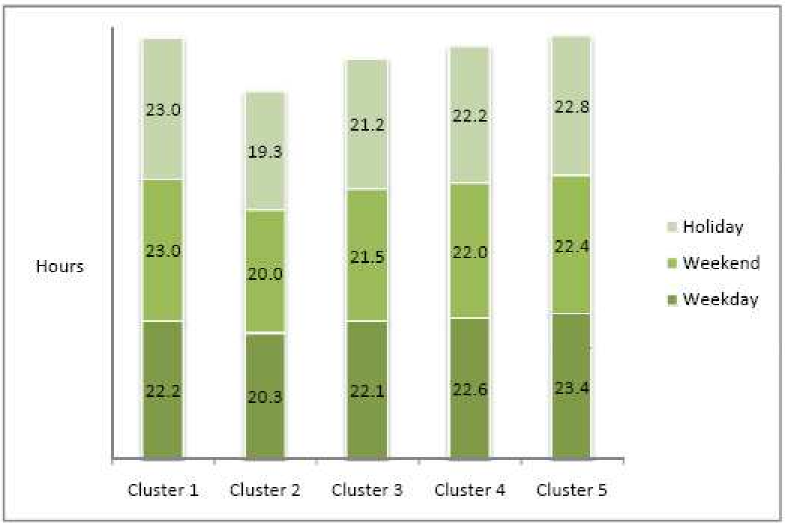


Figure 3.40: Time in Standby Mode: VCR's

### 3.9.2 Invariable Time Spent in Standby Mode Across Clusters

Time spent in standby mode for microwave ovens, mobile phone battery chargers, printers and multifunction devices can be considered unchanging across clusters and across the different days as seen in Figures 3.41, 3.42, 3.43, and 3.44.

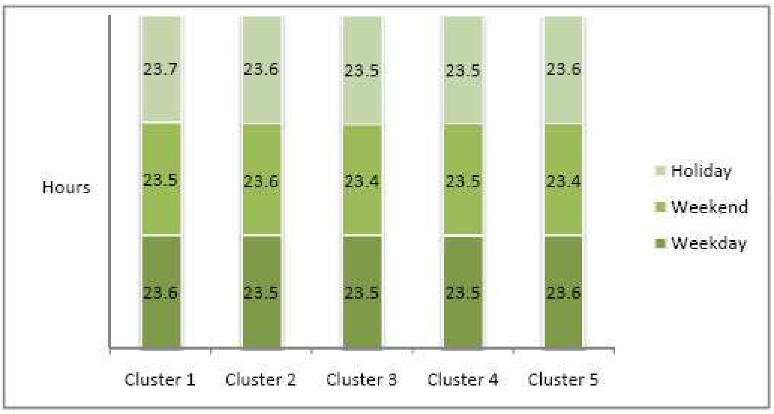


Figure 3.41: Time in Standby Mode: Microwave Ovens

All these appliances in which minimal and insignificant variations occur are non-remote controlled appliances. In most suburbs, most of these appliances are switched on only when required, but for small numbers that are left on all the time, we find low usage and hence the resultant high times in standby mode. The insignificant variations can also be attributed to the appliance functionality that can not be differentiated across the clusters. For example the function of a mobile phone is the same and it cannot be differentiated across different households. Cellphones

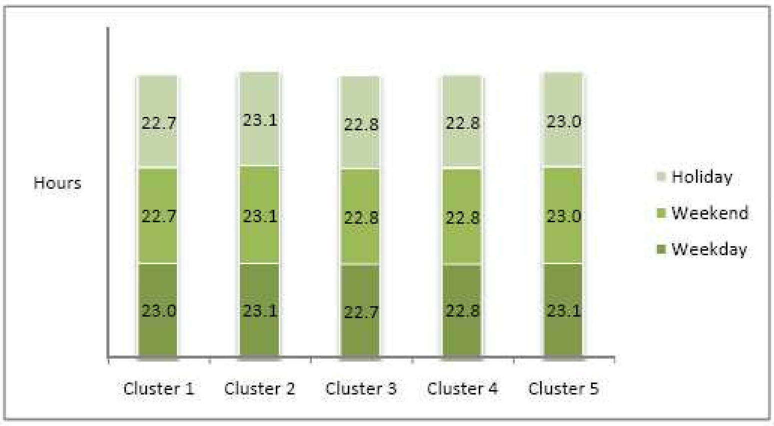


Figure 3.42: Time in Standby Mode: Mobile Phone battery Chargers

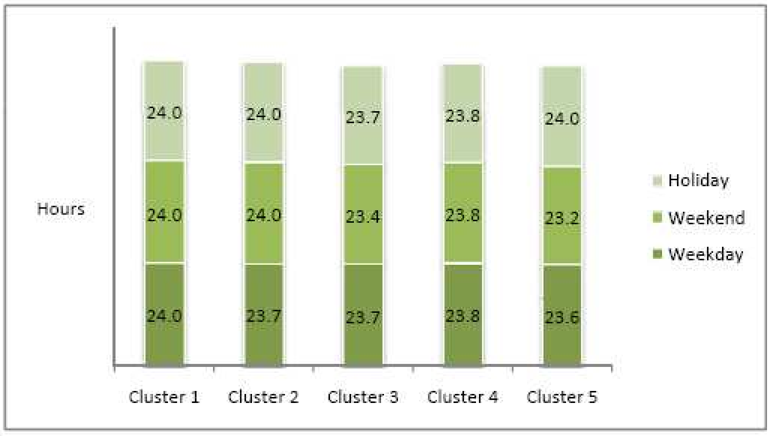


Figure 3.43: Time in Standby Mode: Printers

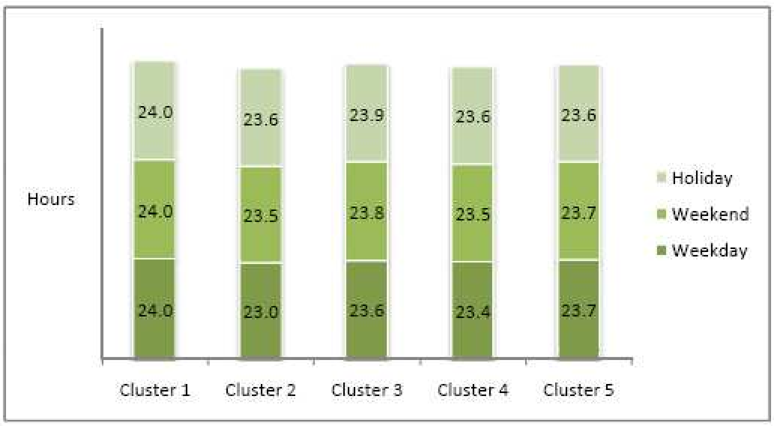


Figure 3.44: Time in Standby Mode: Multi function Devices

charging is the same in all households. In most households, microwave ovens are used for warming or defrosting a function that cannot be differentiated across the households. The case of personal computers and monitors is a little bit different from the other non-remote controlled appliances as seen in figure 3.45.

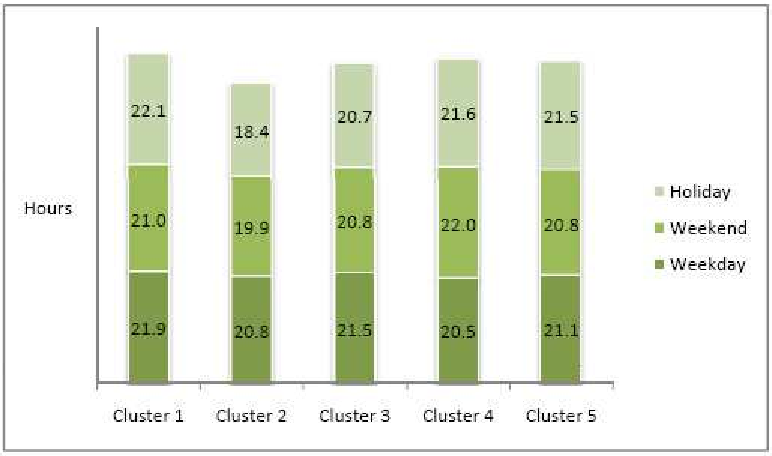


Figure 3.45: Time in Standby Mode: PC and Monitors

In figure 3.45, there are marginal differences across the different clusters in the different days of the time spent in standby mode. These changes are small in the order of 0.1 hours and can be considered insignificant. Therefore, within limits to the variations of ±0.1 hours there are no changes in the time spent in standby mode by personal computers and monitors across the clusters.

## 3.10 Conclusion

Conventional houses were dominant in the survey sample and there was low incidences of town houses and property clusters. This finding is a direct result of the sampling criteria used to ensure high accessibility to households in the sample which automatically excluded high security residential area. The number of households with three, four, five, and six or more members dominated in the household sample across all suburbs. The classifications couple with children, and family group dominate in all suburbs. In general it can be said that the type of dwellings in the sample supported the sample family size and the family constitution indication medium to large family sizes.

Based on the concepts of *appliance saturation clusters, universal appliances and appliance classification* it can be concluded that:

- There are 5 distinct appliance saturation clusters in the survey sample
- *Copious* appliances have saturation rates of 50% or higher
- *Middling* appliances have saturation rates greater than or equal to 10% but less than 50%
- *Scanty* appliances have saturation rates of less than 10%
- *Universal* appliances are *copious* appliances common in all saturation clusters
- Number of *copious* and *middling* appliances in a particular cluster largely determine the cluster contribution to standby power losses
- *scanty* appliances have minimal contribution to standby power mainly due to the diminished saturation rates of these appliances
- Contribution to standby power losses is clustered within the survey sample and it is expected to diminish from cluster 5 to cluster 1
- Standby energy losses are clusterd across the household sample due to the clustering of time spent in standby mode

There are five appliance penetration clusters within the household sample. The penetration clusters correspond to the saturation clusters. This indicates that the clusters established by appliance saturation rates are indicators of the appliance penetration rates in the sample and therefore standby losses are also expected to be clustered.

The resultant time spent in standby mode for the different appliances in different clusters is a function of $AEU$ indexes. Where the $AEU$ indexes lend themselves to high energy efficient appliance operational behaviour the time spent in standby mode is low, and the opposite is also true. The establishment of $AEUI$ for each appliance makes it possible to strongly argue that appliance ownership does not by itself imply contribution to standby power and energy losses. What determines if an appliance does contribute to the losses is the $AEUI$ which is a measure of a household propensity to operate their appliances efficiently. $AEUI$ is a random variable governed by appliance technical attributes and appliance functionality.

The time spent in standby mode defines the energy losses per appliance. There is variability in time spent in standby mode across the different clusters. It is observed that in cluster 5 appliances spend longer hours in standby mode when compared to appliances in cluster 1. Therefore, standby energy as well as power losses are clustered in the household sample and are expected to be higher losses in cluster 5. The least standby power and energy losses are expected in cluster 1.

# Chapter 4

# Appliance Standby Power Measurements and Analysis

There have been various national studies conducted worldwide to estimate standby power losses in households [14]. In some countries estimates have been based on whole-house measurements and in some other countries bottom-up estimates are carried out [14, 27]. Field studies have been conducted in France, Japan, China, Australia, United Kingdom, United States of America, Italy, Greece, Denmark, Sweden and Portugal [14, 23, 44, 55, 62]. Field measurements are actual measurements of appliance power consumption conducted on a sample of households.

Bottom-up estimates have been done in USA [14]. In bottom-up estimates, measurements of standby consumption of a wide range of appliances are done in homes, offices and retail stores. The average consumption obtained is then multiplied by the number of appliances sold in the country [27]. Measurements have also been carried out in major retail stores in other studies where the focus has been on new appliances [63]. Data from such studies has been used mainly for providing trend data in standby power for new products. In-store measurements of standby power consumption data can be used to complement measurements done in individual households and is very useful in identifying new appliances types entering the consumer market. Table 4.1 [14] presents some of the different studies done in different countries.

In this research, field measurements were carried out in 30 households as well as in three major appliance retail stores in South Africa in 2006. The measurement campaign was carried out in individual homes within the suburbs of greater Johannesburg Metropolitan of which most were included in the survey. The issue of crime in South Africa made it extremely difficult to obtain access into homes picked up randomly. This meant that the household sample was identified through personal

Table 4.1: Standby power Studies

| Country | Number of Households | Year |
|---|---|---|
| Australia | 64 | 2001 |
| Australia | 120 | 2005 |
| Canada | 75 | 2000 |
| China | 28 | 2000 |
| Sweden | 400 | - |
| Denmark | 30 | 2004 |
| Japan | 51 | 2001 |
| United Kindom | 32 | 2001 |
| France | 178 | 2001 |
| Greece | 100 | 2001 |

contacts at home, place of worship and at work. Drawing from the group of the willing it was possible to obtain a sample that characteristically represented most of the suburbs that were involved in the appliance ownership survey. The household sample was made of households in the following suburbs: Lenasia, Devland, Moletsane, White City, Florida Park, Midrand, Fourways, Randburg, Sandhurst, Northcliff Extension 19, Cresta, Bryanston, Buccleuch, Edenvale and Kagiso.

## 4.1 The Measurement System

The IEC 62301 standard published in 2005 provides a detailed common technical basis for the formal and accurate measurement of standby power in appliances and equipment around the world [16]. Accurate determination of power consumption in the different appliance low power modes requires careful measurement using accurate measurement systems as well as excellent understanding of the appliance operational modes. In the IEC 62301 standard the following is stipulated regarding the measurement equipment [16]:

- Power resolution of 1 mW or better
- An available current crest factor of 3 or more at its rated range value
- Minimum current range of 10 mA or less
- Ability to measure harmonic components up to at least 2.5 kHz

- Ability to average active power accurately over any user selected time interval

The selected power measurement equipment was the Yokogawa WT 210 digital power meter [64].

### 4.1.1 Suitability of the Yokogawa WT 210 Power Meter

The Yokogawa WT 210 digital power meter is a single phase two wire power meter specifically designed to handle standby low-power measurements and rated power measurements. Accurate measurements can be made using the Yokogawa WT 210 digital power if load wiring techniques stipulated in the user's manual for measuring relatively small and large currents are employed [64].

The following are characteristics of the WT 210 digital power meter [64]:

- Wide current range of 5 mA to 20 A
- Basic voltage and current accuracy of 0.1% of reading +0.1% of range
- Basic power accuracy of 0.1% of reading +0.1% of range
- Measures up to the 50th harmonic
- Can measure down to 5 mA when crest factor is 3 and 2.5 mA when crest factor is set to 6

Crest factor is a ratio of the peak amplitude value to the root mean square value of a sinusoidal waveform [64]. Normally the crest factor is computed for the voltage and current waveform.

The above listed characteristics of the WT 210 digital power meter ascertain that the meter is suitable for measurement of standby power as documented in the IEC 62301. The WT 210 meter is not internally equipped with an anti-aliasing filter. For the WT210 digital power meter, in the fundamental frequency range between $40Hz$ and $70Hz$, aliasing accidental errors may occur when harmonic components of the 256th or higher exist [64]. The highest harmonic of interest to standby power measurement is the 50th harmonic because harmonics components greater than the 49th harmonic (2450 Hz) have little active (real) power associated with them [16]. The Yokogawa WT 210 has an input line filter that was set on to filter out any noise on the line.

### 4.1.2 Measurements

A group of appliances known as *Basket of Core Products* for estimation of standby power has been formulated to enhance comparisons and reporting of standby power losses from different countries [65]. Appliances included in this group are: Clothes washers, microwave ovens, cathode ray tube television sets, LCD TV's, Plasma TV's, DVD's, Hi-Fi's, computer monitors, printers, MFD, and external power supplies [65]. The appliances included in the measurement campaign were those identified as the most common appliances in the appliance survey due to high saturation and penetration rates in the sample and the clusters. These appliances are: Television sets, cell phone battery chargers, VCR's, microwave ovens, DVD's, Digital Satellite Television decoders, Hi-Fi systems, personal computers, computer monitors, printers and multifunction devices. A good number of the appliances on *Basket of Core Products* were therefore included in the measurements. Instantaneous measurements were performed on the appliances found in the household sample and retail stores.

In South Africa in general and especially in large cities, security systems such as automated gates, automated garage doors, alarm systems, intercom systems, closed circuit TV (CCTV) are installed in households. In the research done in Australia, these systems were considered to be sources of standby power losses and measurements were done [21]. Security systems are essential for monitoring and control of access into households. It is therefore necessary that the security systems be 'on' all the time! In addition, because easy accessibility was used as a criteria for household sampling the resulting sample can not be considered to be representative in terms of security systems. Furthermore, the wiring of security systems and swimming pool pumps makes them difficult to isolate and measure [21]. Therefore, although security systems and swimming pool pumps were found in the households during the survey, they were not included in the measurements campaign.

In every household, measurements were recorded for all standby capable appliances found plugged in and drawing power in full, passive standby, active standby or in soft-off mode [66]. In appliances where a standby mode was evident, the measurements were taken in the standby mode. Measurements were also done in all other low power appliance operational modes that could be effectively distinguished. Measurements in the full operational/active mode were taken while the appliance was set to user preferable settings. The variables that were measured are: Peak and root mean square (RMS) voltage, peak and RMS current, real power, reactive power, apparent power and power factor. During measurements the appliance models and specified operating voltage and power ratings were recorded as well as the manufacturers name.

All measurements were done at the fundamental frequency of 50 Hz. The crest factor used for the measurements was 6. Connections to the meter were made to obtain maximum accuracy as illustrated in the WT 210 digital power user's manual [64].

## 4.2 Measurement Results

The measurement results are presented for all pertinent operational modes found on the appliances. For each appliance, detail of the maximum, average, and minimum power consumption in all relevant operational modes are provided. Where applicable, measurement results are presented for used appliances in households and new appliances in retail stores.

### 4.2.1 Cathode Ray Tube (CRT) Television Sets

Three distinguishable and measurable operational modes were found in CRT television sets. These modes are:

- Soft-off Mode
- Standby mode
- Full/active mode

#### Measurements on CRT Television Sets in Households

Household measurements were done on 40 CRT television sets of different screen sizes and different manufacturers. The full operational mode power consumption levels are presented in figure 4.1 and figure 4.2.

The results indicate a wide range of full operational power for CRT TV's for the different screen sizes. There are also variations in power consumption levels within TV's of the same screen sizes. Large screen CRT TV have higher real power consumption levels and smaller screens consume less real power. In some cases, large screen have lower real power consumption than the immediate lower screen size. Differences in apparent power are evident and more pronounced across all CRT TV's as well as between same size screens. This suggests differences in power factors

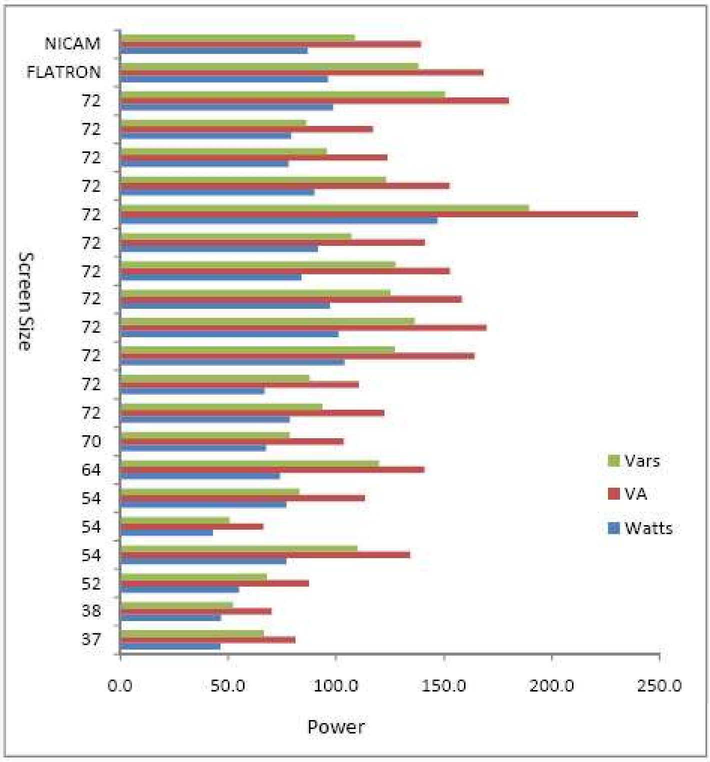


Figure 4.1: Full Mode Power Results for CRT TV's in Households

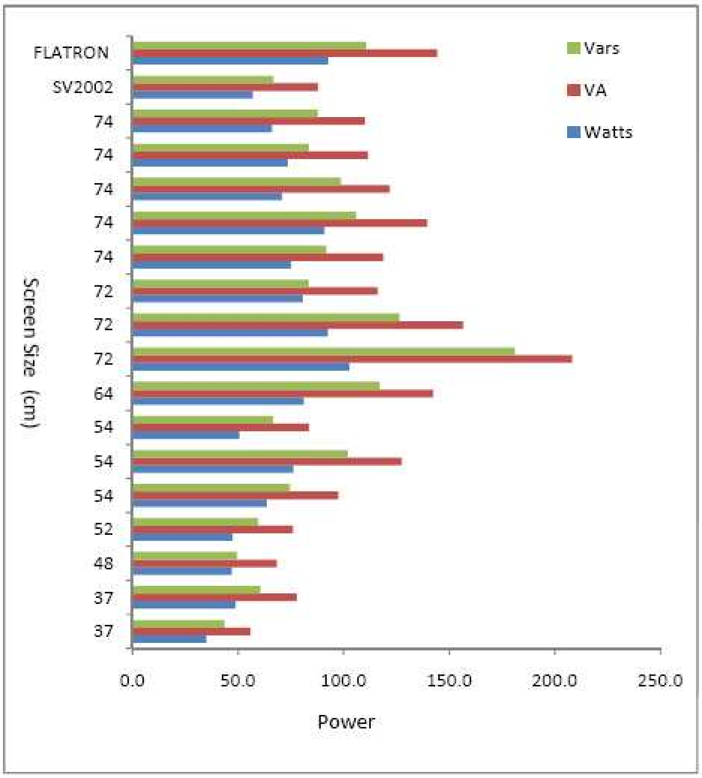


Figure 4.2: Additional Full Mode Power Results for CRT TV's

in different appliances and the relatively large apparent power signifies poor power factors. The values of power factors measured for CRT TV in full operational mode ranged between 0.57 and 0.65.

The average, maximum and minimum power consumption levels for all screen sizes are presented in Table 4.2

Table 4.2: Average Full Mode Power consumption for CRT TV in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 147.0 | 239.8 | 189.4 |
| Average | 76.0 | 124.3 | 98.3 |
| Minimum | 35.0 | 55.9 | 43.6 |

Power measurements in standby mode for CRT TV's in households is presented in Figure 4.3 and Figure 4.4.

As seen in figure 4.3 and figure 4.4, variations in power consumptions levels for CRT TV's across all screen sizes are large, but what is more noticeable are the large variations across same screen sizes. In standby mode, incidences where large screen size CRT TV's consume less than smaller screen sized TV's are evident. The apparent power is considerably large and as before this is attributed to the poor power factors of the appliances in standby mode. The measured power factors for CRT TV's in standby mode ranged between 0.48 and 0.67. The Presence of relatively high reactive power components in standby mode as well as in full operational mode suggests the presence of circulating currents in the low voltage network, and the creation of harmonic voltage sources.

The average, maximum and minimum power consumption levels for all screen sizes are presented in Table 4.3.

Table 4.3: Average Standby Mode Power consumption for CRT TV in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 14.9 | 25.8 | 21.1 |
| Average | 8.2 | 15.2 | 12.8 |
| Minimum | 2.7 | 5.6 | 4.9 |

The range between maximum and minimum power values in table 4.3, further point to the wide variations in power consumption levels across the different CRT TV sets.

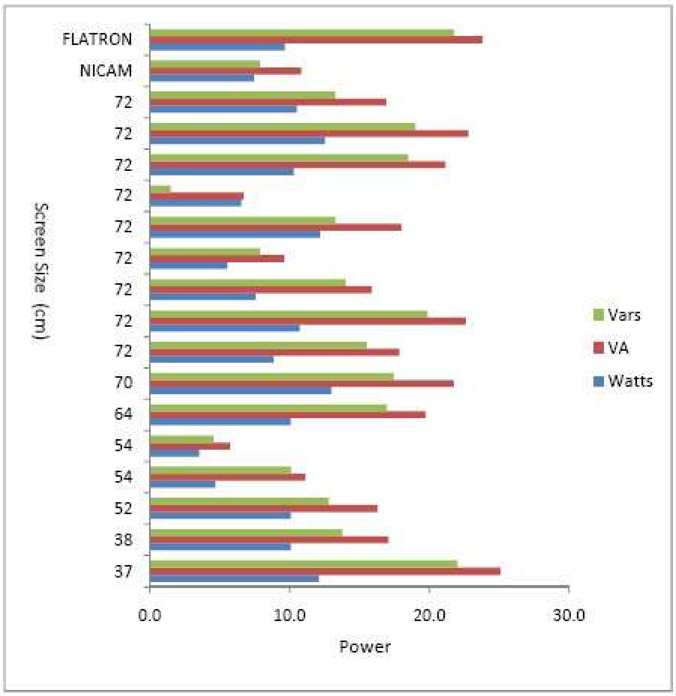


Figure 4.3: Standby Mode Power Results for CRT TV's in Households

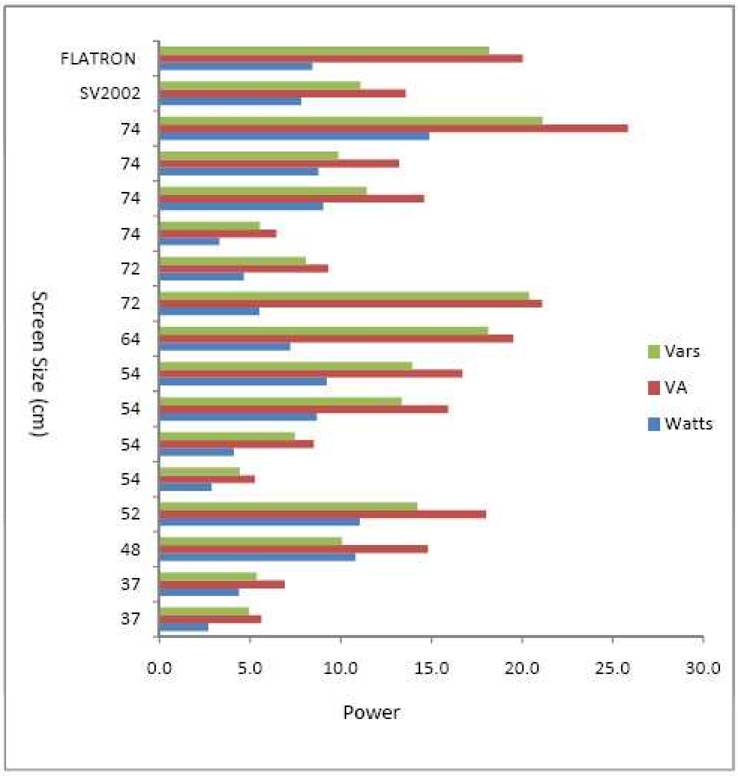


Figure 4.4: Additional Standby Mode Power Results for CRT TV's

**Measurements on New CRT TV's**

Measurements were done on 28 new CRT TV's of different screen sizes in three major appliance retail stores. The power consumption levels in full operational mode for new CRT TV's are presented in Figures 4.5 and 4.6.

Variations across different screen sizes are observed and as expected, large screen sizes consume more power than small screen TV's. There are also variations within same size TV's and these are more pronounced in the 72 cm screen group. In some of the 72 cm and 74 cm screen TV's the power consumption levels are almost the same. The power factor values for new CRT TV's lies between 0.55 and 0.68 and it can be seen that there are no differences in power factor ranges for in house and new CRT TV's suggesting the same design philosophies for new and much older TV's in households. These poor power factor results in large apparent power components which increases as the screen size increases.

If new and in house CRT TV's with same screen sizes are compared, the full operational power consumption levels are found to be within the same ranges. This suggests that there are no differences in the end-use efficiencies of new and in house CRT TV's.

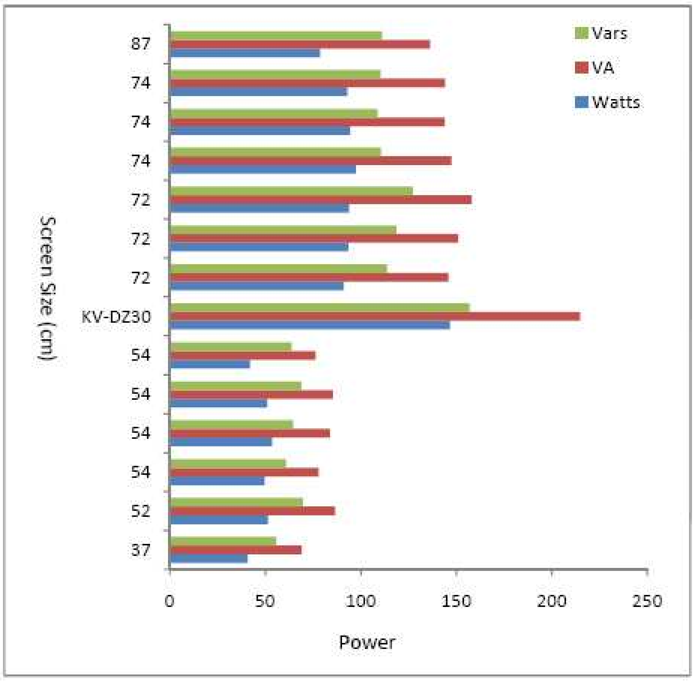


Figure 4.5: Full Mode Power Results for New CRT TV's

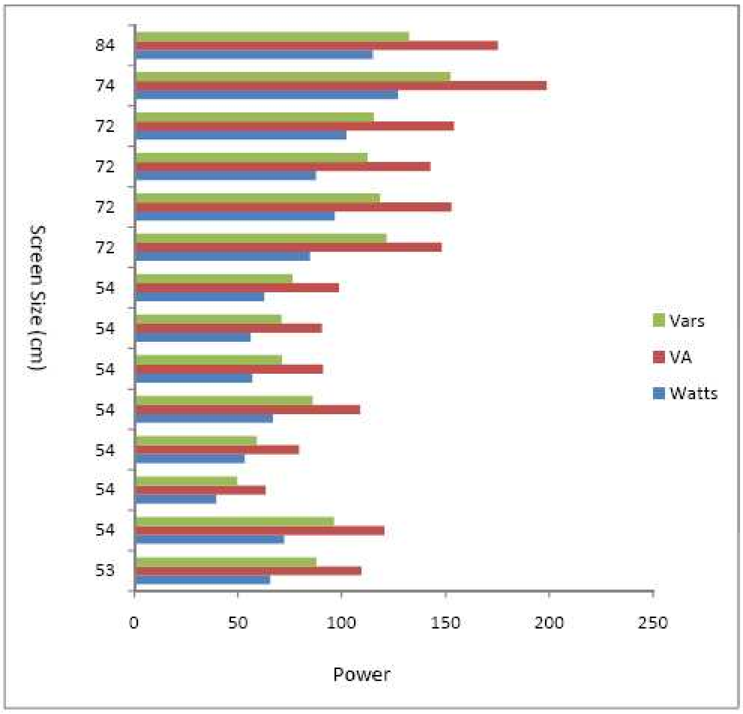


Figure 4.6: Additional Full Mode Results for New CRT TV's

The average, maximum and minimum power consumption levels of new CRT TV's in retail stores are presented in Table 4.4

Table 4.4: Average Full Mode Power Consumption for New CRT TV's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 146.7 | 214.7 | 156.8 |
| Average | 77.3 | 123.2 | 96.0 |
| Minimum | 39.5 | 63.4 | 49.6 |

The averages in Table 4.2 and Table 4.4, further confirm the wide variations in power consumption levels and that there are no significant differences in the power consumption levels between used CRT TV's in households and new CRT TV's in retail stores. Standby mode power consumptions values for CRT TV's of different screen sizes are shown in Figures 4.7 and 4.8.

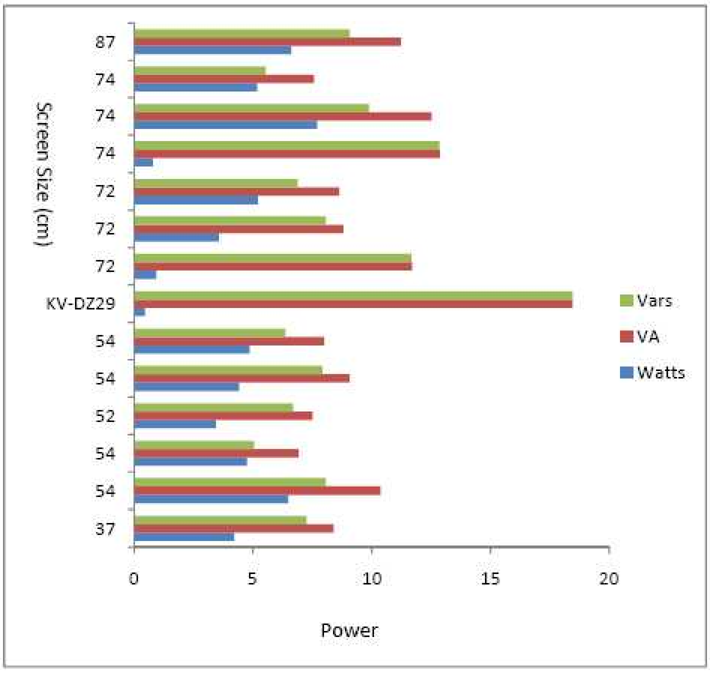


Figure 4.7: Standby Mode Power Results for New CRT TV's

Variations across different screen sizes are again evident. In this case smaller screen sizes i.e. 54 cm TV screens show higher power consumption levels than 72 cm and 74 cm sized screens though there are a few cases where the opposite is true. This further confirms that end-use efficiencies of new small screen CRT TV's been manufactured or imported into the country have not yet improved. The measured power factor for the different new CRT TV's in standby mode ranged between 0.02 and 0.79 indicating a wide range of apparent and reactive power components. Where

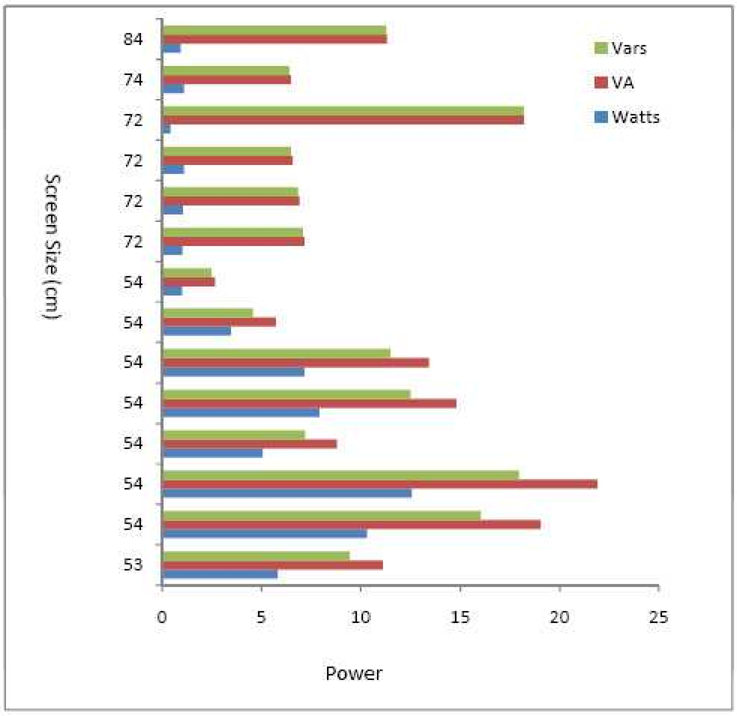


Figure 4.8: Additional Standby Mode Results for New CRT TV's

very poor power factors are indicated, these are accompanied by relatively large components of both apparent and reactive power. Table 4.5 present the maximum, average and minimum power consumption levels in new CRT TV's in standby mode.

Table 4.5: Average Standby Mode Power Consumption for New CRT TV's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 12.5 | 21.9 | 18.0 |
| Average | 4.2 | 10.8 | 9.9 |
| Minimum | 0.4 | 18.2 | 18.2 |

Comparing average power consumption levels of in house and new CRT TV's indicates that real power in new appliances has decreased by 50% from 8.2 Watts to 4.2 Watts. This could be due to new technologies with lower power consumption as we have seen in the case of 72 cm and 74 cm screen sizes in Figures 4.7 and 4.8.

### Measurements on CRT TV's in Soft-off Mode

Measurements in soft-off mode were done on three CRT TV sets found in households, and for all new CRT TV's the soft-off mode was not identifiable on any of the TV sets. The power consumption levels measured in CRT TV's in soft-off mode are very low as seen in Table 4.6.

Table 4.6: Power Consumption: CRT TV's in Soft-off Mode

| Screen Size(cm) | Watts | VA | Vars |
|---|---|---|---|
| 37 | 0.03 | 0.03 | 0.02 |
| 54 | 0.02 | 3.16 | 3.16 |
| 54 | 0.01 | 1.53 | 1.53 |

### 4.2.2 Television Sets with Liquid Crystal Displays (LCD)

Measurements were carried out on 35 LCD TV's, 5 were found in the households and 30 in retail stores.

#### Measurements on LCD TV's in Households

The low number of LCD TV's compared to CRT TV's reflects the fact that penetration and saturation levels of these appliances are still very low in households. The standby power consumption levels for in house LCD TV's range from 0.6 W for an 104 screen size TV to 12.7 W for an LCD TV with screen size of 84 cm. Figure 4.9 present the power measurements.

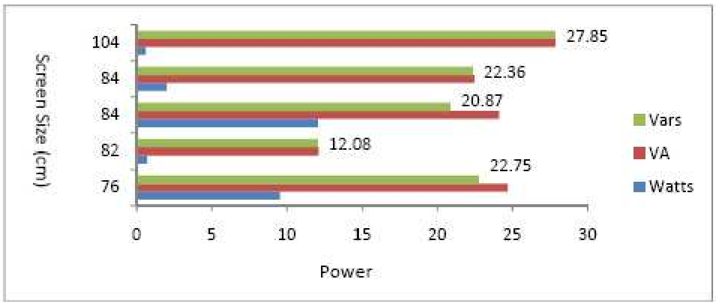


Figure 4.9: Standby Mode Power Results for LCD's in Households

The variations in standby power consumption cannot be directly linked to the TV screen size suggesting that the differences can be explained only by differences in design philosophies. Relatively large components of both apparent and reactive power are evident in Figure 4.9. These reactive and apparent power consumption levels are supported by extremely poor power factors. In standby mode the measured power factors were between 0.02 and 0.39. In standby mode LCD TV's have worse power factors than CRT TV's. The average, maximum and minimum power consumption for LCD TV's are shown in table 4.7

Table 4.7: Average Standby Mode Consumption for LCD TV in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 12.1 | 24.1 | 20.9 |
| Average | 5.0 | 21.8 | 21.8 |
| Minimum | 0.6 | 27.9 | 27.9 |

If values in table 4.7 are compared to values in table 4.3, the following are observed:

- The average value of real power in LCD TV's is almost half of the average real power consumption in CRT TV's
- The average values of apparent and reactive power components for LCD TV's are about 4 times greater than the values for CRT TV's.

The average values are used to compute total power consumption. Thus, while total real power consumption is expected to decreases in LCD's in standby mode their total apparent power in standby mode is expected to increase if compared to CRT TV's. The cost implications if an uptake of LCD TV's in households is considered will result in lowered costs to the consumer as far as standby real power losses are concerned but increased costs to the supplier because of the increase in apparent power. The high levels of reactive power components for LCD TV's TV's brings in the question of harmonics and cable sizing especially where the appliance is found in large numbers within a localized area.

In full operational mode, power consumption is generally higher than for CRT TV's. Power consumption levels for LCD TV's in full operational mode are shown in figure 4.10.

As seen in figure 4.10, real and apparent power components in full mode are very close to each other indicating good power utilization in all TV's. This observation is backed by measured values of power factors which ranged between 0.96 and 0.98. The improved power factors are due to the presence of power factor correction capacitor in the power supply circuit of LCD TV's. Average power consumption values for in house LCD TV's in full mode are presented in table 4.8.

In general all power consumption levels are higher in LCD TV's than in CRT TV's. The average real power in LCD TV's is almost double that of CRT TV's as seen in

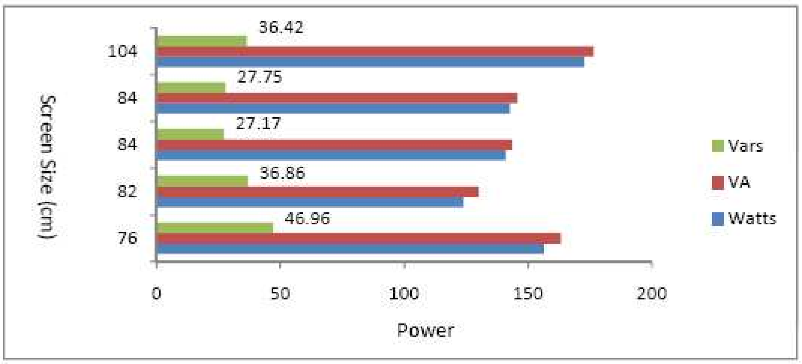


Figure 4.10: Full Mode Power Results for LCD's in Households

Table 4.8: Average Full mode Consumption for LCD TV in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 172.6 | 176.4 | 36.4 |
| Average | 147.2 | 151.4 | 35.0 |
| Minimum | 123.8 | 130.0 | 36.4 |

table 4.2 and table 4.8. The anticipated change from analog TV broadcasting to digital TV broadcasting will bring changes from CRT to LCD TV's. These changes will be accompanied by increased costs to the consumer due to the increased real power consumption in LCD TV's in full mode and the supplier costs will increase in standby mode due to increase in apparent power.

**Measurements on New LCD TV's in Retail Stores**

Thirty out of thirty five measurements on LCD TV's was carried out in retail shops. While many more TV's could have been measured, the availability of input signals to the TV's on the shop floors meant that only those sets found fully connected were included in the measurement sample. This was done to keep disturbances due to shifting of appliances on the shop floors to a minimum and as much as possible to not disrupt normal shop operations. Standby Power consumption levels for new LCD TV's of different screen sizes are presented in figure 4.11 and figure 4.12.

There are variations in real power consumption within TV's with same size screens. The variations could be due to different manufacturer's design practices and philosophies. In relation to real power in most cases the apparent and reactive power components are large. Measured power factors in standby mode are poor and range between 0.00 and 0.54 with the majority of television sets being between 0.04 and

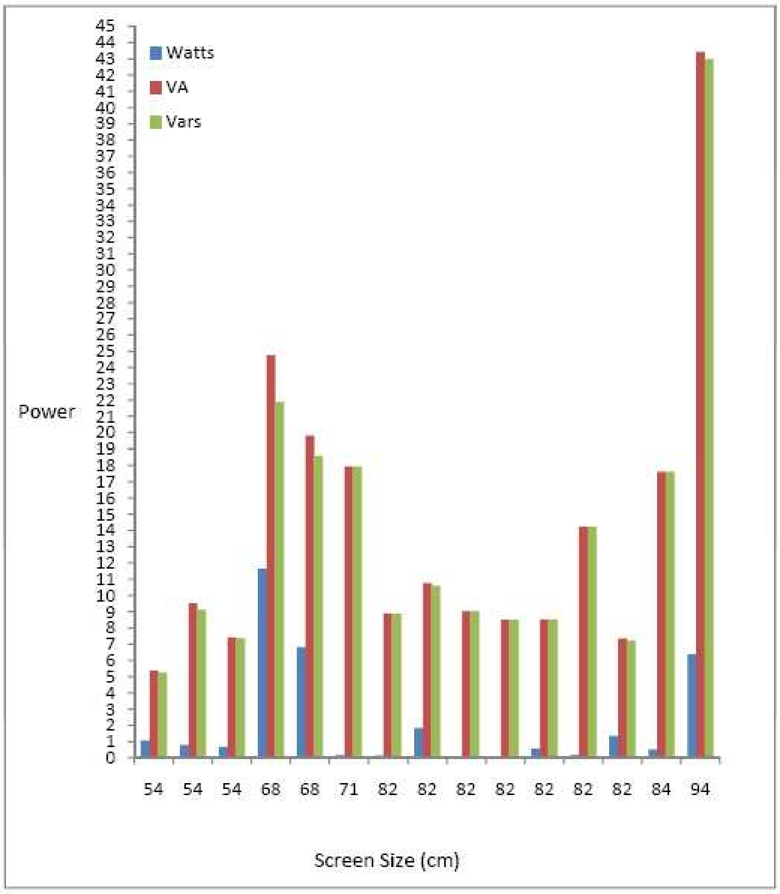


Figure 4.11: Standby Mode Power Results for New LCD's

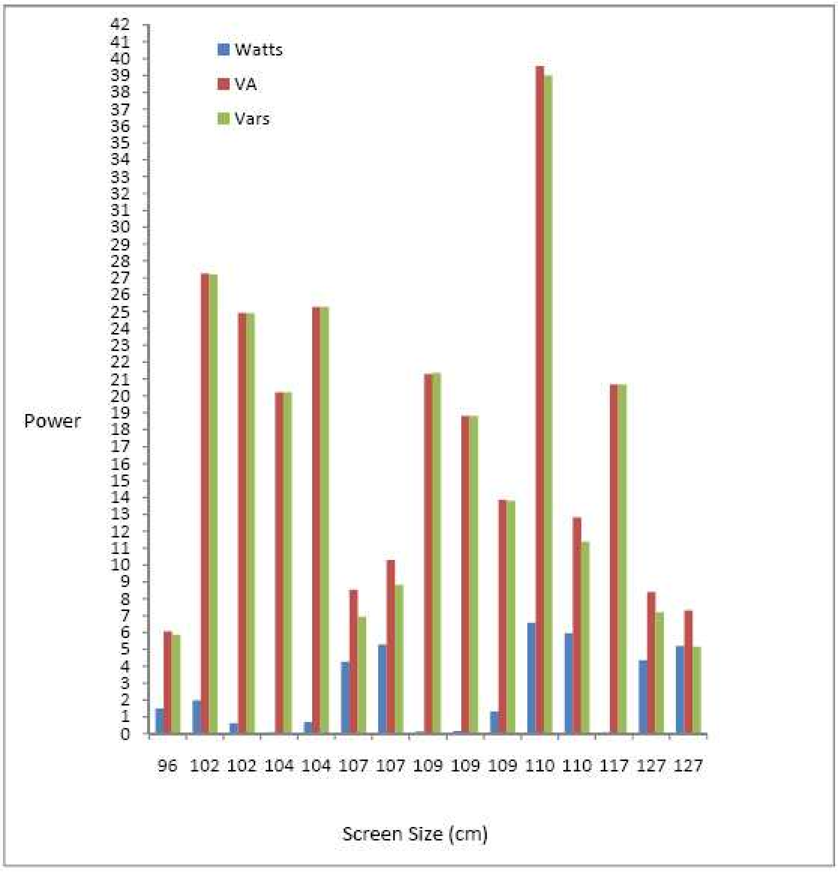


Figure 4.12: Additional Standby Mode Results for New LCD's

0.18.

Four new LCD TV's were found to have an Energy Star logo indicating the presence of energy efficient screens in the market. The real power consumption in these four sets in standby mode was found to be 0.2 W for a 71 cm screen, 0.5 W for an 82 cm screen, 0.5 W for an 84 cm screen and 0.1 W for an 117 cm screen. All the real standby power consumption in these four sets are $\leq 0.5W$, adhering to Energy Star energy efficient standards (Energy Star standard).

Average, maximum and minimum power consumption values for the set of measured LCD TV's is presented in table 4.9.

Table 4.9: Average Standby mode Power Consumption for New LCD TV

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 11.6 | 24.8 | 21.9 |
| Average | 2.3 | 15.7 | 15.5 |
| Minimum | 0.0 | 8.5 | 8.5 |

The average standby power consumption is lower in the new LCD TV's when compared to in house LCD TV's as seen in figure 4.7. Power consumption of LCD TV's in full power mode is presented in figure 4.13.

It can be observed in figure 4.13 that in most cases, a relatively smaller reactive power component is present in full mode. The magnitudes of the real and apparent power components are close to each other demonstrating better power factors in full operational mode. Generally the magnitude of real and apparent power components increase with increasing TV screen size. The maximum, minimum, and average power consumption levels for the measured new LCD TV's are provided in table 4.10.

Table 4.10: Average Full Mode Power Consumption for New LCD TV

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 232.8 | 239.2 | 55.1 |
| Average | 153.7 | 168.6 | 69.2 |
| Minimum | 48.0 | 80.6 | 64.7 |

From table 4.10 it is seen that the average real power consumption for new LCD TV's is the highest full mode real power consumption for both CRT and LCD TV's. This suggests that LCD TV's as expected consume more real power in full mode

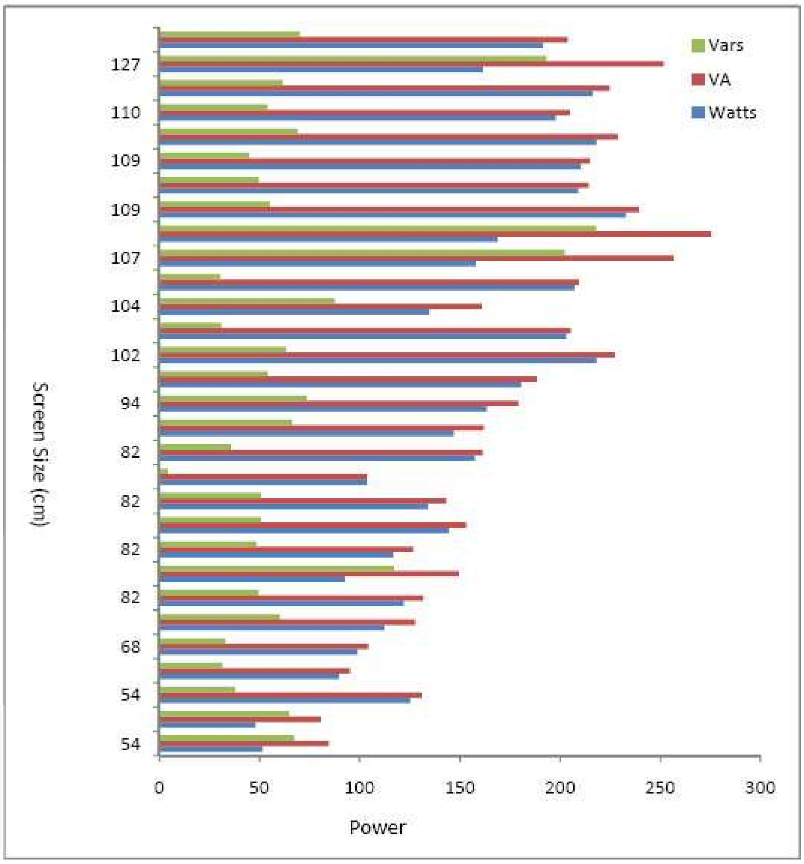


Figure 4.13: Full Mode Power Measurement Results for New LCD's

than CRT TV's. The apparent power is also the highest indicating an increased demand and increased costs to the supplier.

### 4.2.3 Plasma Television Sets

As was the case of LCD TV's, power measurements were performed on only a few Plasma TV's found in households. This can be attributed to the fact that the technology is still new and it has yet to be spread into many households. The soft-off mode was observed in one of the four Plasma TV's found in the households. Its power consumption level in soft-off mode was measured to be the same as the standby mode power consumption as seen in figure 4.14.

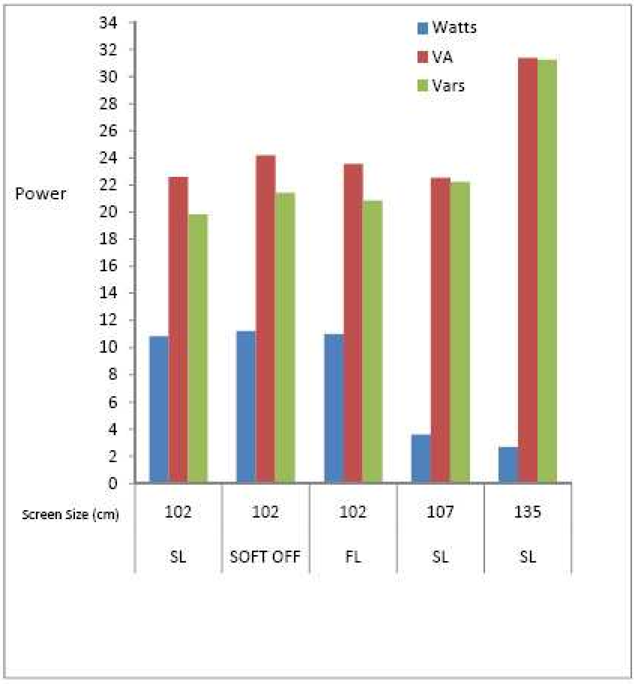


Figure 4.14: Standby Mode Results for Plasma TV's in Households

The real power consumption in soft-off mode was 11.2 W a figure much higher when compared to CRT TV's soft-off real power consumption of less than 0.1 W.

#### Measurements on Plasma TV's in Households

Figure 4.14 presents the standby mode power consumption levels of the different plasma television sets measured in households. The presence of relatively large apparent and reactive power components is still evident here. The differences in magnitudes of real, apparent and reactive power components is well pronounced for the screen size 135 cm. The range of power factors obtained from measurements range between 0.48 and 0.06.

In table 4.11 the maximum, average and minimum power consumption levels are presented. The total numbers of television sets in the measurement sample was very

Table 4.11: Average Standby Consumption for Plasma TV's in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 11.2 | 24.2 | 21.4 |
| Average | 7.9 | 24.4 | 23.1 |
| Minimum | 2.7 | 31.4 | 31.3 |

limited and therefore these figures should be treated as indicators only. Average power consumption levels are higher than those of LCD TV's in households as seen in table 4.7. Full operational mode power consumption for Plasma TV's in households is indicated in figure 4.15.

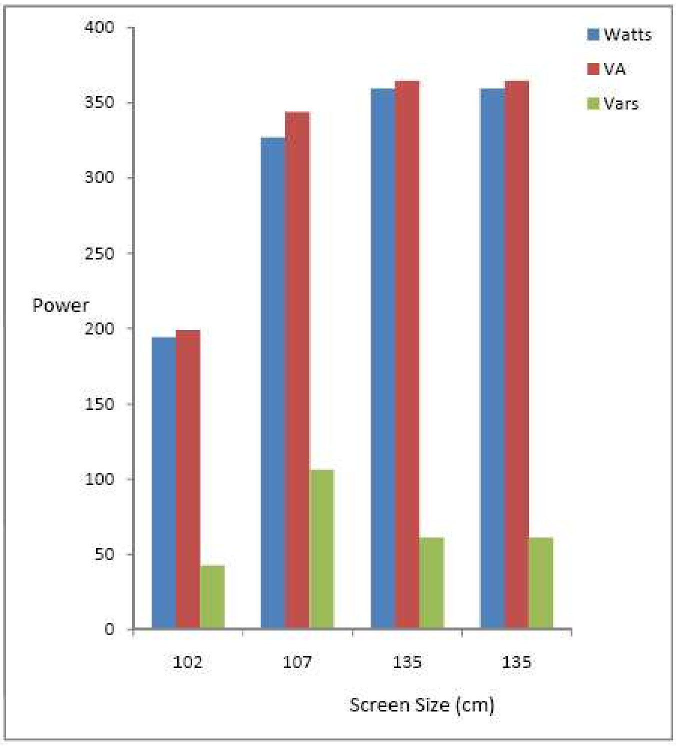


Figure 4.15: Full Mode Results for Plasma TV's in Households

The power consumption levels in Plasma TV's are higher than those for LCD TV's. For example in figure 4.15 a Plasma TV with screen size of 102 cm consumes 194.1W while an LCD TV with 104 cm screen size consumes 172.6 W. The difference in power consumption levels of Plasma and LCD TV's are inherent in the differences in technologies used where plasma technology results in higher power consumption levels than LCD screen technology. These power consumption differences can be seen more clearly if full mode average, maximum and minimum values are considered for LCD and Plasma TV's. Table 4.12 presents the full mode minimum, maximum and average values for Plasma TV in households. Once again because of the small numbers involved these figure should only be taken as indicators.

Table 4.12: Average Full Mode Consumption for Plasma TV's in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 359.4 | 364.5 | 61.0 |
| Average | 309.9 | 317.3 | 67.7 |
| Minimum | 194.1 | 198.7 | 42.6 |

The power factor recorded in full mode measurements ranged between 0.95 and 0.98 and these figures explains why the magnitudes of the real and apparent power components follow each other closely as observed in figure 4.15. TV screen size does not appear to be a clear indicator of the level of power consumption levels in both modes because it appears that larger screen sizes have lower power consumption levels and this can only be explained by advancement in technology or design improvements.

**Measurements on Plasma TV's in Retail Stores**

Measurements were performed on a total of 14 new Plasma TV's. Soft-off mode was found on 2 new appliances. As seen in figure 4.16 the real power component in soft-off mode was measured as 0 W with very small reactive and apparent power components.

Small magnitudes of the apparent and reactive power was measured on both TV's. These components were equal as expected and the values are 1.5 VA/Vars for 107 cm screen and 1.5 VA/Vars for 109 cm screen. This indicates the presence of very small circulating currents with zero real power consumption in soft-off mode.

The real standby power consumption levels as seen in figure 4.16 are low and as before the values for different TV's cannot be related to the screen sizes. The power factors measured ranged between 0.02 and 0.32 and these figures support the measured levels of apparent and reactive power components. The maximum, minimum and average values are presented in table 4.13

The average power consumption values are higher than those presented for new LCD

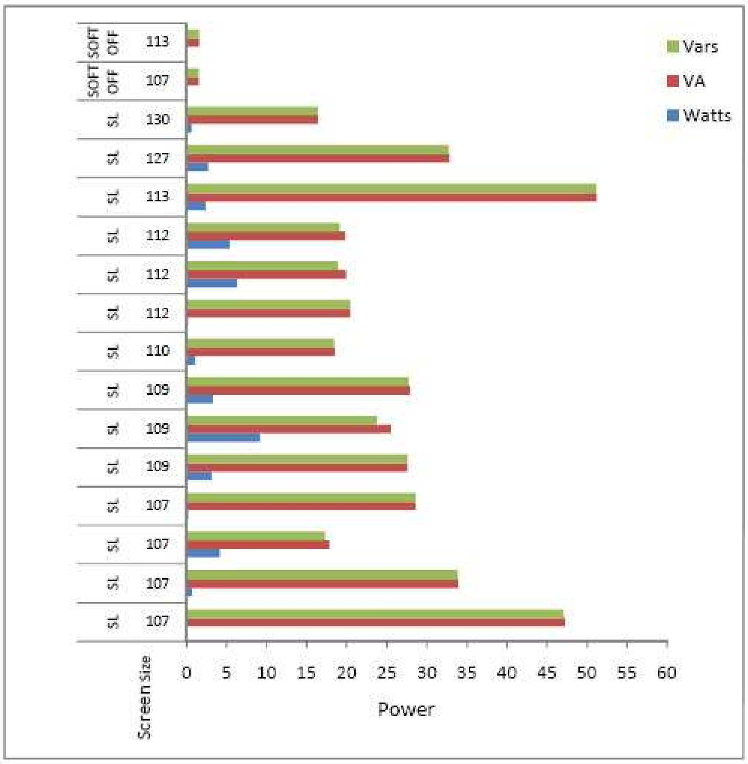


Figure 4.16: Standby Mode Power Measurement Results for New Plasma TV's

Table 4.13: Average Standby Mode Power Consumption for New Plasma TV's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 9.2 | 25.4 | 23.7 |
| Average | 3.0 | 27.5 | 27.4 |
| Minimum | 0.1 | 20.5 | 20.5 |

TV's in table 4.9. Average power consumption in full mode for new plasma TV's are presented in Table 4.14.

Table 4.14: Average Full Mode Power Consumption for New Plasma TV's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 412.9 | 421.6 | 84.9 |
| Average | 215.1 | 223.8 | 61.7 |
| Minimum | 140.5 | 146.7 | 42.2 |

The maximum real power of 412.9 W for plasma TV with screen size of 130 cm was the largest that was measured both in households and in retail stores. The average power consumption levels as expected are higher than those for new LCD TV's in full mode in table 4.10. Therefore, Plasma TV's power consumption levels are higher than for LCD TV's and are more pronounced in full power mode. The full mode power consumption levels for new Plasma TV's are presented in figure 4.17.

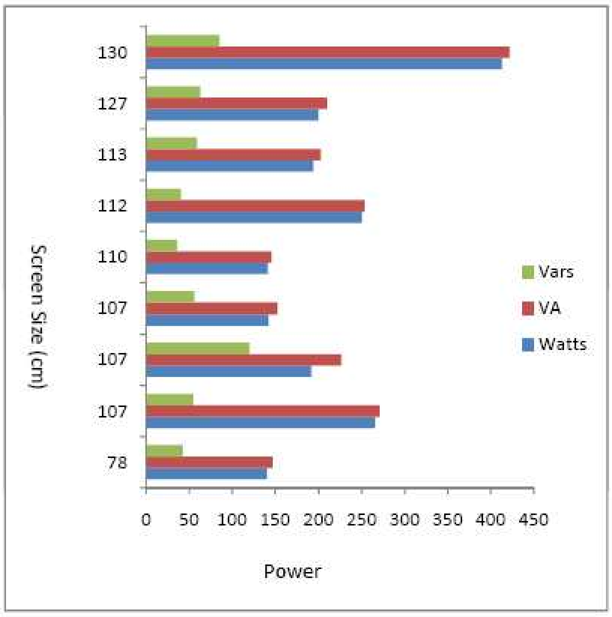


Figure 4.17: Full Mode Power Measurement Results for New Plasma TV's

As it can be observed in figure 4.17 the magnitudes of the real and apparent power components follow each other closely and this tendency is confirmed by the recorded values of power factor which ranges between 0.84 and 0.99. The average power consumption levels for Plasma TV's measured in both new and used appliances are higher than those measured in LCD TV's. As it can be observed in figures 4.14, 4.15, 4.16 and 4.17, there are variations in power consumption levels in both modes in TV's with same size screens. Furthermore, there are also variations in power consumption levels across different screen sizes and these variations cannot be directly based on the variations in screen sizes.

### 4.2.4 Mini Hi-Fi Systems

The term Mini Hi-Fi in this study incorporates the following appliances which were found in households and retail stores during the measurement campaign.

- CD/Tape/Tuner
- CD/Tuner
- CD/Tape
- DVD/Tuner
- DVD/CD/Tape/Tuner
- DVD/CD/Tuner
- DVD/MP3/CD/Tape/Tuner
- MP3/CD/Tuner
- MP3/CD/Tape/Tuner

It is expected that because of the wide range of functionalities in these appliances, there would also be a wide range of power consumption levels across the sample. The different operational modes which could be distinguished and measured are: Soft-off, Demo-on, Full, and Standby modes. The Demo-on is an operational mode in which a Hi-Fi set is not performing its primary function, it continuously displays some eye catching effects in different colours and shapes.

### 4.2.5 Mini Hi-Fi Measurements in Households

The power consumption levels of mini Hi-Fi in standby and full modes are presented in figure 4.18. Mini Hi-Fi number 7 can be seen to have exceptionally large power consumption levels in both modes when compared to the rest. This is a further indication of a wide range of power consumption levels within appliances performing same primary function. Mini Hi-Fi number 10 is the only set where there is an appreciable difference between full and standby power consumption levels. In all

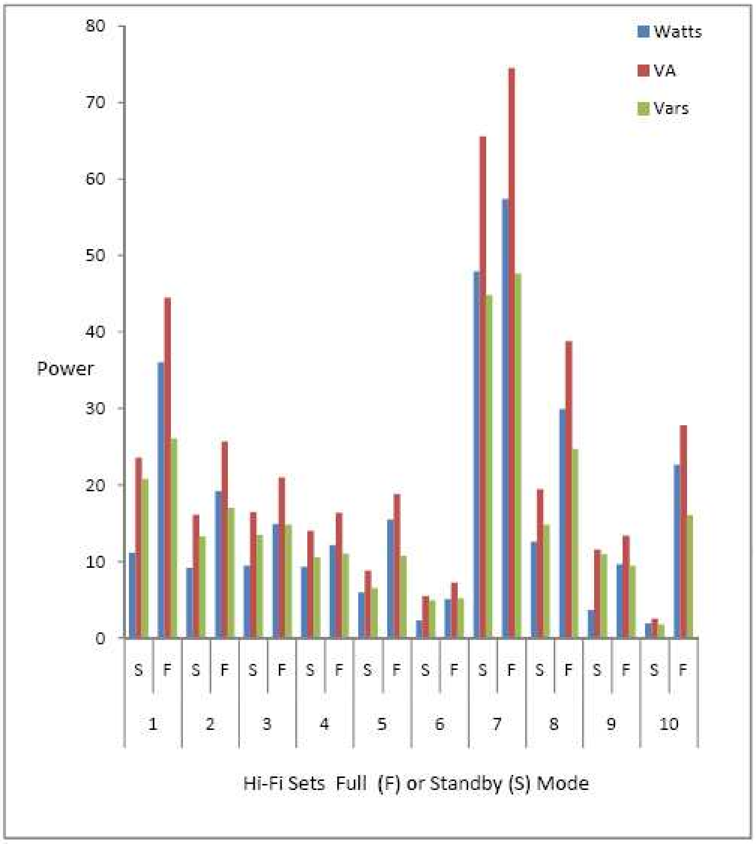


Figure 4.18: Power Measurement Results for Mini Hi-Fi's in Households

the rest of the mini Hi-Fi's, the real standby power consumption level in standby mode is approximately one third to a half of the real power in full mode. This indicates high real standby power losses. The power factor measured in standby mode ranged between 0.42 and 0.73 and in full mode the values varied between 0.69 and 0.82. In all 10 Mini Hi-Fi's as seen in figure 4.18, the apparent power component is relatively large in both modes and the question which arises is: *What are the necessary functions in Mini Hi-Fi in standby mode that require such high levels of apparent power to be supplied?*

The maximum, minimum and average power consumption levels for Mini Hi-Fi's in households in both standby and full modes are presented in table 4.15 and table 4.16 respectively. In both tables the maximum and minimum values indicate the

Table 4.15: Average Standby Power Consumption for Mini Hi-Fi's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 47.9 | 65.6 | 44.8 |
| Average | 11.3 | 18.1 | 14.2 |
| Minimum | 1.9 | 2.5 | 1.7 |

Table 4.16: Average Full Power Consumption for Mini Hi-Fi's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 57.4 | 74.5 | 47.6 |
| Average | 22.2 | 28.8 | 18.3 |
| Minimum | 5.1 | 7.2 | 5.2 |

wide variations in power consumption levels in Mini Hi-Fi's. As assumed earlier on, this could partly be due to the different functionalities but also it could be due to different manufacturers with different design philosophies.

### Measurement Results for New Mini Hi-Fi's

Twenty new Mini Hi-Fi's were measured in retail stores and the demo on mode was found on three sets as seen in figure 4.19 and figure 4.20.

In set 9 and 20 the power consumption in Demo On mode is an appreciable fraction of the power consumption in full mode. In set 19 the power consumption in demo on mode is equal to the power consumption in standby mode. While the function of

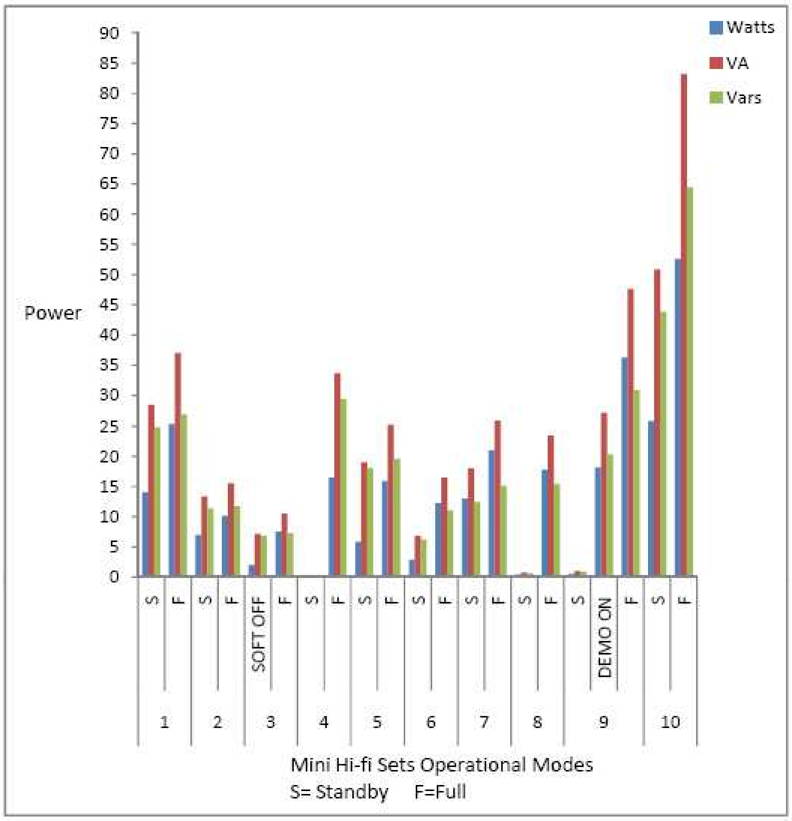


Figure 4.19: Power Measurement Results for New Mini Hi-Fi's

the appliances is the same in demo on mode, the power consumption levels required to sustain the function differ significantly in the two sets. As was the case of the mini Hi-Fi's in households it is still the case in most new sets that standby power consumption is an appreciable fraction of the full power consumption except in sets 4, 8, 9, 11, and 15 as seen in figures 4.19 and 4.20. Furthermore the wide variation in power consumption levels across all sets is also evident in new Mini Hi-Fi sets in both standby and full mode operation. The power factors measured on new appliances ranged between 0.24 to 0.82 in standby mode and 0.49 to 0.83 in full mode. The range in power factors explain the variations in the apparent and reactive power consumption levels across different sets for both operational modes.

The maximum, minimum and average power consumption values or Mini Hi-Fi's in standby and full operational modes are provided in table 4.17 and figure 4.18.

The average power consumption levels in new appliances are lower than those for in house Mini Hi-Fi's as seen when average values in standby mode and full mode in tables 4.15 and 4.16 are compared with the values in tables 4.17 and 4.18. This could be due to newer technologies that require less power or advancements in power supply design. However the ranges between maximum and minimum values

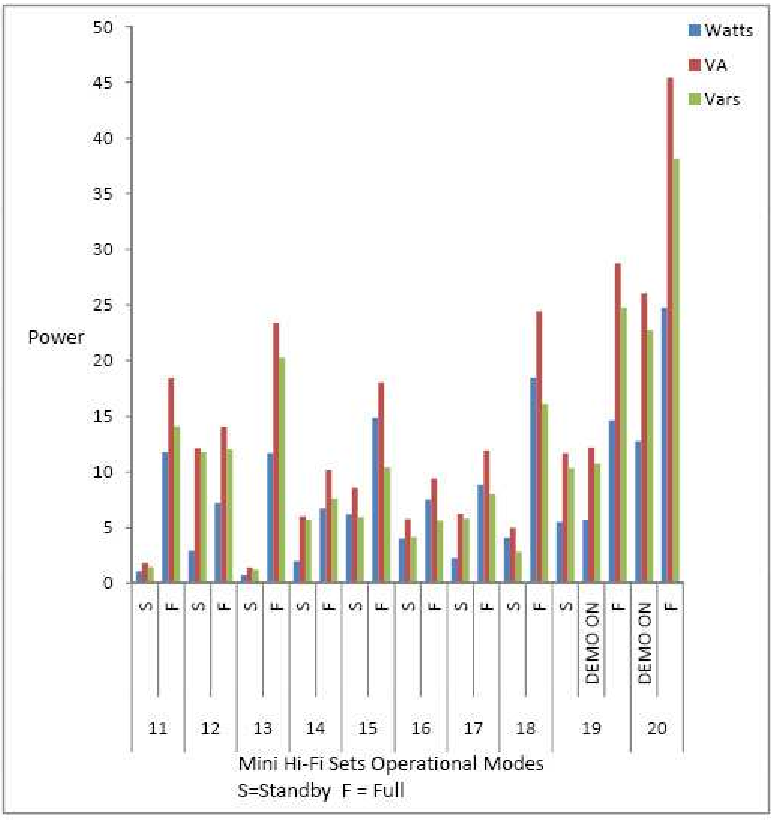


Figure 4.20: Power Measurement Results for New Mini Hi-Fi's

Table 4.17: Average Standby Mode Power Consumption for New MiniHi-Fi's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 25.9 | 50.9 | 43.8 |
| Average | 5.8 | 11.4 | 9.9 |
| Minimum | 0.5 | 0.8 | 0.7 |

Table 4.18: Average Full Mode Power Consumption for New Mini Hi-Fi's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 52.6 | 83.2 | 64.4 |
| Average | 17.1 | 25.9 | 19.4 |
| Minimum | 6.0 | 10.2 | 7.6 |

in both full and standby mode are still large.

### 4.2.6 Microwave Ovens

Measurements were done on 20 microwave ovens found in the households. No measurements were done on new microwave ovens. The power consumption levels for microwave ovens in standby mode are presented in figure 4.21. The magnitudes of

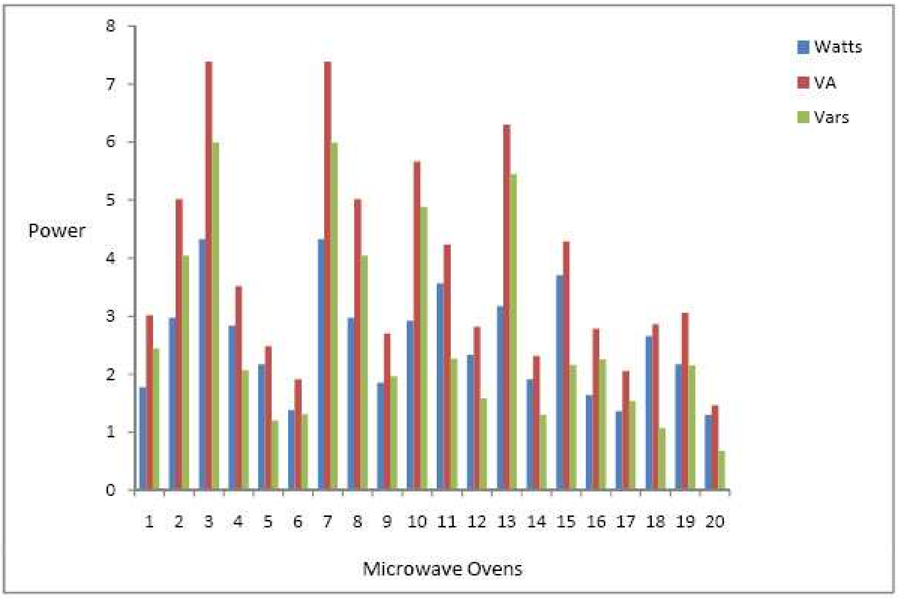


Figure 4.21: Standby Mode Results for Microwave ovens in Households

the apparent and reactive power components in standby mode are higher than the real power component and the power factor values were recorded to be between 0.50 and 0.93. There is wide variations in the magnitudes of real power consumed by the different appliances though in most cases the only function maintained in standby mode is the digital clock.

The maximum, minimum and average power consumption levels for microwaves in standby mode are shown in table 4.19. Full mode measurements for microwaves are shown in figure 4.22. The reactive power component is observed to be significant in most of the ovens and the apparent power component is large. The power factor of all except two ovens range between 0.74 and 0.99 and for the exceptional two, the power factors are 0.17 and 0.30. The minimum, maximum and average power consumption levels in full mode are presented in table 4.20.

Table 4.19: Average Standby Mode Power Consumption for Microwave Ovens

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 4.3 | 7.4 | 6.0 |
| Average | 2.6 | 3.7 | 2.7 |
| Minimum | 1.3 | 1.5 | 0.7 |

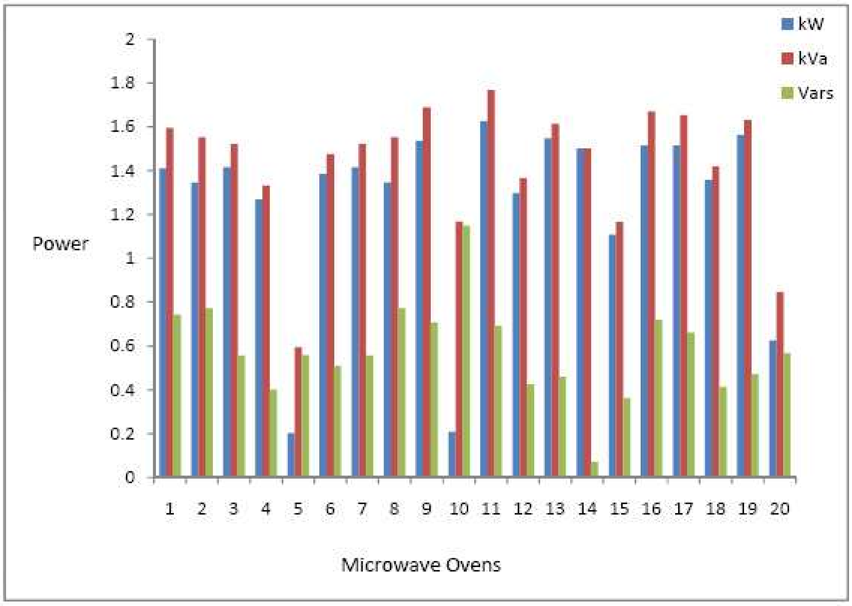


Figure 4.22: Full Mode Power Measurement Results for Microwave Ovens

Table 4.20: Average Power Consumption for Microwave Ovens in Full Mode

| | kW | kVA | kVars |
|---|---|---|---|
| Maximum | 1.6 | 1.8 | 0.7 |
| Average | 1.3 | 1.4 | 0.6 |
| Minimum | 0.2 | 0.6 | 0.6 |

### 4.2.7 DVD Players

In the measurement campaign several variations in DVD's were found. These variations with numbers in brackets are DVD recorder (1 new), DVD player/VCR combo (4 new, 1 used), DVD recorder/VCR combo (1 used), DVD writer (1 used), and DVD player/VCR/Home theatre (1 new) and DVD players (20 used, 14 new). Only DVD players results are presented due to the high numbers found both in households and retail stores.

#### DVD Players in Households

Measurements were done on 20 DVD players found in households. The power consumption results of measurements in standby and full mode are presented in figure 4.23 and figure 4.24.

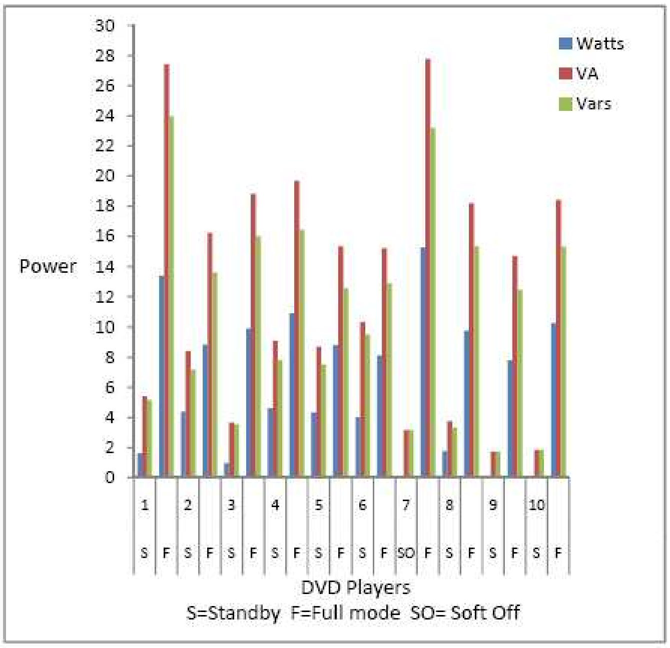


Figure 4.23: Power Results for DVD Players in Households

The variations in power consumption levels in both modes are seen in figures 4.23 and 4.24 as well as in tables 4.21 and table 4.22 which illustrate the maximum, minimum and average values in both modes.

In both standby and full mode the apparent power component is much larger than the real power component. The power factor values in standby mode range between 0.03 to 0.79 and in full mode the power factors range between 0.46 and 0.86. As

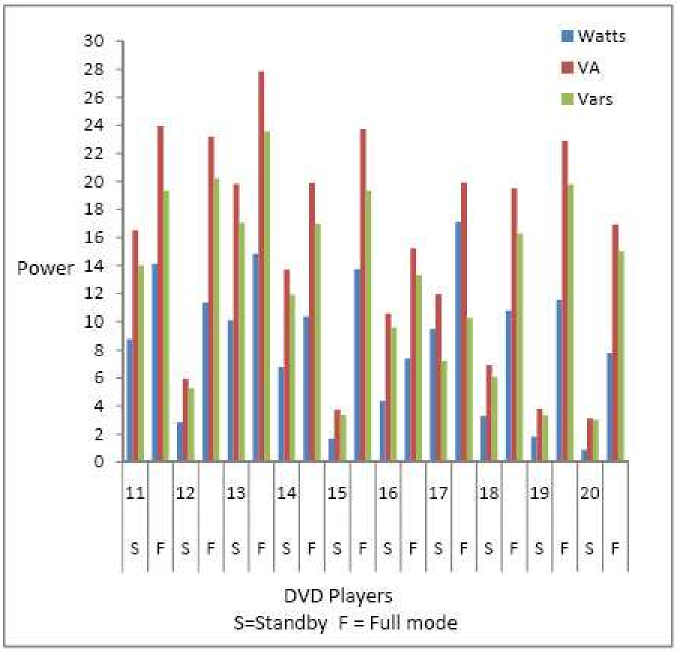


Figure 4.24: Power Results for DVD Players in Households

Table 4.21: Standby Power Average Consumption for DVD in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 10.1 | 19.8 | 17.1 |
| Average | 3.8 | 7.7 | 6.8 |
| Minimum | 0.1 | 1.7 | 1.7 |

Table 4.22: Full Power Average Consumption for DVD's in Households

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 17.1 | 19.9 | 10.2 |
| Average | 11.1 | 20.2 | 16.8 |
| Minimum | 7.4 | 15.2 | 13.3 |

seen in figures 4.23 and 4.24, in some DVD players the standby mode real power consumption levels are a considerable fraction of the full mode power consumption. Figure 4.25 presents the ratio of the standby real power to full mode real power as a percentage for each of the DVD players. The ratio of standby mode real power

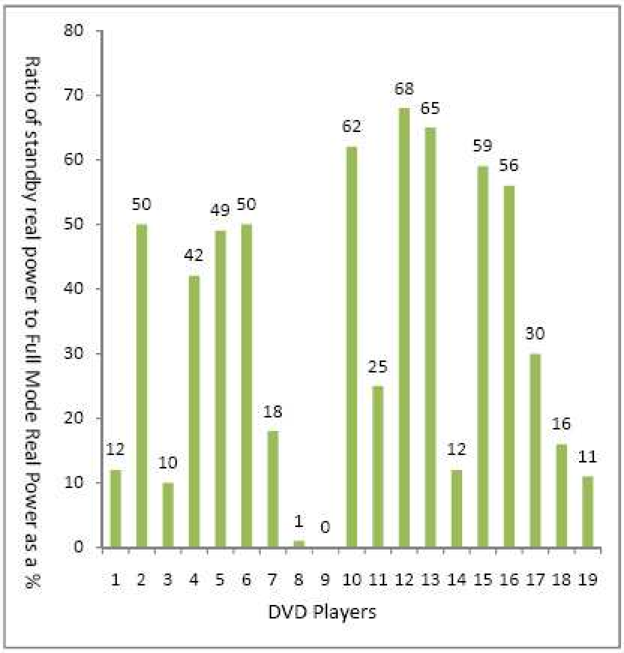


Figure 4.25: Standby Real Power as a % of Full mode Real Power

to full mode real power as a percentage differs significantly across the DVD players from an insignificant 0% to as high as 68%. Only 2 DVD players are below 10%, 10 DVD players results in fraction less than or equal to 30% implying that the real power in standby mode in these DVD's players forms a significant amount of real power power losses.

#### Power Measurements for New DVD Players

Power measurements results in standby and full modes of 14 new DVD players are presented in figure 4.26. Variations in power consumption levels across different DVD players are evident. The extent of the power consumption variations can be seen in tables 4.23 and 4.24 in which maximum, minimum and average power values in standby and full mode are presented.

The variations in power consumption levels across different DVD players could be due to the presence of different models with different energy efficiency levels, or different manufacturers with different design philosophies. The power factor for

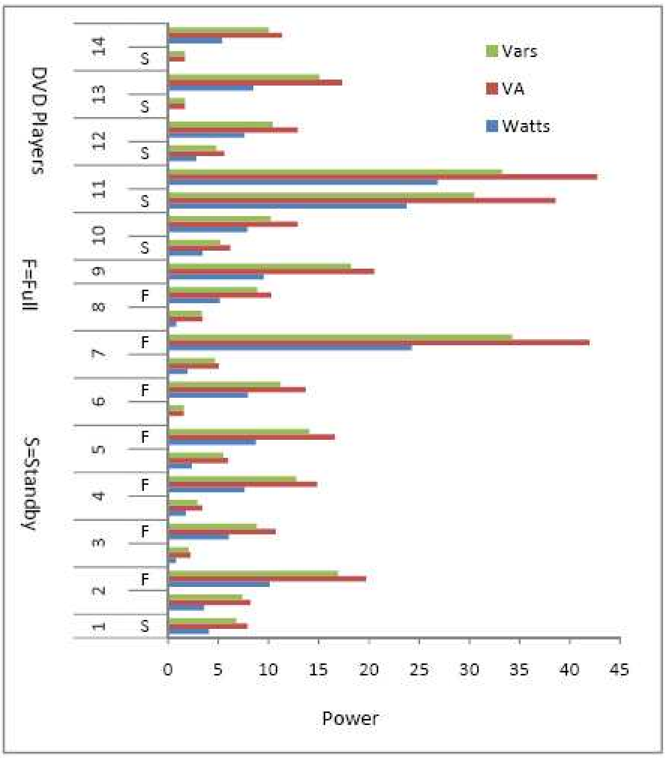


Figure 4.26: Power Results in Standby and Full Mode for New DVD Players

Table 4.23: Average Standby Power Consumption for New DVD Players

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 4.1 | 7.9 | 6.8 |
| Average | 1.8 | 4.3 | 4.0 |
| Minimum | 0.1 | 1.7 | 1.7 |

Table 4.24: Average Full Power Consumption for New DVD Players

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 24.2 | 41.9 | 34.3 |
| Average | 9.1 | 16.9 | 14.2 |
| Minimum | 5.1 | 10.3 | 8.9 |

new DVD's in standby mode vary between 0.05 to 0.55 and in full operational mode the range is 0.46 to 0.61. In new DVD players the ratio of real power in standby mode to real power in full mode is also a significant fraction as was in used DVD players. Figure 4.27 indicates the proportions of standby real power to full mode real power as a percentage. As was the case for used DVD players in households

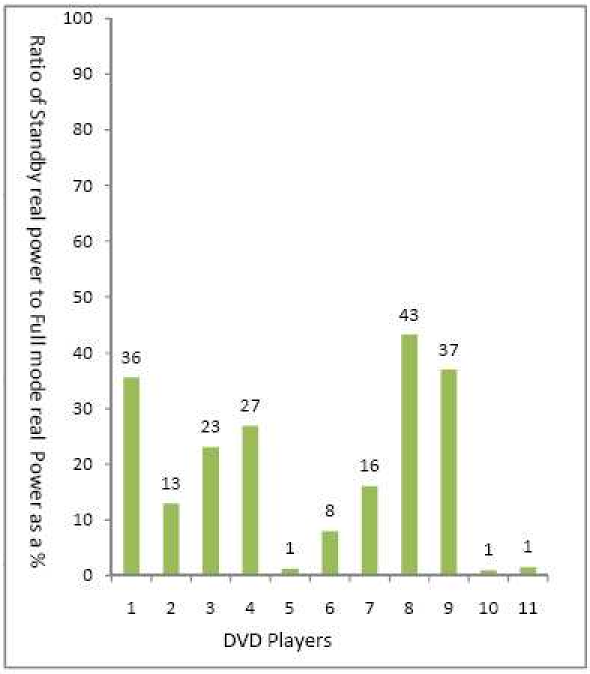


Figure 4.27: Standby Real Power as a % of Full mode Real Powerfor New DVD's

the standby mode real power is a considerable fraction of the full mode real power consumption. The desirable observation across all DVD's would be the cases in which the magnitude of standby real power is 1% or less of the real power consumed in full mode.

### 4.2.8 Power Measurements on VCR's

Measurements were performed on 14 VCR machines found in the households. It should be noted that although VCR technology is fading slowly these machines are still found in large numbers in the households as confirmed by saturation rates and the age of appliances in households.

**Power Measurements on Used VCR's**

Standby and full mode power consumption levels for the VCR's are presented in figure 4.28 and once again wide power variations in both modes of operation are observed.

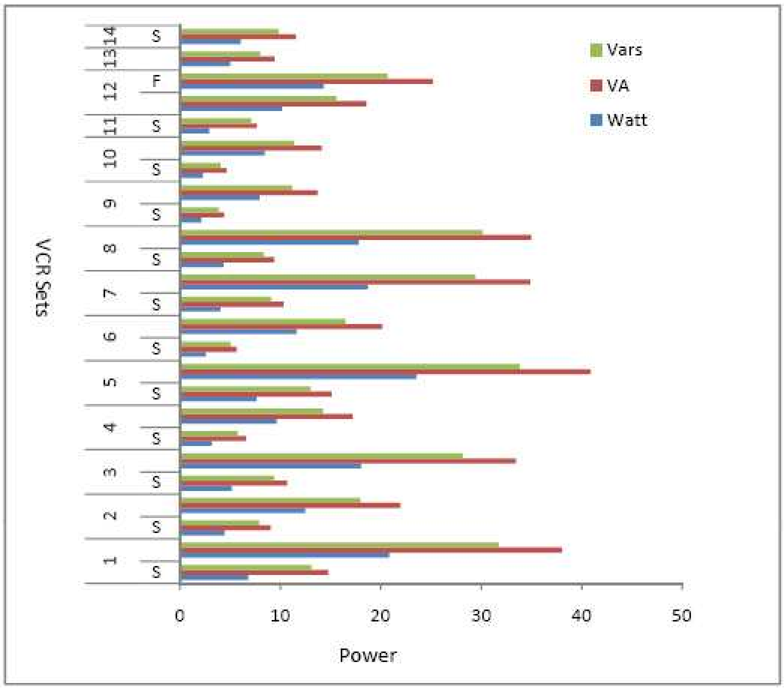


Figure 4.28: Standby and Full Mode Power Consumption for Used VCR's

The apparent power component in full mode is large compared to the real power component and the power factors measured range between 0.56 to 0.58. These poor power factors also observed in standby mode (0.41 to 0.53) and indicate the presence of small currents circulating in the low voltage network in both operational modes. The extent of the variations in the power consumption levels in the two operational modes is further substantiated by the data in table 4.25 and table 4.26.

Table 4.25: Average Standby Power Consumption for Used VCR's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 10.2 | 18.6 | 15.6 |
| Average | 4.8 | 9.8 | 8.6 |
| Minimum | 2.1 | 4.4 | 3.9 |

In 13 of the VCR's machines measured, the ratio of the real power in standby mode to real power in full mode is between 0.21 and 0.36 but in VCR machine 12 as seen in figure 4.28 the ratio is large at 0.71 indicating a very energy inefficient appliance.

Table 4.26: Average Full Power Consumption for Used VCR's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 23.5 | 40.9 | 33.8 |
| Average | 14.8 | 26.8 | 22.3 |
| Minimum | 7.9 | 13.7 | 11.2 |

**Power Measurements on New VCR's**

Measurements were performed on five new VCR machines and the results are presented in figure 4.29. In standby mode the maximum real power consumption is 5.2 W,

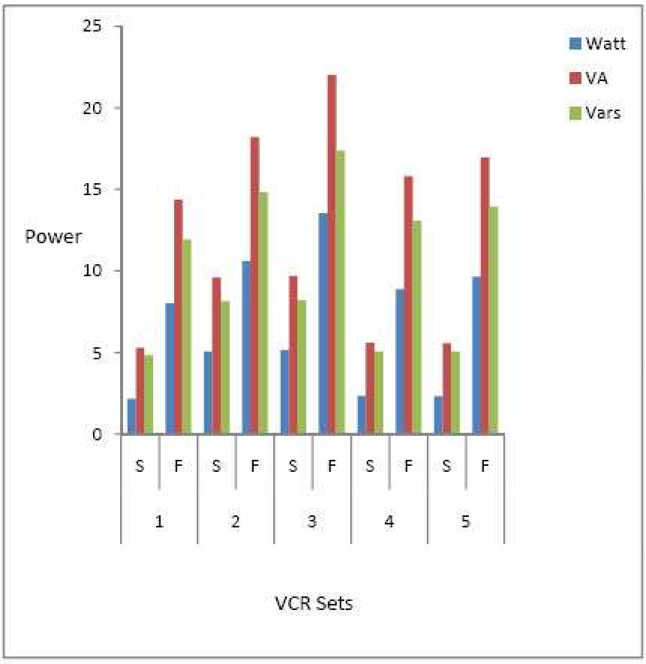


Figure 4.29: Standby and Full Mode Power Consumption for New VCR's

average is 3.4 W, and the minimum is 2.2 W. In full operational mode, the maximum real power consumption is 13.5 W, average is 10.1 W and minimum is 8.0 W. As was for VCR's in households the apparent power components in each machine are large and these are substantiated by the power factor values in standby and full mode which ranged between 0.41 and 0.53 and 0.56 and 0.61 respectively. The maximum, average, and minimum power consumption values in both modes are presented in tables 4.27 and 4.28.

It can be observed that the maximum values for new VCR machines are much lower than those of used VCR's in both operational modes, indicating the presence of less

Table 4.27: Average Standby Power Consumption for New VCR's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 5.2 | 9.7 | 8.2 |
| Average | 3.4 | 7.1 | 6.3 |
| Minimum | 2.2 | 5.1 | 4.8 |

Table 4.28: Average Full Power Consumption for New VCR's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 13.5 | 22.0 | 17.4 |
| Average | 10.1 | 17.5 | 14.2 |
| Minimum | 8.0 | 14.4 | 11.9 |

power consuming VCR's in retail shops. The minimum values for new and used VCR's in standby and full operational mode are of the same magnitude suggesting that appliances with lower power consumption levels are finding their way into households.

### 4.2.9 Digital Satellite TV (DSTV) Decoders

DSTV decoders are also generally known as subscription TV set top boxes. Measurements on a total of 17 DSTV decoders were performed in households and no measurements were carried out on new decoders. Measurement results indicating power consumption levels in both standby and full operational mode are presented in figure 4.30.

From figure 4.30 it is seen that there are no variations in power consumption levels in the two operational modes in any of the 17 decoders. The differences in power consumption levels observed across the decoders is due to different decoder complexities and functionalities. The decoders with the highest power consumption have more functionalities and are more complex when compared to the decoders with lower power consumption levels. As expected, increase in functionality and complexity results in increased power consumption levels.

Table 4.29 and table 4.30 present the maximum, average, and minimum power values for DSTV decoders in standby and full mode respectively.

In general all the DSTV decoders were found to consume the same amounts of

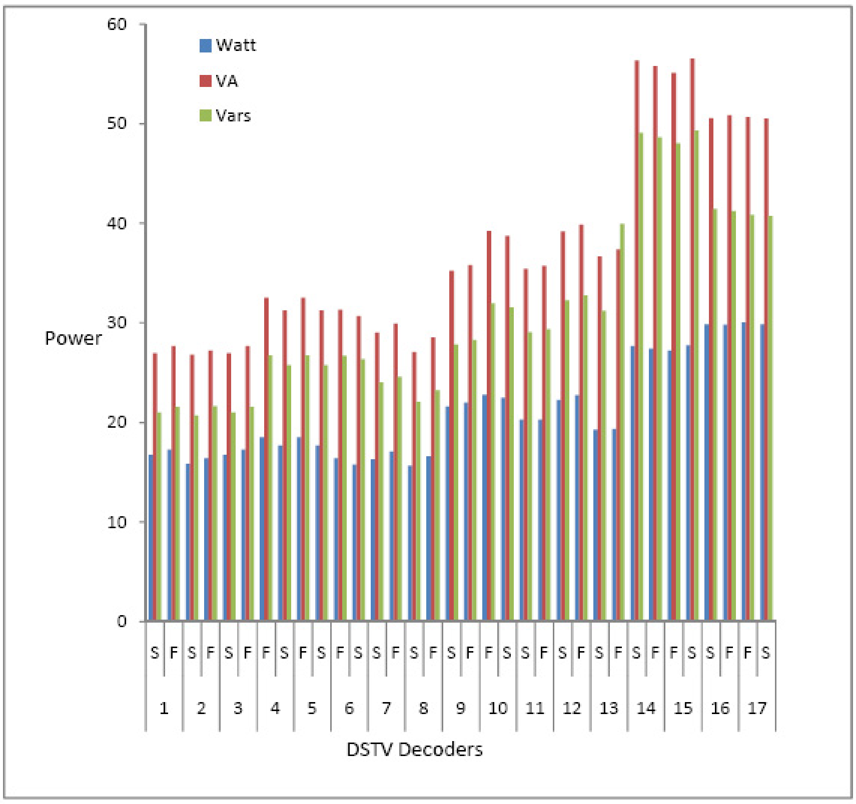


Figure 4.30: Standby and Full Mode Power Consumption for DSTV's

Table 4.29: Average Standby Power Consumption for DSTV Decoders

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 29.8 | 50.6 | 41.4 |
| Average | 20.8 | 36.9 | 30.5 |
| Minimum | 15.7 | 27.0 | 22.0 |

Table 4.30: Average Full Power Consumption for DSTV Decoders

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 30.0 | 50.7 | 40.8 |
| Average | 21.1 | 37.8 | 31.4 |
| Minimum | 16.4 | 31.3 | 26.7 |

power in both modes as is substantiated by maximum, average and minimum power levels in the two modes in table 4.29 and 4.30. In figure 4.30 it can be seen that the apparent power component is large indicating increased costs to the supplier with no cost differentiation between the two operational modes. The power factors associated with standby mode were measured to be between 0.49 and 0.62 and these figures are also true in the full mode. The poor power factors result in circulatory currents that hint on the presence of harmonic sources in the low voltage network.

### 4.2.10 Measurements on Mobile Phone Battery Chargers (MPBC)

Mobile phone battery charger measurements were conducted only in households. Measurements were performed on 33 chargers from different manufacturers. Figure 4.31 and figure 4.32 present the power consumption levels for MPBC's in standby and full operational modes.

Large variations can be observed in both operational modes suggesting a wide range of power consumption levels of appliances with the same functionality and capability. The variations in power consumption levels was observed within chargers of the same manufacturer as well as across different manufacturers. Though there are wide variations in standby power consumption levels it is important to note that all the value recorded are below 1 watt. Of interest are the relatively large reactive and apparent power components in some of the chargers. The maximum, average and minimum power consumption levels are presented in table 4.31.

Table 4.31: Average Standby Power Consumption for MPBC's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 0.9 | 2.4 | 2.2 |
| Average | 0.2 | 0.7 | 0.7 |
| Minimum | 0.1 | 0.3 | 0.3 |

The values in Table 4.31 are very low indicating very low power consumption in standby mode. Poor power factors were recorded in standby mode ranging between 0.08 and 0.47. The power factors measured in full operational mode ranged between 0.34 and 0.95 indicating different and wide spread power supply designs. Table 4.32 presents the power consumption levels in full operational mode.

The minimum values in standby and full mode indicate the presence of MPBC that are very energy efficient while the maximum values are an indication of the presence

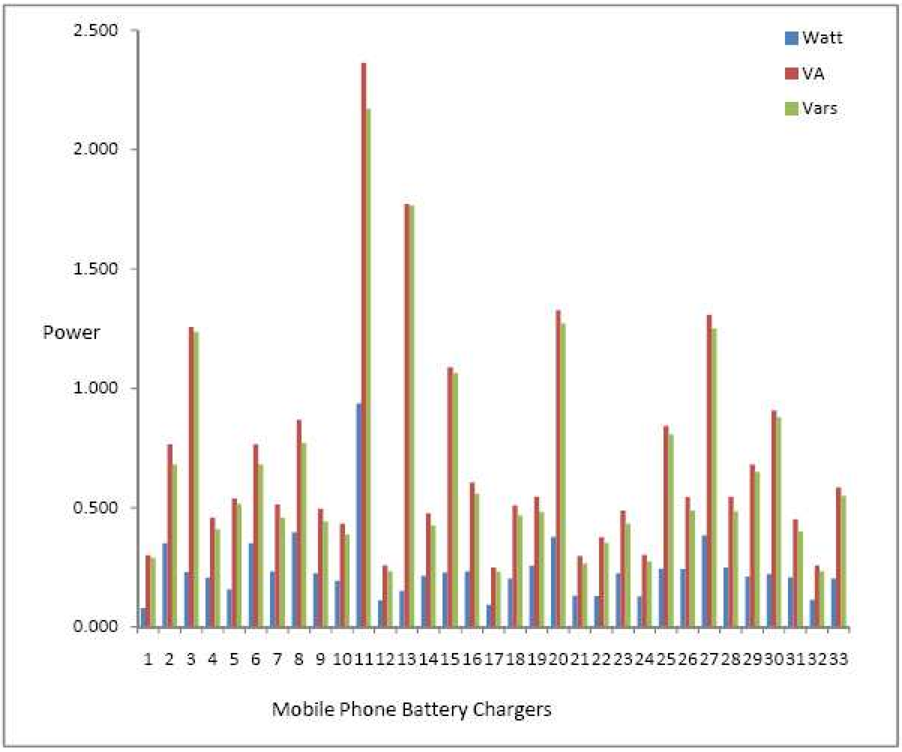


Figure 4.31: Standby Mode Power Consumption for MPBC's

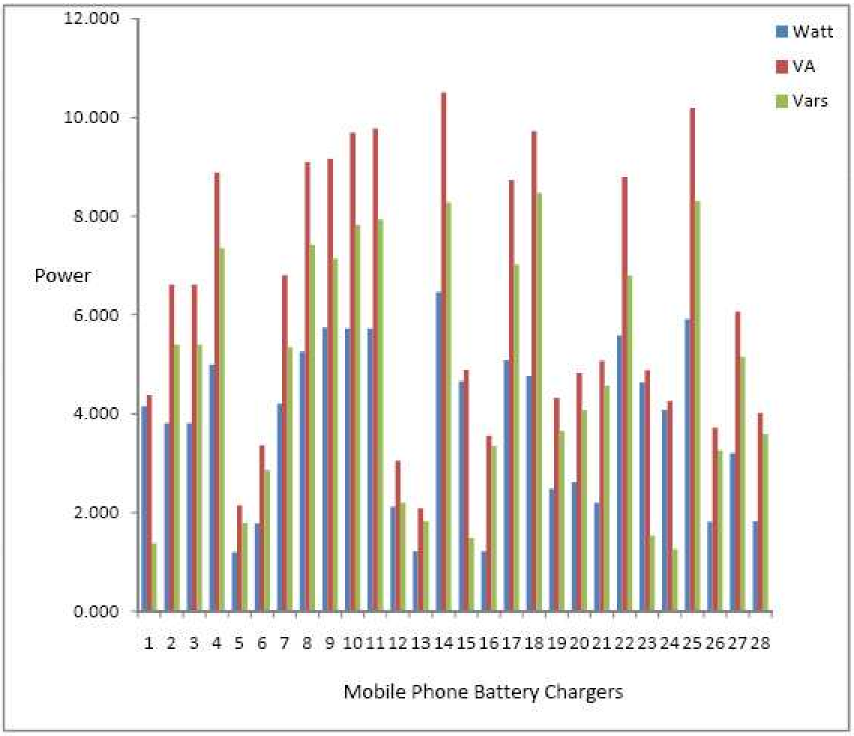


Figure 4.32: Full Mode Power Consumption for MPBC's

Table 4.32: Average Full Power Consumption for MPBC's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 6.5 | 10.5 | 8.3 |
| Average | 3.8 | 6.1 | 4.8 |
| Minimum | 1.2 | 2.1 | 1.8 |

of mobile phone battery chargers that are capable of consuming relatively high power while performing the same function.

### 4.2.11 Measurements on Personal Computers (PC)

All measurements on personal computers were performed in households. Three operational modes were found to be relevant in personal computers namely: Full, standby and soft-off. The soft-off mode is the mode in which a personal computer operates when its power switch is switched off.

#### PC Power Measurements in Soft-Off Mode

The soft-off mode was found to be true in all PC's. In soft-off mode the PC continues to consume power as shown in the measurement results in figure 4.33.

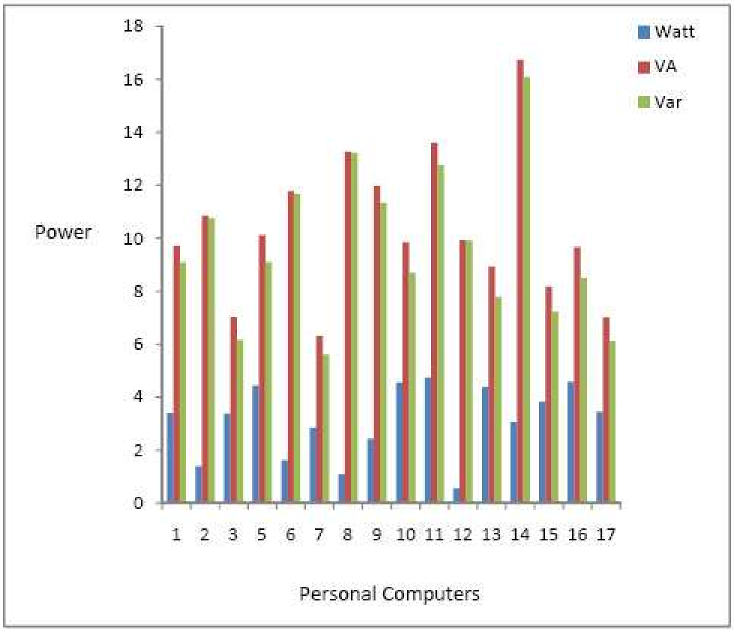


Figure 4.33: Soft-Off Mode Power Consumption for PC's

In soft-off mode the magnitudes of reactive and apparent power components are much larger than the real power components suggesting increase in circulating currents as well as in power demand. The real power in soft-off mode varies between a minimum of 0.6 W and a maximum of 4.7 W and the average is 3.1 W. The target is to have the minimum real power consumption of 0.56 W be true in all PC's in soft-off mode.

#### PC Power Consumption in Standby/Full Mode

Standby mode was initiated by clicking onto the standby option of shutting down the PC. Measurement results obtained for PC's in standby and full modes are presented in figure 4.34. In some PC's standby power levels are small compared to full mode power consumption and the ratios of standby real power to full mode real power calculated in these cases are 0.025, 0.041, and 0.122. These are examples of energy efficient designs. In the rest of the PC's, the ratio of the real power in standby mode to real power in full mode is $\geq 0.325$ and the highest ratio is 0.834 indicating that standby real power can be a substantial fraction of the full real power.

The power consumption both in standby and full mode vary substantially across the different PC's as seen in figure 4.34. In full operational mode the apparent power component is large suggesting higher demand from the supplier especially in establishments where high concentration of PC's are found such as in large offices and in call centre's. The power factors in standby mode range between 0.22 and 0.64 and in full mode 0.47 to 0.78. The poor factors in standby by and full mode suggest the presence of harmonic distortions in the low voltage network. The wide variations in power consumption levels in standby and full mode are further indicated in table 4.33 and table 4.34 which presents the maximum, average, and minimum power consumption levels.

### 4.2.12 Measurement Results for Personal Computer Monitors

The soft-off mode was found to be true in three of the 14 monitors and the corresponding real power consumption levels in these three cases were all below 1.5 W with the least being 0.05 W. The power consumption levels in standby and full mode are presented in figure 4.35. The observation here is the relatively small ratios of the standby mode real power and full mode real power which range between 0.02 and 0.12 much lower than in any other appliance. These results are a desired feature in appliance end-use efficiencies. The much lower ratios are an indication of an energy

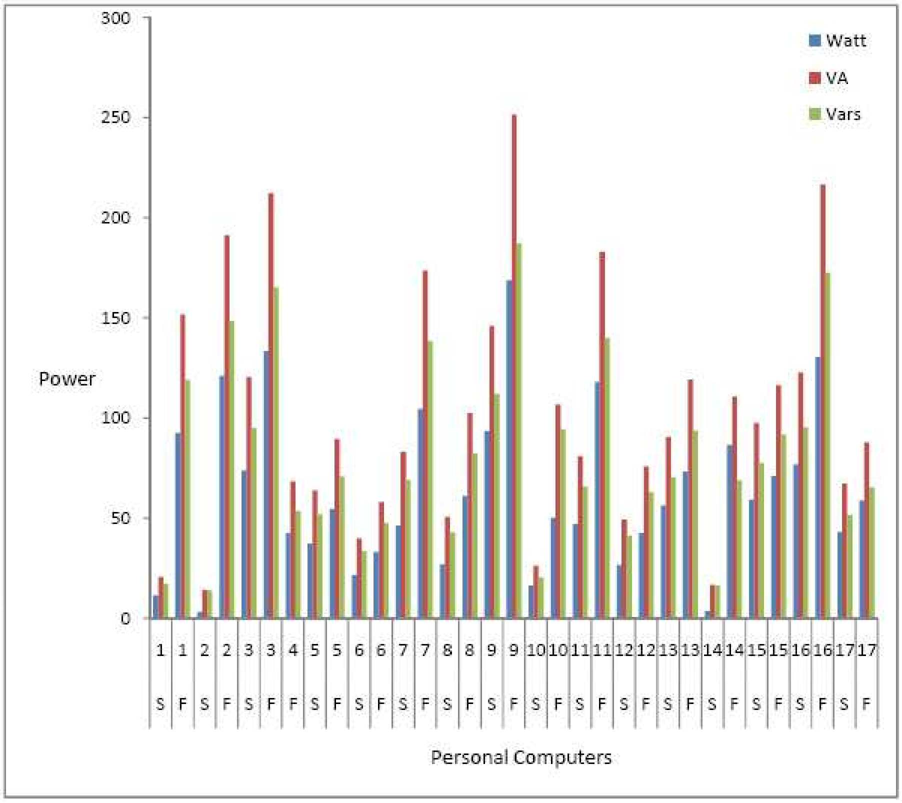


Figure 4.34: Standby and Full Mode Power Consumption for PC's

Table 4.33: Average Standby Power Consumption for PC's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 93.4 | 145.8 | 111.8 |
| Average | 40.2 | 67.8 | 54.7 |
| Minimum | 3.1 | 14.2 | 13.8 |

Table 4.34: Average Full Power Consumption for PC's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 168.6 | 251.5 | 187.0 |
| Average | 82.8 | 132.2 | 103.1 |
| Minimum | 33.2 | 58.0 | 47.6 |

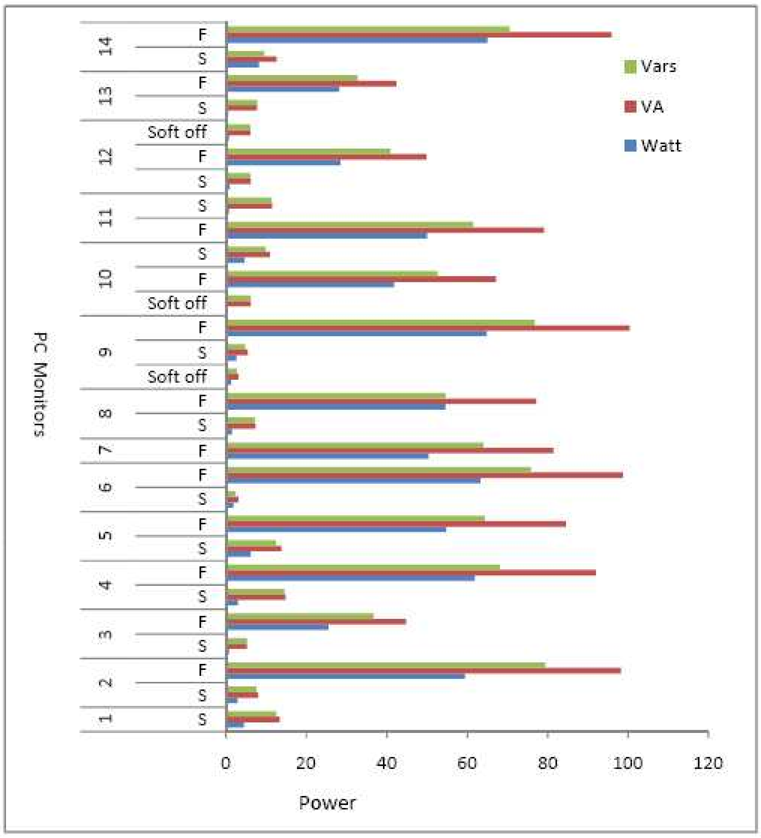


Figure 4.35: Standby and Full Mode Power Consumption for PC Monitors

efficient appliances and can be directly attributed to the Energy Save program. It can also be observed that there is less variations in power consumption levels in both standby and full modes across the different monitors. The power factors recorded ranged between 0.07 to 0.65 in standby mode and 0.57 to 0.69 in full mode operation.

The maximum, average and minimum values recorded in standby and full mode for PC monitors are presented in table 4.35 and table 4.36. Large differences between the maximum and minimum values measured indicates the presence of appliances with same functionalities but large differences in power consumption levels.

### 4.2.13 Measurements on Printers and Multifunction Devices

Measurements were performed on nine printers and seven multifunction devices all found in households. The small numbers of printers and MFD's found is a direct reflection of the low saturation and penetration rates within the sample. No measurements were done on new printers or MFD's. The full mode power consumption level on printers and MFD's was initiated by printing a document from a personal computer. The standby mode is the mode in which the printer or MFD enters when it is not printing. No power measurements were done for other functions possible on MFD's.

#### Measurements on Printers

Figure 4.36 present the standby and full mode power consumption levels for printers. Variations in power consumption levels in both modes as well as higher apparent power components in full mode are evident. The power factors measured in standby mode range between 0.41 and 0.56 while power factors in full operational mode were found to be between 0.57 and 0.86. The power consumption variations between maximum and minimum power levels in both modes are presented in table 4.37 and table 4.38.

#### Measurements on MFD's

The power consumption of the multifunction devices are presented in figure 4.37 and the maximum, average and minimum power consumption values are found in table 4.39 and table 4.40.

Table 4.35: Average Standby Power Consumption for PC Monitors

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 8.2 | 12.6 | 9.6 |
| Average | 3.0 | 9.1 | 8.6 |
| Minimum | 0.6 | 7.7 | 7.7 |

Table 4.36: Average Full Power Consumption for PC Monitors

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 65.0 | 95.9 | 70.5 |
| Average | 49.8 | 77.9 | 59.8 |
| Minimum | 25.5 | 44.7 | 36.8 |

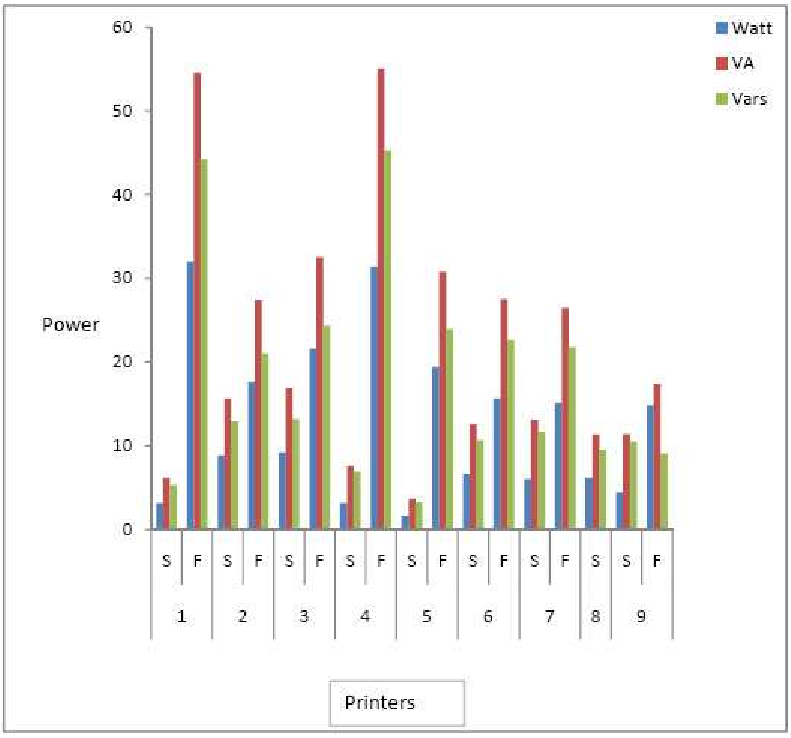


Figure 4.36: Standby and Full Mode Power Consumption for Printers

Table 4.37: Average Standby Power Consumption for Printers

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 9.2 | 16.9 | 13.2 |
| Average | 5.5 | 10.8 | 9.3 |
| Minimum | 1.6 | 3.6 | 3.2 |

Table 4.38: Average Full Power Consumption for Printers

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 32.0 | 54.6 | 44.2 |
| Average | 20.9 | 33.8 | 26.5 |
| Minimum | 14.9 | 27.5 | 22.6 |

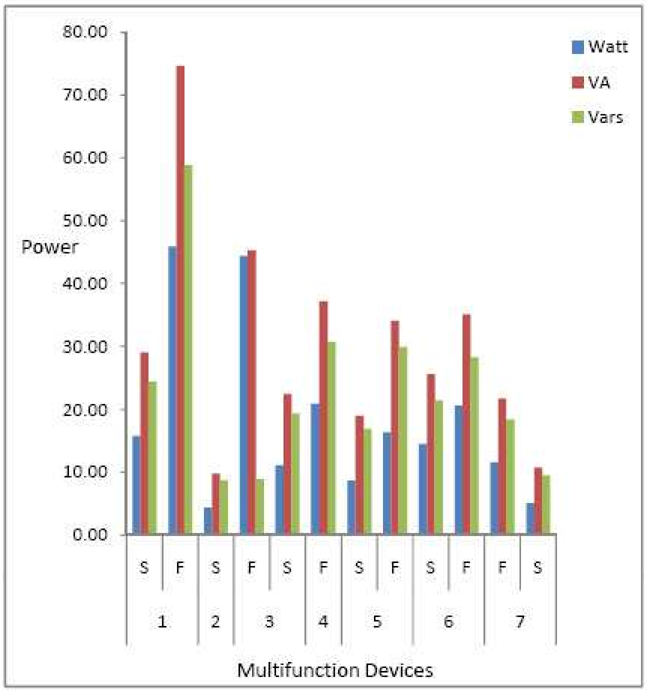


Figure 4.37: Standby and Full Mode Power Consumption for MFD's

Table 4.39: Average Standby Power Consumption for MFD's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 15.8 | 29.1 | 24.4 |
| Average | 9.9 | 19.5 | 16.7 |
| Minimum | 4.4 | 9.8 | 8.7 |

Table 4.40: Average Full Power Consumption for MFD's

| | Watts | VA | Vars |
|---|---|---|---|
| Maximum | 45.9 | 74.6 | 58.8 |
| Average | 26.6 | 39.5 | 29.2 |
| Minimum | 11.6 | 21.7 | 18.4 |

The Maximum, average, and minimum power consumption levels in both modes of operation are higher than the values for printers and this could be due to the added functionalities such as photocopying, scanning and faxing. In MFD's, variations in power consumption levels in both modes across different devices are also evident. The apparent and reactive power components are also well pronounced and the corresponding power factors range between 0.45 and 0.57 in standby mode and in full mode 0.48 to 0.98.

## 4.3 Conclusions

Measurement results indicate wide variations of power consumption levels across appliances of same functionality and same capability. The large variations are evidenced in the range between the maximum and minimum power consumption levels in a specific operational mode for each appliance. The large variations are indicative of the absence of appliance energy efficiency standards. Poor power factors in standby and full operational mode were observed in all appliances except LCD TV's and Plasma TV in full mode. Poor power factors results in higher components of apparent power and reactive power that causes the presence of circulating currents in the low voltage network. The higher apparent power components results in increased costs to the supplier of power.

LCD and Plasma TV's were found to have very poor power factors in standby mode with an almost zero real power consumption but relatively large apparent and reactive power components. These results suggests that the cost to the consumer in maintaining the TV's in standby decrease but the cost to the supplier of power increases when compared to CRT TV's. Furthermore, the presence of harmonics and circulating currents in the low voltage network becomes a concern to the distribution network operator.

The real power component in standby mode is a substantial fraction of the real power component in full operational mode suggesting poor appliance end-use efficiencies especially in DVD's and PC's. Computer monitors were found to have the lowest ratios of real standby power to real full mode power suggesting energy efficient monitor's which are a direct result of the Energy Star program. In DSTV decoders the power consumption levels in standby and full operational modes are equal suggesting high power losses in standby mode.

Soft-off mode was found to be true in PC's, CRT TV's, and some Hi-Fi. The soft-off mode power consumption levels were generally very low but with poor power factors. In Hi-Fi the Demo-On mode consumes substantial amount of power and this raises the question of the value of such a capability in these appliances.

The average full and standby mode power consumption values for the different appliances found in households are presented in table 4.41 and table 4.42. The average power consumption values in tables 4.41 and 4.42 are what will be considered to be $p_{active}$ and $p_{st}$ respectively in the mathematical equations in Section 5.1.

The total number of appliances measured in households and in retail stores are summarized in table 4.43 indicating that in households high number of measurements were possible for appliances with high saturation and penetration levels.

Table 4.41: Appliance Average Full Mode Power Consumption

| | Watts | VA | Vars |
|---|---|---|---|
| Microwave Ovens | 1260.0 | 1390.0 | 580.0 |
| Plasma TV's | 309.9 | 317.3 | 67.7 |
| LCD TV's | 147.2 | 151.4 | 35.0 |
| PC's | 82.8 | 132.2 | 103.1 |
| CRT TV's | 76.0 | 124.3 | 98.3 |
| PC Monitors | 49.8 | 77.9 | 59.8 |
| MFD's | 26.6 | 39.5 | 29.2 |
| Mini Hi-Fi's | 22.2 | 28.8 | 18.3 |
| DSTV decoder's | 21.1 | 37.8 | 31.4 |
| Printers | 20.9 | 33.8 | 26.5 |
| VCR's | 14.9 | 26.8 | 22.3 |
| DVD Player's | 11.1 | 20.2 | 16.8 |
| MPBC | 3.8 | 6.1 | 4.8 |

Table 4.42: Appliance Average Standby Mode Power Consumption

| | Watts | VA | Vars |
|---|---|---|---|
| PC's | 40.2 | 67.8 | 54.7 |
| DSTV Decoder's | 20.8 | 36.9 | 30.5 |
| Mini Hi-Fi's | 11.3 | 18.1 | 14.2 |
| MFD's | 9.9 | 19.5 | 16.7 |
| CRT TV's | 8.2 | 15.2 | 12.8 |
| Plasma TV's | 7.9 | 24.4 | 23.1 |
| Printers | 5.5 | 10.8 | 9.3 |
| LCD TV's | 5.0 | 21.8 | 21.8 |
| VCR's | 4.8 | 9.8 | 8.6 |
| DVD Player's | 3.8 | 7.7 | 6.8 |
| PC Monitors | 3.0 | 9.1 | 8.6 |
| Microwave Ovens | 2.6 | 3.7 | 2.7 |
| MPBC | 0.2 | 0.7 | 0.7 |

Table 4.43: Number of Measured Appliances

| | Households | Retail Stores |
|---|---|---|
| CRT TV's | 40 | 28 |
| LCD TV's | 5 | 30 |
| Plasma TV's | 4 | 14 |
| Mini Hi-Fi's | 10 | 20 |
| DVD Player's | 20 | 14 |
| VCR's | 14 | 5 |
| MPBC | 33 | - |
| Microwave Ovens | 20 | - |
| DSTV Decoder's | 17 | - |
| PC's | 17 | - |
| PC Monitor's | 14 | - |
| Printer's | 9 | - |
| MFD | 7 | - |

# Chapter 5

# Load Estimation

At any point in time, an electrical appliance can be in any of its possible operational modes and each of the operational modes defines a different electrical end-usage. Standby mode energy consumption is therefore one of the possible energy end-uses and can be seen as a special case of the total household electrical energy end-use consumption. Energy consumption of a specific household is said to be directly related to the following [42, 43, 67]:

- Stock of appliances present in the households
- Grass root level consumption data of each appliance
- User behaviour pattern
- Appliance use times or daily usage pattern
- Appliance specific features

Three main approaches have been discussed and implemented in studies on household electricity end-use consumption [39, 42, 67, 68, 69, 70, 71]. These approaches are:

- engineering
- econometeric
- combined engineering and econometeric

The engineering and econometric models are also known as the Bottom-Up and Conditional Demand Analysis (CDA) models respectively [43, 67, 68, 69]. The CDA model estimates the appliance energy consumption without the need to use theoretical engineering data or end-use metered data making the model a much cheaper approach to obtaining end-use estimates [68]. The CDA model takes into consideration that the end-use consumption depends upon a variety of other factors which can not be directly quantified but can instead be represented as conditional demand functions a factor not considered in bottom-up estimates. A major drawback of the CDA model is the multi-collinearity problem which is pertinent for appliances with high saturation rates and results in less accurate estimate [39, 40].

The engineering model is backed up by direct metering data and unfortunately there are large costs involved in obtaining vast amounts of detail grass root level consumption data for each appliance [42, 43]. The data collection through actual metering is the main disadvantage of this approach. However it has been argued that the need for detail data can be bypassed by using a representative data sample and statistical averages obtained by metering of all end-uses in a few test houses [43]. The resulting loss of accuracy is outweighed by the reduction in the costs of obtaining vast amounts of detailed data. Another drawback of the engineering model is omission of other factors that affect end-use consumption and causes the random nature of the consumption generated by stochastic processes and probability distribution functions in the econometric model. If the assumption that the appliances and the environmental conditions are similar across different households, then variability in customer behaviour is the main cause of variability of the load [72]. The combined model approach brings together the econometric and engineering model by using some metering data as prior knowledge in the econometric model.

Household consumption of standby power is a component of total electrical consumption of each appliance also known as unit energy consumption (UEC) as indicated in the equation 5.1 [73].

$$UEC = AEC + SEC \tag{5.1}$$

Where: UEC is the Unit Energy Consumption (kWh/year), AEC is the Active Energy Consumption (kWh/year) and SEC is the Standby Unit Energy consumption (kWh/year). Of interest to this research is the estimation of the second term *SEC*. To determine the standby component using the econometric model is much more computational intensive because of the need for more regressors. Additional regressors are required to be able to disintegrate each appliance standby energy component from the total appliance energy consumption because the model output are estimates of *UEC* for the different household appliances and end-uses.

The common approach used to estimate household standby power consumption is the bottom-up approach in which either average standby power consumption per home or national standby power consumption are estimated by calculating average home standby power use from a combination of field measurements and known appliance saturation rates [22, 24, 74]. In the bottom-up approach, the goal is to establish the standby *UEC* for a household using measured data of *standby consumption* of different appliances, appliance use times, and appliance saturation rates. Other approaches used in the assessment of standby power are whole-house measurements and new product measurements [22, 24, 74].

## 5.1 Mathematical Equation for Estimation of Standby Power

The parameters of interest in the estimation are:

- Average appliance standby power consumption $P_{sb}$
- Average time spent in standby mode $t_{sb}$
- Appliance saturation $s$ and penetration $p$ rates
- Appliance Efficient Use Index $AEUI$

The mathematical equation that has been used to define standby unit energy consumption ($SUEC$) of an appliance in a day is 5.2 [75]:

$$SUEC = P_{sb} * t_{sb} \tag{5.2}$$

Where $P_{sb}$ is the average real power consumed in standby mode in Watts obtained for each appliance of interest from the measurements and $t_{sb}$ is the time spent in standby mode for each appliance in a day estimated from the survey.

### 5.1.1 Estimation of a Single Household

The total standby unit energy consumption of appliance $j$ in a household is given by equation 5.3

$$TSUEC_j = SUEC_j * p_j \tag{5.3}$$

Where $p_j$ is the penetration rate of appliance j.

The total household standby energy consumption ($THSEC$)is given by equation 5.4

$$THSEC = \sum_{j=1}^{n} TSUEC_j \tag{5.4}$$

### 5.1.2 Estimation for All Households in a Sample

The premise *ownership implies standby energy consumption* omits the consideration of user operational behaviour in total standby power and energy losses estimations. User behaviour accounts for the randomness in standby power and energy losses by differentiating between users with different levels of energy efficient behaviour in operating appliances. User efficient behaviour determines the final appliance operational state when an appliance is not being utilised. Therefore, the total number of appliances contributing to standby power and energy losses is a direct result of the user operational behaviour. The measure of efficient appliance use $AEUI$ was established for different clusters in section 3.7.3.

Suppose the total number of households in a sample is $K$. Then the total number of households that own an appliance $j$ ($TNHA_j$) is given by equation 5.5

$$TNHA_j = K * s_j \tag{5.5}$$

Where $s_j$ is the saturation rate of appliance $j$.

We coin and define the term appliance concentration $AC_j$ to be the ratio of $p_j$ to $s_j$ i.e. $AC_j = p_j/s_j$. Large values of $AC$ imply large numbers of appliances in a sample and low values indicate lower appliance numbers. The total number of appliance $j$ ($TNA_j$) found in the household population $K$ is given by equation 5.6

$$TNA_j = TNHA_j * AC_j \tag{5.6}$$

The total number of appliance $j$ in standby mode is given in equation 5.7

$$TNASM_j = TNA_j * AEUI_j \tag{5.7}$$

In equation 5.7 it is clear that if $AEUI$ is zero then none of the appliances contribute to the losses and if $AEUI$ is 1 all the appliances present in a sample contribute to standby power and energy losses. User appliance operational behavior defines the total number of appliances in standby ($TNASM$) as opposed to total number of appliances ($TNA$). The end result is $TNASM < TNA$ indicating that ownership of a particular appliance does not by itself imply standby energy consumption. Energy consumption in standby mode in a particular appliance is true only if the user appliance operational behavior results in an appliance in standby mode when not in use.

The total standby energy losses $TSEL$ due to all households in a sample is then given in equation 5.8

$$TSEL = \sum_{j=1}^{n} SUEC_j * TNASM_j \tag{5.8}$$

The implication of using the $AEUI$ is a decline in the total number of appliances that contribute to standby power and energy losses in a given sample as seen in 5.7. Appliance operational behaviour that lends itself to energy efficient behaviour, results in appliances that are not left in standby mode, and therefore do not contribute to standby energy consumption. This observation was first made in the Chinese household standby study where mostly TV's were found switched off when not in use [23]. This is also found to be true in the South African study where households with pre-paid electricity meters tend to switch off appliances at the wall switch because household members could not explain some electricity waste. Where $AEUI$ is low, the total number of appliances actively contributing to standby power is low. The values of $AEUI$ are characteristically very random within a day or even a week mainly because of multiple operator factor and the repeated operation factor discussed earlier on in section 3.7.3 and this brings in the randomness in power and energy losses. The challenge lies in an accurate determination of $AEUI$ for each appliance.

## 5.2 Estimation of Standby Energy and Power Consumption

The total standby energy and power consumption per year for each appliance with standby power loss capability is estimated for:

- Total sample
- Each of the five clusters

At the sample level, the sample appliance saturation and penetrations levels obtained in Section 3.5.1, average real power consumption in standby mode $p_{sb}$ detailed in Table 4.42 and the average appliance use time in standby mode $t_{sb}$ developed in Section 3.9 and detailed in Table 3.26 are used to evaluate the sample total standby energy consumption for each appliance using Equations in 5.1.

### 5.2.1 Estimation based on Sample Parameters

The values used for the estimation of household standby power and energy consumption are presented in detail in Appendix 8.. The estimated standby power and energy for a household using the sample statistics are presented in Table B.1 found in Appendix 8.

The household total real standby power consumption *TSPC* is estimated to be 73.5 W and the total standby power energy consumption *THSEC* per household in a year amounts to 561.8 kWh. In these estimates it is assumed that all TV's are CRT TV and this could be justified by the small number of LCD and plasma TV screens found in households during measurements. The power losses of 73.5 W based on sample statistics indicate that standby power consumption in South African households is comparable to figures obtained for countries around the world presented in Table 5.1. The figures in Table 5.1 are the household standby power (W) and standby energy (kWh/yr) consumptions [14].

Table 5.1: Estimation Results for Other Countries

| Country | Watt/household | kWh/year per household |
|---|---|---|
| United Kingdom | 32 | 277 |
| USA | 50 | 440 |
| Australia | 86.8 | 760 |
| France | 38 | 235 |
| Germany | 44 | 389 |
| Japan | 46 | 398 |
| The Netherlands | 37 | 330 |
| New Zealand | 100 | 880 |
| Switzerland | 19 | 170 |

The household standby consumption figure of 73.5 W for South Africa, is below that of Australia and New Zealand but is higher than the figures for UK, USA, France, Germany, Japan, The Netherlands, and Switzerland. The figure obtained for the household standby energy consumption in a year is 561.38 kWh/year and as in Table 5.1 this figure is higher than the figures of all the other countries except for Australia and New Zealand.

### 5.2.2 Estimations Based on Cluster Parameters

Five appliance saturation and penetration clusters were identified in the household sample of 555 homes. Relevant cluster penetration and time spent in standby mode for different appliances in the different clusters are detailed in Section 3.5.3 and Section 3.9 respectively. The same average standby real power consumption for the different appliances presented in Table 4.42 are used in the calculation of the household real power and energy consumption. Tables C.1, D.1, E.1, F.1 and G.1 in the relevent Appendix provide the values used in detail. The power and energy consumption results for different clusters are presented in Figure 5.1 and Figure 5.2 respectively.

There are variations observed across the clusters in the total estimate for standby power and energy consumption caused mainly by differences in appliance penetration rates and appliance use times across different clusters. Appliance use times are driven by appliance operational behaviour and define time spent in standby mode by different appliances. Cluster 1 standby power consumption is 28.2 W and this increases across the clusters to 111.7 W in cluster 5. The standby energy losses are 181.6 kWh/yr for a single household in cluster 1 and 862.2 kWh/year for a household in cluster 5. The standby power consumption in cluster 5 is 10% more of the power consumed by a 100 W incadencent bulb!

Household in cluster 5 exhibit the largest standby energy losses and power consumption while households in cluster 1 have the least energy losses as well as power consumption. The differences between cluster 2 and 3 are not as large as between the other subsequent clusters, as was depicted in Figure 3.12. Figures 5.1 and 5.2 indicate clearly that standby energy losses and power consumption are clustered within a household population.

### 5.2.3 Significant Appliances

The clustered standby energy and power consumption can be used to inform the introduction of energy efficient interventions. Interventions to reduce standby energy losses and decrease power consumption should be directed first toward clusters and

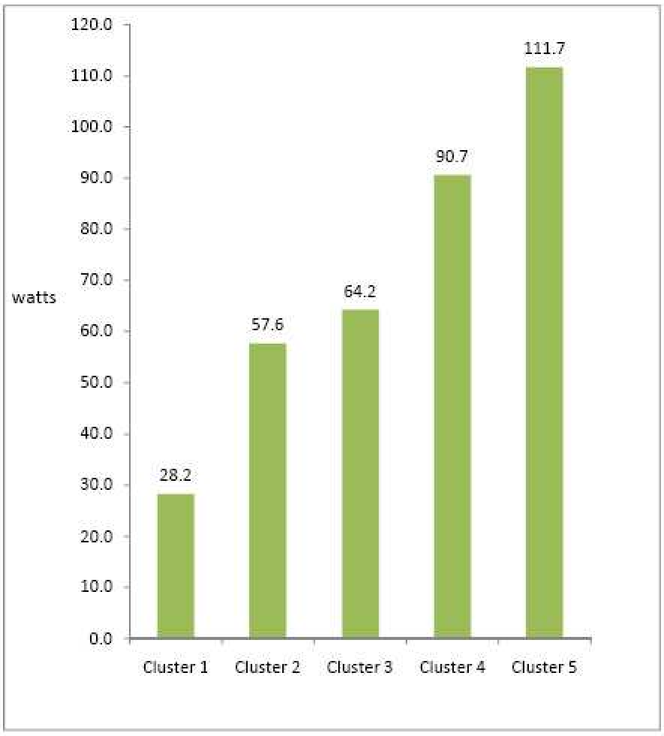


Figure 5.1: Estimated Total Standby Power Losses per Household in Clusters

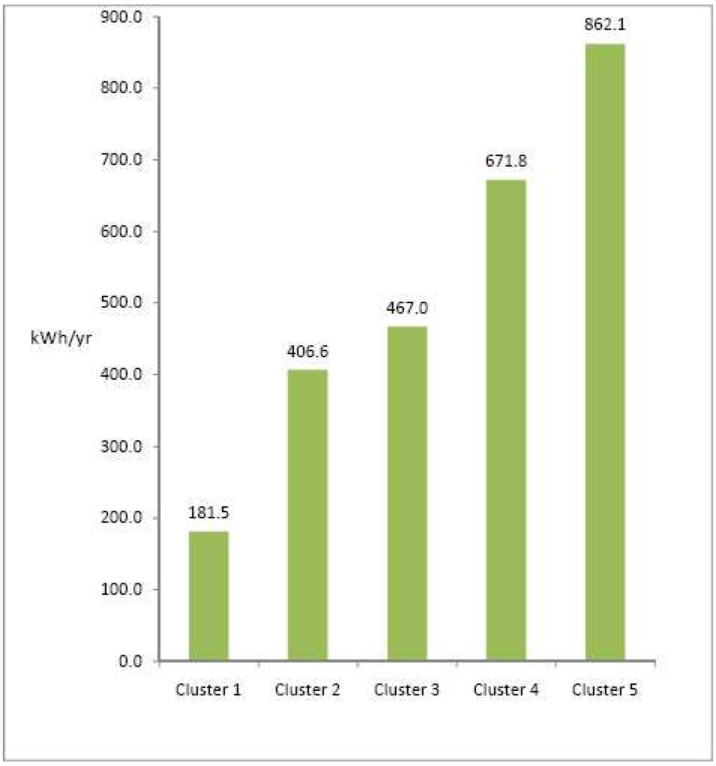


Figure 5.2: Estimated Total Standby Energy Losses per Household in Clusters

appliances in which the largest reduction in energy losses and power consumption can be realised. The total estimated standby energy losses and power consumption across different clusters is determined by the cluster appliance standby power consumption, penetration rates and appliance use times. Figure 5.3 presents the kilowatthour per year consumption of each appliance in the different clusters.

From figure 5.3 the variations in each cluster's contribution to the total energy and power losses are presented. Tables 5.2 and 5.3 illustrate further the *copious* appliances and *universal* appliances percentage contribution to standby power and energy losses for each cluster respectively.

Table 5.2: Total Power and Energy Losses: *Copious* Appliances

| Cluster | Total Power (W) | Total Energy (kWh/year) |
|---|---|---|
| Cluster 1 | 75% | 70% |
| Cluster 2 | 50% | 49% |
| Cluster 3 | 45% | 44% |
| Cluster 4 | 96% | 95% |
| Cluster 5 | 100% | 100% |

Table 5.3: Total Power and Energy Losses: *Universal* Appliances

| Cluster | Total Power (W) | Total Energy (kWh/year) |
|---|---|---|
| Cluster 1 | 75% | 70% |
| Cluster 2 | 50% | 47% |
| Cluster 3 | 45% | 42% |
| Cluster 4 | 39% | 38% |
| Cluster 5 | 29% | 29% |

These two appliance groups *universal* and *copious* appliances were discussed in Section 3.4. In cluster 1, *universal* appliances are also *copious* appliances and therefore there are no differences in the % contribution from the two appliance groups to total power and energy losses. In the other clusters the number of *copious* appliances increases as you move from cluster 1 to cluster 5 as seen in Tables 3.8, 3.9, 3.10, 3.11 and 3.12 and the percentage contribution of clusters 4 and 5 increase significantly.

What emerges out of these scenarios is the fact that *copious* appliances in cluster 5 encompass *copious* appliances in all the other clusters. We coin and define the term *significant* appliances to standby power and energy losses to be the set of *copious* appliances in the cluster with the highest standby power and energy losses in this case cluster 5. The *copious* appliances in each cluster forms concentric circles in

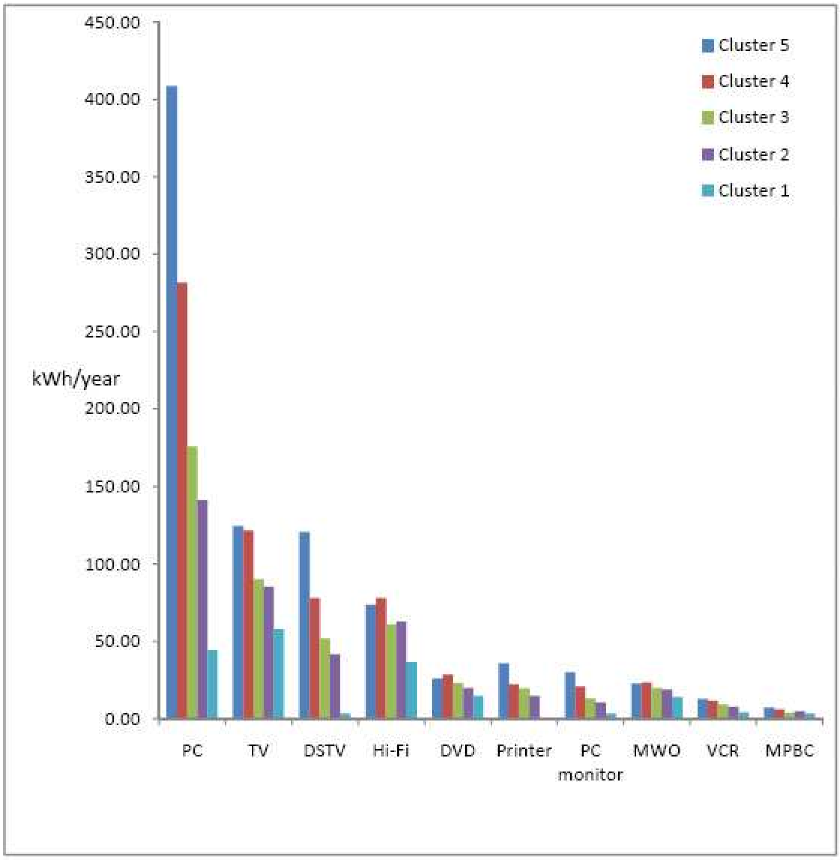


Figure 5.3: Appliance Standby Energy Losses per Household in Clusters

which *universal* appliances is the smallest and innermost circle representing cluster 1 *copious* appliances and the *significant* appliances is the largest or outermost circle representing *copious* appliances in cluster 5. In essence the other appliances in the rest of the clusters are subsets of the set of *significant* appliances as illustrated in Figure 5.4.

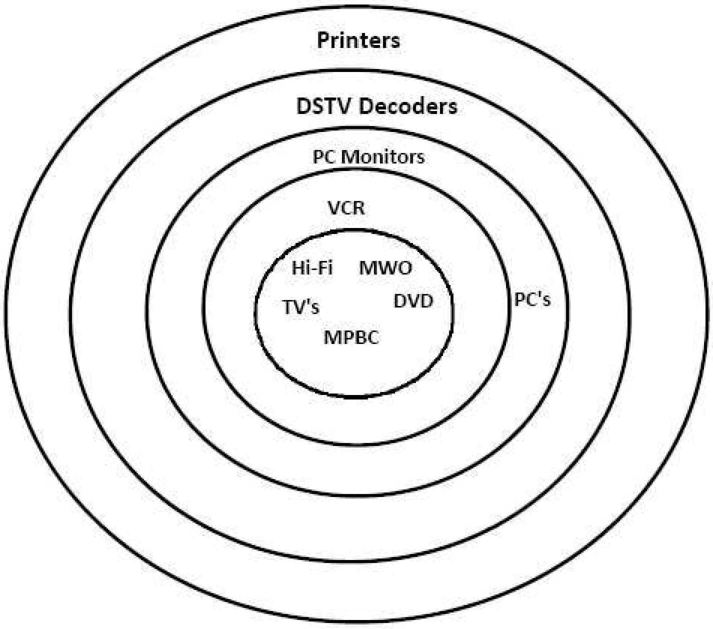


Figure 5.4: Significant Appliances

The *significant* appliances identified in this study are:

- Television sets
- DSTV decoders
- PC's
- DVD players
- Hi-Fi sets
- Microwave Ovens
- VCR's
- PC monitors
- Mobile phone battery chargers

It is therefore possible to identify *significant* appliances to standby power and energy losses in every household sample. It is also prudent to recommend that the focus of energy efficient interventions should be geared toward *significant* appliances because these appliances have been shown to be responsible for the highest standby power and energy losses. This in turn results in the highest possible impact in energy savings across the household population.

## 5.3 Conclusions on Estimation of Standby Energy and Power

A modified engineering/mathematical model was developed for the estimation of household standby energy and power losses in a single household and for households in a sample. In the modified mathematical equation to estimate sample standby power and energy losses, the effect of user behaviour is included by introducing appliance efficiency use indexes for each appliance. The $AEUI$ account for the randomness due to different user appliance operational behaviour. The total number of appliances that actively contribute to standby power and energy losses in a household population is determined by $AEUI$.

The estimated magnitude of standby power losses per household based on estimation parameters obtained for the sample is 73.5 W and the estimated standby energy losses per household in a year is 561.4 kWh. Estimates based on parameters obtained for the clusters indicate large variations in the contribution to the total standby power and energy losses by different clusters. The largest losses are found in cluster 5 and the least losses are found in cluster 1. These differences are driven mainly by differences in penetration rates as well as appliance use times across the clusters.

The total standby power losses per household in the different clusters are provided in table 5.4. The magnitudes of standby power in the clusters are directly related

Table 5.4: Cluster Household Standby Power and Energy Losses

| Cluster | Total Power (W) | Total Energy (kWh/year) |
|---|---|---|
| Cluster 1 | 28.2 | 181.6 |
| Cluster 2 | 57.6 | 406.7 |
| Cluster 3 | 64.2 | 467.0 |
| Cluster 4 | 90.7 | 671.8 |
| Cluster 5 | 111.7 | 862.2 |

to the number of appliances in the different clusters with standby power capability. As predicted before the magnitudes correctly reflect the clustering of appliance saturation and penetration rates, and appliance use times in the clusters. The standby energy losses per household are also clustered indicating differentiated contribution to standby energy losses by the different clusters.

It is suggested that focus of energy efficient interventions should be on *significant appliances* in cluster 5 because this set of appliances covers all other appliances in the rest of the clusters and will also have the largest possible impact on standby energy and power losses. The *significant appliances* are: Television sets, Personal computers and monitors, Hi-Fi sets, VCR's, microwave ovens, DVD's, DSTV decoders, mobile phone battery chargers and Printers/MFD's.

# Chapter 6

# Conclusion

In this thesis the household survey carried out in eleven suburbs of Greater Johannesburg has been explained and the results have been presented. The results on measurements done on appliances in thirty households within the survey sample and new appliances in three major retail stores have been presented as well. Estimation of standby power energy losses in the household sample has been done using bottom-up estimation model. A modified model has been suggested in which the user appliance operational behaviour is accounted for.

## 6.1 Survey

From the survey the following has been fully established for the household sample:

- Sample demographics
- Sample and suburb saturation and penetration rates
- Sample and suburb average appliance use times
- Consumer appliance operational behaviour

The sample demographics indicate that the survey was conducted mostly in conventional houses and this is expected because of the sampling criteria. Most of the households in the sample were made of medium to large size families and this hinted on higher appliance usage times.

Sample appliance saturation and penetration rates for the households in the sample are comparable with figures from other documented studies done in Europe, Japan, China, Canada and Australia. Appliance saturation and penetration rates are clustered within the sample of 555 households. Five distinct clusters have been shown to be present in the sample. Cluster 5 is the group of households with the highest concentration of appliances with standby power capabilities, while cluster 1 is the group of households with the lowest concentration of appliances with standby power capabilities. The concentration of appliances in the other clusters is bounded by cluster 5 at the top and cluster 1 at the bottom.

From the household clusters *universal* and *significant* appliances to standby power and energy losses have been identified. The *universal* appliances are found in large numbers in all clusters i.e. saturation rates of 50% or above. *Significant* appliances are the appliances with highest power and energy losses within a cluster.

The target appliances for any policies and/or standards implementation geared toward energy efficient appliances has been shown to be significant appliances in cluster 5 as they cover appliances in all the other lower clusters.

The clustering phenomenon is an essential characteristic of standby power and energy losses in households and it has not been accounted for before in any other study. Without considering the clustering effect, the total power and energy losses are underestimated for households in the upper clusters and are overestimated for households in the lower clusters. If clustering is not considered the end result is an estimate that cannot be substantiated in case of the lower clusters and an estimate that is easily ignored or brushed aside by household members in the upper clusters. The estimate should reflect the reality closely and this is only possible if a clustering approach is used.

It has also been established that the variations in appliance operational behaviour and average use time are also clustered. The high clusters have low average appliance use times which implies that appliances in households in these clusters spend longer times in standby mode. In the lower clusters, average appliance use times are long and this is supported by the type of family and number of people in the family results obtained from the demographics. Therefore, appliances in lower clusters spend less time in standby mode. This again points to the fact that the upper clusters have larger standby energy losses than households in the lower clusters.

Appliance operational behaviour has been linked to appliance efficient use index ($AEUI$) which is a measure of energy efficient behaviour in operating appliances. It has been shown that households in upper clusters have high $AEUI$ implying that their appliance operational behaviour lends itself to inefficient behaviour implying larger losses. The opposite is true for lower clusters, and therefore their appliance operational behaviour lends itself to energy efficient behaviour implying lower losses.

The measure of $AEUI$ as determined only from a questionnaire as it was in this work has been argued not to be very accurate mainly because one cannot ascertain consistent behaviour in the case of multiple operators and/or repeated operation by same individual. This is an area of research where more work can be done. Real time monitoring of appliance operational modes can be used to ascertain both the operational behaviour and secondly the time spent in specific operational modes.

## 6.2 Measurements

The Yokogawa WT210 digital power meter was used in the measurement of appliances power consumption in 30 households within the household sample and three retail stores. The measurement procedure was done according to the IEC 62301 standard for measurement of standby power. Measurements were taken for all appliances found in use within a household. Measurements were obtained for all distinguishable appliance operational modes.

The measurements indicate a wide range of power consumption levels for appliances with same capabilities and functionalities. The wide range between maximum and minimum values within an appliance category indicated different design philosophies. In some appliances the power consumption levels between full operational mode and standby mode are very close and in some cases are almost equal. This raises the issue of the presence of energy inefficient appliances in households as well as in retail stores.

Measurements also indicated poor power factors especially in standby mode and these were substantiated by comparatively large components of reactive and apparent power. In LCD and Plasma television screen technologies the standby power consumption is almost zero but the corresponding apparent power and reactive power components are comparatively very large. This raises the issue of circulating currents as well as harmonics in the low voltage network. Furthermore, the cost to the utility of maintaining LCD and Plasma screen technologies in standby mode is a concern as many of these appliances will enter the market due to change from analogue to digital television broadcasting in South Africa.

## 6.3 Estimation of Standby Energy and Power Losses

The mathematical model for estimation of standby power and energy losses is presented. The model used is what is commonly known as the Bottom-Up model for the estimation of electricity end-uses. Using the estimation equation results are obtained for the household sample and the each of the five clusters.

The sample standby power losses are estimated to be 73.5 W per household. The cluster results as expected are largest for the highest cluster 5 and lowest for cluster 1. In cluster five the total standby power losses per household is 111.7 W and 28.2 W for cluster 1. Cluster 4 standby power losses are 90.7 W, cluster 3 is 64.2 W and cluster 2 is 57.6 W. As suggested before the sample figure of 75.5 underestimates the figure for clusters 5 and 4 and over estimates the figures for clusters 1 to 3.

Estimates on standby energy losses do not include the effect of appliance operational behavioural index which is a measure of operator energy efficient behaviour because:

- the methodology used to obtain the measure of $AOBI$ is not considered accurate enough
- to be able to compare the results of this study with other results done in other countries in the world, it is necessary to harmonize the methodology across the board

In general if the indexes are used they affect the total number of appliances in standby mode in the determination of the total national standby power and energy losses.

The standby energy losses estimated using figures obtained for the sample are 561.4 kWh per year per household. The estimates obtained per household in each of the identified cluster using figures obtained for the clusters are, Cluster 5: 862.2 kWh/yr, cluster 4: 671.8 kWh/yr, Cluster 3: 466.9 kWh/yr, cluster 2: 406.7 kWh/yr and cluster 1: 181.6 kWh/yr.

## 6.4 General

Characteristically standby power losses are clustered. Without using clusters the final estimates per household are either over estimated or they are under estimated.

Correct estimation calls for the use of clusters to account for differences in appliance saturation and penetration rates, and average appliance usage times which are driven by appliance operational behaviour.

The sample standby power losses of 73.5 are comparable to findings in other studies and the power losses for clusters 3 to 5 are higher than what has been recorded for other countries. These are considerable losses and calls for mitigation strategies to minimise the losses as it has already been done in other countries with much lower levels of losses.

Significant appliances to standby power and energy losses in the households are: Television sets, microwave ovens, DVD's, mobile phone battery chargers, Hi-Fi sets, PC's, VCR's, PC monitors, DSTV decoders and printers.

The standby power and energy losses are more pronounced in clusters 5, 4, and 3 because of the long hours that appliances spend in standby time, the large number of appliances in these clusters, and appliance operational behaviour that lends itself to standby losses. In clusters 1 and 2 appliances spend long hours in full operational mode especially television sets and Hi-Fi systems and this raises the issue of energy efficient appliances in both operational modes and this was not the case as observed from the measurement results.

Data on appliance saturation and penetration rates now exists, initial data on power consumption measurements of appliances in households and retail stores also exists and the first estimates of standby power and energy losses in South African households have been established. A benchmark for standby power and energy losses in South African households has been created.

# Chapter 7

# Recommendations

Further to the work presented in this thesis the following recommendations are made:

- The appliance saturation and penetration clusters as well as the linkages to appliance use times and appliance operational behaviour was obtained on sample of 555 households in greater Johannesburg in Gauteng province. There is a need to establish these clusters across the entire household population because the sample used eliminated some households in informal settlements, townhouses and other secluded suburbs with stringent security measures. This finding should also be tested on other large metropolitan cities in South Africa using a larger sample

- As a result of poor power factors especially in standby mode, there is the presence of circulating currents and harmonics in the low voltage network and the effects have not yet been studied or quantified. In the light of the change from analogue to digital broadcasting in South Africa, there is a need to evaluate these effects

- Work on quantification of the measure of $AEUI$ should be done using real time monitoring of appliance operational modes to decrease the uncertainty due to multiple operators and repeated operations

- Standby power and energy losses should be quantified in the commercial sector, especially because of the large concentration of office and networked equipment

- There is a need to improve on household appliance saturation and penetration data. This can be done by incorporating some more items in the Statistics South Africa Household survey questionnaire. The questionnaire could include all the significant appliances to standby power losses. At present the results of the survey reports only on television sets, mobile phones and radios. The

SAARF questionnaire could be another alternative where the variables could be expanded to include all significant appliances as well as reporting on the number of appliances available in the households

- To curb the increase in standby power and energy losses in households there is a need to introduce effective policies and standards to ensure the availability of energy efficient appliances in the South African appliances retail market. This work is ongoing and it is being informed by the results of this work
- The results of this work have been used in consumer awareness campaigns on standby power and energy losses but these awareness campaigns should be intensified and expanded to include appliance labeling and energy efficient appliances

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# Appendix A

# Questionnaire

The Questionnaire has 5 sections namely:

- Appliance ownership
- Appliance use
- Appliance average use times
- Standby power awareness
- Demographics

### A.0.1 Appliance Ownership

In the list of Electrical appliances below, which ones are in your household?

| Appliance | Remote Control | Total Number | Brand | Year of Purchase |
|---|---|---|---|---|
| | Yes/No | | | |
| Television | | | | |
| Video Cassete Recirder | | | | |
| Hi-Fi system/Stereo | | | | |
| Digital Video Disk | | | | |
| DSTV decoder | | | | |
| Microwave Oven | | | | |
| Personal Computer | | | | |
| PC Monitor | | | | |
| Printer | | | | |
| MFD | | | | |
| Fax Machine | | | | |
| Cellphone | | | | |
| Clock (alarm) radio | | | | |
| Alarm system | | | | |
| Automatic Garage(s) | | | | |
| Automatic gates | | | | |
| Intercom system | | | | |
| CCTV | | | | |
| swimming pool | | | | |
| others | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

### A.0.2 Appliance Use

| When not in use appliances are normally | Switch off with remote controller | Switched off at appliance power switch | Switch off at wall |
|---|---|---|---|
| Television | | | |
| Video Cassette Recorder | | | |
| Hi-Fi system/Stereo | | | |
| Digital Video Disk | | | |
| DSTV decoder | | | |
| The Microwave Oven has a clock display | Yes | No | |
| | | | |
| **The mobile phone battery charger(s)when not in use is/are normally** | Left on all the time | Switched off at the wall | |
| | | | |
| **The following appliances are normally** | Left on All The Time | Switched on only When Required | |
| Printer | | | |
| MFD | | | |
| Personal Computer | | | |
| PC Monitor | | | |
| Fax machine | | | |
| Swimming pool has a timer | yes | No | |
| | | | |

### A.0.3 Appliance Average Use time

| Activity | Weekday | Weekend Day | Holiday |
|---|---|---|---|
| Watching Television | | | |
| Using Microwave Oven | | | |
| Hi-Fi system use | | | |
| DVD use | | | |
| VCR use | | | |
| MPBC use | | | |
| DSTV decoder use | | | |
| PC/Monitors use | | | |
| MFD use | | | |
| Printer use | | | |

### A.0.4 Standby Power Awareness

1. I knew what domestic appliance standby power is before this day:
   - **(a)** Strongly Agree
   - **(b)** Agree
   - **(c)** Do not know
   - **(d)** Disagree
   - **(e)** Strongly disagree
2. If I manage appliances with standby power capabilities properly I can save on my utility bill
   - **(a)** Strongly agree
   - **(b)** Agree
   - **(c)** Do not know
   - **(d)** Disagree
   - **(e)** Strongly disagree
3. Standby power use is very small and does not have a significant effect on my utility bill
   - **(a)** Strongly agree
   - **(b)** Agree
   - **(c)** Do not know

- **(d)** Disagree
- **(e)** Strongly disagree

4. Now standby power losses are of concern to me

   - **(a)** Strongly agree
   - **(b)** Agree
   - **(c)** Do not know
   - **(d)** Disagree
   - **(e)** Strongly disagree

### A.0.5 Demographics

1. Type of house

    **(a)** Flat

    **(b)** Townhouse/cluster house

    **(c)** Conventional house

    **(d)** Other

2. Number of people who live in the house is:

    **(a)** One

    **(b)** Two

    **(c)** Three

    **(d)** Four

    **(e)** Five

    **(f)** Six or more

3. How weould you describe your family? Are you

    **(a)** A couple with children

    **(b)** A couple without children

    **(c)** One parent family

    **(d)** A group of household members

    **(e)** Single person

4. The electricity bill is

    **(a)** Pre-paid

    **(b)** Monthly utilty bill

# Appendix B

# Sample Energy and Power Estimation

The standby power and energy estimates based on the household sample parameters are presented in table B.1.

Table B.1: Estimation Results Based on Sample Statistics

| Appliance | $t_{sb}/week$ | $P_{sb}$(W) | p | Power(W) | TSEC/week | TSEC/year |
|---|---|---|---|---|---|---|
| CRT TV | 119.5 | 8.2 | 1.8 | 15.1 | 1.8 | 93.8 |
| MPBC | 160.3 | 0.2 | 2.4 | 0.6 | 0.1 | 4.8 |
| Microwave Oven | 164.5 | 2.6 | 0.9 | 2.4 | 0.393 | 20.4 |
| DVD | 161.7 | 3.8 | 0.8 | 3.1 | 0.5 | 25.7 |
| Hi-Fi | 140.0 | 11.3 | 0.8 | 8.8 | 1.2 | 64.3 |
| VCR | 163.3 | 1.8 | 0.7 | 1.2 | 0.2 | 10.0 |
| PC | 161.6 | 40.2 | 0.7 | 26.1 | 4.2 | 219.4 |
| PC Monitor | 161.6 | 2.9 | 0.7 | 1.9 | 0.3 | 16.1 |
| DSTV | 128.3 | 20.8 | 0.4 | 8.7 | 1.1 | 58.2 |
| Printer | 167.3 | 5.5 | 0.4 | 2.2 | 0.4 | 18.9 |
| MFD | 167 | 9.93 | 0.4 | 3.5 | 0.6 | 30.2 |
| Total | | | | 73.5 | 10.8 | 561.8 |

The largest contribution of standby power losses are from CRT television sets, personal computers, DSTV decoders and Hi-Fi systems. Personal computers top the list at 219.4 kWh per year and this finding is important especially in the commercial sector where the saturation and penetration rates of PC's are much higher than in the households. CRT TV's are slowly being replaced by LCD and Plasma screens which have very small standby power losses. The flip side of these technologies are the much higher power consumption levels in full operational mode and the poor power factors in standby mode. As a result of poor power factors, there are appreciable apparent power and reactive power components in standby mode which are associated with circulating currents in the low voltage network and the presence of harmonics.

# Appendix C

# Cluster 1: Power and Energy Estimation per Household

Presented in Table C.1 are the detailed data used in the estimation of standby power and energy losses in cluster 1. Characteristics of cluster 1 data are:

Table C.1: Cluster 1: Power and Energy per Household

| Appliance | $t_{sb}$ (h)/week | $P_{sb}$ (W) | p | Power (W) | TSUEC (kWh/week) | TSUEC (kWh/year) |
|---|---|---|---|---|---|---|
| CRT TV | 106.1 | 8.2 | 1.3 | 10.5 | 1.1 | 57.9 |
| MPBC | 160.4 | 0.2 | 1.6 | 0.4 | 0.1 | 3.2 |
| Microwave Oven | 165.0 | 2.6 | 0.6 | 1.6 | 0.3 | 14.1 |
| DVD | 130.1 | 3.8 | 0.6 | 2.2 | 0.3 | 14.8 |
| Hi-Fi | 110.8 | 11.3 | 0.6 | 6.3 | 0.7 | 36.5 |
| VCR | 157.0 | 1.8 | 0.3 | 0.5 | 0.1 | 4.0 |
| PC | 151.6 | 40.2 | 0.1 | 5.6 | 0.9 | 44.3 |
| PC Monitor | 151.5 | 2.9 | 0.1 | 0.4 | 0.1 | 3.3 |
| DSTV | 105.0 | 20.8 | 0.03 | 0.6 | 0.1 | 3.4 |
| Total | | | | 28.2 | 3.5 | 181.5 |

- Lowest saturation and penetration levels for all appliances when compared to the other clusters
- Smallest values of time spent in standby in all remote controlled appliances when compared to other clusters
- Microwave ovens have the longest time spent in standby mode of 165 hrs a week

There were no printers or multifunction devices found in households in cluster 1, and as seen in Table C.1 these appliances are not included. From table C.1 the standby power losses for households in cluster 1 is 28.2 W and the standby energy losses are 181.5 kWh/year. The results obtained indicate that cluster 1 has the least standby power and energy losses across all the clusters.

# Appendix D

# Cluster 2: Power and Energy Estimation per Household

The penetration rates and the time spent in standby mode by appliances in cluster 2 are generally higher than those in cluster 1. The time spent in standby mode by mobile phone battery chargers and micro wave ovens are comparable between the two clusters. This can be attributed to a common use of the appliances whose use cannot be differentiated between households. In such appliances user operational behaviour is the same across the households.

Table D.1: Estimation Results: Cluster 2

| Appliance | $t_{sb}$ (h)/week | $P_{sb}$ (W) | p | Power (W) | TSUEC (kWh/week) | TSUEC (kWh/year) |
|---|---|---|---|---|---|---|
| CRT TV | 116.8 | 8.2 | 1.71 | 14.0 | 1.6 | 85.2 |
| MPBC | 161.7 | 0.2 | 2.3 | 0.6 | 0.1 | 4.7 |
| Microwave Oven | 164.7 | 2.6 | 0.9 | 2.2 | 0.4 | 18.9 |
| DVD | 146.1 | 3.8 | 0.7 | 2.6 | 0.4 | 119.8 |
| Hi-Fi | 143.9 | 11.3 | 0.7 | 8.4 | 1.2 | 62.7 |
| VCR | 141.5 | 1.8 | 0.59 | 1.0 | 0.1 | 7.6 |
| PC | 143.8 | 40.2 | 0.5 | 18.9 | 2.7 | 141.2 |
| PC Monitor | 143.8 | 2.9 | 0.5 | 1.4 | 0.2 | 10.4 |
| DSTV | 116.6 | 20.8 | 0.3 | 6.9 | 0.8 | 41.6 |
| Printer | 166.5 | 5.5 | 0.3 | 1.7 | 0.3 | 14.6 |
| Total | | | | 57.6 | 7.8 | 406.7 |

The power losses result for cluster 2 is 57.6 W per household. The total estimated energy losses per household per year are 406.7 kWh. The power losses double those of cluster 1 and the energy losses in cluster 2 are 2.2 times more than in cluster 1.

# Appendix E

# Cluster 3: Power and Energy Estimation per Household

As is the case in cluster 1 and 2 the time spent in standby mode by microwave ovens and mobile phone battery chargers is comparable to the other two clusters. This underlines the fact that these appliances serve a common function that is not differentiated across the households or the clusters. This is also true in the case of printer as seen in table D.1 and E.1. The time spent in standby mode by all the other appliances is higher in cluster 3 suggesting a gradual increase from cluster 1 to cluster 3.

Table E.1: Estimation Results: Cluster 3

| Appliance | $t_{sb}$ (h)/week | $P_{sb}$ (W) | p | Power (W) | TSUEC (kWh/week) | TSUEC (kWh/year) |
|---|---|---|---|---|---|---|
| CRT TV | 124.4 | 8.2 | 1.7 | 13.8 | 1.7 | 90.2 |
| MPBC | 159.1 | 0.2 | 1.9 | 0.5 | 0.1 | 3.8 |
| Microwave Oven | 164.3 | 2.6 | 0.9 | 2.3 | 0.4 | 19.8 |
| DVD | 150.2 | 3.8 | 0.8 | 2.9 | 0.4 | 22.9 |
| Hi-Fi | 141.3 | 11.3 | 0.7 | n8.3 | 1.2 | 60.7 |
| VCR | 153.5 | 1.8 | 0.7 | 1.1 | 0.2 | 9.1 |
| PC | 147.7 | 40.2 | 0.6 | 22.9 | 3.4 | 175.9 |
| PC Monitor | 149.1 | 2.9 | 0.6 | 1.7 | 0.3 | 13.0 |
| DSTV | 119.9 | 20.8 | 0.4 | 8.3 | 0.9 | 51.8 |
| Printer | 165.3 | 5.5 | 0.4 | 2.3 | 0.4 | 19.7 |
| Total | | | | 64.2 | 8.9 | 467.0 |

The estimated standby power losses for households in cluster 3 is 64.2 W. There is an increase of about 11.5% from the standby losses estimated for cluster 2. The standby energy losses per household per year in cluster 3 is 467.0 kWh. As seen from tables C.1 and D.1 there is a gradual increase in energy losses. The energy losses in cluster 3 are 2.6 times the losses in cluster 1.

# Appendix F

# Cluster 4: Power and Energy Estimation per Household

The cluster data used for estimation of standby power and energy losses in cluster 4 are presented in table F.1. There are marked differences in the estimate parameters $t_{sb}$ and penetration rates (p) for cluster 4 and clusters 1, 2 and 3. It can be said that there is a clear separation between cluster 4 and 1 as well as between cluster 4 and clusters 2 and 3. The penetration rates are higher in cluster 4 and the time spent in standby mode are longer. However the case of mobile phone chargers, and microwave ovens is the same as it was for clusters 1, 2, and 3 in that the time spent in standby mode is approximately equal across all clusters.

Table F.1: Estimation Results: Cluster 4

| Appliance | $t_{sb}$ (h)/week | $P_{sb}$ (W) | p | Power (W) | TSUEC (kWh/week) | TSUEC (kWh/year) |
|---|---|---|---|---|---|---|
| CRT TV | 131.4 | 8.2 | 2.2 | 17.8 | 2.3 | 121.6 |
| MPBC | 159.6 | 0.2 | 3.0 | 0.7 | 0.1 | 5.9 |
| Microwave Oven | 164.5 | 2.6 | 1.1 | 2.7 | 0.5 | 23.5 |
| DVD | 150.3 | 3.8 | 0.9 | 3.7 | 0.6 | 28.6 |
| Hi-Fi | 141.2 | 11.3 | 0.9 | 10.6 | 1.5 | 78.1 |
| VCR | 157 | 1.8 | 0.8 | 1.4 | 0.2 | 11.6 |
| PC | 146.5 | 40.1 | 0.9 | 37.0 | 5.4 | 281.5 |
| PC Monitor | 146.5 | 2.9 | 0.9 | 2.7 | 0.4 | 20.7 |
| DSTV | 131.2 | 20.8 | 0.6 | 11.4 | 1.5 | 78.0 |
| Printer | 166.6 | 5.5 | 0.5 | 2.6 | 0.4 | 22.2 |
| Total | | | | 90.7 | 12.9 | 671.8 |

The standby power losses per household in cluster 4 is estimated to be 90.7 W. This figure is an increase of 41.3% increase from the 64.2 W for cluster 3 and 221% more than the figure for cluster 1. This is a large step change. The energy losses per year per household in cluster 4 is 671.8 kWh.

# Appendix G

# Cluster 5: Power and Energy Estimation per Household

Cluster 5 is the cluster in which the estimation parameters $t_{sb}$ and p have the largest values i.e highest penetration rates and longest time spent in standby mode as seen in table G.1. These estimation parameters are markedly different from the figures for cluster 4 and signify a step change in the estimated standby power and energy losses. As noted in clusters 1, 2, 3, and 4 it is also the case in cluster 5 that the time spent in standby mode by mobile phone battery chargers and microwave ovens is approximately the same across all clusters.

Table G.1: Estimation Results: Cluster 5

| Appliance | $t_{sb}$ (h)/week | $P_{sb}$ (W) | p | Power (W) | TSEC (kWh/week) | TSEC (kWh/year) |
|---|---|---|---|---|---|---|
| CRT TV | 144.7 | 8.2 | 2.0 | 16.6 | 2.4 | 124.6 |
| MPBC | 161.5 | 0.24 | 3.5 | 0.8 | 0.1 | 7.1 |
| Microwave Oven | 164.8 | 2.6 | 1.0 | 2.6 | 0.4 | 22.7 |
| DVD | 159.9 | 3.8 | 0.8 | 3.1 | 0.5 | 26.0 |
| Hi-Fi | 150.5 | 11.3 | 0.8 | 9.4 | 1.4 | 73.5 |
| VCR | 161.8 | 1.8 | 0.9 | 1.5 | 0.2 | 12.9 |
| PC | 147.1 | 40.2 | 1.3 | 53.4 | 7.9 | 408.7 |
| PC Monitor | 147.7 | 2.9 | 1.33 | 3.9 | 0.6 | 30.0 |
| DSTV | 145.1 | 20.8 | 0.8 | 16.0 | 2.3 | 120.7 |
| Printer | 164.4 | 5.5 | 0.8 | 4.2 | 0.7 | 35.9 |
| Total | | | | 111.7 | 16.6 | 862.1 |

Standby power losses per household in cluster 5 are estimated to be 111.7 W. This figure is almost four times the estimate for households in cluster 1 and almost double the figure for cluster 2. There is a 23% increase on the standby power losses figure for cluster 4 if compared to the figure estimated for cluster 5. In general, the differences are significant and they underline the importance of the clustered approach. The estimated standby energy losses per household per year in cluster 5 is 862.1 kWh.

# Appendix H

# Research Outputs

The research work presented in this thesis has has been presented and discussed in various national and international forums as indicated below.

## H.1 National Conferences

1. M. V. Shuma-Iwisi and G. J. Gibbon. *Stand-by power load in the South African Domestic Sector: Why and How to Benchmark*, Proceedings of Domestic Use of Energy Conference, 31st March - 3rd April, Cape Town, South Africa, pp5-11, 2003.

2. M. V. Shuma-Iwisi and G. J. Gibbon. *Estimation of Standby Power load in South Africa Domestic Sector: Initial Survey Results*, Proceedings of Domestic Use of Energy Conference, 11-12 April, Cape Town, South Africa, pp89-94, 2007.

3. M. V. Shuma-Iwisi and G. J. Gibbon. *Estimation of Appliance Standby Power Load in South Africa: Household Measurement Results*, Proceedings of Domestic Use of Energy Conference, 18-19 March, Cape Town, South Africa, pp13-18, 2008.

4. M. V. Shuma-Iwisi and G. J. Gibbon. *Domestic Appliance Energy Consumption in South African Households: A Question of Energy Sustainability*, Proceedings of Southern Africa Energy Efficiency Convention, Birchwood Hotel and Conference Centre, Gauteng South Africa, 6-7 November 2008.

5. M. V. Shuma-Iwisi and G. J. Gibbon. *Appliance Standby Power and Energy Consumption in South African Households*, Proceedings of Domestic Use of Energy Conference, 15-16 April, Cape Town South Africa, pp17-24, 2009.

## H.2 International Conferences

1. M. V. Shuma-Iwisi and G. J. Gibbon. *Domestic Appliances Standby Power Losses: The Case of Eleven Suburbs in the Greater Johannesburg*, Proceedings of International Conference on Energy Efficiency in Domestic Appliances and Lighting (EEDAL'09), Estrel Hotel and Convention Center, Berlin Germany, 16-18 June, 2009.

2. M. V. Shuma-Iwisi and G. J. Gibbon. *Domestic Appliances End-Use Efficiencies: The Case of Eleven Suburbs in the Greater Johannesburg*, Proceedings of International Conference on Energy and Sustainability, Royal Hotel Carlton, Bologna Italy, 23-25 June, 2009.

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