An Artificial Intelligence Energy Management System for an Education Building

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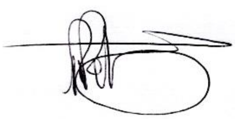
Declaration

I, RION PRETORIUS, identity number , and student number , do hereby declare that this research project which has been submitted to the Central University of Technology (CUT), Free State, for the degree MASTERS OF ENGINEERING IN ELECTRICAL ENGINEERING, is my own independent work and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology (CUT), Free State, and has not been submitted before by any person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.



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Abstract

The study of energy demand and consumption has become a topic of increasing importance as a result of the growing interest in energy sustainability. In the present energy crisis of South Africa, where Eskom is currently the only electricity provider, it cannot always meet the electricity needs of the customers. Therefore, the consideration of electrical power savings in education buildings can play a huge role, which was implemented in this study.

University campuses represent a specific group of various buildings with significant energy demands and consumptions. Due to the various buildings, a University campus can be seen as a small town on its own, therefore, it offers an excellent test bed to monitor energy consumption and to understand the demand for electricity of the different buildings.

In addition, it was possible to predict with an artificial intelligence concept using different prediction models when peak load will occur and to determine a maximum demand. A suitable database for the Engineering Technology Building (ETB) at the Central University of Technology (CUT), Free State, was created and available data of the electricity energy usage were collected and analysed for this purpose, with the aid of utilising methods, namely Moving Average, Straight Line and Kalman Filter. The available data were tested and evaluated by the switchgear, according to the priority list, and it proved to be successful. There was a total saving of approximately 5.83% on the power consumption per day. This proved to work well and a greater percentage of savings could be achieved by switching another circuit breaker according to the priority list.

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Central University of Technology, Free State

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Chapter 1

Preface

This chapter provides an overview of the proposed research problem, aim, methodology, and hypothesis with the chapter layout necessary to design, test and implement an artificial intelligence model to predict and control power consumption and energy peaks that will reduce the energy demand and therefore reduce energy costs.

Introduction

The study of energy demand and consumption in buildings has become a topic of increasing importance as a result of the growing interest in energy sustainability. University campuses represent a specific group of various buildings with significant energy demands and consumptions. Due to the variety of buildings, a University campus can be seen as a small town on its own, therefore, it offers an excellent test bed to monitor energy consumption and to understand the demand for electricity of the different buildings.

Education buildings are one of the highest energy consumers in comparison with other economic sectors. In the present energy crisis of South Africa, where Eskom is currently the only electricity provider, it cannot always meet the electricity needs of its customers. Therefore, the consideration of electrical power savings in education buildings can play a huge role.

Current statistics on energy use in different sectors show that the building sector uses approximately 40% of the world's electricity [1] and [2]. Commercial buildings and university buildings, however, are classified amongst the buildings having the highest energy consumption [3]. The study of energy demand and consumption in commercial buildings has become a topic of growing importance as a result of the increasing interest in energy sustainability [4].

Problem Statement

In the prevailing energy crisis of South Africa, where Eskom cannot always supply the demand, the consideration of electrical power savings in education buildings can play a huge role. The target is set by Eskom to save at least 10% or more on electrical power consumption [5].

In addition to the task at hand, would it be possible to predict when peak load will occur and determine a maximum demand?

Purpose of Study

A target building is to be identified and an electrical measuring strategy must be implemented for obtaining the electrical consumption data of the inherent systems and equipment of the building.

In order to develop an artificial intelligence (AI) energy management system, a summary of the building's electricity supply, demand and equipment must be obtained in order to be able to make informed choices.

Once the information is obtained, a load analysis will be conducted to create a priority list. The list will be drawn up from the equipment that is not to be controlled or switched off, to equipment that is less important at a certain time that is to be controlled.

The creation of a simulation program to test the concepts of different management and control purposes is to be developed in a platform like Matlab® and Microsoft® Excel. This program will involve predictive energy management by switching equipment ON and OFF. A human preference factor should also be considered in the implementation of this program.

Hypothesis

Electrical power savings can be achieved by controlling the electrical equipment. Controls can be as simple as manually turning off a switch, however, often automated controls may be required. The control should be as simple and reliable as possible [6].

There are several control strategies, such as time control, occupancy control, and management through priority projection of the electrical equipment.

A simulation program can be created to test the different control strategies and will allow the possible practical implementation thereof that could lead to real-life cost savings.

Specific Objectives

The aim of this dissertation is to analyse energy consumption of the Engineering Technology Building (ETB) at the Central University of Technology (CUT), using measured data for energy consumption. Collected information of the energy consumption will then be used to create a model. Creating a model of energy usage can assist in future building planning; it may provide useful information about the energy consumption for similar buildings, or it can potentially predict energy usage in different conditions. This model can be used to show the impacts of possible energy savings measures and help to find an optimal way of reducing energy costs.

In order to develop an artificial intelligence (AI) energy management system, a summary of the building's or, more specifically, each floor's energy demand and equipment must be obtained to be able to make informed choices. It is very important to have the correct measured data from the energy meters, otherwise it is impossible to monitor and prove the benefits of applying energy saving measures in order to increase the energy efficiency.

This study aims to differ from a normal load analysis in that it will provide useful information in terms of the day-to-day operation of the building. Emphasis will be placed on mapping the pattern of measured daily electrical consumption of the building against the daily room activities and occupancy. By doing this, it may assist to identify the potential electricity savings that can be achieved.

Expected Outcomes

A simulation program to predict and control energy peaks to be able to conserve electricity supply to an education building.

Limitations of Study and Future Research

A real-time load analysis aimed at understanding the reasons for excessive energy consumption for the Engineering Technology Building (ETB) in operation at the Central University of Technology (CUT) in the Free State.

Due to the limited number of current transformers (CTs) available, only two floors will be monitored at a time for specific time periods.

A compilation of information on the daily occupancy and the key activities that take place within the Engineering Technology Building (ETB).

The creation of a tool to determine and control the power consumption and load distribution of the Engineering Technology Building (ETB) in its simulation phase.

The establishment of a system to conserve electrical energy.

Operationally, it is difficult to implement the system; therefore, a simulation will be established to prove the concept for possible implementation by consideration of practical switching components and integration.

Chapter 2

University Campuses and their Role in Sustainable Developments

This chapter provides background on the important role that universities and colleges play in the promotion of sustainable development. It is also necessary to take action to improve the energy efficiency of buildings. It may be possible to determine the energy usage of a building through a calculation model. Energy management is a means of controlling and reducing the energy consumption of a certain building.

2.1 Introduction

University campuses are groups of diverse buildings with significant energy consumption. They consist of many different buildings, with a variety of usage patterns (offices, laboratories, lecture halls, etc.), representing a small-scale town. Therefore, they provide an excellent test bed to characterise and understand the energy consumption of “mixed use buildings”.

2.2 Sustainable Development

The particular importance of universities in promoting sustainable development has been highlighted in several significant declarations [7]. Policy content typically addresses both academic programs, for example the promotion of environmental causes plus the integration of environmental concepts into the wider curriculum, and the practical day-to-day operational activities of the university as a community [7]. As institutions for research, teaching and policy development, with their influence and resources, universities and colleges play an important role in promoting sustainable development [8]. The potential of education institutions for contributions within this area, is now being recognised by various quarters, such as the United Nations, the European Union, Government policies, agreements, and numerous research reports [8].

In a time faced with increasing environmental challenges, the tertiary sector is being recognised as well-suited to take on the leadership for environmental protection [8]. By greening their own campuses, higher education (HE) institutions can teach and demonstrate the principles of awareness and stewardship of the natural world, whilst increasing the chances of clean and pleasant local and global environments for the future [9].

However, as the 'greening of higher education institutions' is a complex and relatively new field of research, further studies are needed to analyse energy use on University campuses, and thereby help HE institutions realise that 'going green' has numerous advantages. Leal Filho [10] suggests that 'going into the specifics', or dealing with specific issues and themes such as energy use and waste management, is one possible way of addressing the task of transforming colleges and universities into green institutions. As Leal Filho [10] indicates, 'such contexts have clear approaches and clear outcomes'.

As many of the people whose decisions will affect the future attend colleges and universities today, HE institutions have the potential of teaching environmental literacy to the politicians, teachers, and decision-makers of tomorrow [11]. Both in the classroom and by the example of its horticultural habits, a university can give students an understanding of the interrelationship between business decisions and the natural environment [9]. A green university can furthermore become a green model for the external community by gathering and sharing effective ideas on environmental issues and practices.

The greening of a college or university can also be cost effective. Eagan and Keniry [11] show that revenues and savings for 23 campus conservation projects in the USA came to more than $ 16 million in just one year. The possibilities of saving costs on campus greening have also been exemplified by the "50-50" pilot project, now widely spread in Germany [10].

Knowing that "you cannot improve what you cannot measure", highlights the fact that the first step in greening campuses would be to analyse the current energy consumption [10].

2.3 Energy Management System

Energy management is a means of controlling and reducing the energy consumption of a certain building, which enables building owners to:

- Reduce costs – this is becoming crucial as energy costs rise.
- Reduce carbon emissions and the environmental damage that they cause – as well as the cost-related implications of carbon taxes, every organisation may be keen to reduce its carbon footprint to promote a green, sustainable image. Not least because promoting such an image is often good for the bottom line, especially for education organisations.

- Reduce risk – the more energy some buildings consume, the greater the risk that energy prices will increase, or supply shortages could seriously affect its functionality.

With energy management, organisations can reduce this risk by reducing the demand for energy and by controlling it so as to make it more predictable. In order to monitor and control energy consumption, the main concern is an efficient data collection strategy. The earlier approach to energy consumption related data collection would see one manually reading meters once a week or once a month. This is quite a chore, it opens room for human error, and weekly or monthly data is not nearly as good as the data that comes easily and automatically from the modern approach [12].

The modern approach to energy-data collection is to install metering equipment that automatically measures and records energy consumption at short, regular intervals. Real-time control and optimisation can help building owners minimise energy consumption and costs based on inputs from occupants, local utilities, as well as weather conditions. Detailed interval energy consumption data makes it possible to see patterns of energy waste that would be impossible to see otherwise. For example, one cannot precisely deduce the amount of energy used at different hours of the day, or on different days of the week, from weekly or monthly meter readings; and therefore a more detailed energy consumption reading makes it much easier to establish the routine energy waste in a desired building [12].

This research will focus on the efficiency aspects of electrical energy usage.

Research shows that a high energy savings potential exists in modern office buildings [8]. Advances in technology are increasing to achieve the desired reduction in energy consumption goals but this does not necessarily lead to an overall reduction. Electrical power savings can be achieved by controlling the electrical equipment. Controls can be as simple as manually turning on and/or off a switch, but often, automated controls may be preferred. In order to develop an efficient energy management system, a summary of the building's electricity demand and equipment must be compiled in order to make informed choices, and therefore, it is very important to have correct and reliable measured data.

There is growing interest in data error analysis and developing methods that can indicate possible malfunction in related meters. Also, without correctly measured data, it is not possible to monitor and improve energy efficiency. In order to determine the sources of errors and improve predictions, the sensitivity of building energy models to different input parameters needs to be evaluated. The human factor (i.e. energy users' behaviour) is a very important element influencing building energy consumption, and has rarely been evaluated [4] and [13]. Several control strategies are taken into consideration such as time control, occupancy control with regard to academic timetables, and management through priority projection of electrical equipment.

Studies [14], [15] and [16] show that in various cases, more than half of the total building energy is typically consumed during the non-working hours, mainly due to occupancy related actions (e.g. equipment and lighting usage after hours) and can be reduced through behavioural changes. Occupancy presence and behaviour in buildings has proven to have a high impact on area heating, cooling and ventilation demand, energy consumption of lighting and appliances, and building controls where careless behaviour can add to a building's intended energy performance.

Practically, energy consumption in non-domestic buildings is a very complex organisational issue due to the diversity of activities (e.g. lecture halls, laboratories, and offices) that take place as well as the energy services such as HVAC, DHW (domestic hot water), lighting, refrigeration and food preparation [17]. Achieving a balance amongst these attributes poses a challenge: on the one hand, to consume energy in a way that meets the energy needs of users and maintain comfort standards and, on the other hand, to minimise energy consumption through effective energy management [13].

Universities consume significant amounts of energy and reducing energy use would be impossible without good data based on which to make informed decisions. Having correct and reliable data is essential, so data error analysis is performed using statistical methods. Creating a model of energy consumption helps in future building planning and can provide useful information about most probable energy consumption for similar buildings. Also, these models can be used to predict energy use in different conditions, show impact of possible energy savings measures, and help in finding optimal ways of reducing energy costs.

2.4 Energy Efficiency

Electricity is used for heating, ventilation and air conditioning (HVAC), lighting, operation of various equipment, including computers, processors and household-related equipment, and so forth [1]. The HVAC systems are said to be the largest energy end-use [17] where inefficient operation and maintenance of such systems can cause energy wastage, poor indoor air quality and environmental damage. To achieve energy efficiency in buildings, the energy optimisation of HVAC systems is particularly important [18] where the energy performance of such systems is affected by operating conditions as well as time sensitivity to a building's heating and cooling energy needs.

Lighting is an area where one can easily save, and where we can make use of energy-saver lighting.

It is, therefore, necessary to do something in order to improve the efficiency of electrical energy usage, and it may be that in future the search for alternative energy resources will be required [1].

2.5 Energy Calculation Model

It may be possible to determine the energy usage of a building through a calculation model, starting from knowing the building features, or to assess the energy usage from energy meters.

These days, engineers are moving from theoretical calculations of energy demands towards real-time control and optimisation of energy consumption. Real-time control and optimisation can help building owners to minimise energy consumption and costs based on inputs from occupants, local utilities and weather conditions [19].

Electrical power savings can be achieved by controlling the electrical equipment. Controls can be as simple as manually turning off a switch, but often automated controls are required [6]. The controls should be as simple and reliable as possible [6]. There are several control strategies, such as time control, occupancy control and management through priority projection of the electrical equipment.

University campuses can play a very important role in promoting of sustainable development. In the next chapter, the different consumer techniques as well as the prediction strategies are discussed, to manage and control the power consumption.

Chapter 3

Current Energy Consumption Measuring Techniques and Prediction Strategies

This chapter provides a background of electrical energy measurement, energy measurement equipment, energy measurement methods and energy measurement strategies. It also gives a background of the prediction strategy methods, prediction categories, ways of prediction and prediction techniques.

3.1 Introduction

A good knowledge of where the energy is to be utilized, is fundamental for customers to decide how to reduce energy waste and maximise energy bill savings. There are different approaches for implementing energy efficiency programs, and basically two types of actions that can be taken: by changing the behaviour and habits of the customers in what concerns the use of general household appliances or by investing in energy-efficient technologies. Often, these two actions must be implemented concurrently in order to achieve a significant improvement in energy savings.

3.2 Programs

Some programs provide direct payments or subsidies (rebates, discounts and loans) to customers who decide to purchase or install a specific energy efficient home appliance. Other programs address non-financial incentives, such as information and technical services. Non-financial incentives/services may be bundled with direct or indirect incentives or may be offered on a stand-alone basis. Depending on the customer type and market characteristics that a given program targets, an effective energy efficiency program design may include any one of these incentive types, or may bundle them together in various ways [20].

The reduction of energy consumption by customers or the adequacy of their consumption behaviour, is strongly related with the quality of feedback on where and why the energy consumption, was used. This can lead to change in behaviour, or it will reduce the power consumption and shift the power consumption from peak periods to off-peak periods. The more detailed the feedback information is that the customer receives, the more efficient and substantial the energy savings are [20].

3.3 Electrical Energy Measurement

3.3.1 Energy measurements basics

Most people do not fully understand the difference between kW and kWh. Energy calculations and energy saving becomes much easier when the difference between a kW and a kWh is fully understood. KWh is a measure of energy, whilst kW is a measure of power. Energy is a measure of how much fuel is contained within something or used by something over a specific period of time. The kilowatt hour (kWh) is a unit of energy. Similarly, the calorie is a unit of energy and the joule (J) is a unit of energy. Electricity and other fuels related resources supply energy in a form that can be used to run the equipment in our buildings.

3.3.2 The relation between energy consumption (kWh) and time

Background to power

Power is the rate at which energy is generated or used. The kW is a unit of power. It is important to note that energy is not actually generated or used, it is converted from one form into another. For instance, the electricity that runs a fan is converted into the motion of the fan blade (kinetic energy) and, therefore, power is a measure of the rate at which work is done or the rate at which electricity is being used at a specific moment.

Explanation of a Watt

The watt (W) is a unit of power. In the International System of Units it is defined as a derived unit of 1 joule per second, and is used to quantify the rate of energy transfer.

3.3.3 Appliances that "generate power"

Items of equipment like boilers, electricity generators, and wind turbines, take energy in one form (e.g. gas or oil or wind) and turn it into another (e.g. heat or electricity). There is a limit to how much useful output these materials can generate and that is expressed as the rate at which they can generate energy. Which is, by definition, their power.

3.3.4 Appliances that "use power"

Items of electrical equipment, like light bulbs, computers and fans, take energy in the form of electricity and use it to perform useful tasks or functions for us. They convert the energy into other forms (heat, motion, etc.), but we say that they are "using" it because we do not really care about what exactly is happening to it; we just want our equipment to work when we switch it on and stop when we switch it off. The rate at which these devices use energy is their power. It is often referred to as their "load" or their "demand", or you might just hear it referred to in terms of a W or kW value.

Light bulbs are a simple example: if you have a 100 W light bulb, you know that it will use 100 W of power when it is turned on (100 W of power being the same as 0.1 kW of power). The watts are not affected by how long the 100 W light bulb is turned on g for. A second, an hour, a day – it makes no difference – as long as it is switched on, it will be using 100 W of power. If it is not switched on, it will not be using any power (i.e. 0 W).

Some equipment is more complicated. Consider a laptop: at any one instant, it might be using 50 W of power, or 30 W of power, or 43 W of power, or any such value. It depends on what it is doing – if it is in standby, it will probably use less power than if you are working on it, for instance, typing values into a Microsoft® Excel spreadsheet, listening to music, and burning a DVD, all at the same time.

3.3.5 Instantaneous and average power

The instantaneous power (or instantaneous demand, or instantaneous load) is the power that something is using (or generating) at any one moment in time. Put your laptop on standby and its instantaneous power will drop immediately. Bring it back to life and its instantaneous power will increase immediately. If, at any moment, everything in an office building is switched on, that office building might be using 42 kW of power. That is 42 kW of instantaneous power. If, at any moment, everything in the office building is switched off, that building should be using 0 kW of power. That is 0 kW of instantaneous power. The instantaneous power of most buildings varies constantly. People are constantly switching things on and off, and many pieces of equipment within the building have instantaneous power that is constantly changing too.

The average power represents the power that something uses or generates, on average:

- over a specific period of time
- over multiple periods of time
- throughout a certain type of operation

The instantaneous power of a typical building varies all the time. If you try to monitor instantaneous power, you get lost in the noise and figures of energy consumption, which are meaningless unless you know the length of the periods that they were measured over. However, average power figures smooth out the constant fluctuations of instantaneous power and make it possible to compare the efficiency of different periods, without worrying about how long those periods were.

One can easily use average-kW figures to compare the energy consumption of different periods and even different buildings (we use the term "energy consumption" loosely because we are really talking about average power, not energy). Average power, typically measured in kW, is a great way to look at the energy usage of a building. In many ways, average-kW figures are easier to work with than kWh figures.

The appeal of average-kW figures is that you can fairly compare them in an instant. The length of time does not really matter. Therefore, you can look at the average-kW figures from 15-minute interval data and compare them directly with the average-kW figures from

60-minute data or from half-hourly data. One can also instantly compare the average kW from last month with the average kW from yesterday and the average kW from the whole of last year. If these were kWh figures, the fact that they come from periods of different length would mean that you would need to normalise them before you could compare them fairly. However, kW figures come ready normalised.

3.3.6 Different names for power

People often refer to power as the "load" or the "demand". Hence, you might hear average power referred to as "average load" or "average demand". Whilst "power" can refer to the power that something is using or generating, "load" and "demand" only ever refer to the power that something is using. You might hear the power that something is generating, or can generate, referred to as its "output". People sometimes use the word "mean" in place of "average", so you might also hear of "mean power", or "mean load", or "mean demand", or "mean kW".

People often do not make the distinction between average power and instantaneous power. You can ask them to clarify, but it can be a little embarrassing if they do not understand the distinction in the first place. Fortunately, when you hear someone talking about "power", or "load", or "demand", or "kW", you can usually tell from the context whether they are talking about average or instantaneous figures.

3.3.7 The equation connection energy and power

The following is the fundamental equation that connects energy and power:

$$Energy = power\ x\ time \qquad 3.1$$

We can express this equation in terms of kW, kWh, and hours (h):

$$KWh = kW \, x \, h \qquad 3.2$$

Where:

KWh is the energy

KW is the power

h is the time in hours

And:

$$Power = energy \, / \, time \qquad 3.3$$

Or:

$$kW = kWh \, / \, h \qquad 3.4$$

Also:

$$Time = energy \, / \, power \qquad 3.5$$

Or:

$$h = kWh \, / \, kW \qquad 3.6$$

3.3.8 Calculating cost

At the simplest level, cost is usually expressed in terms of R/kW. It makes sense that cost should be calculated per kWh (not per kW), because cost is cumulative – the more energy you use, the more it costs.

However, in reality, cost calculations are usually more complicated:

- Prices change over time. One month you are paying x R/kWh, the next month you are paying y R/kWh. Unfortunately, y is usually greater than x, as energy prices typically rise over time.

- Electricity costs can depend on the time of the day, the day of the week, and the time of the year. Energy suppliers/utilities come up with complicated tariffs to define these rules. Just like prices, tariff structures can also change over time.

- Electricity costs can also depend on the maximum demand, or peak load, across a period. For example, given half-hourly data for a month, the peak load or maximum demand could be defined as the half-hour period that had the highest average kW. The higher the peak load, the higher the peak-load charge (or maximum-demand charge).

- Electricity tariffs often charge different rates depending on how many kWh you use. For example, the first 100 kWh might cost x R/kWh, the next might cost y R/kWh.

- There are often standing charges – regular fixed fees that are not related to how much energy you use.

All in all, looking to reduce energy consumption is usually much easier working in units of kW and kWh.

Power is, by definition, work done per unit of time. Measured in Watts (W), electrical power is commonly acquired indirectly by measuring the voltage and the current of the circuit. In alternating current (AC) circuits, instantaneous electrical power is calculated by multiplying the instantaneous values of the voltage and current:

$$Pi = Vi \times Ii \qquad 3.7$$

Electrical energy is obtained by accumulating instantaneous power measurements over a period of time, and is written as:

$$E = \int_0^t V(t) \times I(t)\, dt \qquad 3.8$$

3.4 Energy Measurement Equipment, Methods and Strategy

3.4.1 Integrated circuits

In the integrated circuits (ICs) present in energy meters, the signals of voltage and current are discretised in time by an analogue to digital converter (ADC), and the electrical energy is then written as:

$$E = \sum_{i=0}^{i=T} Vi \times Ii \qquad 3.9$$

The voltage is usually obtained using a resistive voltage divider connected directly to the alternating current (AC) line, and the current can be acquired by measuring the voltage drop across a shunt resistor or across a burden resistor connected to a current transformer (CT).

Figure 3.1 shows the basic schematic diagram of an electrical energy meter IC. A current transformer CT) with a burden resistor is used to provide the current-to-voltage conversion needed by the current channel ADC, and a simple resistive divider network attenuates the line voltage which will be fed into the voltage input channel ADC. In order to achieve high accuracy, modern electrical energy metering ICs perform the signal processing, such as multiplication and filtering, in the digital domain. This approach provides superior stability and accuracy over time even in extreme environmental conditions. Their operation is based on high precision Sigma-Delta Analogue to Digital Converters with resolution between 16 - 24 bits, and signal data processing integrated on hardware level.

To achieve high resolution and reduce noise, the Sigma-Delta Analogue to Digital Converters in the IC convert the signals from the current and voltage channels using oversampling. The signals are sampled at a frequency that is many times higher than the bandwidth of interest and this spreads the quantisation noise over a wider bandwidth. With the noise spread over a wider bandwidth, the quantisation noise within the band of interest is lowered [21].

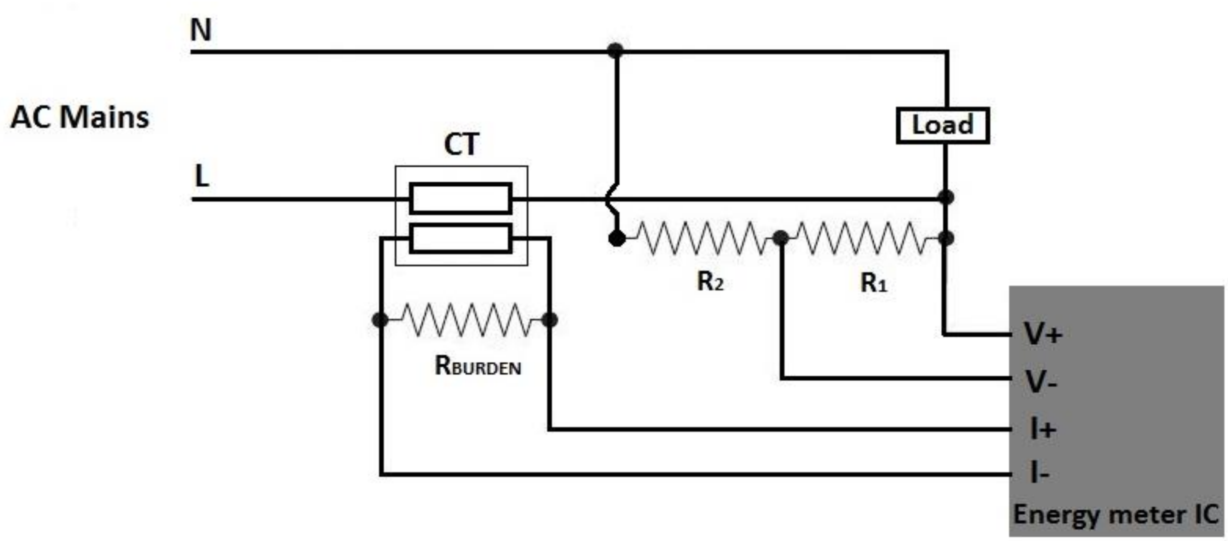

Figure 3.1 Energy meter IC connected to a resistive voltage divider and current transformer with burden resistor

This analogue input structure greatly simplifies sensor interfacing by providing a wide dynamic range for direct connection to the sensor, and also simplifies the antialiasing filter design. A high-pass filter in the current channel removes any direct current (DC) component from the current signal, eliminating inaccuracies in the real power calculation which may appear due to offsets in the voltage or current signals [22].

The real power calculation is derived from the instantaneous power signal, which is generated by a direct multiplication of the current and voltage signals. To extract the real power component (that is, the DC component), the instantaneous power signal is low-pass filtered. Figure 3.2 presents a graph of the instantaneous real power signal and shows how the real power information is extracted by low-pass filtering of the instantaneous power signal. This scheme calculates real power for sinusoidal current and voltage waveforms at all power factors [22].

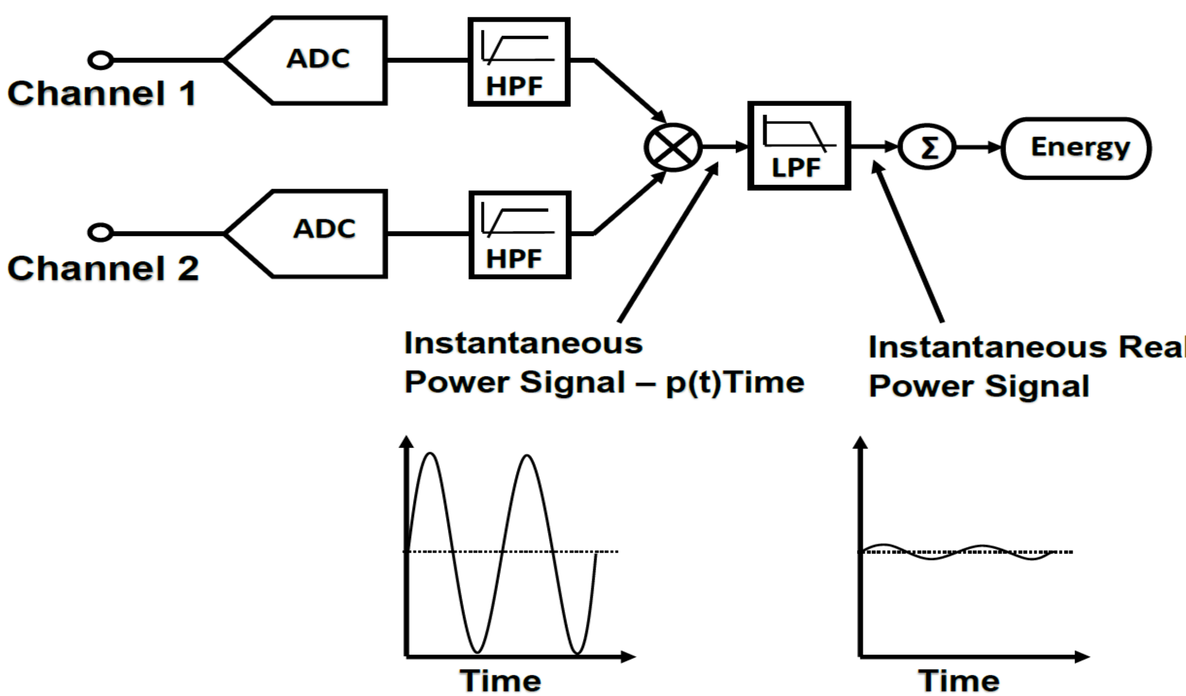

Figure 3.2 Signal Processing Block Diagram

Practically every current waveform in real appliances have some harmonic content. Using the Fourier transform, the instantaneous voltage can be expressed in terms of their harmonic content as:

$$v(t) = V_0 + \sqrt{2} \times \sum_{h \neq 0}^{\infty} V_h \times sin(h\omega t + \alpha_h) \qquad 3.10$$

Where:

$v(t)$ = instantaneous voltage

V_0 = average value

V_h = RMS value of Voltage Harmonic *h*

α_h = phase angle of the voltage harmonic

And the instantaneous current is given by:

$$i(t) = I_0 + \sqrt{2} \times \sum_{h \neq 0}^{\infty} I_h \times sin(h\omega t + \beta_h) \qquad 3.11$$

Where:

$i(t)$ = instantaneous current.

I_0 = dc component.

I_h= RMS value of Current Harmonic *h*.

β_h = phase angle of the current harmonic.

Thus, using Equations 1, 4 and 5, the real power *P* can be expressed in terms of its fundamental real power (P_1) and the harmonic real power (P_h) as:

$$P = P_1 + P_h \qquad 3.12$$

Where P_1 is given by:

$$P_1 = V_1 \times V_1 \, cos(\Phi_1) \qquad 3.13$$

$$\Phi_1 = \alpha_1 - \beta_1 \qquad 3.14$$

And P_h is:

$$P_h = \sum_{h \neq 1}^{\infty} V_h \times I_h cos(\Phi_h) \qquad 3.15$$

$$\Phi_h = \alpha_h - \beta_h \qquad 3.16$$

Some energy meter ICs store in registers, the information processed in the digital domain. According to the energy meter IC, a great deal of the information can be retrieved via serial communication (like SPI, I2C or RS-232). Access to that information is a key element to the development of centralised systems that can identify different appliances on a household installation.

3.4.2 Microcontroller integrated circuits

Another technique to implement precision low-cost electrical energy meters is to perform all the signal processing at software level. This can be done by using microcontroller ICs with integrated analogue-to-digital converters (ADCs). If a hardware multiplier is integrated in the microcontroller IC, the multiplications that are constantly executed during the energy metering process can be executed very quickly, and measuring energy with these general purpose microcontroller ICs can be very competitive when compared to the energy meter ICs.

This technique is similar to the one implemented at hardware level, using the same acquisition methods and digital processing principles. However, using this approach, the system can be customised to operate in ultra-low power, as in the technique developed in [23] to design a battery-powered energy meter using the microcontroller MSP430AFE2xx [24]. The system was configured to operate in a 60 Hz AC line and during every period of one second, make the measurements only during 3 cycles, and stay sleeping for the others 57 cycles. The system calculates the RMS value of the product $V \times I$ and adds this value to a register. Assuming that there is no significant change in the current and voltage during each period of less than one second, the accumulated value in the register is equal to the energy.

3.4.3 Measurement methods

Decentralised measurement methods

Establishing mesh networks using wireless and Power Line Communications (PLC) modem concentrators/routers, together with smart metering sensors which are connected to the home appliances, can provide both accumulated and real-time information of the energy spent in various appliances. Adding actuators to these smart sensors makes it possible to manage the status (ON-OFF) of a few important loads (e.g. clothes dryer or air conditioning) remotely in order to avoid these loads being turned on during a peak period. In this case, the household has to buy the system, since the information has to be continuously monitored and the energy savings will be dependent on this monitoring.

Another possibility, which does not involve the costs associated with the ownership of the measurement system, is offered as a service by the utilities or an ESCO (Energy Service Company). The energy monitoring is performed through the installation of low-cost smart metering sensors to the home appliances, and after a sampling period (typically 2 weeks), the meters are read and a diagnosis report of the energy use is prepared by the company offering the service. When there is no need for getting real-time information, the installation is extremely easy, since the devices do not need to form a mesh network.

Centralised measurement methods

With the main objective of minimising the number of sensors needed to monitor all appliances and reducing the complexity of the installation service, many researchers are proposing centralised measurement approaches. There are several proposals of different techniques to identify the appliances connected in the same circuit.

In [25] the authors presented the design and implementation of a wireless monitoring system for residential spaces, based on a multi-layer decision architecture called TinyEARS. This system was able to recognise the appliances by deploying one acoustic sensor node per room that will identify the acoustic signatures of the appliances. Combining this information with the data acquired by a real-time power meter installed at the main electric panel, and with relatively simple processing algorithms, the system can recognise the appliances with an overall success rate of 94%.

Load Signatures

Another widely adopted technique is the identification based on load signatures. Load signature is an electrical expression that an appliance distinctly possesses regarding its electrical consumption behaviour. It can be measured in various forms – from power consumption levels to waveforms of electrical quantities such as voltage and current. Almost every electrical measurement can be treated as a load signature. It can be represented in the frequency domain [12], in the time domain [26] and can also be represented mathematically in terms of wavelets, eigenvalues, or components of the Singular Value Decomposition (SVD) [27].

Methodologies which use signal processing techniques and estimation algorithms for signal load recognition based on load signatures allows the use of a single intelligence device in only one point of the installation (in the electric panel). The detailed energy breakdown of the whole installation is then calculated by sophisticated algorithms.

One of the earliest works (1980s) in nonintrusive monitoring was developed at MIT and had its origins in load monitoring for residential buildings [28]. In the developed technique, the operating schedules of individual loads are determined by identifying times at which electrical power measurements change from one steady-state value to another.

These steady-state changes, known as events, correspond to the load either being turned on or turned off, and can be characterised by the magnitude and sign in real and reactive power values.

Figure 3.3 shows the power consumption of a refrigerator and a microwave oven, where two different-sized step changes are clearly present, providing characteristic signatures of the refrigerator and the microwave oven. Knowing the time of each on and off event, it is possible to determine the total energy consumption of the refrigerator and the microwave oven.

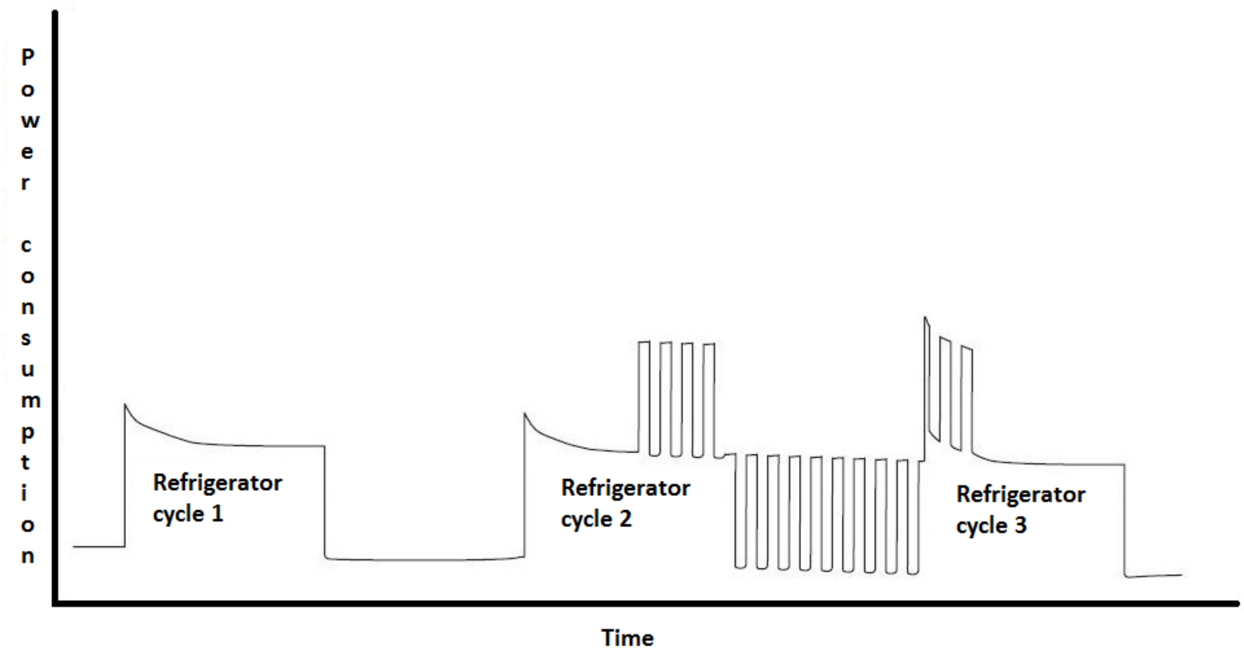

Figure 3.3 Characteristic signatures of a refrigerator and a microwave oven sensed on the same circuit

In [27] the authors highlighted the fact that the complex electrical loads of today have signatures that vary over time, depending on their state and mode of use and considering that common appliances can have non-linear load characteristics. They propose a conceptual modelling to characterise an appliance based on three sets of signatures that are extracted from the appliance: steady state, transient state and operational pattern, and thus construct a taxonomy for the appliances.

A method to construct a taxonomy of electrical appliances based on load signatures is presented in [29]. In this work, the authors suggest a 2-dimensional form of load signature denominated voltage-current (V-I) trajectory to characterise typical household appliances. The V-I trajectory load signatures consist of acquiring the steady-state voltage and current in one-cycle long, normalising them to eliminate the effect of the current magnitude in the size of V-I trajectory, and then plot the V-I trajectory. After creating the trajectories for the appliances, the shapes of the trajectories of the appliances can be analysed.

The proposed methodology for constructing the load taxonomy is summarised as: (1) the voltage and current waveforms of the household appliances are measured; (2) load signatures in the form of V-I trajectory are constructed; (3) shape features are extracted from the V-I trajectories; (4) hierarchical clustering method is applied to cluster the appliances; and (5) the load taxonomy is constructed according to the clustering results.

In [30] the authors proposed a methodology of using load signatures and Genetic Algorithms (GA) to identify electrical appliances from a composite load signal. They introduced a classification method to group the appliances and how to disaggregate the composite load signals by a GA identification process from generated random combinations of load signatures from the groups of appliances.

The methodology consists of defining a signature for each appliance by averaging 50 consecutive one-cycle steady-state current waveforms. Then the current waveforms are grouped by the ratio of their fundamental (50 Hz) component versus their Root-Mean-Square (RMS) total, after a Fast Fourier Transform (FFT) calculation. That means that the higher the ratio, the more the sinusoidal shape of the signature is. They considered a sampling rate of 200 points per cycle (50 Hz), which is sufficient for steady-state assessment in the time-domain. However, a higher sampling rate is desirable if transients will also be analysed.

The appliance identification can be done by making use of Genetic Algorithms, which are stochastic global search methods based on the principle that the fittest will survive. A fitness function, which calculates the least sum squared error between the proposed aggregated signal and the measured signal, is firstly defined. A group of potential solutions are also defined as the initial population. Different variables/attributes, termed the genes, which would affect the fitness function, are allowed to cross-over and mutate to form a new generation of potential solutions. In each generation, those matches having the highest fitness value would be retained for further reproduction. The process repeats itself until the best fit is found or the generation limit is reached.

The identification accuracy of the Genetic Algorithm technique is very high for a small number of appliances, but it decreases as the number of aggregated appliances increases. Also, the identification accuracy for sinusoid and quasi-sinusoid waveforms is lower than those of non-sinusoid signatures.

A different approach based on centralised measurement is presented in [31]. The proposed methodology detects the state changes of appliances and acquires energy information simultaneously. The appliance identification is performed using power meters installed in the circuit-level of the electrical panel, and measures the total electrical consumption every 5 seconds, if all appliances and the states of these appliances in the circuit are known.

In addition, user behaviour is taken into account, as the algorithms assume that there are some patterns for using appliances. For example, when using the computer, first the user may switch on the light in the room, then start up the power of the computer and finally turn on the monitor. If the user has a regular lifestyle, the pattern is likely to be regular.

Based on that assumption, the temporal character is taken into consideration, therefore, the Dynamic Bayesian Network (DBN) is applicable.

3.4.4 Electrical measuring strategy

The electrical measuring strategy to be implemented in the Engineering Technology Building (ETB) on the ground and second floor will include a set of dedicated current transformers (CTs), strategically placed on each outgoing circuit, as such, connected to an already installed eGauge meter which allows for remote monitoring of real-time energy usage.

eGauge meter

The metering device of choice for this research project is the EG3000 from eGauge Systems Limited Liability Company (LLC). The eGauge meter is an affordable, flexible, secure, web-based electric energy and power meter that can measure up to 12 circuits on up to three phases. The range of this meter is between 120 V−480 V and the frequency between 50 Hz – 60 Hz. This meter can be used to measure and record the total building electrical consumption, as well as the consumption of individual circuits in the building. The data can be viewed on any web-enabled device through the built-in webserver. The display is updated every second, giving immediate feedback on any load or generation changes. This meter is a combination of an energy meter, data logger and a web server into one as seen in Figure 3.4.

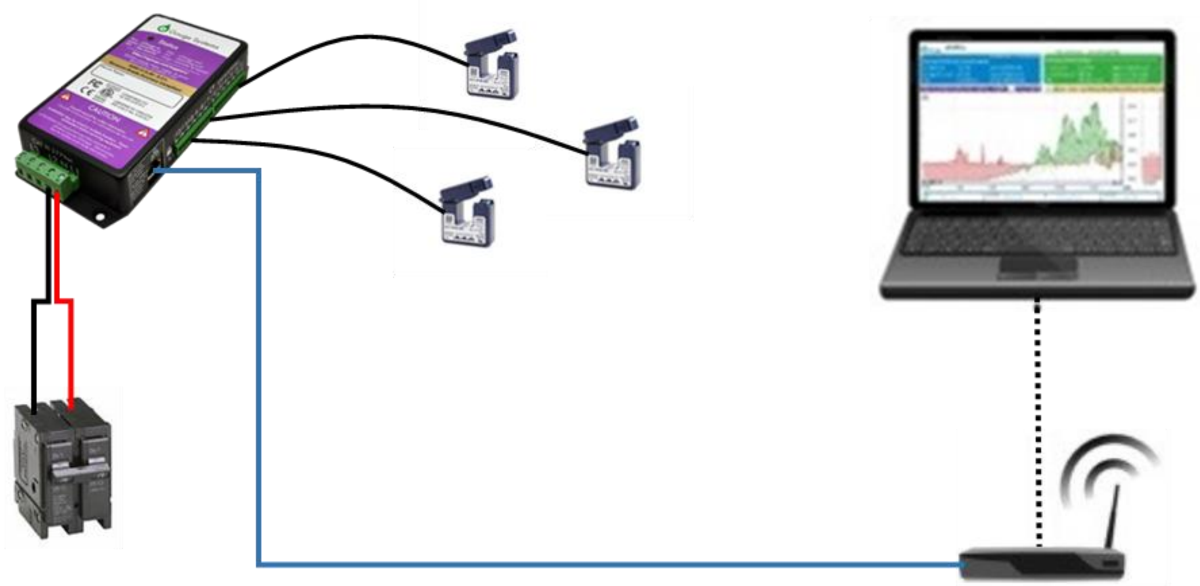

Figure 3.4 A typical setup of the eGauge EG3000 meter connected via Ethernet to the network

The eGauge records and stores data from the twelve CT sensors and three voltage taps and is able to send this data to the local area network and onto the internet using power line communication. The data can be viewed on any web-enabled device through the built-in webserver. The display is updated every second, giving immediate feedback on any load or generation changes.

The device records the most recent 30 years of data in its built-in solid-state memory. The measurements can also be accessed through BACnet and/or can be pushed to a server.

Device overview

As shown in Figure 3.5, the eGauge has two input connectors: The Power Connector is a 5-pin connector used to wire the device to the building supply. The current transformer (CT) Connector is used to connect up to 12 current transformers (CTs).

The unit also has an ethernet port (RJ45 connector) which can be used to hardwire the device to a local area network (LAN). The ethernet port may be used only when the device is installed in its own, suitably rated enclosure exterior to a distribution panel. Shielded RJ45 plugs must not be used.

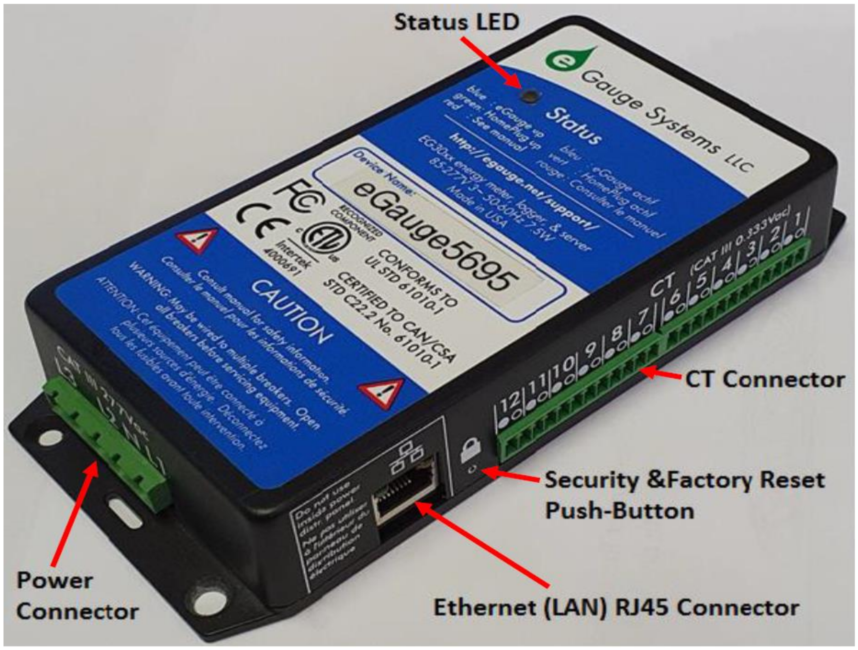

Figure 3.5 eGauge inputs and outputs

The power connector

The Power Connector, as shown in Figure 3.6, is CAT III rated (for measurements performed in the building installation, such as circuit breakers).

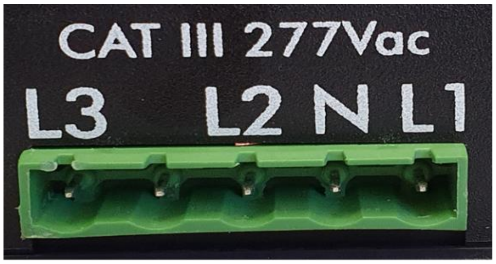

Figure 3.6 Power Connector

Table 3.1 shows the pin connection for the power connector. Pin L1 serves three purposes: it powers the device (2W typical, 7.5W maximum), the voltage on the line is measured to calculate power used/generated on phase L1. The pin is wired to the building's power supply with a voltage in the range of 85–277 Vrms (to neutral). In contrast, pins L2 and L3 are used purely as voltage-taps so that power used/generated on phases L2 and L3 can be calculated. Wiring these pins is necessary only if there are CTs measuring current(s) on L2/L3, as in the case of this research project. The voltage on these lines is 0-277 Vrms (VAC or VDC). The input impedance for L2 and L3 is approximately 950k at 60Hz. By connecting L2 or L3 to a DC-voltage, it becomes possible to monitor, for example, the voltage on a battery backup.

Table 3.1 Pin connections for the Power connector

Pin	Name	Description
1	L1	Wired to phase 1 of the building supply
2	N	Wired to the buildings Neutral
3	L2	Wired to phase 2 of the building's supply for split- and three-phase installations
4		Unused
5	L3	Wired to phase 3 of the building's supply for split- and three-phase installations

The CT connector

This connector is shown in Figure 3.7 and it provides 12 positions for the CT plugs. The silk-screened numbers indicate which CT should be connected to which pair of pins. The

CT Connector is rated for wiring one to twelve units of the CTs. The input voltage rating is 0.333 Vrms at the rated current. The input impedance is approximately 10k Ω at 50 Hz.

Figure 3.7 CT Connector

The CTs installed and connected to the meter are Split-core CTs from J&D Sensing, as shown in Figure 3.8. They offer a well-constructed hinged body and are accurate to +/- 1% from 1-100% of their stated current rating. The small interval for physical size options (10mm, 24mm, and 36mm) allows for a flexible installation. Each CT size has a hinge and clipping mechanism, making it easy to close the CT in tight situations.

Figure 3.8 Split-core CTs from J&D Sensing

Time reference

During normal operation, the eGauge maintains accurate time by synchronising with an NTP server, such as one of the public servers available at ntp.org. Since NTP provides atomic-clock accuracy, there is usually no need to set the time manually.

When the NTP server is not accessible, either temporarily (e.g. after a power failure) or permanently (e.g. at a remote site), the eGauge relies on a battery-backed real-time clock to maintain proper time.

The battery backup is designed only to cover relatively short power outages. Specifically, after a week of charging, the battery can maintain proper time for about one day. It takes approximately two months to fully charge the battery and, once fully charged, the battery is able to maintain proper time for about a week. Should the eGauge remain without power for longer than that, real time is lost. When power is restored after such an event, the eGauge will attempt to restore proper time via the NTP server. If unavailable, the device will fall back to using the time that was in effect when the last data item was recorded prior to the power failure.

Installation of eGauge system

The first step is to install the eGauge main unit. The eGauge main unit is generally installed inside or near the main breaker panel. The installer needs to determine whether or not the eGauge main unit (size 177.8 x 88.9 x 30.48 mm) can fit into the existing electrical panel. If not, a separate enclosure will be needed. The eGauge main unit has three voltage inputs, and twelve CT inputs. The eGauge main unit needs to be connected to each phase that you wish to monitor. The preferred method of connection is to hardwire the eGauge to a designated breaker. Two 15 A single-pole breakers or one double-pole 15 A or 20 A breaker will do the job in the standard residential 240 V system. When no available breaker slots are present, the connection may be accomplished by using a splice or insulated lug onto an existing circuit. Once eGauge is connected to the voltage, power up the device and check the signal to the home plug. The eGauge system uses split core CTs to monitor the current flow of a given conductor or circuit. A 200 A (31.75 mm) split core CT is generally used to monitor the main feeds from the utility. There is one CT on each phase of a 240 V system. The smaller 10.16 mm inner diameter split core CT is generally used to monitor circuits within a building application or in renewable energy generation. Each CT will have a CT plug and 2.4 m of wire. The CTs come in a variety of different sizes and amperage ratings. The eGauge main unit has twelve CT inputs slots.

Once the eGauge main unit and CTs have been installed, the installer must connect to the device and configure the device from the local area network. To configure the device, the installer must go to the settings option and then select INSTALLATION. The installer must then define the CTs that are used in the system.

The second section is the register's area. This area is where the installer defines the different items that are being monitored.

The final section is totalling. This is where the eGauge calculates the total net usage of energy. The installer must always save any changes.

The channel checker tool is a good tool to use when first commissioning a system to make sure you are getting readings from all voltage connections and CT inputs. The channel checker can also be found in the tools menu under channel checker.

The eGauge WEB Interface

The main screen of the eGauge web interface, as shown in Figure 3.9, presents current consumption and generation information with a live, high-resolution graph. The left portion of the graph displays recent historical data (most recent 24 hours in the example below), whereas the right portion is a gauge that is updated every second and displays current generation (green) and consumption (red).

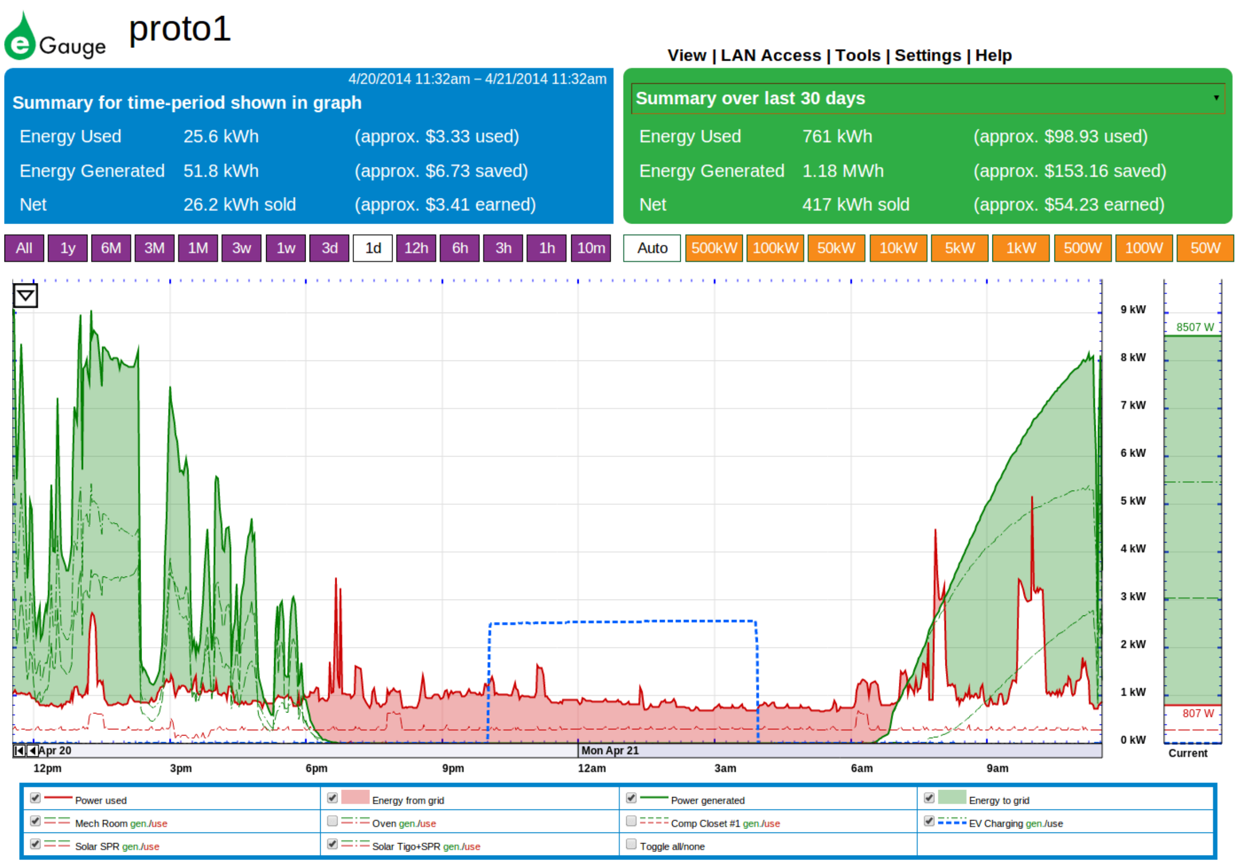

Figure 3.9 The main screen of the eGauge web interface

Benefits of using this meter

Installing an eGauge often pays for itself in a short amount of time. It poses the following benefits:

- ***Optimise your carbon footprint***

  Track your usage and compare it on a single screen to your renewable energy generation, helping you achieve net-zero energy consumption, maximise your payback and lower your monthly electricity bill.

- ***Lower your peak demand***

  With second-by-second updates, you will immediately see major loads turning on and off, giving you the tools needed to minimise peaks.

- ***Monitor your system health remotely***

  Since eGauge is accessible through the internet at no extra charge, you can easily check on your home and/or renewable energy system while travelling. For renewable energy-system installers, the eGuard Manager service provides a convenient way to monitor all your installed systems on a single screen and detect failures even before your customers do.

- ***Measure individual appliances***

  Use a single eGauge to meter up to twelve separate circuits or gang multiple eGauges together for virtually unlimited capacity.

Accessing the eGauge

Once the eGauge is installed, you can access it from any computer on your local area network (LAN) with a compatible web-browser. The related software will be configured accordingly.

Due to the limited number of current transformers (CTs) available, the building will be monitored two floors at a time, each floor for specific time periods.

The time periods for each floor will include their respective peak times (i.e. when lecture halls, laboratories, and offices are in full use), times of minimal occupancy, and various weather conditions, as per the different seasons.

Once the electrical measuring stage is complete, a load analysis is to be undertaken aiming at understanding the reasons for excessive energy consumption for the Engineering Technology Building (ETB) in operation at the Central University of Technology (CUT) in the Free State. Electrical demand profiles will be analysed, appliance usage patterns will be derived, and information on the daily occupancy and the key activities that take place within the case study building will be gathered.

In order to develop an energy management system as such, a summary of the building's electricity supply demand and equipment must be made to make informed choices.

A priority list will be drawn up of the equipment that is not to be controlled or switched off to less importance at a certain time to be controlled.

By using the obtained data, a data projection model will be attempted on a platform such as LabVIEW® or similar in operation to test different control strategies and will allow the possible practical implementation thereof that could lead to real-life cost savings.

This data projection model will involve time management, occupancy management and physical control of the on and/or off status of equipment. A human preference factor should also be considered in the implementation of this program.

Setup of CT connections and configurations

Figure 3.10 displays the setup of CT connections and configuration as connected to the meter and used throughout this thesis. This setup represents the management/monitoring configuration for one floor where the distribution board is comprised of four sections, with three CTs connected per section for red, white, and blue phases, respectively.

As mentioned above, Power, by definition, is work done per unit of time. Measured in Watts (W), electrical power is commonly acquired indirectly, by measuring the voltage and the current of the circuit. In alternating current (AC) circuits, instantaneous electrical power is calculated by multiplying the instantaneous values of the voltage and current:

Equation 3.1 is configured in the eGauge metering system software to deduce the real-time energy usage patterns as desired.

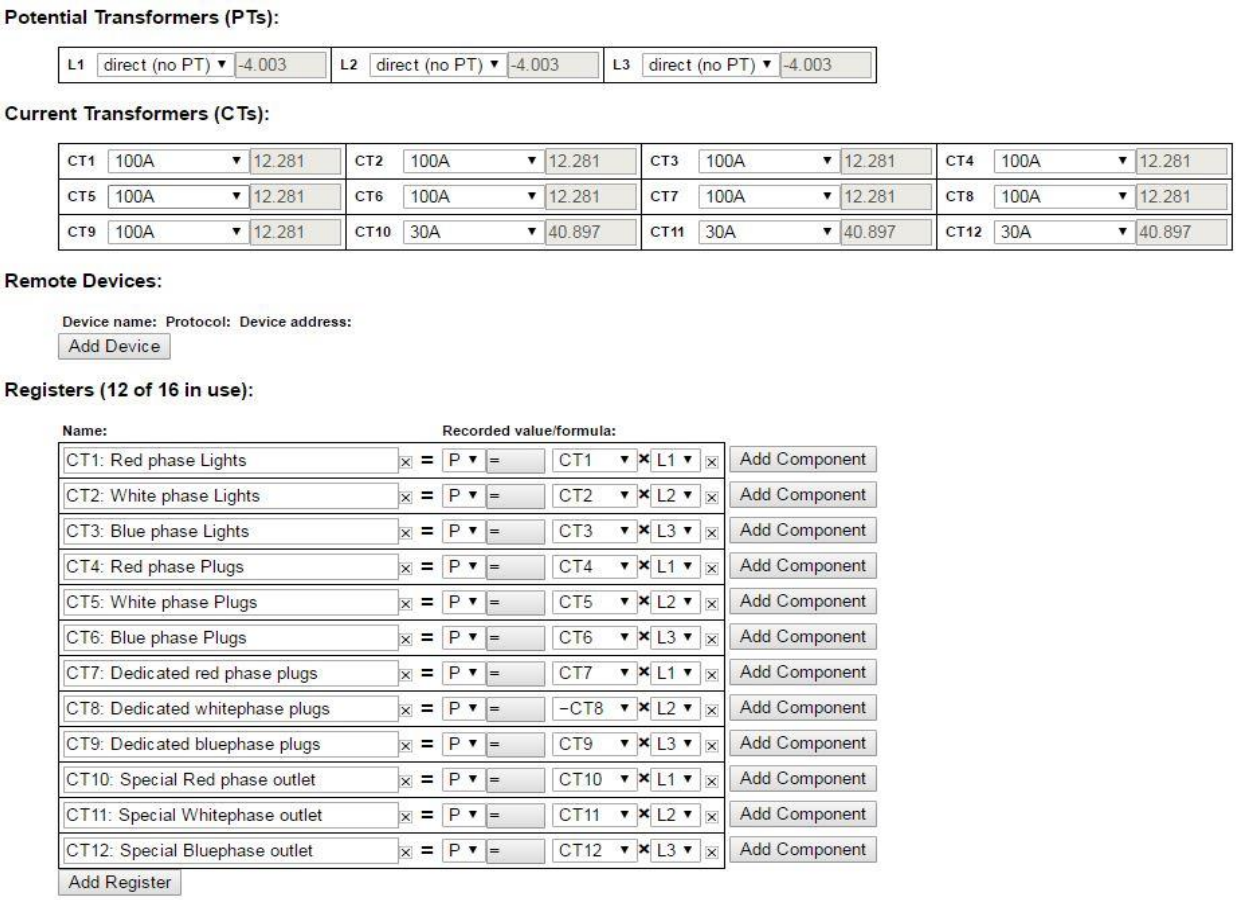

Figure 3.10 Setup of CT connections and configuration as connected to the meter

A real-time load analysis is undertaken aiming at understanding the reasons for excessive energy consumption for the Engineering Technology Building (ETB) in operation at the Central University of Technology (CUT) in the Free State. Electrical demand profiles are analysed, as well as information gathered on the daily occupancy and the key activities that take place within the case study building.

By using the proposed acquired data, a data projection model can be created on a platform such as LabVIEW® or similar in operation to test the different control strategies and will allow the possible practical implementation thereof that could lead to real-life cost savings.

3.5 The Prediction Strategy (Load Forecasting)

To predict the power demand within a building, it is necessary to consider numerous energy consuming elements, such as illumination, electric devices, Heating, Ventilation and Air Conditioning (HVAC) systems, and more [32]. Power consumption demand forecasting plays a central role in the process of power system planning and operation. The main purpose of forecasting is to meet future requirements, reduce unexpected cost and provide a potential input to decision making [33].

3.5.1 Prediction methods

The prediction methods are generally classified into two methods, namely ***statistical-based (classical) methods*** and ***artificial intelligence-based methods***. There is no clear preference of one group of methods over the other. It all depends on the application on hand. However, due to advents in computer technology, in the hardware and software areas, the artificial intelligence-based methods have recently overtaken the statistical-based methods and are being adopted by more users at present [33] and [34].

3.5.2 Prediction categories

According to the authors in [35], power consumption predictions can be classified into three categories, namely *short-term, medium-term and long-term predictions*.

- ***Short-term predictions:*** Covers hourly to weekly predictions. Factors to be considered are, time factors (time of year, day of week and hour of day), weather data and possible customer categories. These forecasts are often needed for day-by-day economic operations of power generation plants.

- ***Medium-term predictions:*** Deals with predictions ranging from weeks to a year. Outage scheduling and maintenance of plants and networks are often rooted in these types of forecasts.

- ***Long term prediction:*** Deals with predictions longer than a year. Factors to be considered are historical load and weather data, number of customers in different categories, number and types of appliances connected and their characteristics such age, economic and demographic data and their forecasts.

3.5.3 Ways of prediction

In [36] the author mentions that there are three main ways in which predictions can be done.

- **Expert Judgements:** Relies heavily on the experience and knowledge in similar forecasts environments and its success depends on historically maintained databases on load forecasts and their accuracy [37].

- **Linear Models:** Models of the unknown parameters are estimated from the data using linear functions and can be implemented using linear regression or time series [37].

- **Nonlinear Models:** Nonlinear regression fits a curve through the data by finding the values of those parameters that generate the curve that comes closest to the data. Examples of nonlinear methods include Artificial Neural Networks, Nonlinear Regression, Fuzzy Logic and Bayesian Networks [37].

According to the authors in [38], various power consumption prediction techniques have been used, including multiple regression, exponential smoothing, iterative reweighted least-squares, adaptive load forecasting, time series, genetic algorithms, fuzzy logic, expert systems and neural networks. They also observed a trend particularly towards neural network-based load forecasting.

The author in [39] observes that modern load prediction techniques, such as expert systems, ANN, and fuzzy logic, are particularly attractive as they have the ability to handle the nonlinear relationships between load and the factors affecting it directly from historical data. ANN are used for nonlinear short-term load prediction owing to their powerful nonlinear mapping capabilities [40].

3.5.4 Prediction techniques

The issue of obtaining reliable prediction methods for electricity consumption has been widely discussed by past research [41]. This is due to the increased demand for electricity and as a result, the development of efficient pricing models. Various techniques have been used in past research to predict power consumption [41].

This includes the use of Forecasting, Time-series Technique (FTST) [42], Artificial Neural networks (ANN) [43] and Modified Newton's model (MNM) [44].

Several other methods such as the regression method, time of delay method, Moving Average method, Straight Line method and Kalman Filtering model have been used in the past.

Moving Average method

This section introduces the Moving Average type to forecast energy consumption. Forecasting models are developed from historical data and predictive estimates are obtained.

Moving Averages are used to gauge the direction of a specific trend. Every type of Moving Average is a mathematical result that is calculated by averaging a number of past data points. Once determined, the resulting average is then plotted onto a chart in order to allow data analysts to look at smoothed data rather than focusing on the day-to-day fluctuations.

The simplest form of a Moving Average is calculated by taking the arithmetic mean of a given set of values. In other words, a set of numbers are added together and then divided by the number of readings in the set.

As new values become available, the oldest data points are dropped from the set and new data points come in to replace them. Thus, the data set is constantly "moving" to account for new data as it becomes available. This method of calculation ensures that only the current information is being accounted for.

Some of the primary functions of a Moving Average are to:

- Identify trends and reversals;
- Reduce the effect of temporary variations in data;

- Improve the 'fit' of data to a line (a process called 'smoothing') to show the data's trend more clearly; and
- Highlight any value above or below the related trend.

Moving Average means we calculate the median of the averages of the data set we have. Microsoft® Excel has a built-in feature for the calculation of Moving Average which is available in the data analysis tab in the analysis section. It takes an input range and output range with intervals as an output.

Calculations based on mere formulas in Microsoft® Excel to calculate Moving Average is difficult, but the built-in function is of great help.

$$Simple\ moving\ average = \frac{[P1+P2+ \ldots\ldots\ldots +Pn]}{n} \qquad 3.17$$

Straight Line method

The Straight Line method is one of the simplest, easy-to-follow forecasting methods. Historical figures and trends of energy usage are used to predict future usage.

Function description

The Microsoft® Excel Forecast function predicts a future point on a linear trend line fitted to a supplied set of x- and y-values.

The syntax of the function is:

FORECAST(**x, known_y's, known_x's**)

Where the arguments are as follows:

x - A numeric x-value for which you want to forecast a new y-value

known_y's - An array of known y-values.

known_x's - An array of known X-values.

Note that the length of the **known_x's** array should be the same length as **known_y's** and the variance of the **known_x's** must not be zero.

Forecast Equations

The Microsoft® Excel Forecast Function calculates a new y-value using the simple Straight Line equation:

$$y = a + bx \qquad 3.18$$

where,

$$a = \bar{y} - b\bar{x} \qquad 3.19$$

and

$$b = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\Sigma(x-\bar{x})^2} \qquad 3.20$$

and the values of $\bar{x}$ and $\bar{y}$ are the sample means (the averages) of the known x- and y-values.

Kalman Filter method

The Kalman Filter method in Microsoft® Excel as well as in Simulink in Matlab® are explored in this section. The Kalman filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process in a way that minimises the mean of the squared error.

The filter is very powerful in several aspects: it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modelled system is unknown [45].

Figure 3.11 shows the three calculations of the Kalman Filter to make a prediction.

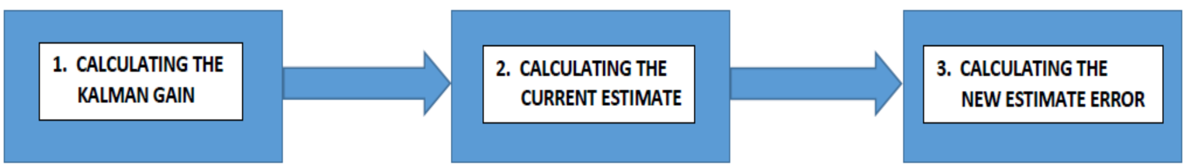

Figure 3.11 The three calculations of Kalman Filter

$$KG = E_{EST}/(E_{EST} + E_{MEA}) \quad 3.21$$

$$EST_t = EST_{t-1} + KG(MEA - EST_{t-1}) \quad 3.22$$

$$E_{ESTt} = (E_{MEA})(E_{ESTt-1})/\,(E_{MEA}) + (E_{ESTt-1}) \quad 3.23$$

Where:

KG	=	Kalman Gain
E_{EST}	=	Error in estimate
E_{MEA}	=	Error in measurement
EST_t	=	Current estimate
EST_{t-1}	=	Previous estimate
MEA	=	Measurement
E_{ESTt}	=	New estimate error

Kalman gain is the relative weight given to the measurements and current state estimate and can be "tuned" to achieve a particular performance.

Chapter 4

Development of Control System

This chapter gives a background of the case study building that has been identified, including the local plan of the building as well as the floor and section plans of the building. Setup of measuring equipment and distribution board outlets for the ground and second floor, as well as monitoring of power consumption for the ground and second floor are discussed. It also provides a background of the power consumption profiles for different seasons and types of days, the effects of air temperature and building occupants on power consumption, and the prediction of power consumption for the second floor.

4.1 Case Study Building

This dissertation observes a case study building that has been identified, as shown in Figure 4.1, and an electrical measuring strategy is implemented for obtaining data representing the electrical consumption of the related inherent systems and equipment of the building. The case study building, the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein, was developed from the need for additional facilities at the Faculty of Engineering.

Figure 4.1 The Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

For practical reasons, the new four-storey building, which covers 3 850 m², needed spacing in close proximity to the existing facilities. The building was orientated on an east-west axis to retain the northern aspect of the existing building and accommodate additional parking needs, as shown in Figure 4.2. The new building also acts as a gateway to the ZR Mahabane Administration Building, connecting the administration facilities to the rest of the campus. To respond to the east-west orientation, the openings on the west façade were reduced to a minimum. This also counteracts traffic noise on the busy President Brand Street adjacent to the building. The section of the building under study is comprised of four levels, namely the lower ground floor, the ground floor, the first floor, and the second floor, each with "mixed building" features such as lecture halls, laboratory rooms, bathrooms, kitchens and offices.

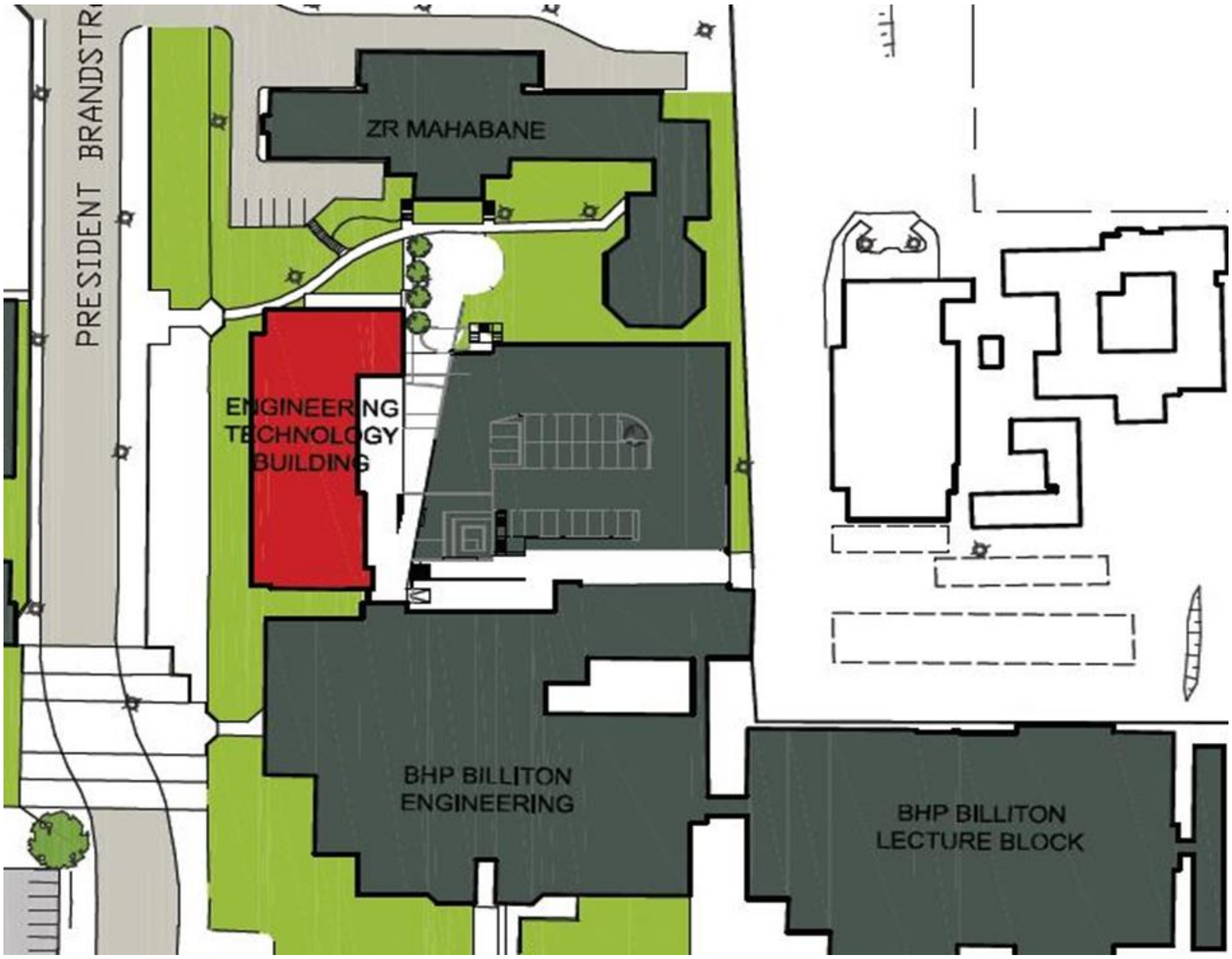

Figure 4.2 Locality plan around the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein with the case study building encircled

In contrast to the enclosed laboratories and lecture halls, the eastern façade is more transparent in order to create a sense of orientation within the building and allow light into the circulation areas.

The eastern elevation with its three-storey glass curtain walls opens up to the campus. All the classrooms and laboratories pour out into the three-storey entrance atrium, which centralises all the activity and acts as a breathing space for the building, as indicated on the floor and section plans of the Engineering Technology Building (ETB) shown in Appendix A, Figures A.1 to A.7.

The external spaces are further defined by smaller projecting concrete canopies that bring the building down to human scale. The choice of materials, namely concrete, steel, aluminium, brick and glass, and the rectilinear design signal the new building's kinship with the original structure and celebrate the scope of the engineering curriculum presented here.

The building investigates how infill architecture can reanimate campus space (i.e. the spaces between buildings) and in a physical sense reflects the transformation of the institution into a centre of excellence.

4.2 Setup of Measuring Equipment

The electrical measuring strategy implemented in the Engineering Technology Building (ETB) included a set of dedicated current transformers (CTs), strategically placed on each outgoing circuit, connected to an already installed eGauge metering system which allows for remote monitoring of real-time energy usage. This setup represents the management/monitoring configuration for one floor where the distribution board is comprised of four sections, with three CTs connected per section for red, white and blue phases, respectively.

Since the first and second floors are similar, in that both are comprised of a similar laboratory room, bathroom and office setup, it was discussed that the usage patterns should prove to be similar. For this reason, as well as due to the limited number of current transformers (CTs) available, only the ground floor and the second floor were monitored and analysed.

Current transformers (CTs) were installed on the ground floor level and the second-floor level. The current transformers (CTs) were connected to an already installed eGauge metering system which allows for remote monitoring of real-time energy usage and the related software was configured accordingly.

4.3 The Distribution Board Outlet

Figure 4.3 shows the distribution board layout of the ground floor. The main switch of the distribution board is a 300 A circuit breaker. From the 300 A main circuit breaker, there are four circuit breakers that feed the light circuits, plug circuits, dedicated plug circuits and special point circuits, as indicated in the Figure 4.3.

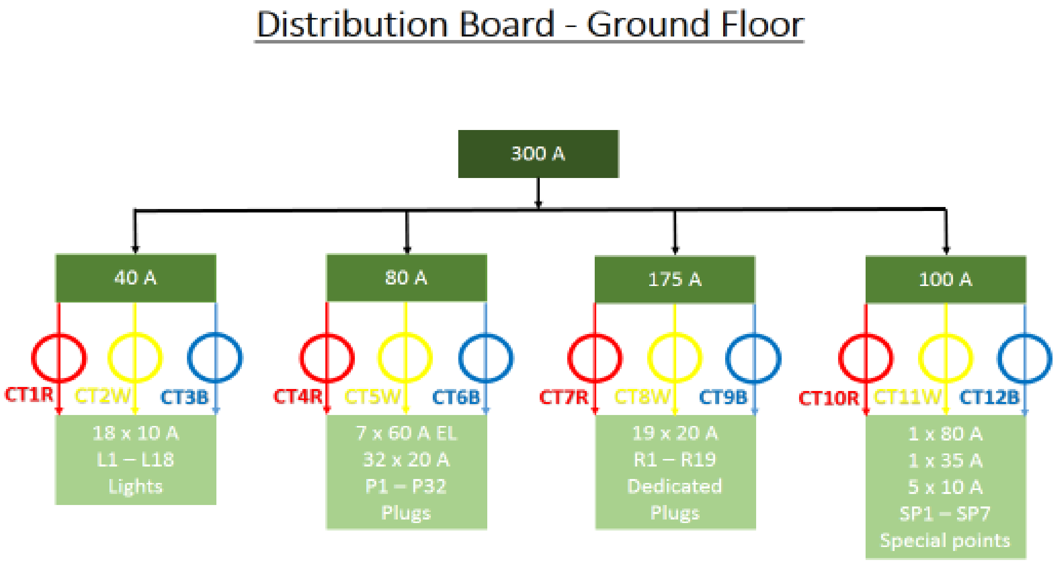

Figure 4.3 *The Distribution Board layout of ground floor showing Circuit Breaker current ratings, as well as Current Transformer installations on each respective outgoing circuit*

The lights are fed from a 40 A circuit breaker and then divided into eighteen outgoing circuits, each with a 10 A circuit breaker. The outgoing circuits are then divided between the three phases namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the lights in each of the phases.

The plugs are fed from an 80 A circuit breaker and then divided into seven outgoing circuits, each with a 60 A earth leakage. From the seven earth leakages, there are thirty-two outgoing circuits, each with a 20 A circuit breaker. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the plugs in each of the phases.

The dedicated plugs are fed from a 175 A circuit breaker and then divided into nineteen outgoing circuits, each with a 20 A circuit breaker. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the dedicated plugs in each of the phases.

The special points are fed from a 100 A circuit breaker and then divided into seven outgoing circuits. The seven outgoing circuits consist of one circuit with an 80 A circuit breaker, one circuit with a 35 A circuit breaker, and five circuits with a 10 A circuit breaker each. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the special points in each of the phases.

Figure 4.4 shows the distribution board layout of the second floor. The main switch of the distribution board is a 300 A circuit breaker. From the 300 A main circuit breaker there are four circuit breakers that feed the light circuits, plug circuits, dedicated plug circuits and special point circuits as indicated in the Figure 4.4.

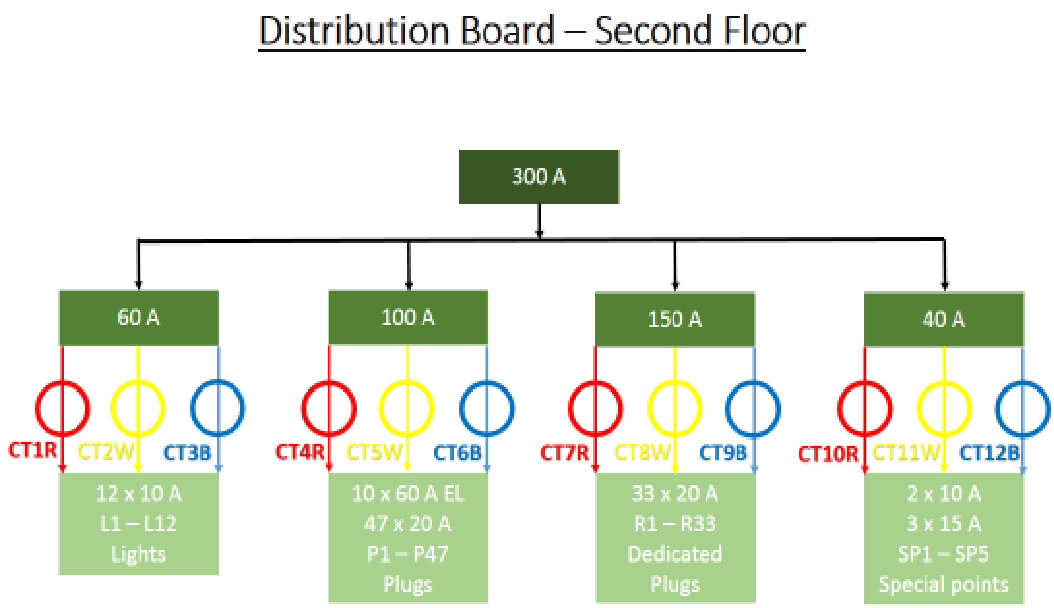

Figure 4.4 The Distribution Board layout of Second floor showing Circuit Breaker current ratings, as well as Current Transformer installations on each respective outgoing circuit

The lights are fed from a 60 A circuit breaker and then divided into twelve outgoing circuits, each with a 10 A circuit breaker. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the lights in each of the phases.

The plugs are fed from a 100 A circuit breaker and then divided into ten outgoing circuits, each with a 60 A earth leakage. From the ten earth leakages there are forty-seven outgoing circuits, each with a 20 A circuit breaker. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase.

The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the plugs in each of the phases.

The dedicated plugs are fed from a 150 A circuit breaker and then divided into thirty-three outgoing circuits, each with a 20 A circuit breaker. The outgoing circuits are then divided between the three phases namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the dedicated plugs in each of the phases.

The special points are fed from a 40 A circuit breaker and then divided into seven outgoing circuits. The seven outgoing circuits consist of two circuits with a 10 A circuit breaker each and three circuits with a 15 A circuit breaker each. The outgoing circuits are then divided between the three phases, namely the red phase, the white phase and the blue phase. The current transformers (CTs) are then linked to the three different phases to monitor the power consumption of the special points in each of the phases.

Table 4.1 shows the legend for the symbols and terms used in the two distribution boards on the ground and second floor as shown in Figures 4.3 and 4.4.

Table 4.1 Legend for symbols and terms from the distribution Board layout

SYMBOL / TERM	DEFINITION
CT1R ○	Installation of Red phase 30A/100A Current Transformer
CT4R ○	Installation of Red phase 30A/100A Current Transformer
CT7R ○	Installation of Red phase 30A/100A Current Transformer
CT10R ○	Installation of Red phase 30A/100A Current Transformer
CT2W ○	Installation of White/Yellow phase 30A/100A Current Transformer
CT5W ○	Installation of White/Yellow phase 30A/100A Current Transformer
CT8W ○	Installation of White/Yellow phase 30A/100A Current Transformer
CT11W ○	Installation of White/Yellow phase 30A/100A Current Transformer
CT3B ○	Installation of blue phase 30A/100A Current Transformer
CT6B ○	Installation of blue phase 30A/100A Current Transformer
CT9B ○	Installation of blue phase 30A/100A Current Transformer
CT12B ○	Installation of blue phase 30A/100A Current Transformer
Lights	Outgoing circuits supplying lights
Plugs with EL	Outgoing circuits supplying plugs with Earth Leakage
Dedicated plugs	Outgoing circuits supplying dedicated plugs
Special points	Outgoing circuits supplying the Special Points (HVAC system)

The generated data was captured and the second floor and ground floor were used to demonstrate the analysis of sections of the data, as well as to prove the working of the projection model.

The data were split into sections, allowing one to analyse the respective outgoing circuits as individual components, namely the outgoing circuits supplying lights, the outgoing circuit supplying plugs with earth leakages, the outgoing circuits supplying dedicated plugs and the outgoing circuits supplying the special points (HVAC system). The data from all circuits combined was then analysed to determine the electrical demand profile as a whole.

Since HVAC systems are said to be the largest energy end use where inefficient operation and maintenance of such systems can cause energy wastage, poor indoor air quality and even environmental damage, the outgoing circuits supplying the HVAC system were analysed separately and its usage patterns were correlated to that of the varying temperature readings.

4.4 Power Consumption – Second Floor

Figure 4.5 shows the power consumption in kW of the second floor from March 2017 to May 2018. From each current transformer (Ct) installation we have the accumulated energy consumption. In other words, we have actual real-world data to work with. The red curve represents the total power consumed and the green curves represent the power consumed for each outgoing circuit measured by the current transformers (CTs) installed on each of the outgoing circuits.

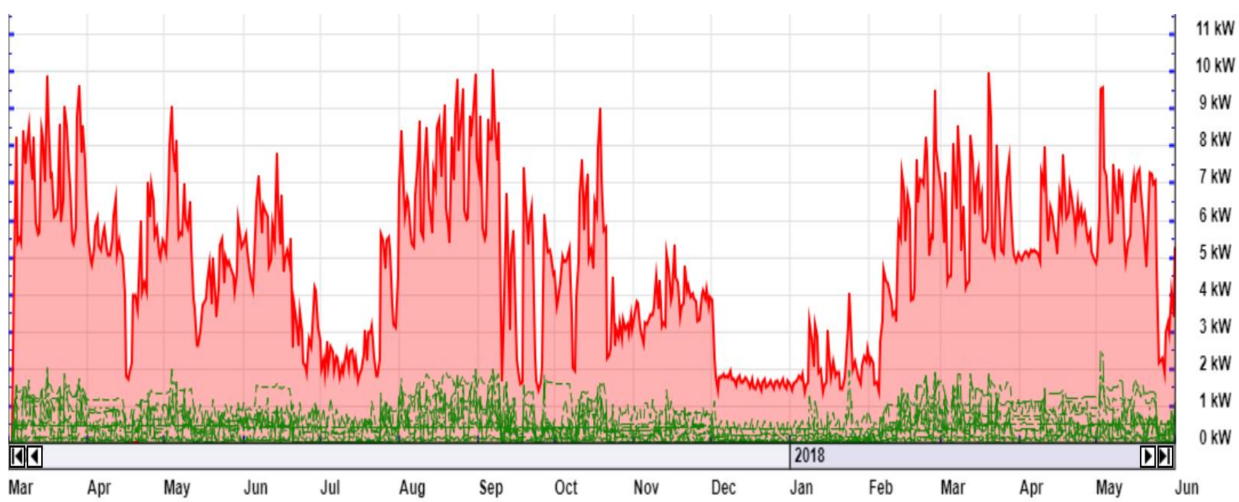

Figure 4.5 Total Power consumption in kW of the second floor – March 2017 to May 2018

Figures 4.6 and 4.7 show a typical power consumption profile for March 2017 and May 2018, respectively. From each current transformer (Ct) installation, we have the accumulated energy consumption per hour (kWh). See Appendix A, Figures A.8 to A.20, for the power consumption profiles for April 2017 to April 2018.

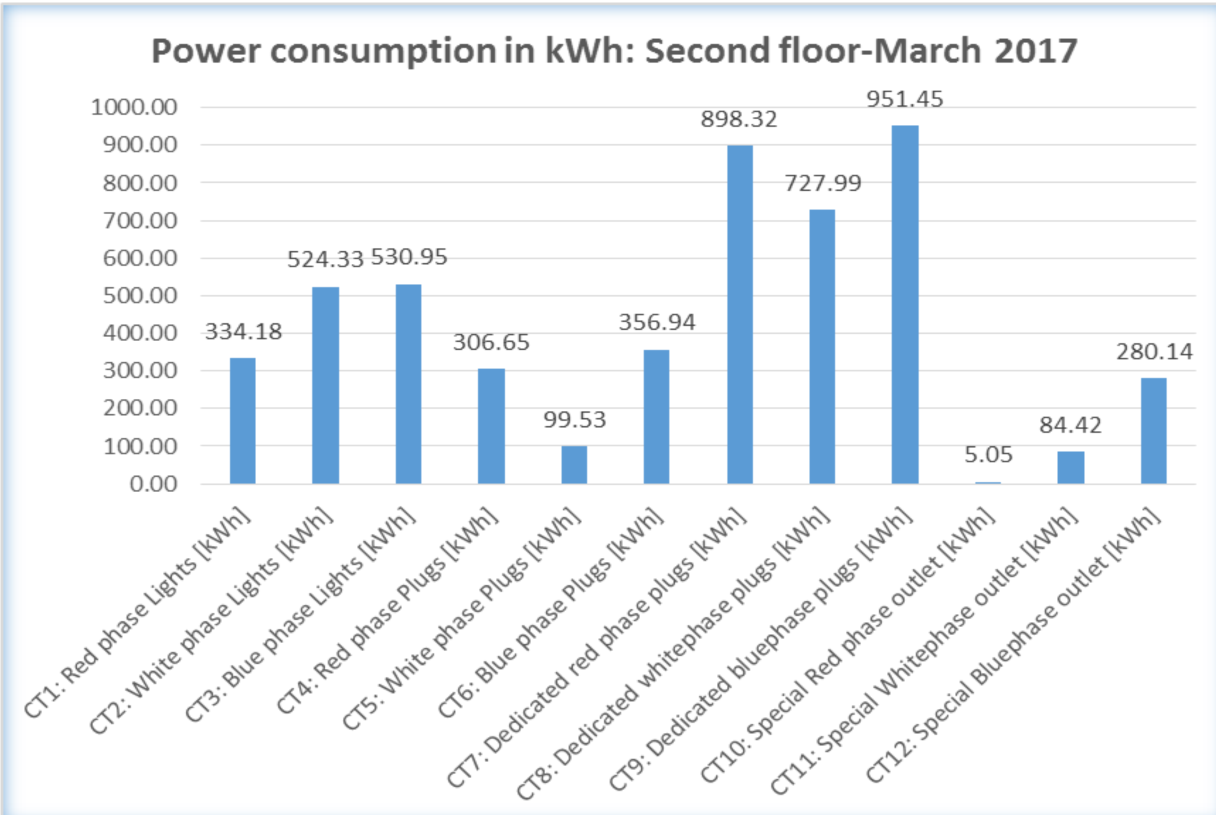

Figure 4.6 Power consumption in kWh of the second floor – March 2017

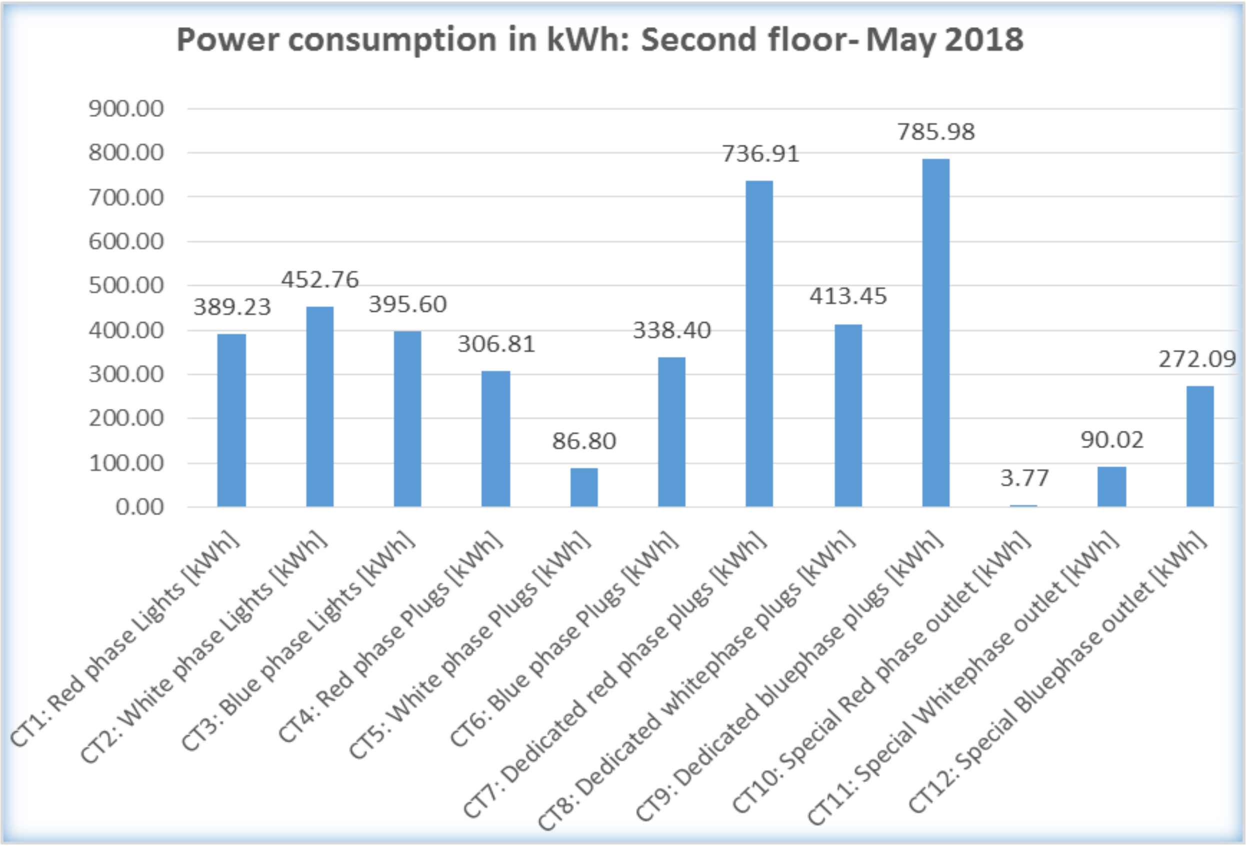

Figure 4.7 Power consumption in kWh of the second floor – May 2018

Figure 4.8 shows the total energy consumption in kWh per month, of the second floor. There is a clear difference in power consumption in the semester during lectures, as seen during March 2017, April 2017, June 2017, August 2017, September 2017, October 2017, November 2017, February 2018, March 2018, April 2018 and May 2018. During the holidays, however, when no lectures are presented, power consumption is much less likely to be observed (e.g. during July 2017, December 2017 and January 2018).

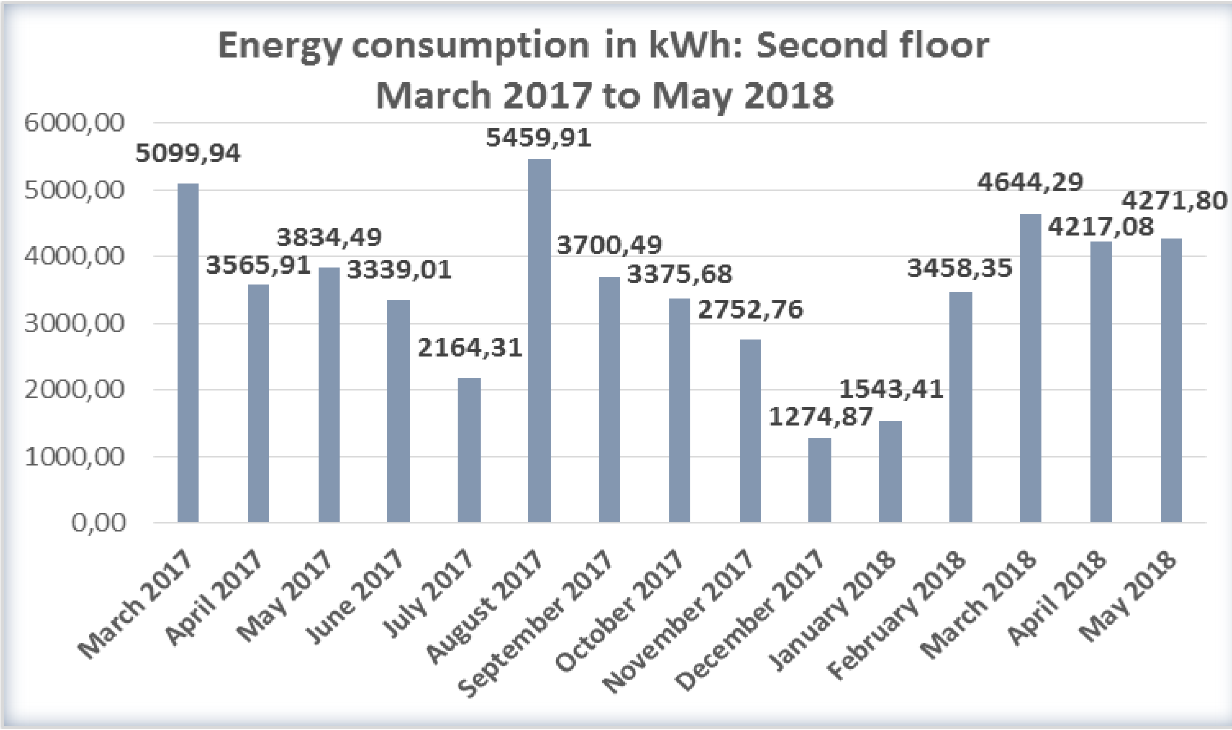

Figure 4.8 Total energy consumption in kWh per month of the second floor

Tables 4.2 and 4.3 show the overall metered circuit usage in kWh and the total usage in kWh, respectively, of the second floor. The total power consumption for the period 1 March 2017 to 31 May 2018 was 52.70233 MWh. The cost per kWh is approximately R1.36 per kWh, thus, the total cost for the second floor amounts to approximately R 71 675.17 for thirteen months. The average per month was approximately R5 513.48.

Table 4.2 Overall circuit usage in kWh of the second floor

Overall circuit usage in kWh: Second floor - March 2017 to May 2018											
Lights usage in kWh			Plugs usage in kWh			Dedicated plugs usage in kWh			Special points usage in kWh		
4761.51	3992.54	7402.56	3825.79	930.20	4646.73	8752.73	5524.17	7896.89	45.15	1325.61	3598.45
16156.60			9402.72			22173.79			4969.21		

Table 4.3 Total usage in kWh of the second floor

Total usage in kWh: Second floor - March 2017 to May 2018
52702.33

Table 4.4 shows the overall percentage usage for the lights, plugs, dedicated plugs and special points for said period. Figure 4.9 shows the pie-chart of the overall percentage usage of the lights, plugs, dedicated plugs and special points for the same period. Evidently, the dedicated plugs and lights circuits are responsible for more than seventy percent of the total power consumption. The reason for this is that there are two large computer laboratories where there are more than 150 computers.

Table 4.4 Overall percentage usage of the second floor

Overall percentage usage: Second floor - March 2017 to May 2018			
Lights usage in kWh	**Plugs usage in kWh**	**Dedicated plugs usage in kWh**	**Special points usage in kWh**
31%	**18%**	**42%**	**9%**

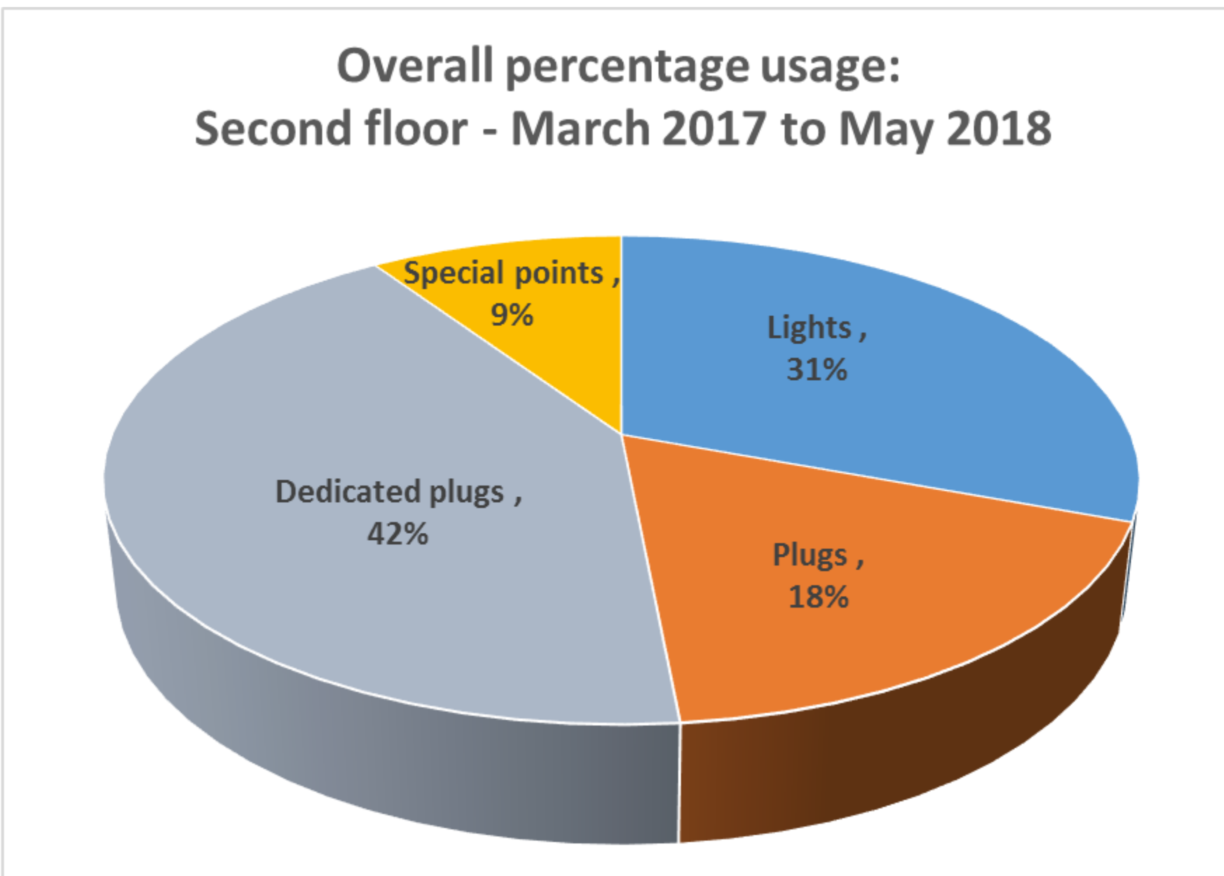

Figure 4.9 Pie-chart of overall percentage usage of the second floor

4.5 Power Consumption – Ground Floor

Figure 4.10 shows the power consumption of the ground floor from September 2017 to May 2018. From each current transformer (Ct) installation, we have the accumulated energy consumption. In other words, we have real-world data to work with. The red curve represents the total power consumed and the green curves represent the power consumed for each outgoing circuit measured by the current transformers (CTs) installed on each of the outgoing circuits.

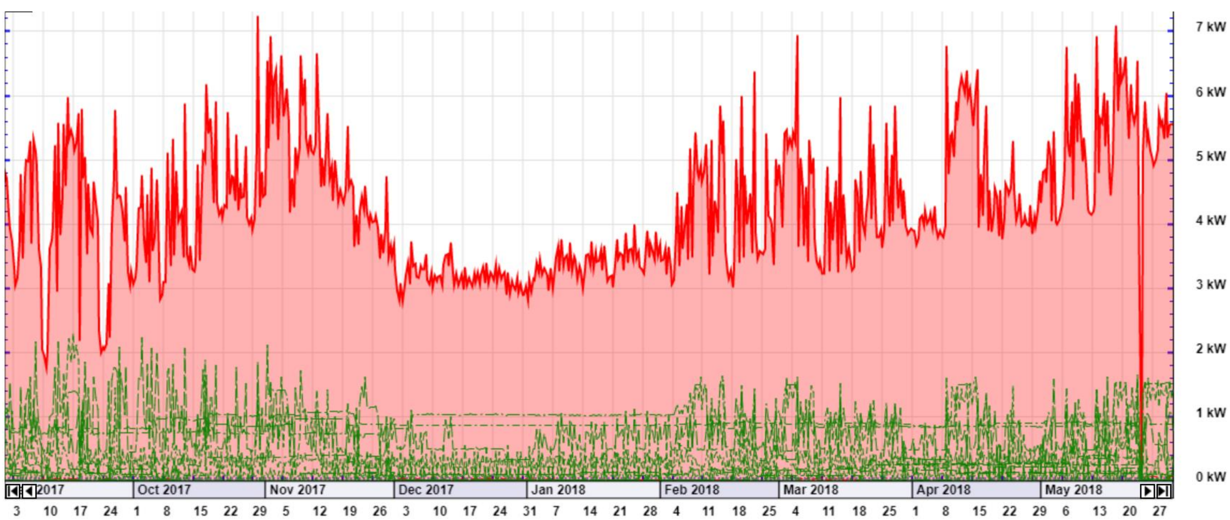

Figure 4.10 Total Power consumption in kW of the ground floor – September 2017 to March 2018

Figures 4.11 and 4.12 show a typical power consumption profile for September 2017 and May 2018, respectively. From each current transformer (Ct) installation, we have the accumulated energy consumption per hour (kWh). See Appendix A, Figures A.21 to A.27, for the power consumption for October 2017 to April 2018.

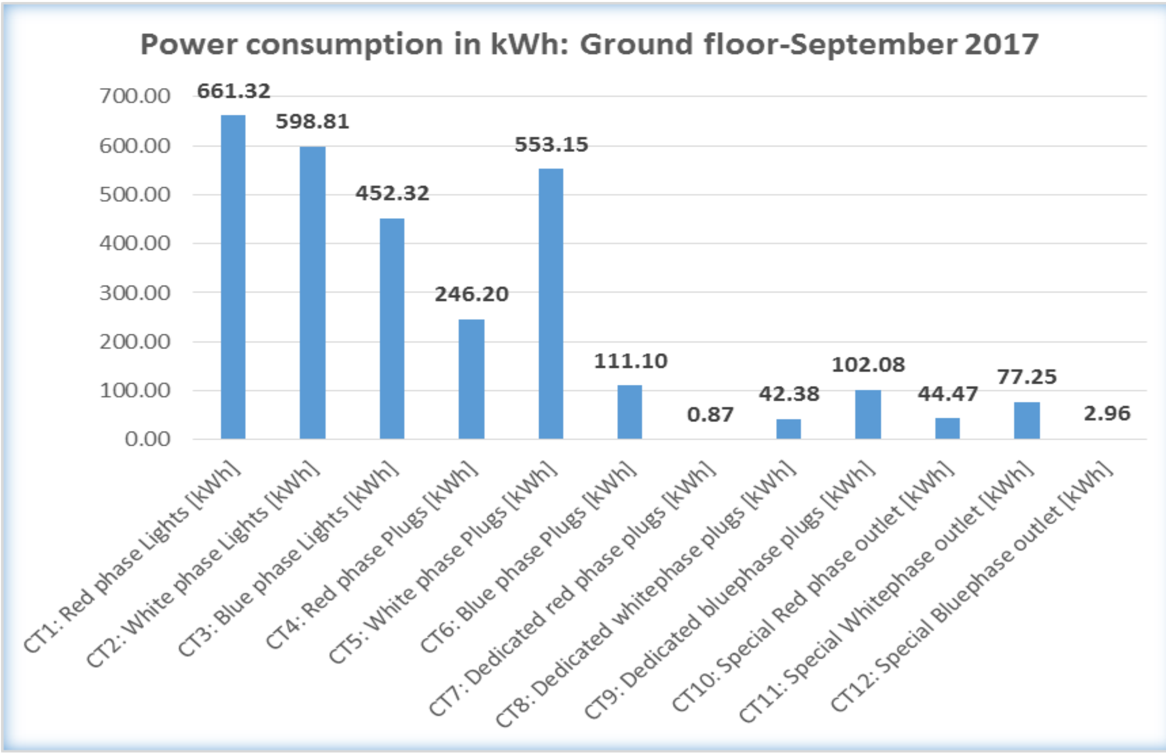

Figure 4.11 Power consumption in kWh of the ground floor – September 2017

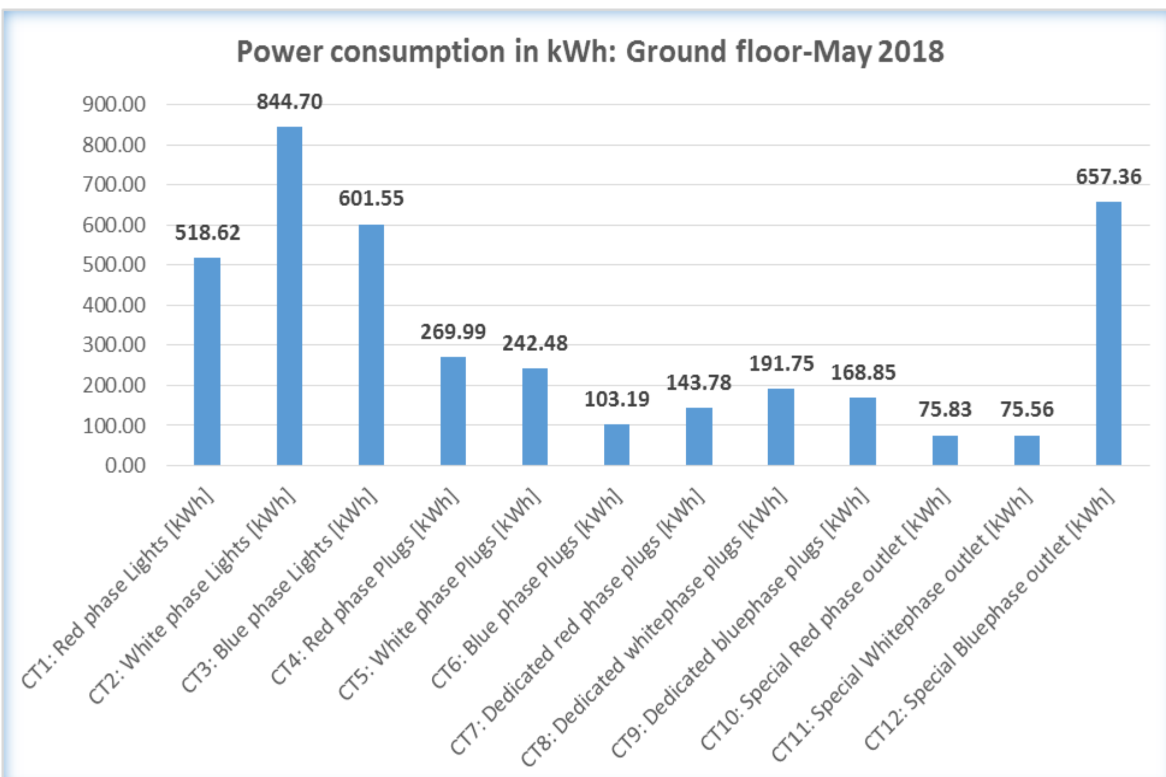

Figure 4.12 Power consumption in kWh of the ground floor – May 2018

Figures 4.13 shows the total energy consumption in kWh per month, of the ground floor. There is a clear difference in power consumption in the semester during lectures, as seen during September 2017, October 2017, November 2017, February 2018, March 2018, April 2018 and May 2018.

During the holidays when no lectures are presented, power consumption is much less likely to be seen (e.g. during December 2017 and January 2018).

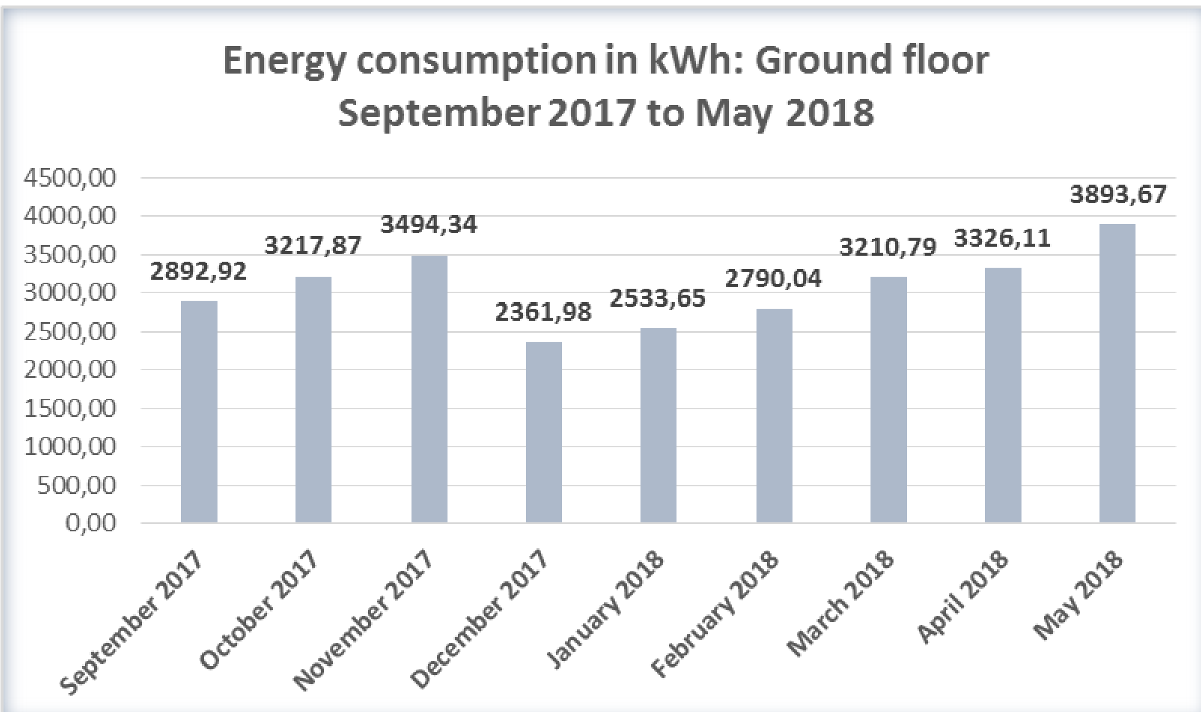

Figure 4.13 Total energy consumption in kWh per month of the ground floor

Tables 4.5 and 4.6 show the overall circuit usage in kWh and the total usage in kWh, respectively, of the ground floor. The total power consumption for the period 1 September 2017 to 31 May 2018 was 27.72136 MWh. The cost per kWh is approximately R1.36 per kWh, so the total cost for the ground floor amounts to approximately R 37 701.05 for nine months. The average cost per month is approximately R4 189.01.

Table 4.5 Overall circuit usage in kWh of the ground floor

Overall circuit usage in kWh: Ground floor - September 2017 to May 2018											
Lights usage in kWh			Plugs usage in kWh			Dedicated plugs usage in kWh			Special points usage in kWh		
4914,84	6339,10	3407,86	2097,75	986,97	1960,13	412,99	837,83	1681,01	346,11	682,66	4054,12
14661,79			5044,85			2931,83			5082,89		

Table 4.6 Total usage in kWh of the ground floor

Total usage in kWh: Ground floor - September 2017 to May 2018
27721.36

Table 4.7 shows the overall percentage usage for the lights, plugs, dedicated plugs and special points for said period. Figure 4.14 shows the pie-chart of the overall percentage usage of the lights, plugs, dedicated plugs and special points for the same period. It can be observed that the light circuits are responsible for more than fifty percent of the total power consumption. The reason for this is that there is a large lecture room that is used for lectures the whole day, and there are also a lot of security lights that burn during the night.

Table 4.7 Overall percentage usage of the ground floor

Overall percentage usage: Ground floor - September 2017 to May 2018			
Lights usage in kWh	Plugs usage in kWh	Dedicated plugs usage in kWh	Special points usage in kWh
53%	18%	11%	18%

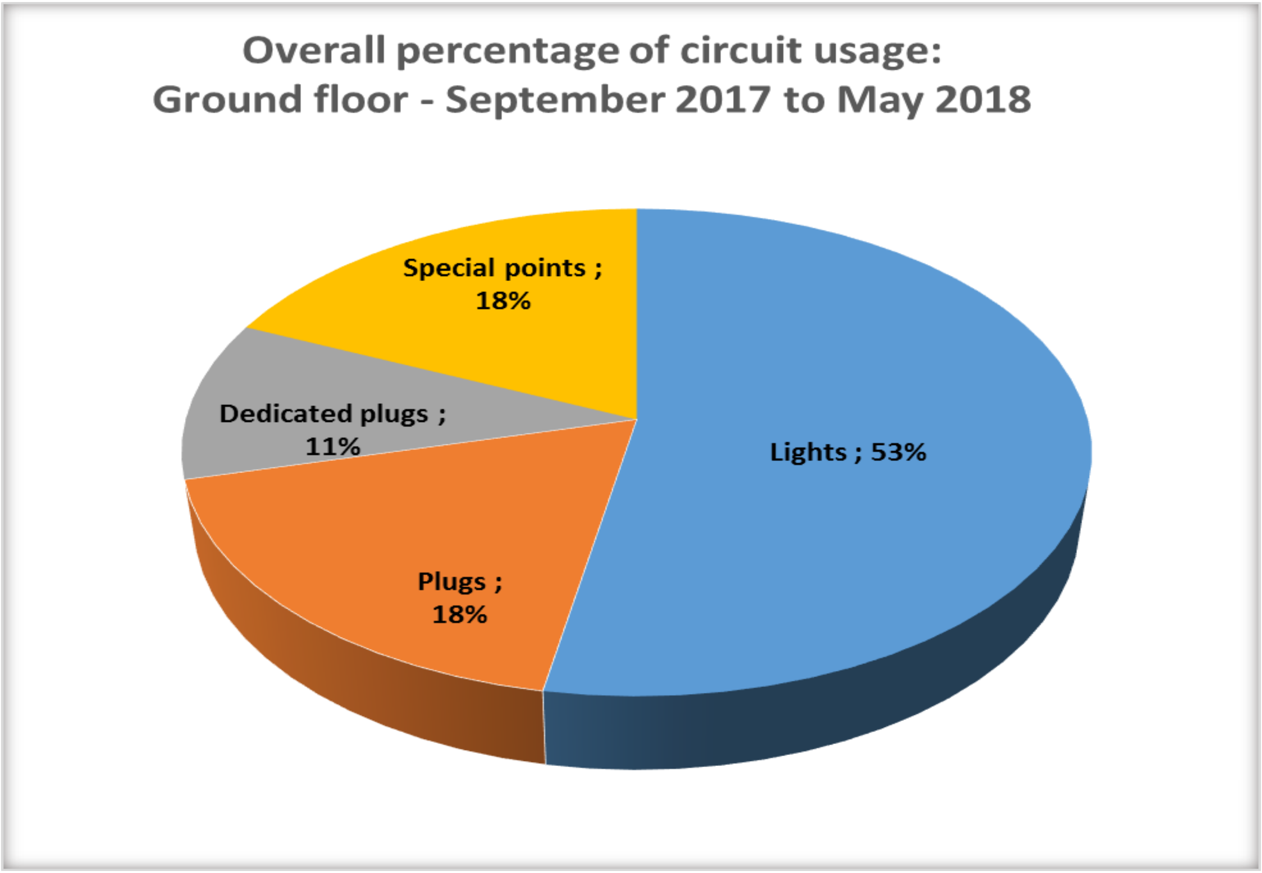

Figure 4.14 Pie-chart of overall percentage usage of the ground floor

4.6 Power Consumption Profiles

Working day and non-working day

To predict the power demand within the building, it is necessary to consider numerous energy consuming elements, such as illumination, electric devices, HVAC systems, and so forth. Table 4.8 shows the average power consumption in kWh of the second floor under several conditions (different season and types of days).

Table 4.8 Average power consumption in kWh under several conditions

Average power consumption in kWh for working and non-working days		
Time	**Working day**	**Non-working day**
12:00:00 AM to 01:00:00 AM	**5.43**	**5.68**
01:00:00 AM to 02:00:00 AM	**5.49**	**5.54**
02:00:00 AM to 03:00:00 AM	**5.41**	**5.60**
03:00:00 AM to 04:00:00 AM	**5.37**	**5.62**
04:00:00 AM to 05:00:00 AM	**5.29**	**5.37**
05:00:00 AM to 06:00:00 AM	**4.60**	**4.69**
06:00:00 AM to 07:00:00 AM	**5.19**	**4.89**
07:00:00 AM to 08:00:00 AM	**6.24**	**4.85**
08:00:00 AM to 09:00:00 AM	**8.96**	**4.88**
09:00:00 AM to 10:00:00 AM	**9.32**	**4.77**
10:00:00 AM to 11:00:00 AM	**9.22**	**4.77**
11:00:00 AM to 12:00:00 PM	**9.16**	**4.79**
12:00:00 PM to 01:00:00 PM	**9.08**	**4.74**
01:00:00 PM to 02:00:00 PM	**8.89**	**5.07**
02:00:00 PM to 03:00:00 PM	**8.98**	**5.14**
03:00:00 PM to 04:00:00 PM	**8.60**	**5.00**
04:00:00 PM to 05:00:00 PM	**7.30**	**4.88**
05:00:00 PM to 06:00:00 PM	**7.09**	**5.46**
06:00:00 PM to 07:00:00 PM	**6.51**	**5.51**
07:00:00 PM to 08:00:00 PM	**6.26**	**5.38**
08:00:00 PM to 09:00:00 PM	**6.05**	**5.34**
09:00:00 PM to 10:00:00 PM	**5.65**	**5.37**
10:00:00 PM to 11:00:00 PM	**5.78**	**5.30**
11:00:00 PM to 12:00:00 AM	**5.71**	**5.40**

The main differences according to typical power demand profiles between working and non-working days have been studied, as presented in Figure 4.15. A typical day for each demand profile, considering working and non-working days, has been selected.

It can be observed that the power demand on working days begins to increase around 08:00 am and starts to decrease at 05:00 pm, reaching a stationary value around 09:00 pm.

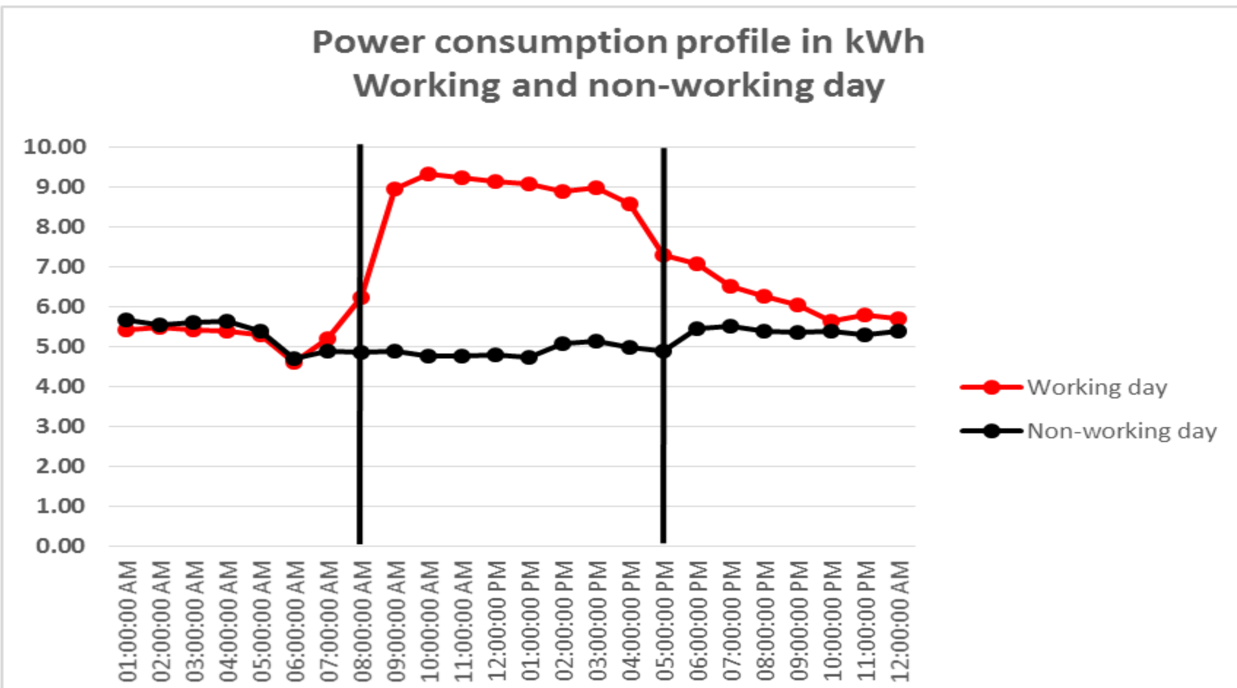

Figure 4.15 Energy demand profiles for working and non-working days

Different seasons

A detailed examination of the power consumption of the ETB-building through a typical week (from Monday to Sunday), along with different environmental conditions has been performed, as shown in Tables 4.9 to 4.15. The power consumption in kWh, was monitored every hour for 24 hours a day, starting at 12:00:00 AM each day, as shown in Tables 4.9 to 4.15

The main objectives of this analysis were to determine if there were representative differences among the different seasons of the year and to identify if there was any characteristic element of the building able to considerably influence its power consumption. More specifically, as it can be deduced from Figures 4.16 to 4.22, the different seasons of the year follow an analogous pattern among working and non-working days.

In addition, it can also be inferred that autumn and winter seasons present a higher power demand in comparison with spring and summer. However, along with the different seasons, there are several power demand peaks that do not follow any specific pattern associated with the type of day.

Table 4.9 Power consumption data in kWh for a Monday for each season

Daily power consumption data for each season				
Monday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	3.92	5.75	5.90	2.42
02:00:00 AM	3.84	5.68	5.53	2.37
03:00:00 AM	3.59	5.92	5.57	2.65
04:00:00 AM	3.65	5.60	5.94	2.52
05:00:00 AM	3.29	5.67	5.54	2.19
06:00:00 AM	3.20	4.81	4.87	1.93
07:00:00 AM	3.99	6.61	4.91	1.97
08:00:00 AM	5.44	7.08	7.23	2.28
09:00:00 AM	6.51	9.05	10.77	6.13
10:00:00 AM	7.97	10.36	10.64	8.18
11:00:00 AM	7.86	9.54	10.15	7.59
12:00:00 PM	8.32	9.76	8.41	8.83
01:00:00 PM	10.82	10.18	7.74	7.40
02:00:00 PM	10.56	11.21	9.54	7.59
03:00:00 PM	9.54	10.06	9.63	7.43
04:00:00 PM	9.38	10.20	10.29	5.25
05:00:00 PM	7.06	9.37	8.31	3.38
06:00:00 PM	5.59	9.13	8.79	5.83
07:00:00 PM	5.19	8.77	8.53	6.76
08:00:00 PM	5.09	7.22	8.28	6.06
09:00:00 PM	5.17	6.41	7.58	5.76
10:00:00 PM	5.08	6.16	6.10	3.88
11:00:00 PM	5.11	6.31	6.02	4.13
12:00:00 AM	5.26	6.19	6.02	3.86

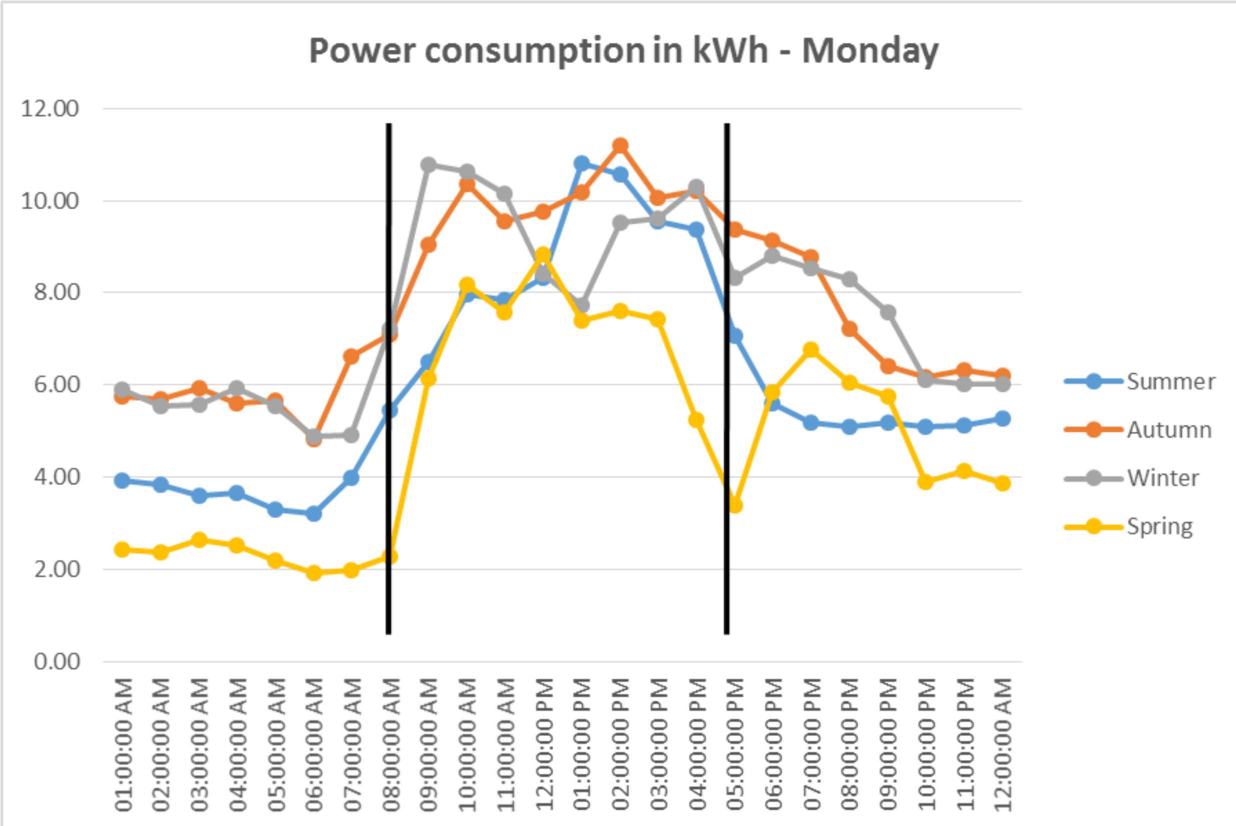

Figure 4.16 Energy consumption profiles for a Monday for each season

Table 4.10 Power consumption data in kWh for a Tuesday for each season

Daily power consumption data for each season				
Tuesday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	4.89	6.20	5.77	3.87
02:00:00 AM	5.02	6.26	6.11	4.03
03:00:00 AM	5.21	6.18	5.97	3.73
04:00:00 AM	4.97	6.15	6.06	3.78
05:00:00 AM	4.92	6.37	6.07	3.99
06:00:00 AM	4.39	5.11	4.91	3.09
07:00:00 AM	4.80	5.77	5.18	4.63
08:00:00 AM	6.88	7.64	8.24	5.59
09:00:00 AM	10.33	11.82	12.39	7.27
10:00:00 AM	9.96	12.27	11.90	8.32
11:00:00 AM	9.09	11.80	11.83	8.46
12:00:00 PM	9.49	10.68	11.61	8.38
01:00:00 PM	9.21	12.61	11.38	7.91
02:00:00 PM	7.41	11.37	11.12	5.95
03:00:00 PM	8.81	10.89	10.07	9.26
04:00:00 PM	8.92	10.03	8.56	9.50
05:00:00 PM	6.48	10.15	6.99	6.89
06:00:00 PM	6.54	11.42	7.38	5.40
07:00:00 PM	5.48	8.71	7.39	5.28
08:00:00 PM	5.48	7.67	6.13	5.19
09:00:00 PM	5.20	6.09	6.26	5.25
10:00:00 PM	5.29	5.70	6.15	4.84
11:00:00 PM	5.67	5.95	6.45	5.27
12:00:00 AM	5.32	5.81	6.20	4.93

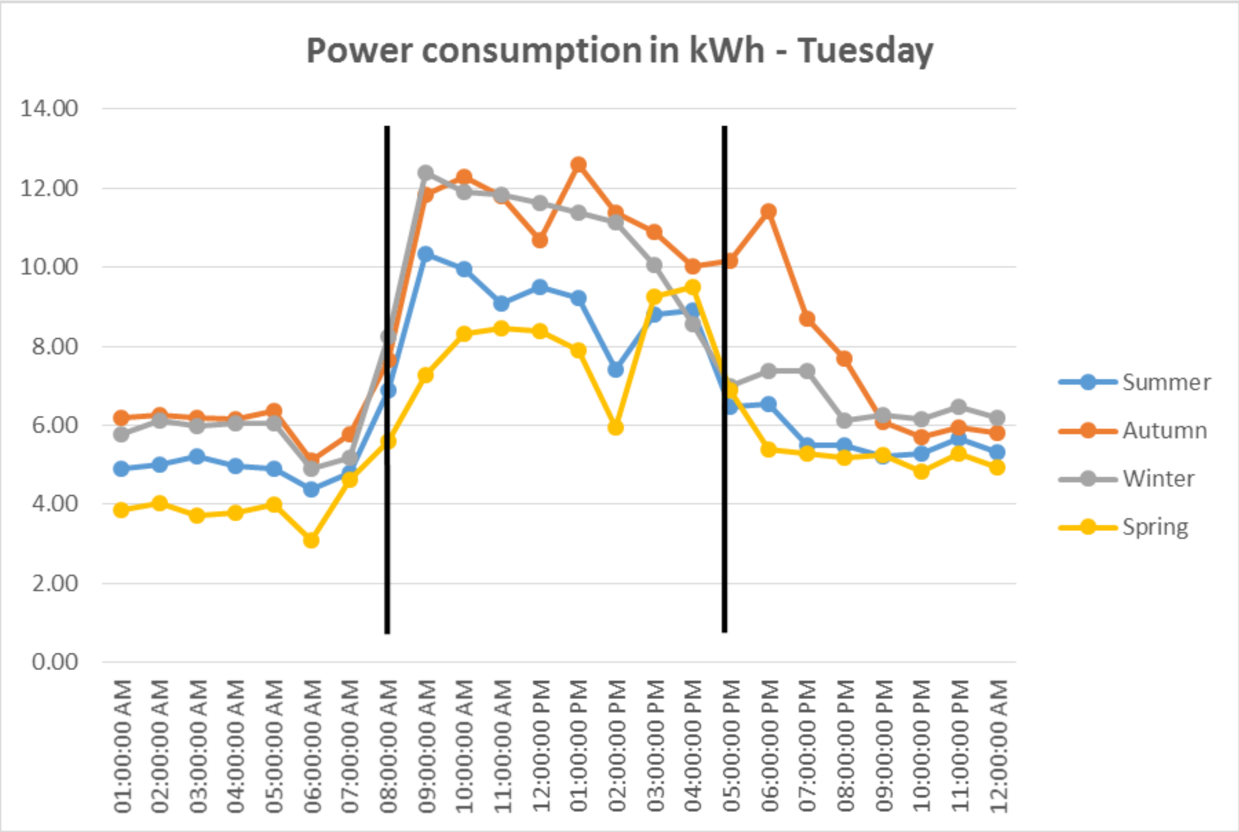

Figure 4.17 Energy consumption profiles for a Tuesday for each season

Table 4.11 Power consumption data in kWh for a Wednesday for each season

Daily power consumption data for each season				
Wednesday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	5.35	5.87	6.30	5.03
02:00:00 AM	5.61	6.04	6.45	5.27
03:00:00 AM	5.31	5.78	6.11	4.88
04:00:00 AM	5.36	5.78	6.15	4.90
05:00:00 AM	5.48	5.85	6.08	5.11
06:00:00 AM	4.69	5.21	5.50	4.18
07:00:00 AM	5.05	5.08	5.30	5.35
08:00:00 AM	5.48	5.06	5.22	6.09
09:00:00 AM	7.75	7.36	5.62	10.43
10:00:00 AM	7.48	9.08	5.32	11.28
11:00:00 AM	7.08	11.36	5.19	11.30
12:00:00 PM	7.69	10.49	5.59	9.45
01:00:00 PM	9.23	11.16	5.20	10.81
02:00:00 PM	9.63	10.70	5.32	11.52
03:00:00 PM	8.97	10.10	5.34	10.26
04:00:00 PM	7.90	8.57	5.55	9.19
05:00:00 PM	6.29	8.67	5.35	6.23
06:00:00 PM	6.63	9.00	5.49	6.84
07:00:00 PM	5.35	9.13	5.39	5.62
08:00:00 PM	5.03	8.77	5.73	5.52
09:00:00 PM	5.22	8.85	5.42	5.64
10:00:00 PM	5.21	6.65	5.48	5.42
11:00:00 PM	5.30	6.47	5.80	5.85
12:00:00 AM	5.02	6.77	5.44	5.48

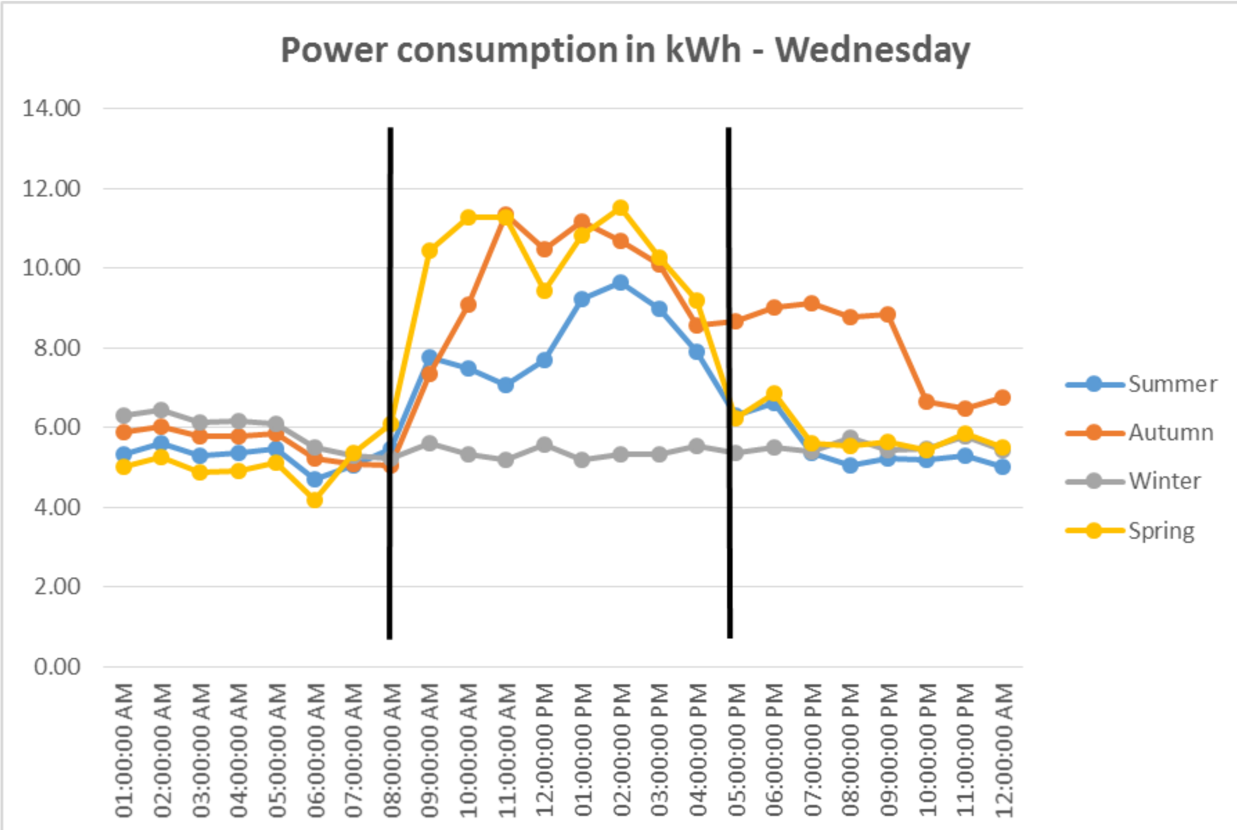

Figure 4.18 Energy consumption profiles for a Wednesday for each season

Table 4.12 Power consumption data in kWh for a Thursday for each season

Daily power consumption data for each season				
Thursday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	5.08	6.54	5.63	5.99
02:00:00 AM	5.45	6.61	5.51	5.45
03:00:00 AM	4.71	6.75	5.93	5.49
04:00:00 AM	4.63	6.55	5.48	5.87
05:00:00 AM	4.55	6.41	5.37	5.29
06:00:00 AM	3.69	5.74	5.12	4.74
07:00:00 AM	5.18	6.40	4.73	5.26
08:00:00 AM	4.99	7.29	6.51	5.91
09:00:00 AM	7.13	8.24	8.10	7.71
10:00:00 AM	6.50	8.95	8.37	7.87
11:00:00 AM	9.43	10.71	7.16	9.23
12:00:00 PM	10.92	11.80	6.03	9.31
01:00:00 PM	10.28	10.18	8.12	7.17
02:00:00 PM	8.75	9.75	7.73	7.47
03:00:00 PM	7.79	9.09	8.73	8.07
04:00:00 PM	7.72	10.24	8.72	6.39
05:00:00 PM	7.45	9.32	9.07	5.54
06:00:00 PM	5.77	8.44	8.15	5.65
07:00:00 PM	5.49	6.69	6.46	5.72
08:00:00 PM	5.39	6.68	6.42	5.62
09:00:00 PM	5.57	6.74	6.47	5.62
10:00:00 PM	5.32	6.58	6.23	5.51
11:00:00 PM	5.44	6.79	6.59	5.89
12:00:00 AM	5.64	6.88	6.23	5.66

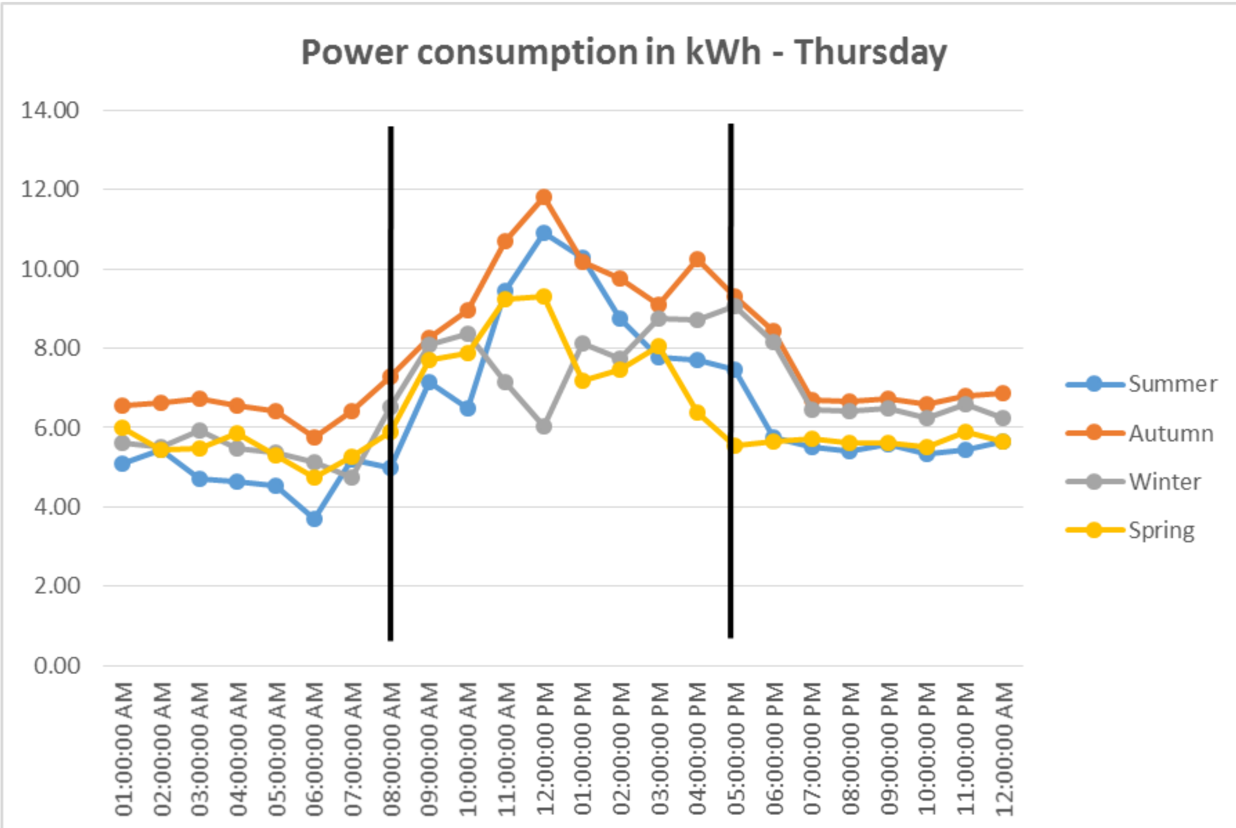

Figure 4.19 Energy consumption profiles for a Thursday for each season

Table 4.13 Power consumption data in kWh for a Friday for each season

Daily power consumption data for each season				
Friday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	5.30	6.71	6.48	5.54
02:00:00 AM	5.47	6.51	6.53	5.99
03:00:00 AM	5.67	6.88	6.24	5.55
04:00:00 AM	5.51	6.62	6.41	5.56
05:00:00 AM	5.26	6.61	6.28	5.43
06:00:00 AM	4.67	5.90	5.20	5.03
07:00:00 AM	6.26	6.49	5.45	5.36
08:00:00 AM	7.43	6.91	8.05	5.55
09:00:00 AM	10.84	11.08	11.22	9.46
10:00:00 AM	9.19	10.45	12.18	10.15
11:00:00 AM	8.39	9.27	10.43	8.63
12:00:00 PM	7.44	9.67	9.58	9.72
01:00:00 PM	4.99	8.74	9.27	9.13
02:00:00 PM	5.75	8.65	10.39	7.45
03:00:00 PM	5.70	10.89	10.52	8.41
04:00:00 PM	6.19	10.18	11.04	8.11
05:00:00 PM	5.73	8.88	8.19	6.64
06:00:00 PM	5.36	6.50	7.15	6.77
07:00:00 PM	4.79	6.40	7.08	5.90
08:00:00 PM	4.65	6.53	6.89	6.77
09:00:00 PM	4.11	6.42	6.81	6.41
10:00:00 PM	4.48	6.67	6.97	5.25
11:00:00 PM	4.27	6.34	6.78	5.21
12:00:00 AM	4.46	6.62	6.92	5.50

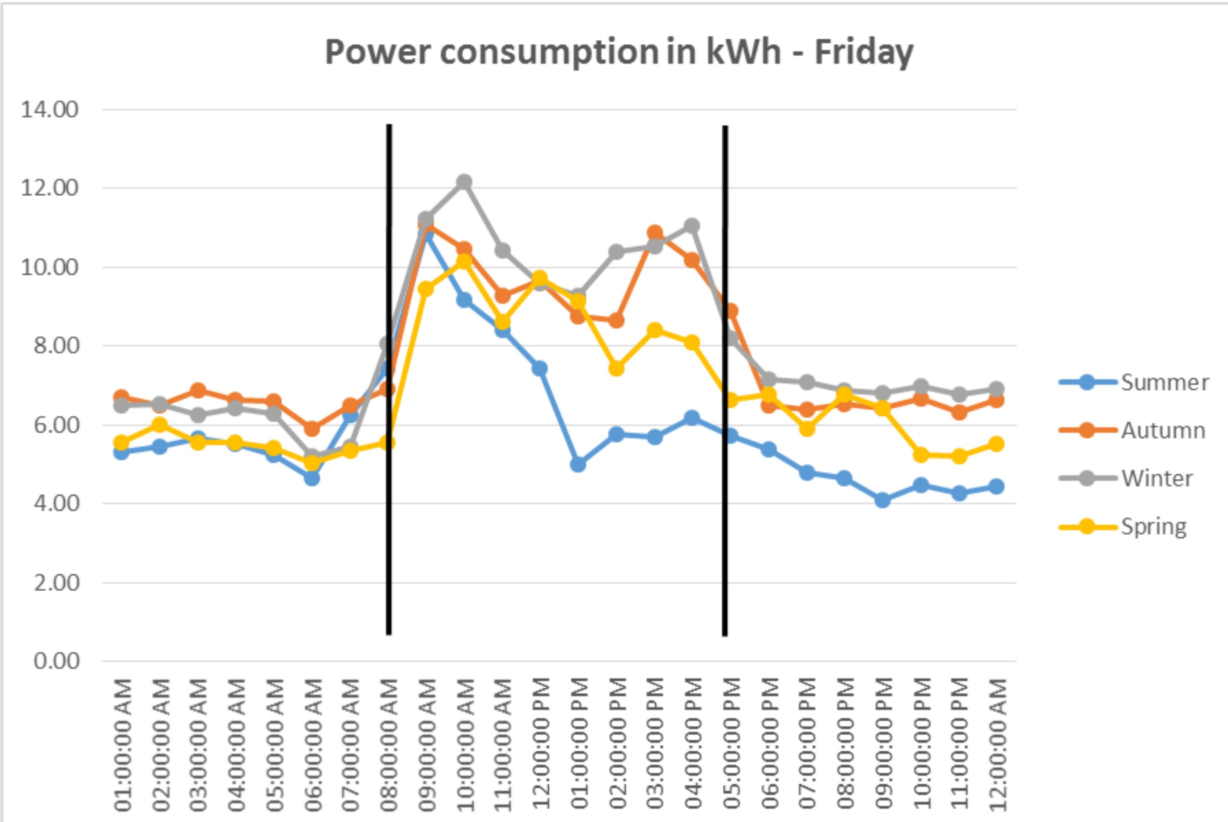

Figure 4.20 Energy consumption profiles for a Friday for each season

Table 4.14 Power consumption data in kWh for a Saturday for each season

Daily power consumption data for each season				
Saturday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	4.24	6.51	7.25	5.32
02:00:00 AM	4.15	6.65	7.13	5.24
03:00:00 AM	4.51	6.48	7.09	4.77
04:00:00 AM	4.40	6.53	7.41	4.98
05:00:00 AM	3.82	6.68	6.62	4.60
06:00:00 AM	3.26	5.46	5.73	4.22
07:00:00 AM	3.86	5.81	6.16	4.17
08:00:00 AM	3.38	5.83	5.76	4.33
09:00:00 AM	3.38	5.88	5.69	4.27
10:00:00 AM	3.56	5.67	6.00	4.55
11:00:00 AM	3.70	5.83	5.76	4.39
12:00:00 PM	3.35	5.85	5.75	4.36
01:00:00 PM	3.41	5.95	5.73	4.05
02:00:00 PM	3.48	5.60	6.01	5.87
03:00:00 PM	3.74	5.97	5.75	6.15
04:00:00 PM	3.46	5.79	5.96	5.69
05:00:00 PM	3.56	4.97	6.13	4.80
06:00:00 PM	3.93	5.85	6.52	5.45
07:00:00 PM	3.95	5.91	6.50	5.13
08:00:00 PM	4.35	5.70	6.73	5.06
09:00:00 PM	4.01	5.68	6.41	5.53
10:00:00 PM	3.94	6.02	6.59	5.15
11:00:00 PM	4.05	5.65	6.41	5.07
12:00:00 AM	4.32	5.83	6.79	5.17

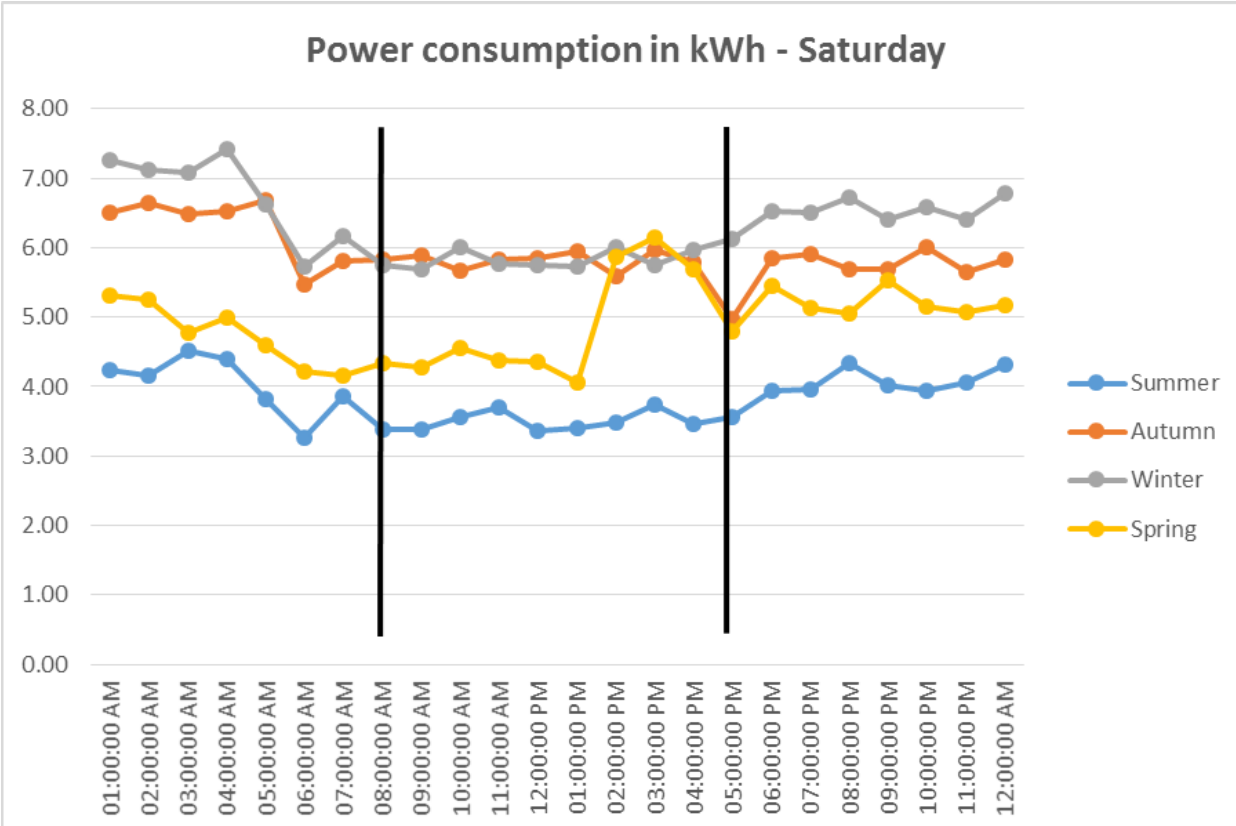

Figure 4.21 Energy consumption profiles for a Saturday for each season

Table 4.15 Power consumption data in kWh for a Sunday for each season

Daily power consumption data for each season				
Sunday	**Summer**	**Autumn**	**Winter**	**Spring**
12:00:00 AM				
01:00:00 AM	4.03	6.17	6.45	5.49
02:00:00 AM	4.00	5.69	6.42	5.04
03:00:00 AM	4.07	5.70	6.96	5.20
04:00:00 AM	4.08	6.07	6.47	5.05
05:00:00 AM	4.07	5.65	6.27	5.28
06:00:00 AM	3.23	5.51	5.71	4.44
07:00:00 AM	3.40	5.11	6.11	4.51
08:00:00 AM	3.56	5.34	5.92	4.66
09:00:00 AM	3.73	5.04	6.06	5.00
10:00:00 AM	3.41	5.13	5.31	4.55
11:00:00 AM	3.44	5.32	5.19	4.50
12:00:00 PM	3.35	5.15	5.43	5.10
01:00:00 PM	4.02	5.13	5.13	4.53
02:00:00 PM	4.26	5.37	5.34	4.60
03:00:00 PM	4.12	5.17	5.55	4.70
04:00:00 PM	4.01	5.19	5.27	4.58
05:00:00 PM	4.22	5.02	5.29	5.06
06:00:00 PM	4.80	6.10	5.90	5.14
07:00:00 PM	4.64	6.58	6.45	4.91
08:00:00 PM	4.57	5.76	6.00	4.90
09:00:00 PM	4.84	5.73	5.93	4.62
10:00:00 PM	4.49	5.84	6.36	4.59
11:00:00 PM	4.47	6.09	5.84	4.85
12:00:00 AM	4.62	5.89	5.93	4.63

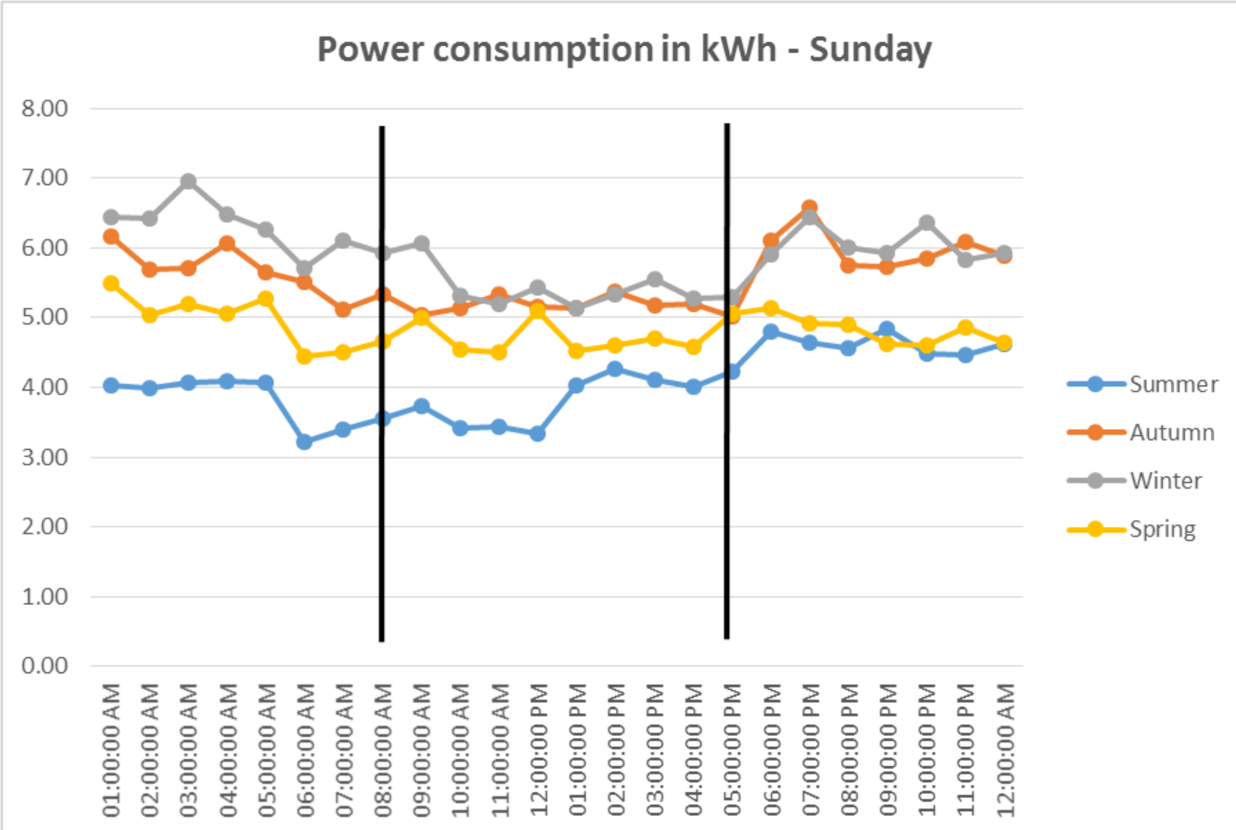

Figure 4.22 Energy consumption profiles for a Sunday for each season

Finally, the inferred conclusion, which has been reached after this detailed analysis can be summarised as follows:

- Power consumption demand profile differs during the days in the week and season.
- There are also differences between the power consumption profiles of working and non-working days.

4.7 Effects of Air Temperature and Building Occupants on Power Consumption

The second floor of the ETB-building consists mainly of offices and two large computer laboratories. A typical day consists mainly of thirteen (13) periods of 40 minutes each with a 5-minute break between periods. Period 1 starts at 7:55 in the morning and period 13 ends at 17:40 in the afternoon.

An investigation has been conducted to determine whether air temperature and building occupants affect the power consumption. The power consumption of the second floor was monitored from Monday, 6 March 2017, to Sunday, 12 March 2017, as shown in Figure 4.23, and from Monday, 13 March 2017, to Sunday, 19 March 2017, as shown in Figure 4.24.

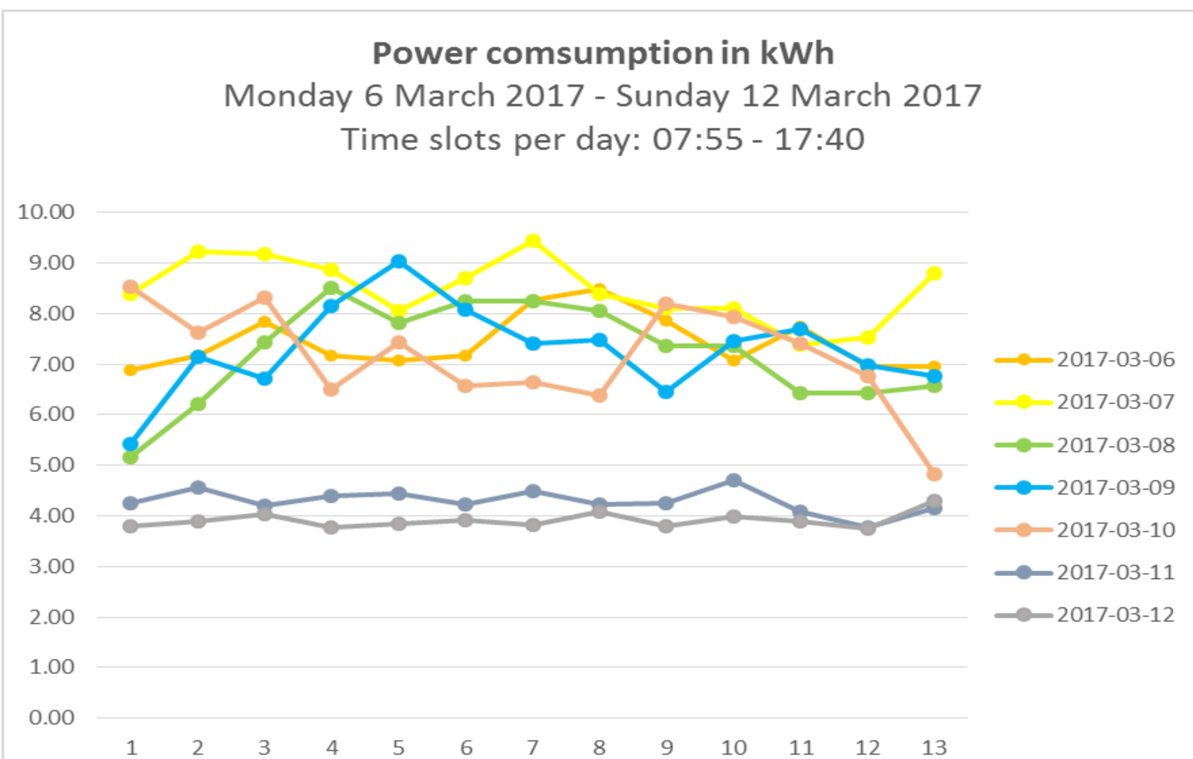

Figure 4.23 Power consumption in kWh per day for week one

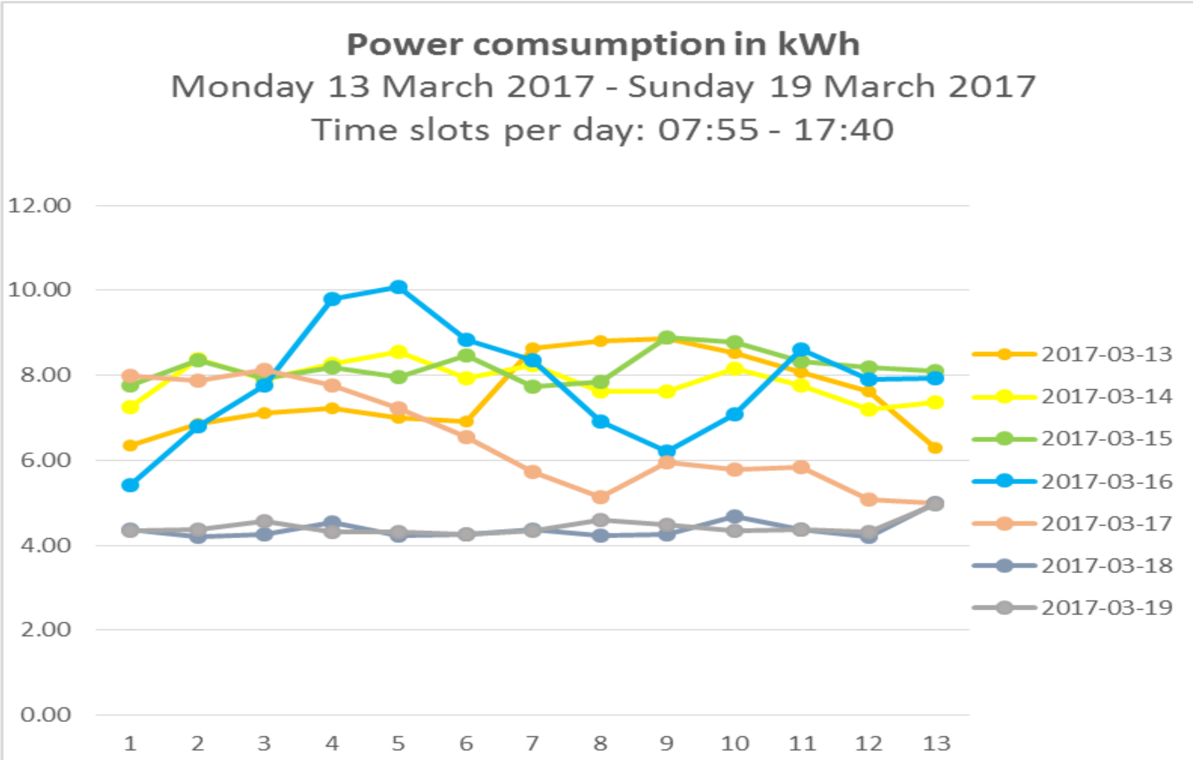

Figure 4.24 Power consumption in kWh per day for week two

The total power consumption per day for the period Monday, 6 March 2017, to Sunday, 12 March 2017, is shown on the pie-chart in Figure 4.25.

It can be observed that the total power consumption throughout the week amounts to approximately 595.17 kWh of which 488.54 kWh is consumed during the week and 106.63 kWh over the weekend.

This gives an average power consumption of 97,708 kWh per day during the week and an average of 53,325 kWh per day over the weekend.

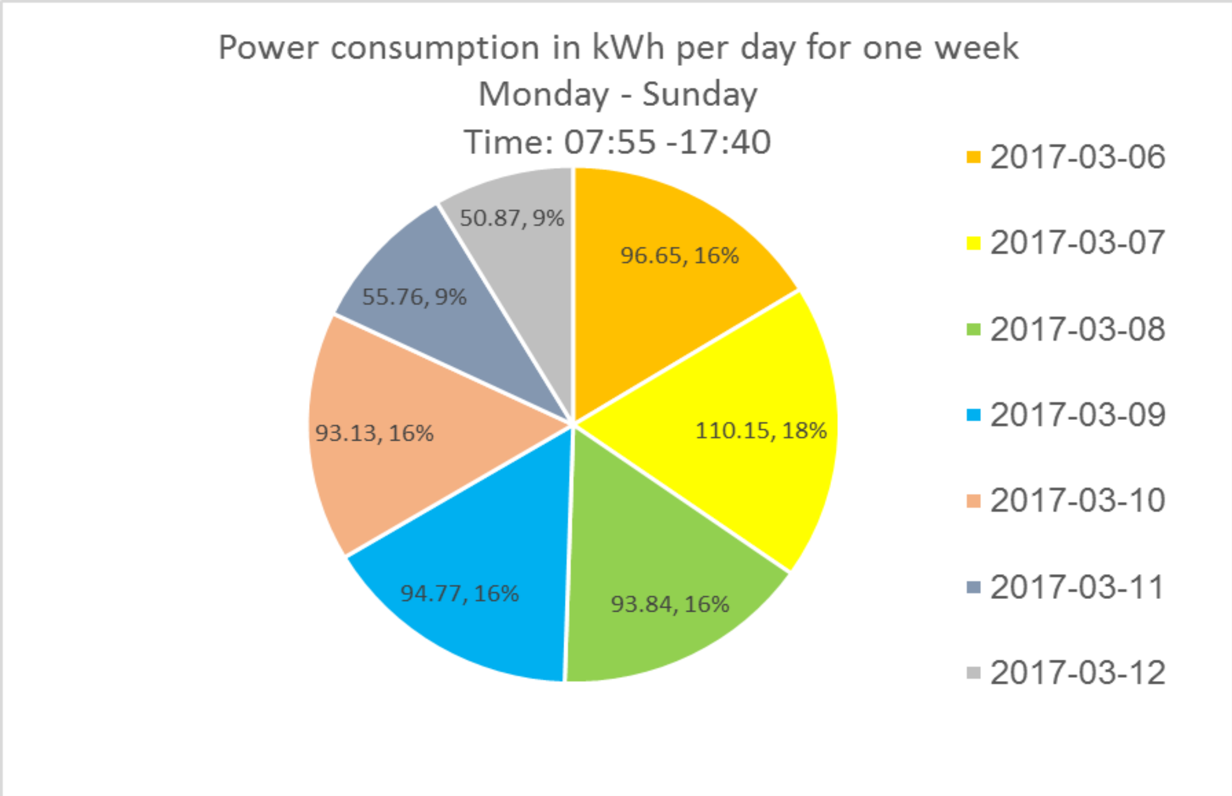

Figure 4.25 Percentage power consumption per day for week one

The total power consumption per day for the period Monday, 13 March 2017, to Sunday, 19 March 2017, is shown on the pie-chart in Figure 4.26.

It can be observed that the total power consumption throughout the week amounts to approximately 608.16 kWh of which 493.67 kWh is consumed during the week and 114.49 kWh during the weekend.

This gives an average power consumption of 98,734 kWh per day during the week and an average of 57,245 kWh per day over the weekend.

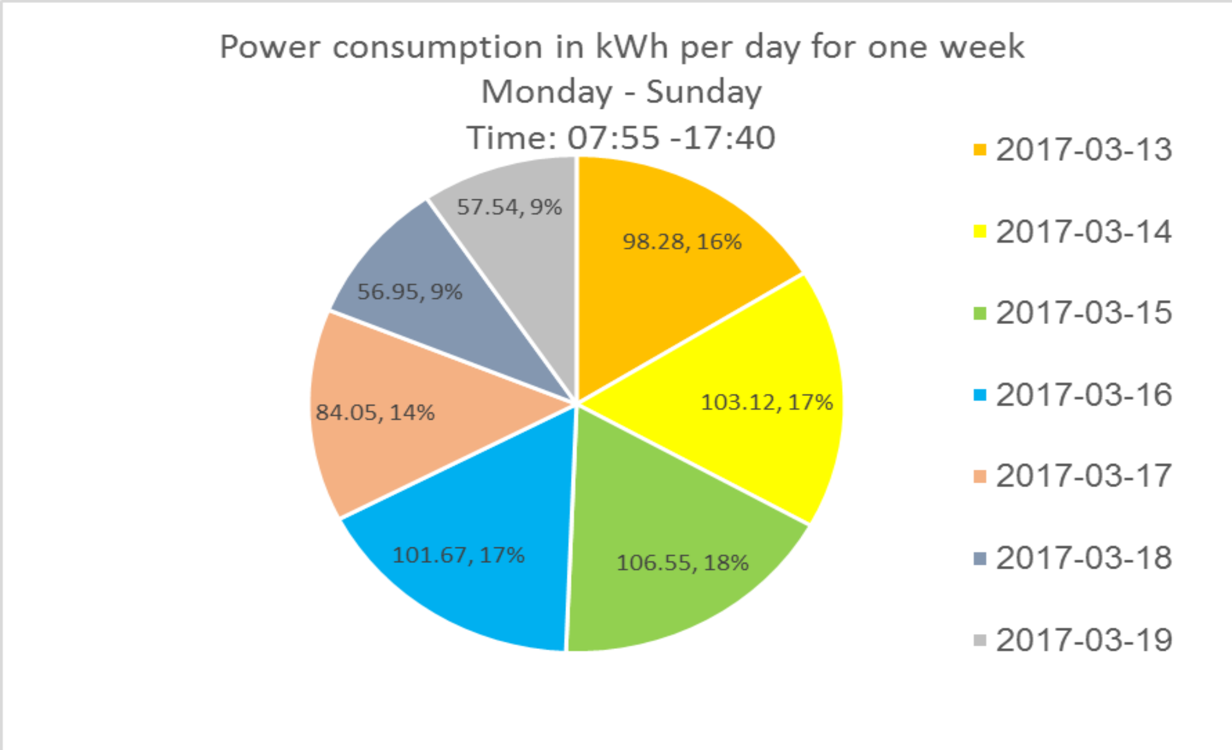

Figure 4.26 Percentage power consumption per day for week two

Air temperature in Bloemfontein

The air temperature in Bloemfontein for the same period as mentioned above has also been monitored, as shown in Figures 4.27 and 4.28.

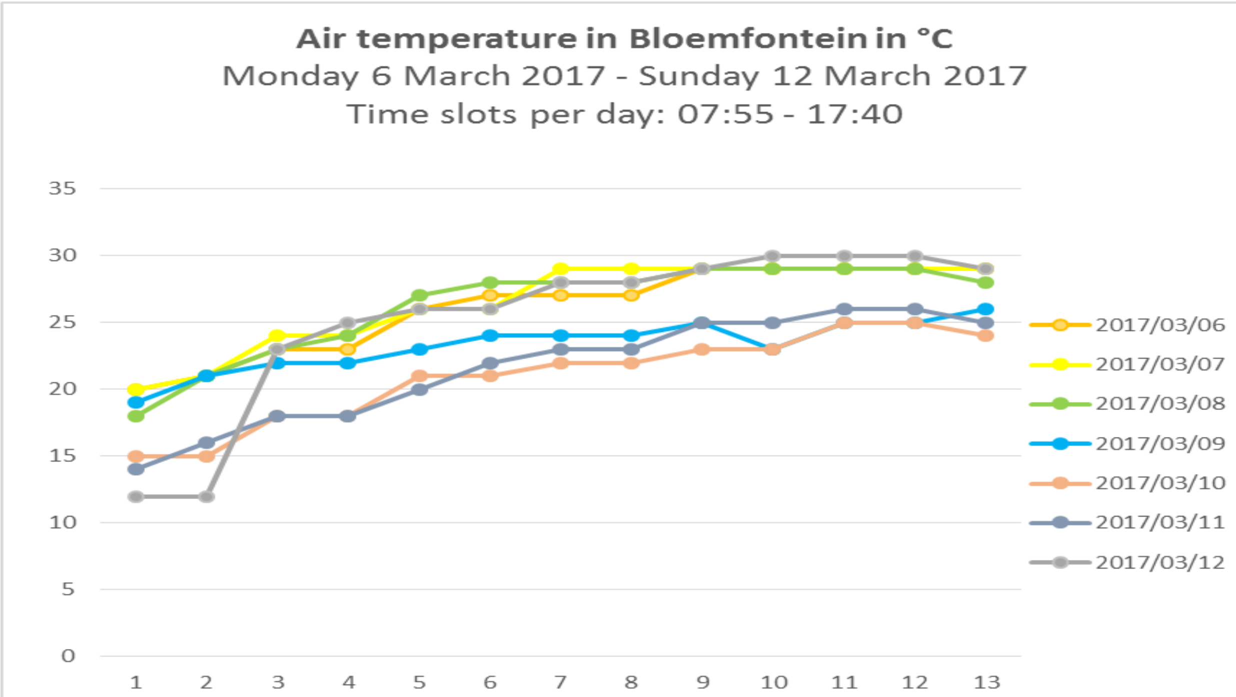

Figure 4.27 Air temperature in degrees Celsius per day for week one

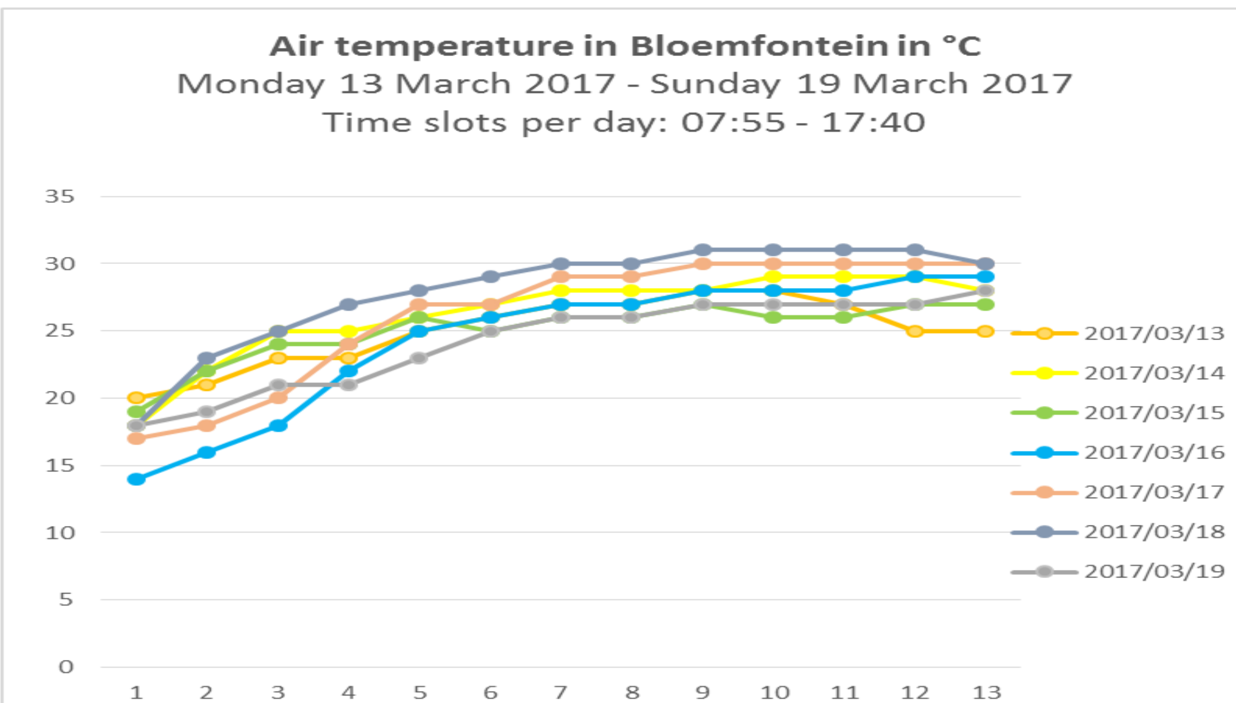

Figure 4.28 Air temperature in degrees Celsius per day for week two

Building occupants

The building occupancy for the same period was also monitored, as shown in Figure 4.29 and Figure 4.30.

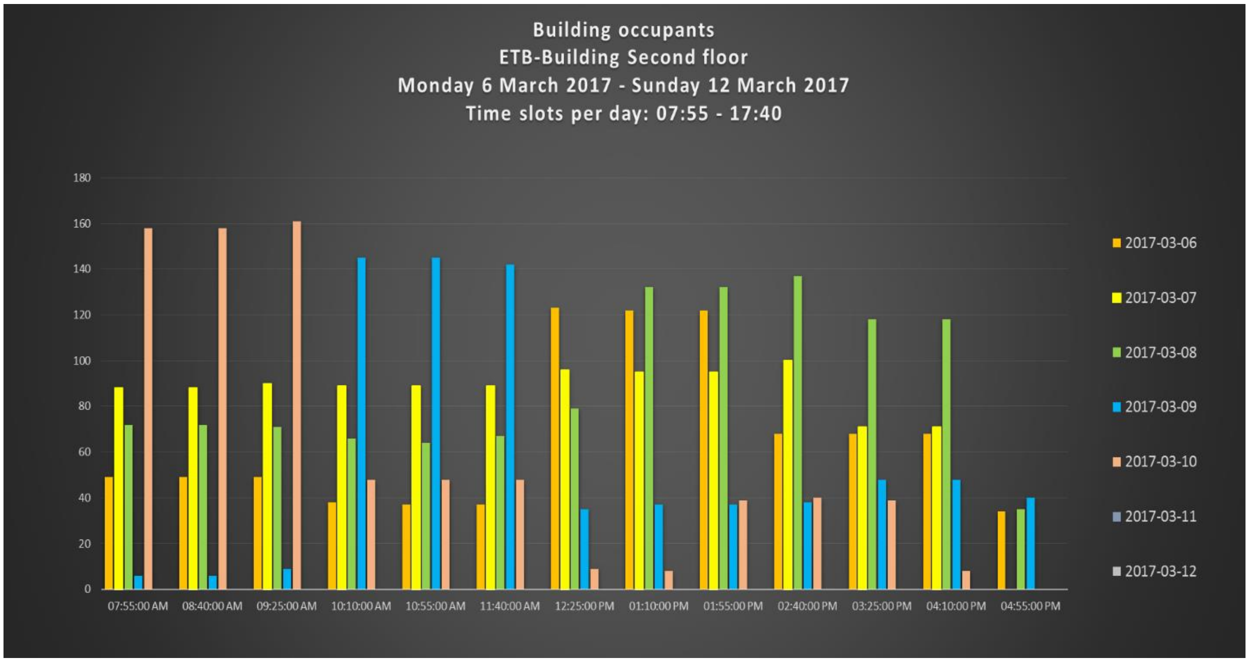

Figure 4.29 Building occupants during time slots for week one

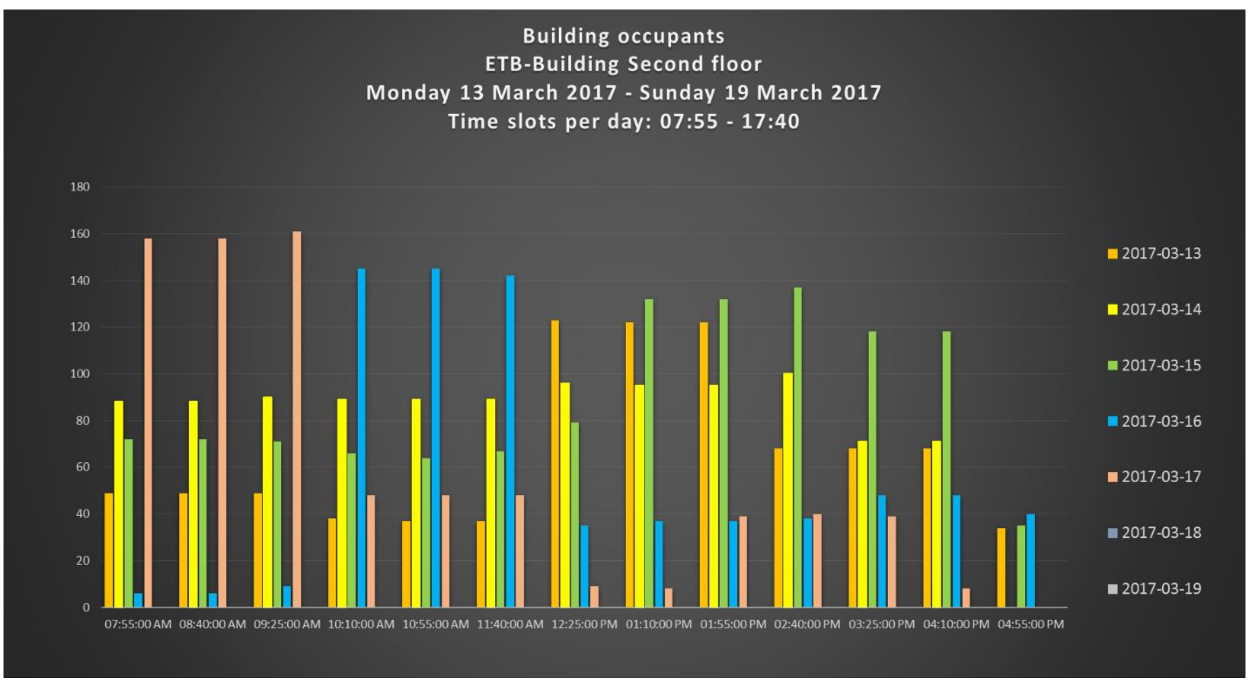

Figure 4.30 Building occupants during time slots for week two

4.8 Power Consumption Special Points (Air-conditioner System) Versus Atmospheric Temperature

From Figures 4.31 and 4.32, one can see the variations in Air-con usage as compared to that of the atmospheric temperature.

On colder days, the Air-conditioner system is used more as compared to warmer days.

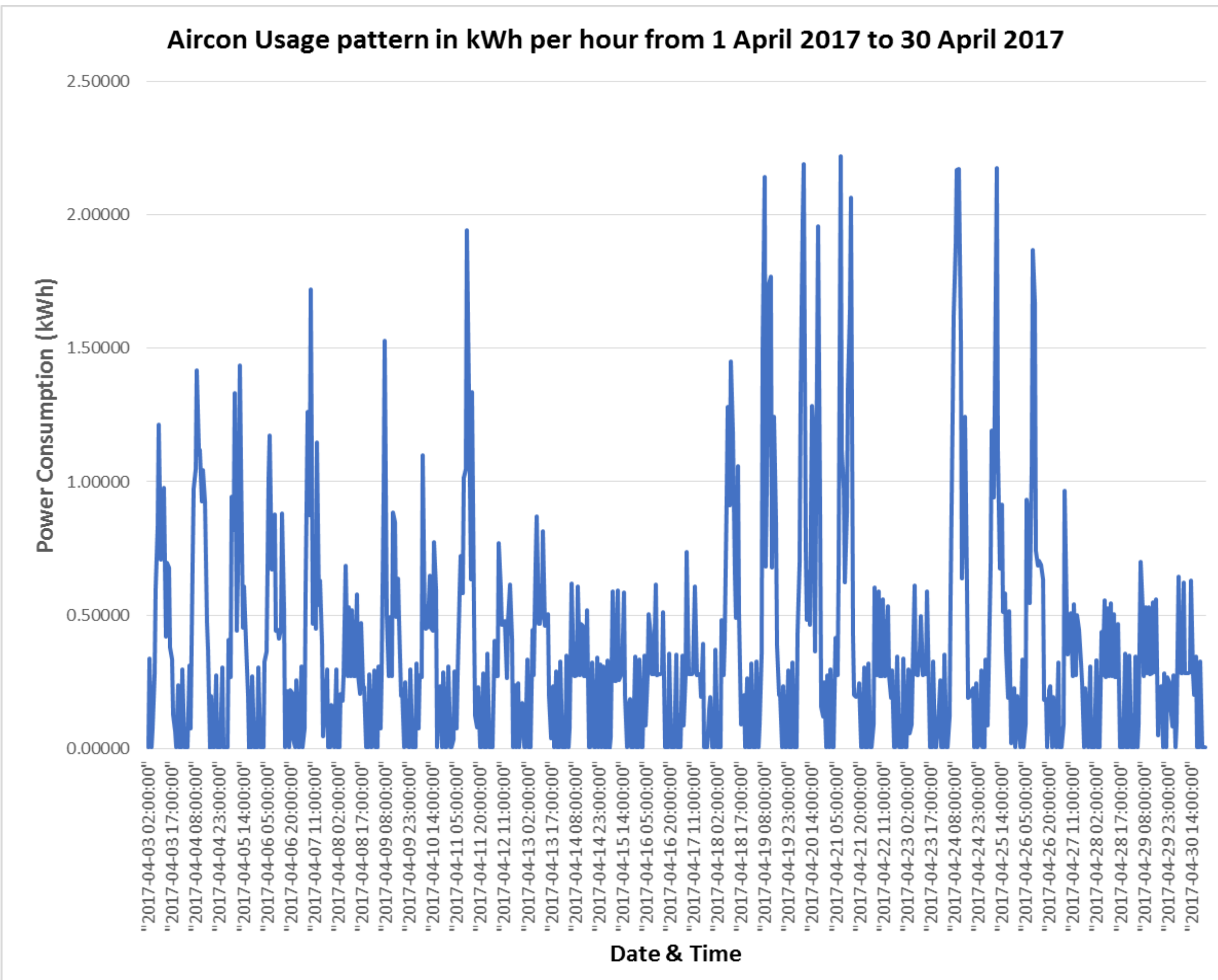

Figure 4.31 Air-conditioner usage in KWh per hour from 1 April 2017 to 30 April 2017

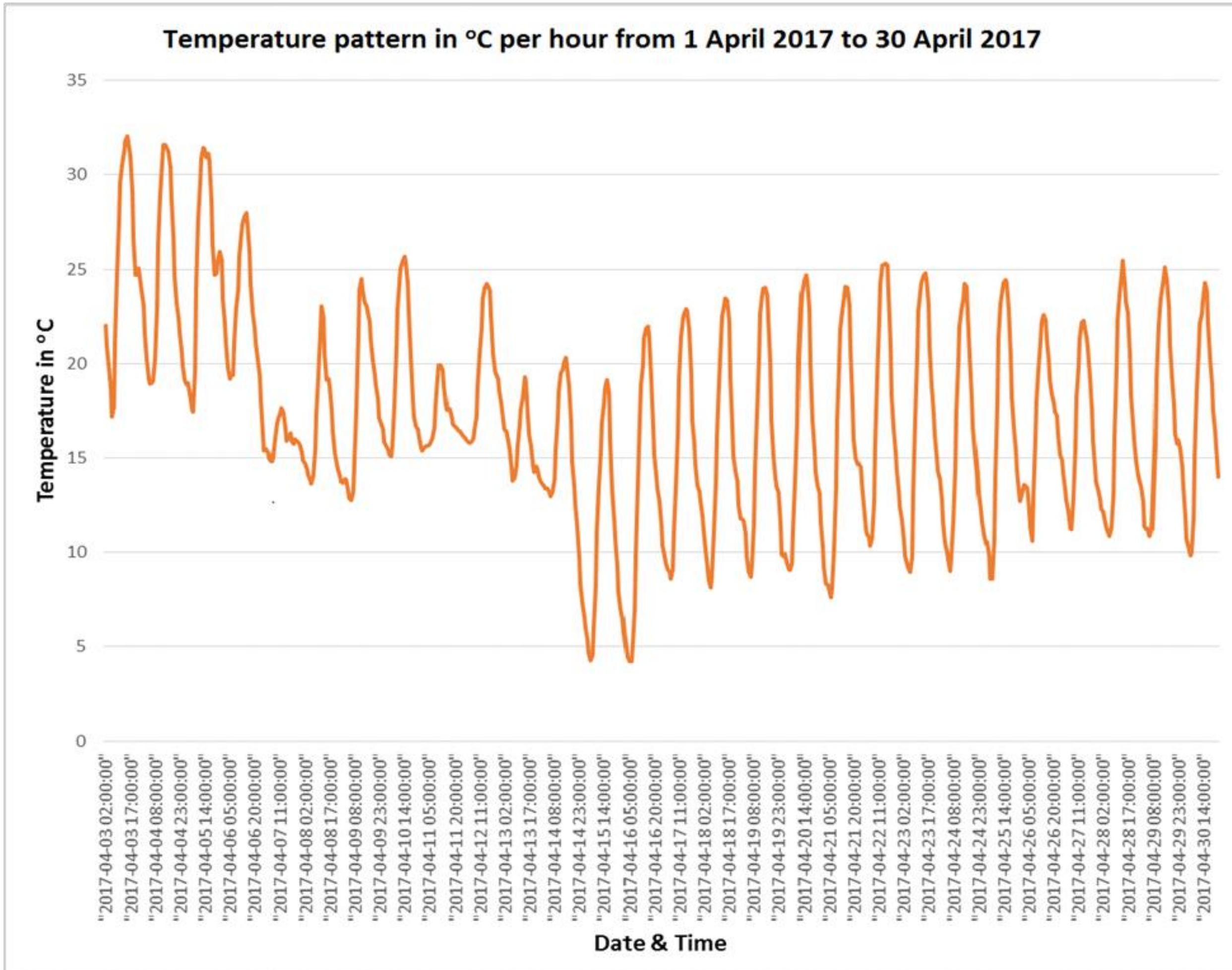

Figure 4.32 Temperature pattern in °C per hour from 1 April 2017 to 30 April 2017

4.9 Load Prediction for Second Floor

One of the main aims of this research project is to create a data projection model to test the different control strategies and allow the possible practical implementation thereof which could lead to real-life cost savings by using the proposed acquired data. This research utilises data from the ETB-building at the Central University of Technology (CUT) from 1 March 2017 to 31 May 2018. The variables considered in this research include electricity consumption for different months, weeks and days over the above-mentioned period, weather, time and customer factors.

4.9.1 The prediction strategy

Since energy in education buildings is used for HVAC (heating, ventilation and air conditioning), lighting, operation of various equipment, such as computers and various other household related appliances, it is inevitable that the data patterns will be irregular from one season to another as mentioned in [32] and [35].

Knowing that the data is seasonal (determined by spikes and dips observed), a method referred to as de-seasonalising was used to smooth out the data.

- The building was monitored over a period of 15 months and the data was downloaded in monthly periods, broken down to weeks, and further separated into ‘warmer’ and ‘colder’ seasons/periods.

- Straight Line, Moving Average and Kalman Filter predictions were then developed where the number of periods was pre-determined.

- In the case of daily data for each current transformer (CT), for example, a Monday, a 24-hour period a Straight Line and Moving Average prediction was created for the following Monday.

- In the case of weekly data, for example, a 7-day period, a Straight Line, Moving Average and Kalman Filter predictions were created for day 8, and then for each period until the end of the series of data.

- In the case of monthly data, for example, March 2017, April 2017 and May 2017, a 29-day period, a Straight Line, Moving Average and Kalman Filter predictions were created for each of the three months for 2018.

4.9.2 Power consumption and prediction over a two-week period

The reason why it was decided to monitor power consumption over a two-week period is to determine how much power is consumed during lectures and how much power is consumed over weekends if there are no lectures. Another reason was to predict the power consumption by using the data for one day, for example Monday, and then to predict the power consumption for the following Monday. A lot of money can be saved if certain equipment can be switched off when not in use, especially over weekends if there are no people in the building.

Power consumption for two weeks

Table 4.16 shows the total power consumption of the second floor for two weeks from Monday, 6 March 2017, to Sunday, 19 March 2017. The power consumption has been monitored for all the outgoing circuits which includes all the lighting circuits, plug circuits, dedicated plug circuits and the special point circuits on the second floor. The power consumption in kWh, as shown in Table 4.16, starts every day at 07:55 in the morning until 05:40 in the afternoon. The power consumption was monitored in the week during lectures, as well as over weekends when no lectures were presented.

Table 4.16 Total daily power consumption in kWh of the second floor for two weeks

Date & Time starts	Date & Time ends	Total consumption in kWh	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Dedicated red phase plugs [kWh]	CT8: Dedicated whitephase plugs [kWh]	CT9: Dedicated bluephase plugs [kWh]	CT10: Special Red phase outlet [kWh]	CT11: Special Whitephase outlet [kWh]	CT12: Special Bluephase outlet [kWh]
2017-03-06 07:55	2017-03-06 17:40	96.65	4.51	22.22	6.09	5.47	1.26	4.35	14.58	11.39	14.35	0.28	2.27	9.90
2017-03-07 07:55	2017-03-07 17:40	110.15	4.49	29.48	6.04	9.12	2.42	5.03	13.78	10.72	14.95	0.26	2.27	11.59
2017-03-08 07:55	2017-03-08 17:40	93.84	4.47	22.14	5.67	6.29	1.56	5.48	12.35	11.40	12.02	0.19	2.24	10.03
2017-03-09 07:55	2017-03-09 17:40	94.77	4.50	19.42	5.90	6.80	1.56	5.37	12.83	11.22	12.57	0.25	2.27	12.07
2017-03-10 07:55	2017-03-10 17:40	93.13	4.56	22.22	6.01	7.40	1.90	5.19	13.23	10.83	12.10	0.12	2.32	7.24
2017-03-11 07:55	2017-03-11 17:40	55.76	4.66	-0.01	4.88	3.95	1.44	4.81	11.90	9.51	10.96	0.07	2.39	1.21
2017-03-12 07:55	2017-03-12 17:40	50.87	4.66	0.00	0.58	3.86	1.45	4.68	11.84	9.53	11.31	0.02	2.40	0.56
2017-03-13 07:55	2017-03-13 17:40	98.28	4.52	22.53	4.93	6.53	1.87	6.11	15.48	11.45	12.92	0.20	2.28	9.46
2017-03-14 07:55	2017-03-14 17:40	103.12	4.49	29.18	2.83	5.53	1.82	6.18	12.02	10.61	15.76	0.19	2.27	12.25
2017-03-15 07:55	2017-03-15 17:40	106.55	4.49	28.31	5.24	5.69	1.89	5.85	12.55	11.39	15.33	0.25	2.28	13.29
2017-03-16 07:55	2017-03-16 17:40	101.67	4.53	21.27	2.98	5.51	1.88	6.10	14.33	12.46	16.86	0.20	2.30	13.24
2017-03-17 07:55	2017-03-17 17:40	84.05	4.53	14.37	3.96	4.79	1.57	6.22	12.31	11.24	15.40	0.17	2.30	7.20
2017-03-18 07:55	2017-03-18 17:40	56.95	4.60	-0.01	6.15	2.98	1.06	5.32	11.62	8.84	13.07	0.02	2.35	0.95
2017-03-19 07:55	2017-03-19 17:40	57.54	4.66	-0.01	6.15	3.17	1.06	5.62	11.62	8.86	13.15	0.02	2.39	0.85
		1203.34	**63.66**	**231.11**	**67.41**	**77.08**	**22.74**	**76.31**	**180.44**	**149.43**	**190.74**	**2.24**	**32.33**	**109.85**
			Lights			**Plugs**			**Dedicated plugs**			**Special points**		
				362.18			176.13			520.61			144.42	

The total power consumption for the two-week period was approximtely 1203.34 kWh as shown in Table 4.16 above. It was the power consumption of all twelve outgoing circuits, including three circuits for lights, three circuits for plugs, three circuits for dedicated plugs and three circuits for special points.

The total power consumption for the lights was 362.18 kWh, as shown in Table 4.16 as well as in Figure 4.33. This represents 30% of the total power consumption for the two weeks, as shown on the pie-chart in Figure 4.34.

The total power consumption for the plugs was 176.13 kWh, as shown in Table 4.16 as well as in Figure 4.33. This represents 15% of the total power consumption for the two weeks, as shown on the pie-chart in Figure 4.34.

The total power consumption for the dedicated plugs was 520.61 kWh, as shown in Table 4.16 as well as in Figure 4.33. This represents 43% of the total power consumption for the two weeks, as shown on the pie-chart in Figure 4.34.

The total power consumption for the special points was 144.42 kWh, as shown in Table 4.16 as well as in Figure 4.33. This represents 12% of the total power consumption for the two weeks, as shown on the pie-chart in Figure 4.34.

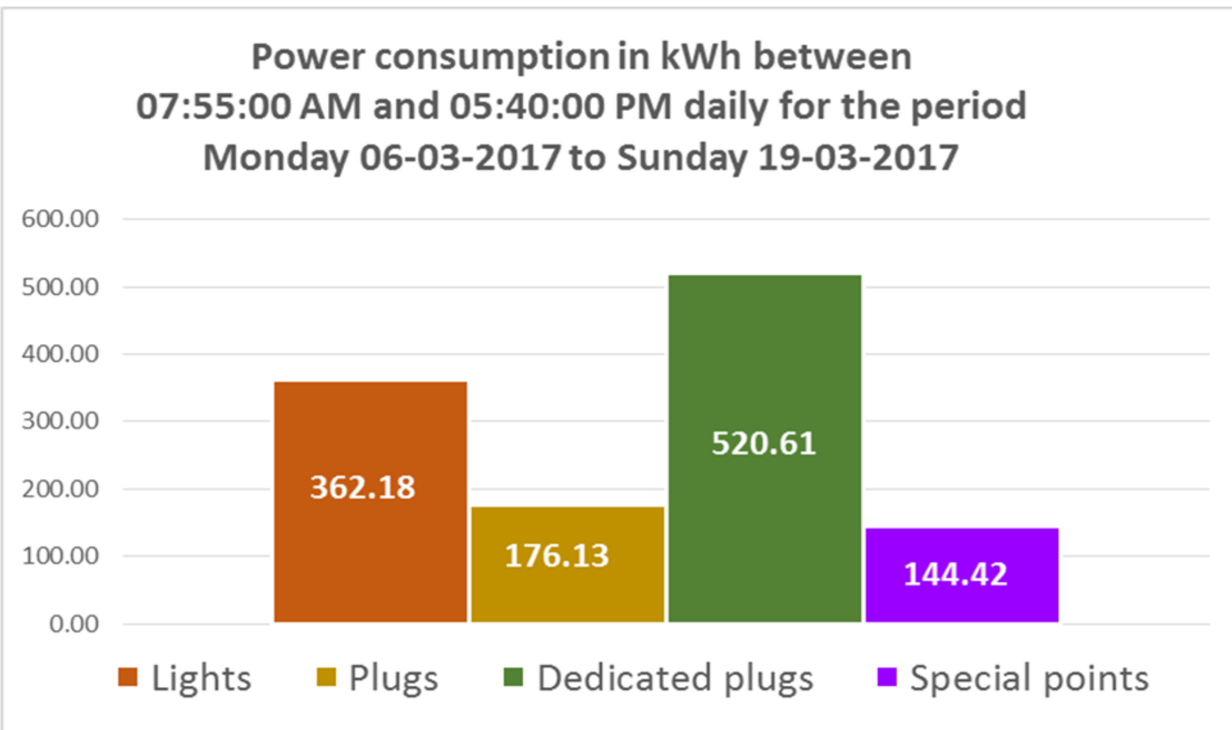

Figure 4.33 Total consumption for each circuit for two weeks (Monday – Sunday)

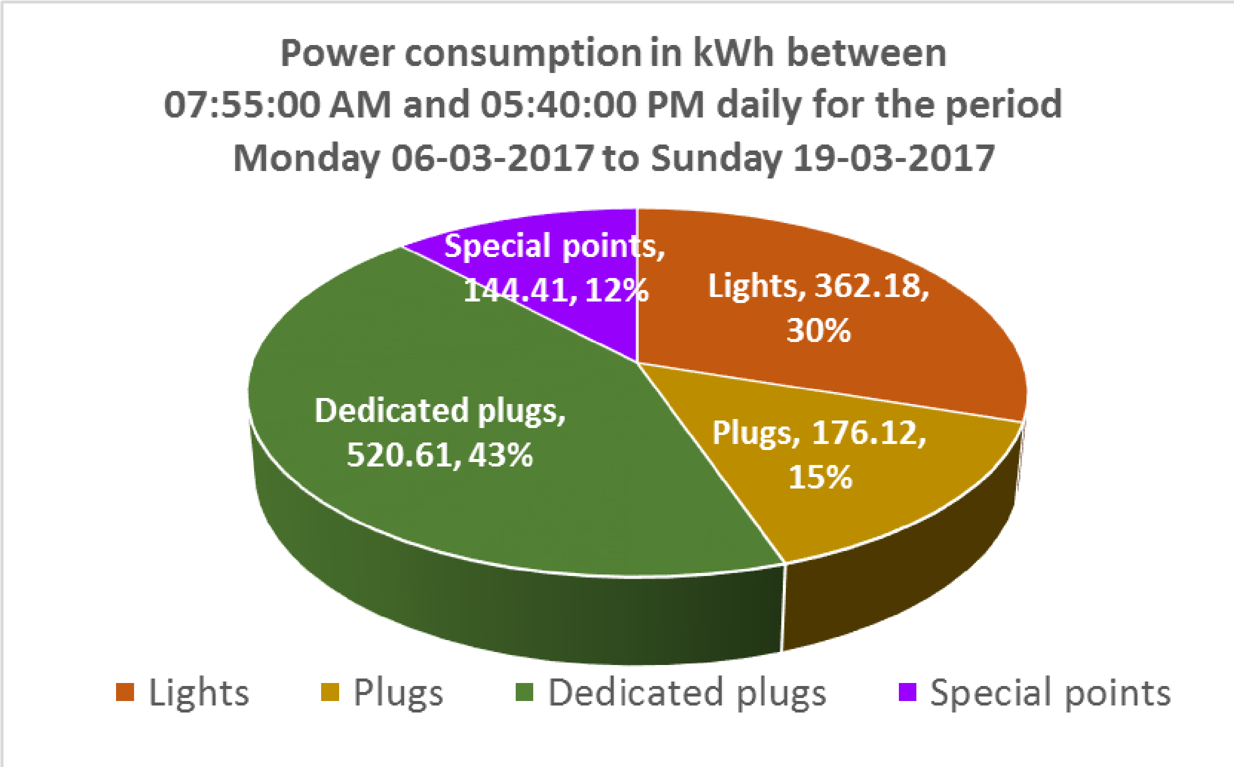

Figure 4.34 Total percentage usage for each circuit for two weeks (Monday – Sunday)

Power consumption during the week and weekends

For the same period mentioned above, an investigation was also conducted to determine how much power is consumed during the week when classes are offered, as well as power consumption over the weekend when no classes are offered.

The power consumption during the week is shown in Figure 4.35, as well as on the pie-chart in Figure 4.36.

The power consumption over the weekend is shown in Figure 4.37 as well as on the pie-chart in Figure 4.38.

The total power consumption during the week for the lights, plugs, dedicated plugs and special points were 325.89 kWh, 136.74 kWh, 388.40 kWh and 131.19 kWh, respectively, as shown in Figure 4.35.

The total power consumption during the week, for the two-week period, was 982.22 kWh.

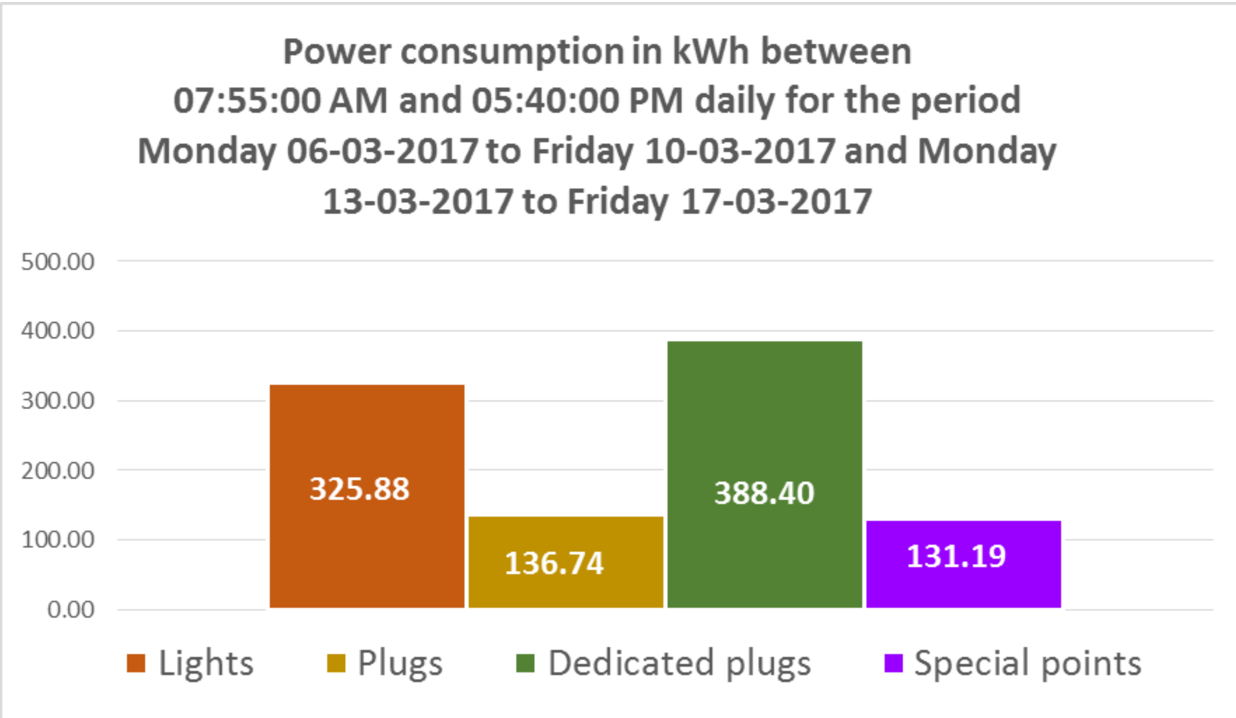

Figure 4.35 Daily consumption for two weeks (Monday – Friday)

As shown on the pie-chart in Figure 4.36, the lights represent 33% and the dedicated plugs represent 40% of the total usage during the above-mentioned period. This is almost 75% of the total usage.

The plugs represent only 14% and the special points represent only 13% of the total usage.

The reason why the lights and dedicated plugs are almost 75% of the power consumption is that there are two large computer rooms that are fully occupied in the day, during lectures.

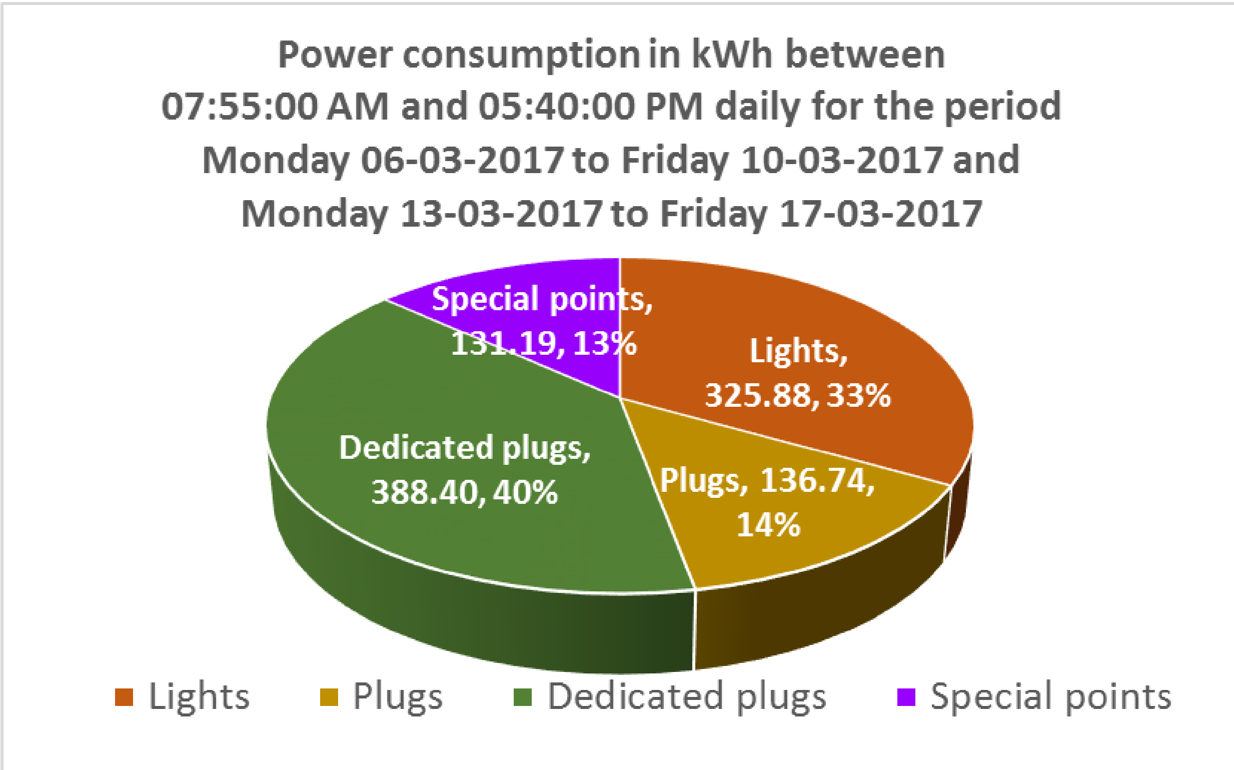

Figure 4.36 Pie-chart for the percentage usage for two weeks (Monday – Friday)

The total power consumption during the weekend for the lights, plugs, dedicated plugs and special points were 36.30 kWh, 39.39 kWh, 132.21 kWh and 13.23 kWh, respectively, as shown in Figure 4.37.

The total power consumption for the two-week period during the weekend was 221.12 kWh.

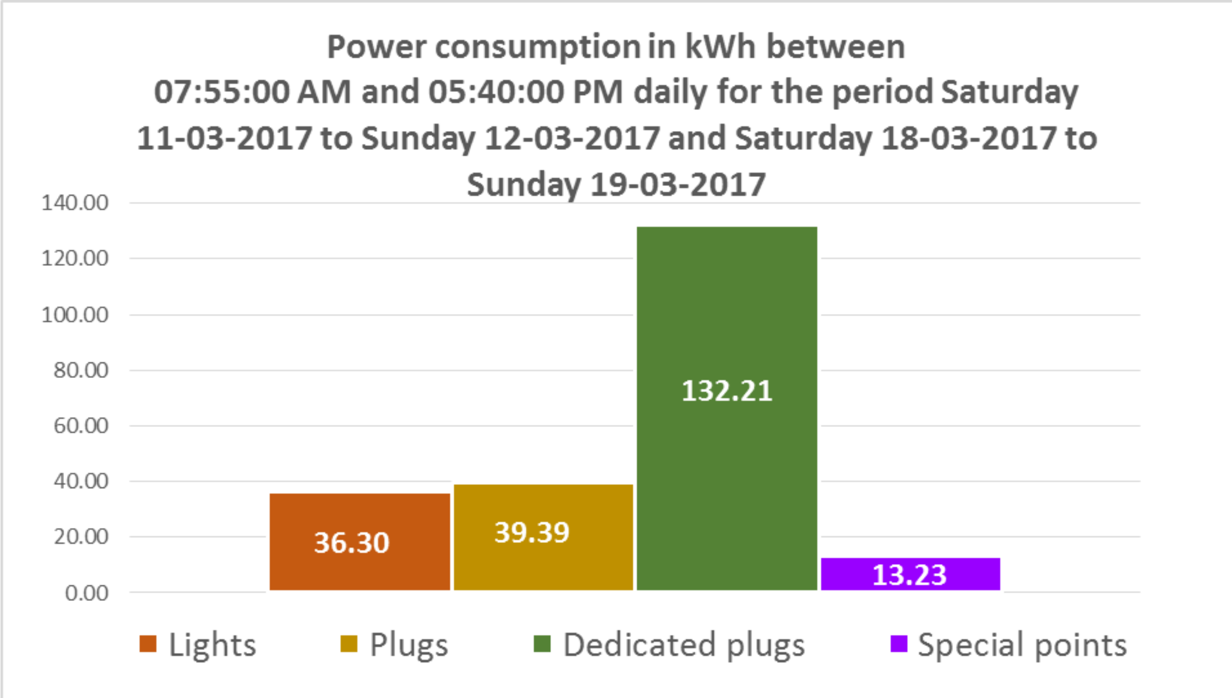

Figure 4.37   Daily consumption for two weeks (Saturday – Sunday)

As shown on the pie-chart in Figure 4.38, the dedicated plugs represent 60% of the total usage during the above-mentioned period.

The lights represent only 16%, the plugs only 18% and the special points only 6% of the total usage during the above-mentioned period.

The reason why the dedicated plugs are 60% of the power consumption is because the students sometimes do not switch off the computers after the lectures are over and then the computers are on the whole weekend.

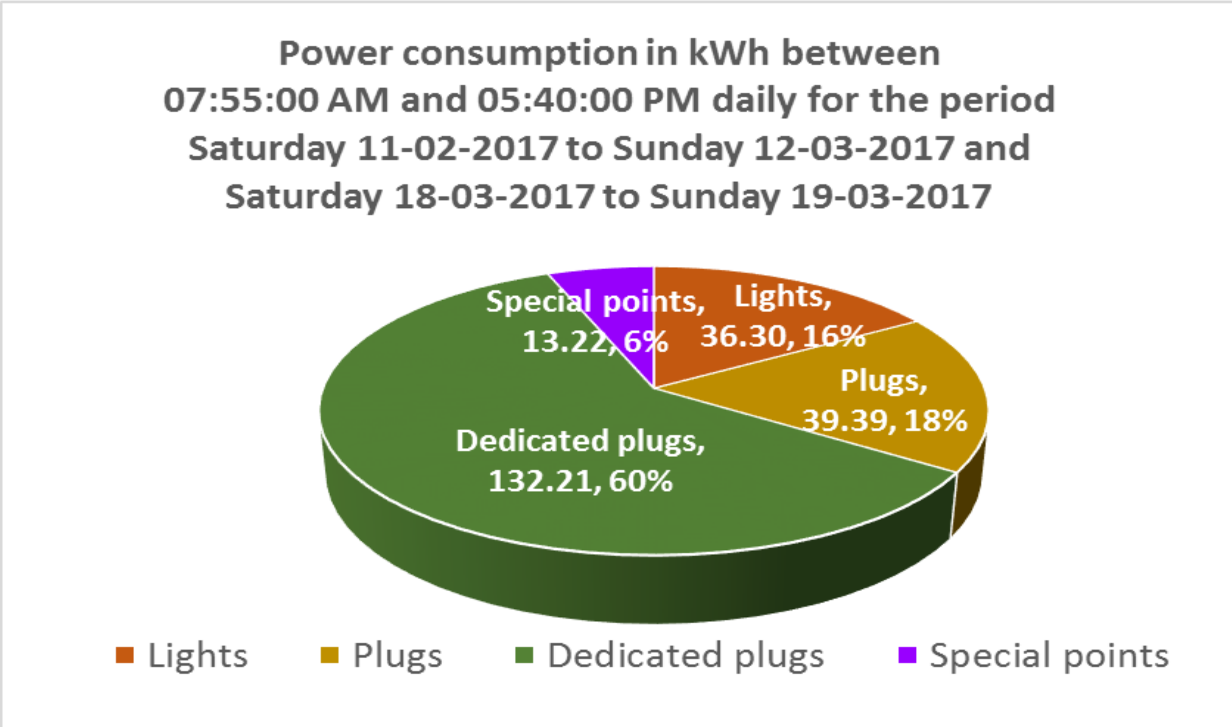

Figure 4.38 Pie-chart for the percentage usage for two weeks (Saturday – Sunday)

Comparison of power consumption between weekdays and weekends

Figures 4.39 to 4.46 show the power consumption as well as the percentage usage of the different circuits for the two weeks during lectures and over weekends when there are no lectures.

As shown in Figure 4.39, the power consumption for the light circuits during the two-week period is approximately 325.89 kWh, compared to 36.30 kWh during the two weekends. That means that 90% of the of the usage is consumed during the two weeks during lectures and only 10% over the two weekends, as illustrated by the pie-chart in Figure 4.40.

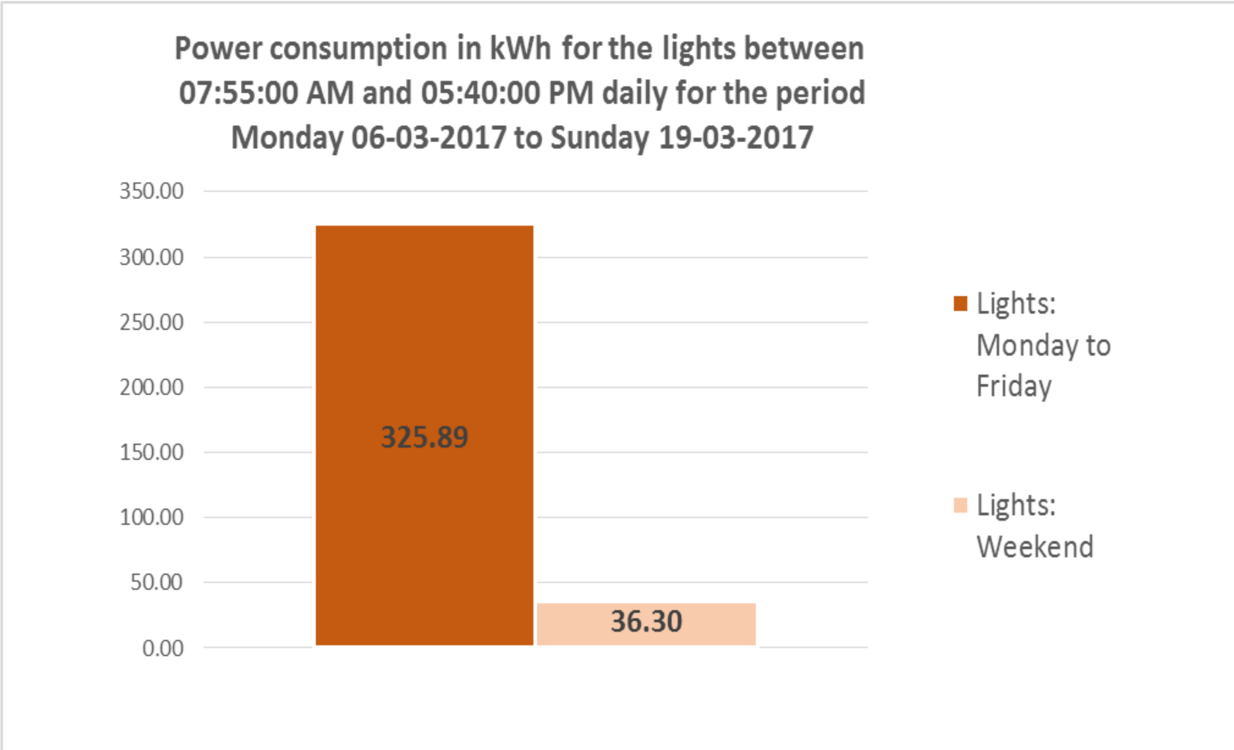

Figure 4.39 Power consumption for light circuits during the week and weekends

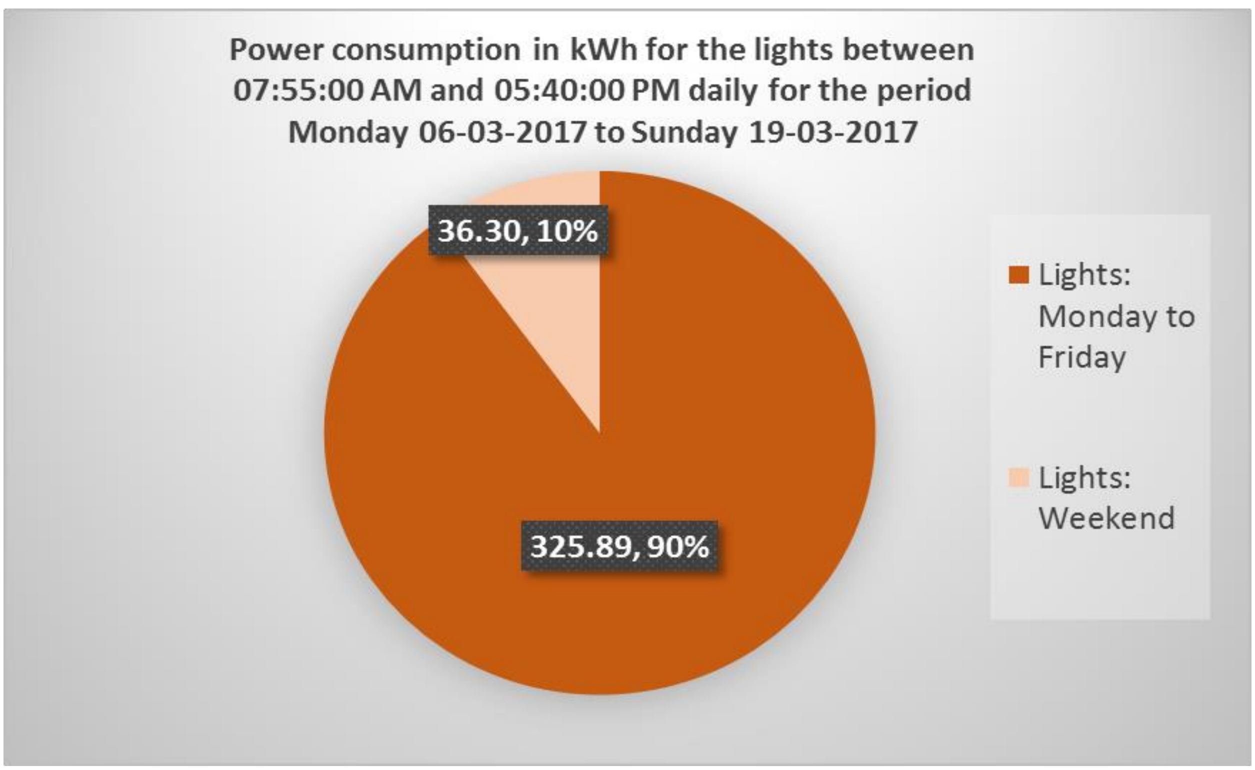

Figure 4.40 Pie-chart for the percentage consumption for light circuits during the week and weekends

As shown in Figure 4.41, the power consumption for the plug circuits during the two-week period is approximately 136.74 kWh compared to 39.39 kWh during the two weekends.

That means that 78% of the usage is consumed throughout the two weeks during lectures and 22% over the two weekends, as shown by the pie-chart in Figure 4.42.

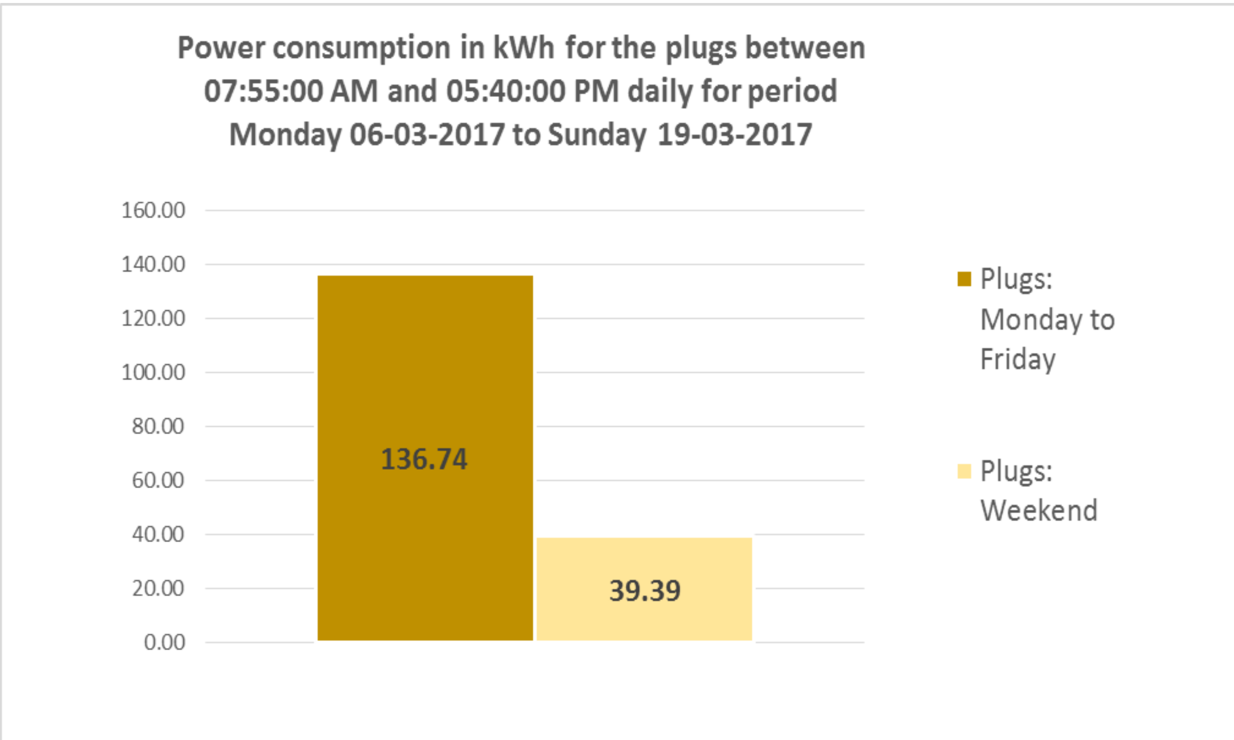

Figure 4.41 Power consumption for plug circuits during the week and weekends

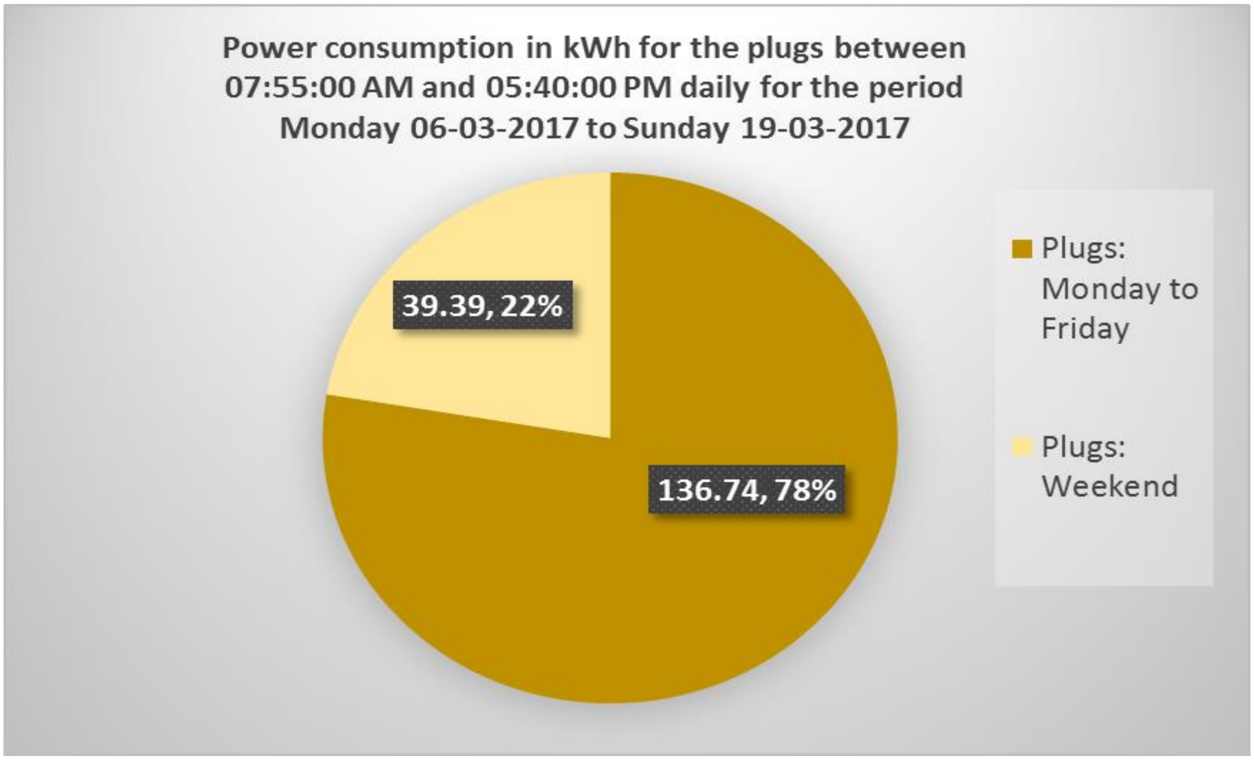

Figure 4.42 Pie-chart for the percentage consumption for plug circuits during the week and weekends

As shown in Figure 4.43, the power consumption for the dedicated plug circuits during the two-week period is approximately 388.40 kWh, compared to 132.21 kWh during the two weekends.

That means that 75% of the usage is consumed in the two weeks during lectures and 25% over the two weekends, as indicated by the pie-chart in Figure 4.44.

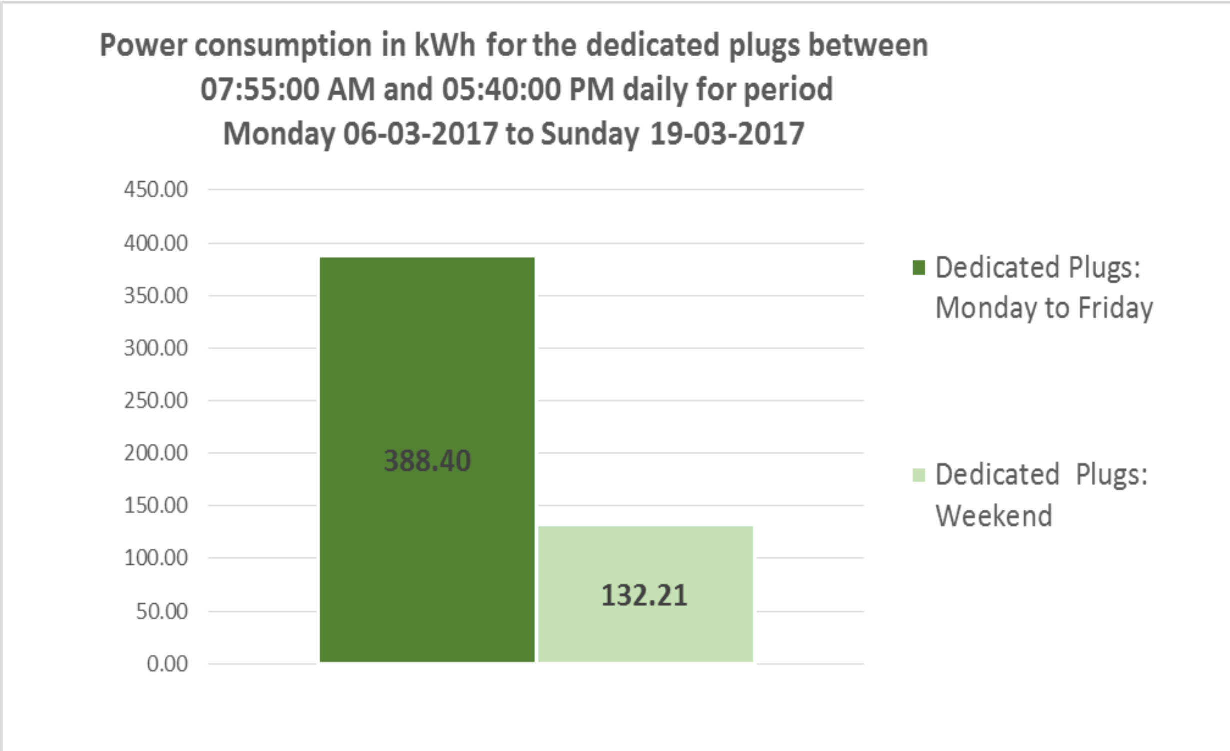

Figure 4.43 Power consumption for dedicated plugs during the week and weekends

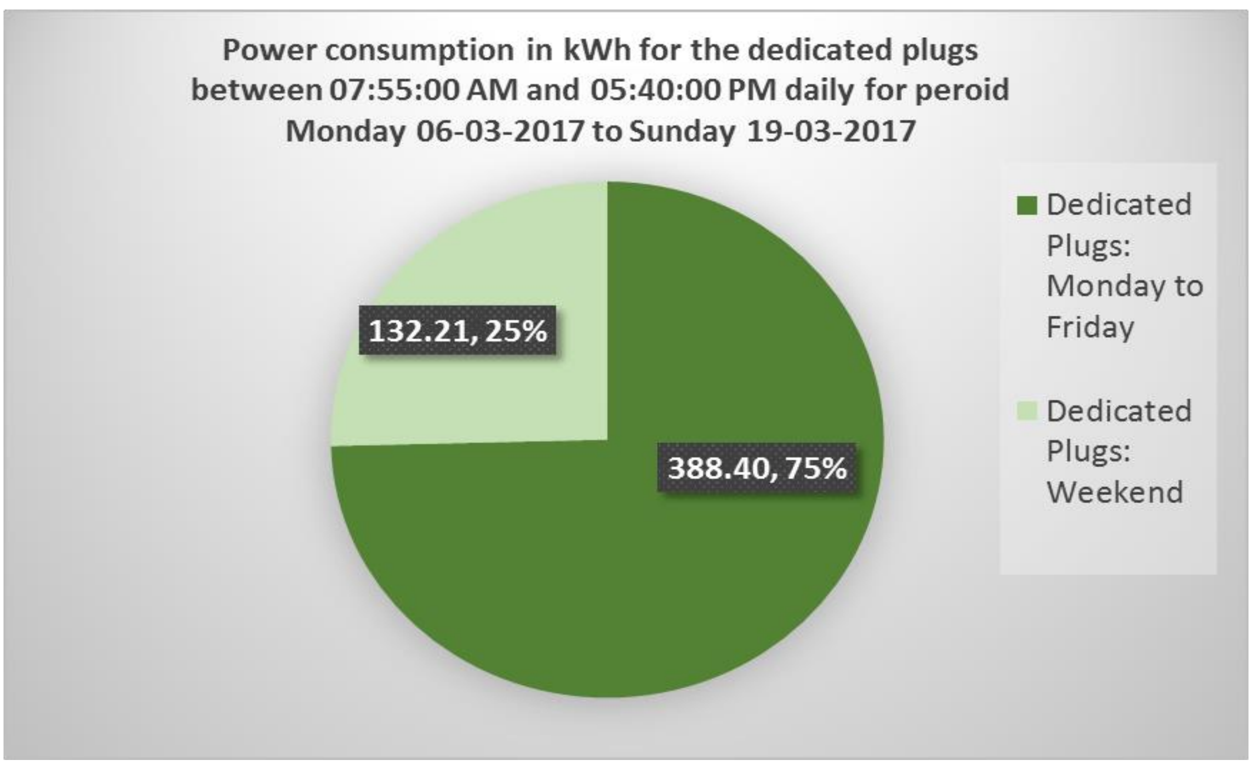

Figure 4.44 Pie-chart for the percentage consumption for dedicated plugs during the week and weekends

As shown in Figure 4.45, the power consumption for the special point circuits during the two-week period is approximately 131.19 kWh, compared to 13.22 kWh during the two weekends.

That means that 91% of the usage is consumed during the two weeks during lectures and only 9% over the two weekends, as shown on the pie-chart in Figure 4.46.

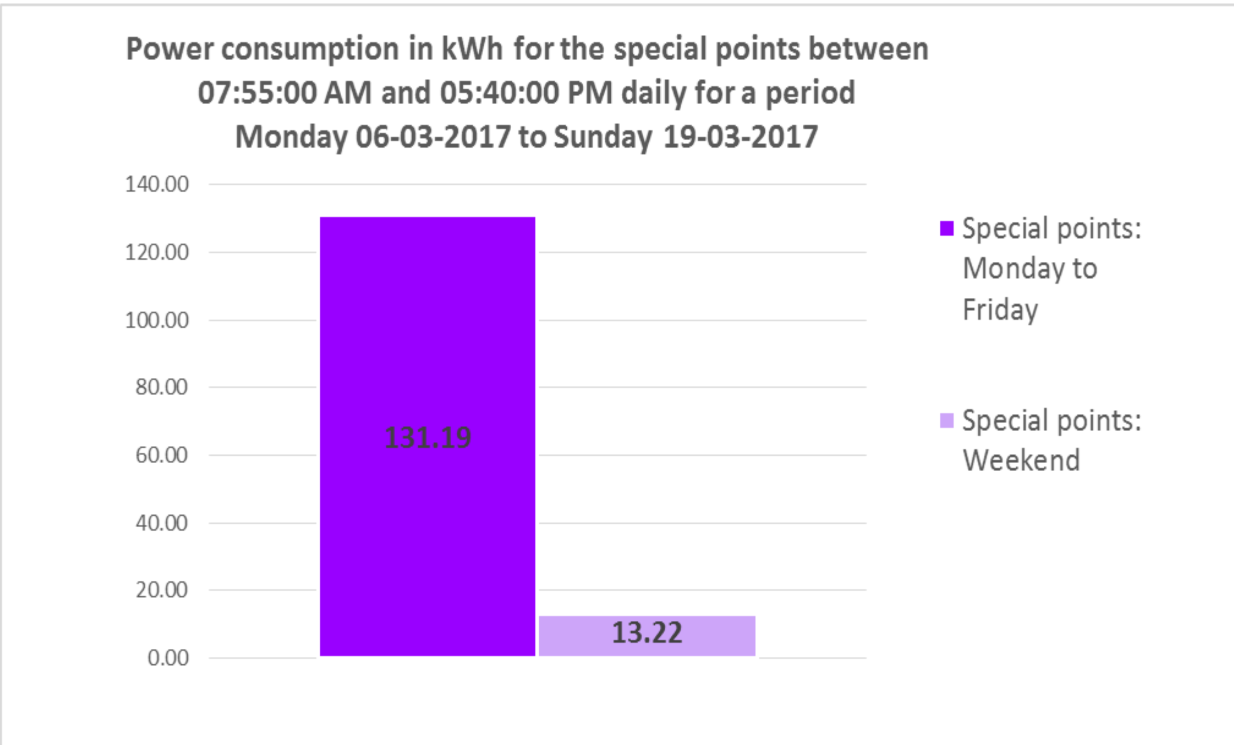

Figure 4.45 Power consumption for special points during the week and weekends

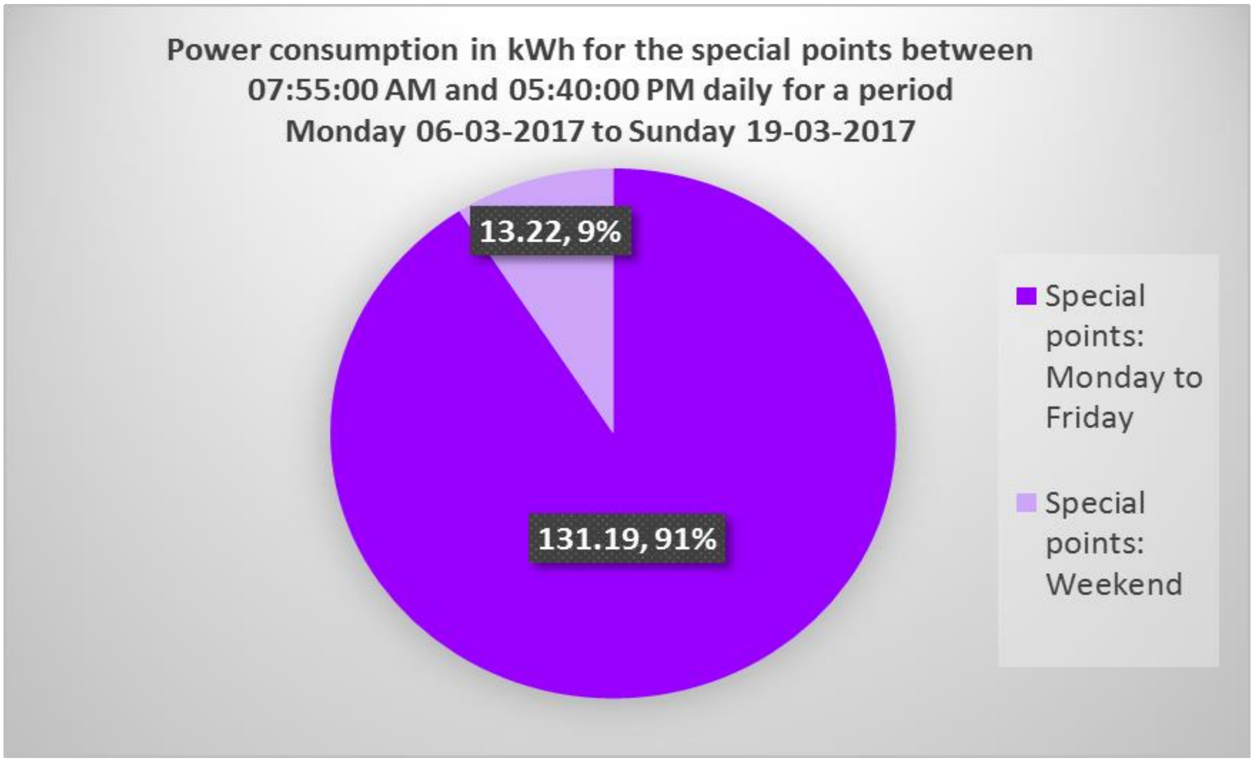

Figure 4.46 Pie-chart for the percentage consumption for special points during the week and weekends

Chapter 5

Results

5.1 Effects of Air Temperature and Building Occupants on Power Consumption

An investigation has been conducted to determine whether there is a correlation between power consumption and air temperature, as well as a correlation between power consumption and occupancy of the building. Table 5.1 shows the average power consumption per day, average air temperature per day, as well as the average building occupancy per day from Monday, 6 March 2017, until Monday, 19 March 2017.

Table 5.1 Average kWh, average air temperature and average occupants per day and correlation

Date	Average Power consumption (kWh) per day	Average Temperature per day	Average Occupants per day	Correlation Temp vs kWh	Correlation Occupants vs kWh
2017-03-06	7.43	26.08	66.46	0.10	0.95
2017-03-07	8.47	26.46	81.62		
2017-03-08	7.22	26.23	89.46		
2017-03-09	7.29	23.31	56.62		
2017-03-10	7.16	20.92	58.77		
2017-03-11	4.29	21.62	0.00		
2017-03-12	3.91	25.23	0.00		
2017-03-13	7.56	25.00	66.46		
2017-03-14	7.87	26.31	81.62		
2017-03-15	8.20	25.00	89.46		
2017-03-16	7.82	24.38	56.62		
2017-03-17	6.47	26.23	58.77		
2017-03-18	4.38	28.00	0.00		
2017-03-19	4.43	24.23	0.00		

By using the correlation function in Microsoft® Excel, one can measure the degree of the linear relationship between two variables. The coefficient value can range between negative one (-1.00) and positive one (+1.00). If the coefficient value is in negative range, one value decreases and the other value increases. If the the coefficient value is in the positive range, the values increase and decrease together. When applied to a sample, the correlation coefficient is commonly represented by the letter r and may be referred to as the sample correlation coefficient.

Microsoft® Excel Correlation Function equation:

$$Correl\ r(X,Y) = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \qquad 5.1$$

Where:

$\bar{x}$ and $\bar{y}$ are the sample means AVERAGE(array1) and AVERAGE(array2)

In this case, the power consumption and air temperature values are the two variables, as well as power consumption and building occupants.

The correlation between the power consumption and air temperature is 0.1, r = 0.1. This indicates a very low positive correlation between power consumption and air temperature.

The correlation between the power consumption and building occupancy is 0.95, r = 0.95. This indiates a very strong positive correlation between power consumption and building occupancy. The coefficient value is in the positive range because the values increase and decrease together.

5.2 Total Power Consumption and Prediction Profiles

5.2.1 Initial consumption

Table 5.2 shows the initial total power consumption in kWh of the second floor for Monday, 6 March 2017. The power consumption has been monitored for all twelve outgoing circuits that include all the light circuits, plug circuits, dedicated plug circuits and the special point circuits. The power consumption was monitored for 13 periods from 07:55 in the morning until 17:40 in the afternoon.

The total power consumption for the above-mentioned period for all the outgoing circuits was about ***96.651 kWh***.

The total power consumption for the three light circuits amounted to ***32.815 kWh***, which was approximately ***33.95%*** of the total consumption during the above-mentioned period.

The total power consumption for the three plug circuits amounted to ***11.073 kWh***, which was approximately ***11.46%*** of the total consumption.

The total power consumption for the three dedicated plug circuits amounted to ***40.32 kWh***, which was approximately ***41.72%*** of the total consumption.

The total power consumption for the three special point circuits amounted to ***12.443 kWh***, which was approximately ***12.87%*** of the total consumption.

Table 5.2 Initial power consumption in kWh for Monday, 6 March 2017

Initial power consumption in kWh - Monday, 6 March 2017														
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]
2017-03-06 07:55	2017-03-06 08:40	1	0.346965	1.415779	0.413345	0.57171	0.059388	0.277999	1.214217	0.952698	1.057083	0.005131	0.193547	0.37194
2017-03-06 08:40	2017-03-06 09:25	2	0.350169	1.406719	0.412811	0.37618	0.068618	0.352657	1.210577	0.930385	1.055596	0.01845	0.196689	0.794417
2017-03-06 09:25	2017-03-06 10:10	3	0.34866	1.385015	0.412746	0.47175	0.068905	0.314072	1.223499	0.905336	1.050693	0.017078	0.195935	1.442613
2017-03-06 10:10	2017-03-06 10:55	4	0.346652	1.380406	0.412391	0.37791	0.07866	0.408921	1.161646	0.898951	1.054455	0.000476	0.193793	0.845246
2017-03-06 10:55	2017-03-06 11:40	5	0.345341	1.388966	0.425908	0.51704	0.083848	0.299137	1.064494	0.842582	1.051492	0.014386	0.191823	0.851956
2017-03-06 11:40	2017-03-06 12:25	6	0.344994	1.518689	0.431378	0.46173	0.078293	0.492248	1.00547	0.792176	1.081545	0.043937	0.191582	0.717403
2017-03-06 12:25	2017-03-06 13:10	7	0.344118	2.265592	0.431779	0.51291	0.105421	0.389406	1.422687	0.898444	1.061479	0.047007	0.191909	0.602226
2017-03-06 13:10	2017-03-06 13:55	8	0.344124	2.268538	0.432266	0.35691	0.090997	0.324059	1.396207	0.854458	1.045853	0.050372	0.191684	1.139227
2017-03-06 13:55	2017-03-06 14:40	9	0.342433	2.007669	0.43295	0.40029	0.098119	0.320249	1.003063	0.806222	1.030236	0.003376	0.189909	1.241766
2017-03-06 14:40	2017-03-06 15:25	10	0.343404	1.445063	0.43275	0.3597	0.111935	0.292455	1.044853	0.921461	1.251124	0.016653	0.190116	0.664555
2017-03-06 15:25	2017-03-06 16:10	11	0.344855	2.245051	0.432237	0.32092	0.140847	0.29438	0.945723	0.889909	1.271841	0.029319	0.191149	0.631969
2017-03-06 16:10	2017-03-06 16:55	12	0.350293	2.046051	0.430875	0.34367	0.133863	0.324638	0.922451	0.850474	1.21239	0.010644	0.151149	0.170988
2017-03-06 16:55	2017-03-06 17:40	13	0.354736	1.447884	0.985051	0.39471	0.13789	0.260788	0.965854	0.848877	1.12312	0.018706	0.000448	0.423837
			4.506743	**22.22142**	**6.08649**	**5.46541**	**1.256785**	**4.351008**	**14.58074**	**11.39197**	**14.34691**	**0.275534**	**2.269733**	**9.898141**
			32.815			11.073			40.320			12.443		
			96.651											

5.2.2 Moving Average method used in prediction

By using the Moving Average method, the formula 3.17 was used in Microsoft® Excel as well as the initial power consumption data for Monday, 6 March 2017, as shown in Table 5.2, to predict the power consumption for the following Monday.

Table 5.3 shows the prediction of the power consumption in kWh for Monday, 13 March 2017, by using the Moving Average. The prediction was made for 13 periods from 07:55 in the morning until 17:40 in the afternoon.

The total predicted power consumption for the above period, using the Moving Average method, was about ***96.757 kWh***, as shown in Table 5.3.

Table 5.3 Moving Average prediction for power consumption in kWh for Monday, 13 March 2017

Prediction for power consumption in kWh (Moving average) - Monday, 13 March 2017														
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]
2017-03-13 07:55	2017-03-13 08:40	1	0.348567	1.411249	0.413078	0.47395	0.064003	0.315328	1.212397	0.941541	1.05634	0.01179	0.195118	0.583179
2017-03-13 08:40	2017-03-13 09:25	2	0.348567	1.411249	0.413078	0.47395	0.064003	0.315328	1.212397	0.941541	1.05634	0.01179	0.195118	0.583179
2017-03-13 09:25	2017-03-13 10:10	3	0.349414	1.395867	0.412779	0.42396	0.068762	0.333364	1.217038	0.91786	1.053145	0.017764	0.196312	1.118515
2017-03-13 10:10	2017-03-13 10:55	4	0.347656	1.382711	0.412569	0.42483	0.073783	0.361496	1.192572	0.902143	1.052574	0.008777	0.194864	1.143929
2017-03-13 10:55	2017-03-13 11:40	5	0.345996	1.384686	0.41915	0.44747	0.081254	0.354029	1.11307	0.870766	1.052973	0.007431	0.192808	0.848601
2017-03-13 11:40	2017-03-13 12:25	6	0.345168	1.453828	0.428643	0.48938	0.08107	0.395692	1.034982	0.817379	1.066518	0.029162	0.191703	0.784679
2017-03-13 12:25	2017-03-13 13:10	7	0.344556	1.89214	0.431579	0.48732	0.091857	0.440827	1.214079	0.84531	1.071512	0.045472	0.191746	0.659815
2017-03-13 13:10	2017-03-13 13:55	8	0.344121	2.267065	0.432023	0.43491	0.098209	0.356732	1.409447	0.876451	1.053666	0.048689	0.191797	0.870727
2017-03-13 13:55	2017-03-13 14:40	9	0.343278	2.138104	0.432608	0.3786	0.094558	0.322154	1.199635	0.83034	1.038045	0.026874	0.190797	1.190497
2017-03-13 14:40	2017-03-13 15:25	10	0.342918	1.726366	0.43285	0.37999	0.105027	0.306352	1.023958	0.863841	1.14068	0.010014	0.190013	0.953161
2017-03-13 15:25	2017-03-13 16:10	11	0.344129	1.845057	0.432494	0.34031	0.126391	0.293417	0.995288	0.905685	1.261483	0.022986	0.190632	0.648262
2017-03-13 16:10	2017-03-13 16:55	12	0.347574	2.145551	0.431556	0.33229	0.137355	0.309509	0.934087	0.870192	1.242116	0.019982	0.171149	0.401478
2017-03-13 16:55	2017-03-13 17:40	13	0.352515	1.746968	0.707963	0.36919	0.135877	0.292713	0.944153	0.849676	1.167755	0.014675	0.075798	0.297412
			4.504459	**22.20084**	**5.80037**	**5.45614**	**1.222149**	**4.396942**	**14.7031**	**11.43273**	**14.31315**	**0.275406**	**2.367853**	**10.08343**
			32.506			**11.075**			**40.449**			**12.727**		
			96.757											

5.2.3 Straight Line method used in prediction

By using the Straight Line method, the formulas 3.18 to 3.20 were used in Microsoft® Excel, as well as the initial power consumption data for Monday, 6 March 2017, as shown in Table 5.2, to predict the power consumption for the following Monday.

Table 5.4 shows the prediction of the power consumption in kWh for Monday, 13 March 2017, by using the Straight Line method. The prediction was also made for 13 periods from 07:55 in the morning until 17:40 in the afternoon.

The total predicted power consumption for the above period, using the Straight Line method, was about ***96.651 kWh*** as shown in the Table 5.4.

Table 5.4 Straight Line prediction of power consumption in kWh for Monday, 13 March 2017

Prediction for power consumption in kWh (Straight line) - Monday, 13 March 2017														
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]
2017-03-13 07:55	2017-03-13 08:40	1	0.346158	1.412286	0.347052	0.49363	0.056255	0.360984	1.257565	0.910166	1.018666	0.017096	0.221414	0.939054
2017-03-13 08:40	2017-03-13 09:25	2	0.346244	1.461795	0.367242	0.48143	0.062992	0.356602	1.234904	0.904522	1.032823	0.017779	0.213611	0.909444
2017-03-13 09:25	2017-03-13 10:10	3	0.34633	1.511304	0.387432	0.46923	0.069729	0.35222	1.212242	0.898879	1.04698	0.018462	0.205808	0.879834
2017-03-13 10:10	2017-03-13 10:55	4	0.346415	1.560813	0.407622	0.45702	0.076466	0.347838	1.18958	0.893236	1.061137	0.019145	0.198005	0.850225
2017-03-13 10:55	2017-03-13 11:40	5	0.346501	1.610322	0.427812	0.44482	0.083202	0.343457	1.166919	0.887592	1.075294	0.019829	0.190201	0.820615
2017-03-13 11:40	2017-03-13 12:25	6	0.346587	1.659831	0.448002	0.43262	0.089939	0.339075	1.144257	0.881949	1.089451	0.020512	0.182398	0.791005
2017-03-13 12:25	2017-03-13 13:10	7	0.346673	1.70934	0.468192	0.42042	0.096676	0.334693	1.121596	0.876306	1.103608	0.021195	0.174595	0.761395
2017-03-13 13:10	2017-03-13 13:55	8	0.346758	1.758849	0.488381	0.40821	0.103412	0.330311	1.098934	0.870662	1.117765	0.021878	0.166792	0.731786
2017-03-13 13:55	2017-03-13 14:40	9	0.346844	1.808358	0.508571	0.39601	0.110149	0.325929	1.076272	0.865019	1.131923	0.022561	0.158988	0.702176
2017-03-13 14:40	2017-03-13 15:25	10	0.34693	1.857868	0.528761	0.38381	0.116886	0.321548	1.053611	0.859375	1.14608	0.023244	0.151185	0.672566
2017-03-13 15:25	2017-03-13 16:10	11	0.347015	1.907377	0.548951	0.37161	0.123623	0.317166	1.030949	0.853732	1.160237	0.023928	0.143382	0.642957
2017-03-13 16:10	2017-03-13 16:55	12	0.347101	1.956886	0.569141	0.3594	0.130359	0.312784	1.008287	0.848089	1.174394	0.024611	0.135578	0.613347
2017-03-13 16:55	2017-03-13 17:40	13	0.347187	2.006395	0.589331	0.3472	0.137096	0.308402	0.985626	0.842445	1.188551	0.025294	0.127775	0.583737
			4.506743	**22.22142**	**6.08649**	**5.46541**	**1.256785**	**4.351008**	**14.58074**	**11.39197**	**14.34691**	**0.275534**	**2.269733**	**9.898141**
			32.815			**11.073**			**40.320**			**12.443**		
			96.651											

5.2.4 Kalman Filter method used in prediction

Two applied methods were used to make the prediction using the Kalman Filter method, namely, using Simulink in Matlab® and Microsoft® Excel.

Kalman Filter method using Simulink in Matlab®

Figure 5.1 shows the diagram designed in Simulink in Matlab® to make predictions for the power consumption.

By using this method, a diagram was designed in Simulink in Matlab® using the Kalman Filter to predict the power consumption for Monday, 13 March 2017, as shown in Figure 5.1. The prediction was made for 13 periods from 07:55 in the morning until 17:40 in the afternoon.

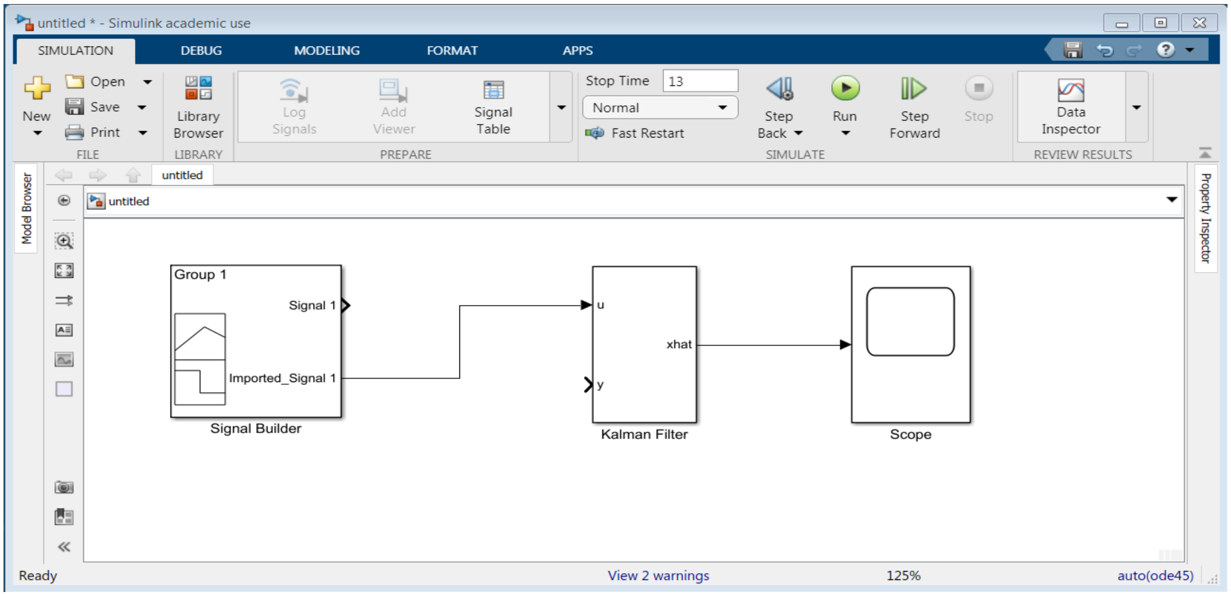

Figure 5.1 Diagram designed in Simulink in Matlab® using Kalman Filter for prediction of power consumption

Figure 5.2 shows the input data to the Signal Builder. The initial power consumption for Monday, 6 March 2017, as shown in Table 5.2 were used as the input data to the Signal Builder to predict the power consumption.

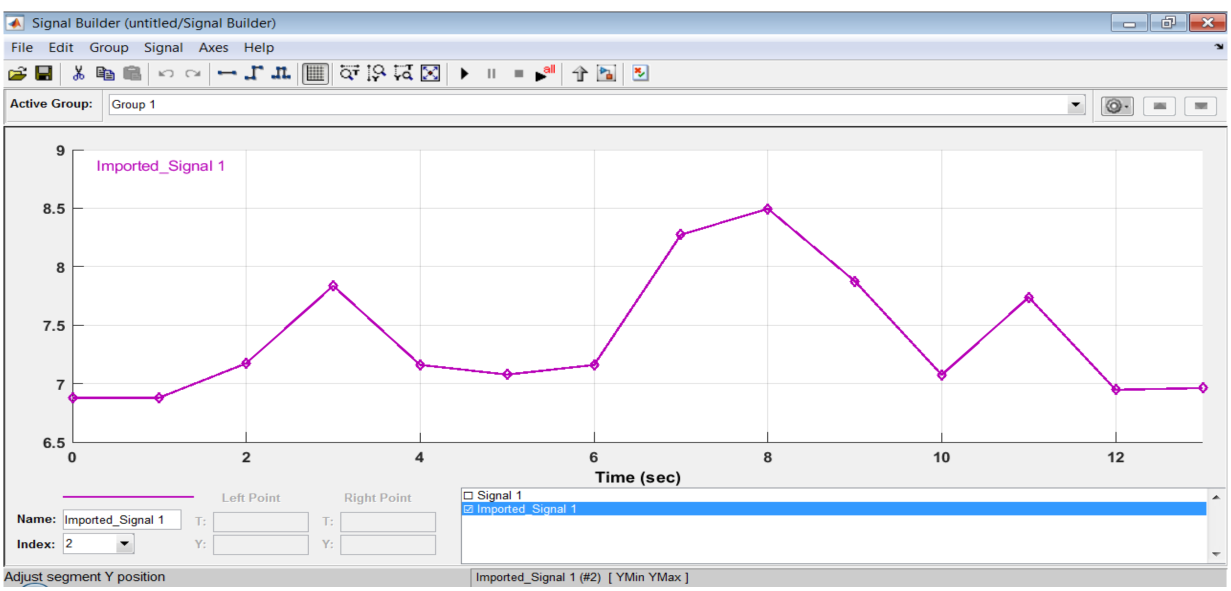

Figure 5.2 Input data to Signal Builder in Simulink in Matlab®

Figure 5.3 shows the output signal from the Kalman Filter to the scope (displayed result). This signal represents the power consumption prediction for the thirteen periods for Monday, 13 March 2017.

The total predicted power consumption for the above period, using this method of the Kalman Filter, was about ***99.08 kWh.***

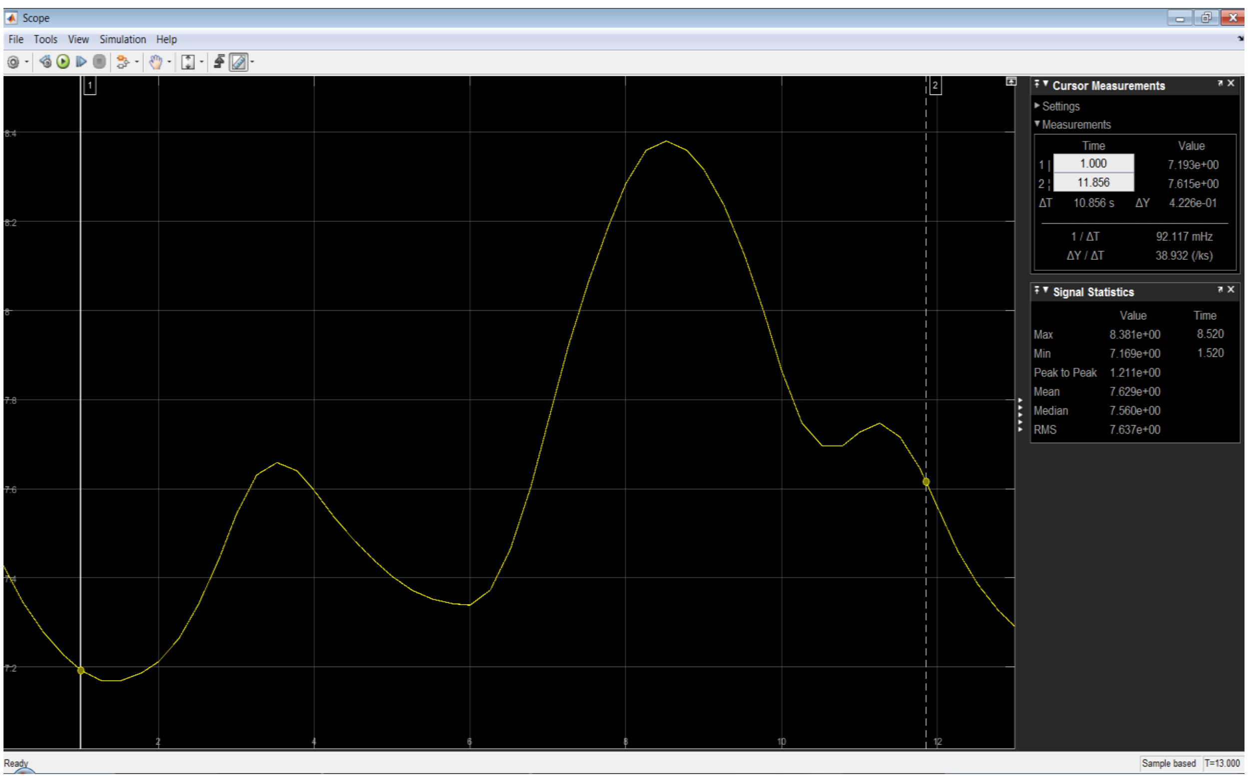

Figure 5.3 Output signal from the Kalman Filter to the Scope

Figure 5.4 shows the imported signal and output signal using Kalman Filter method in Simulink.

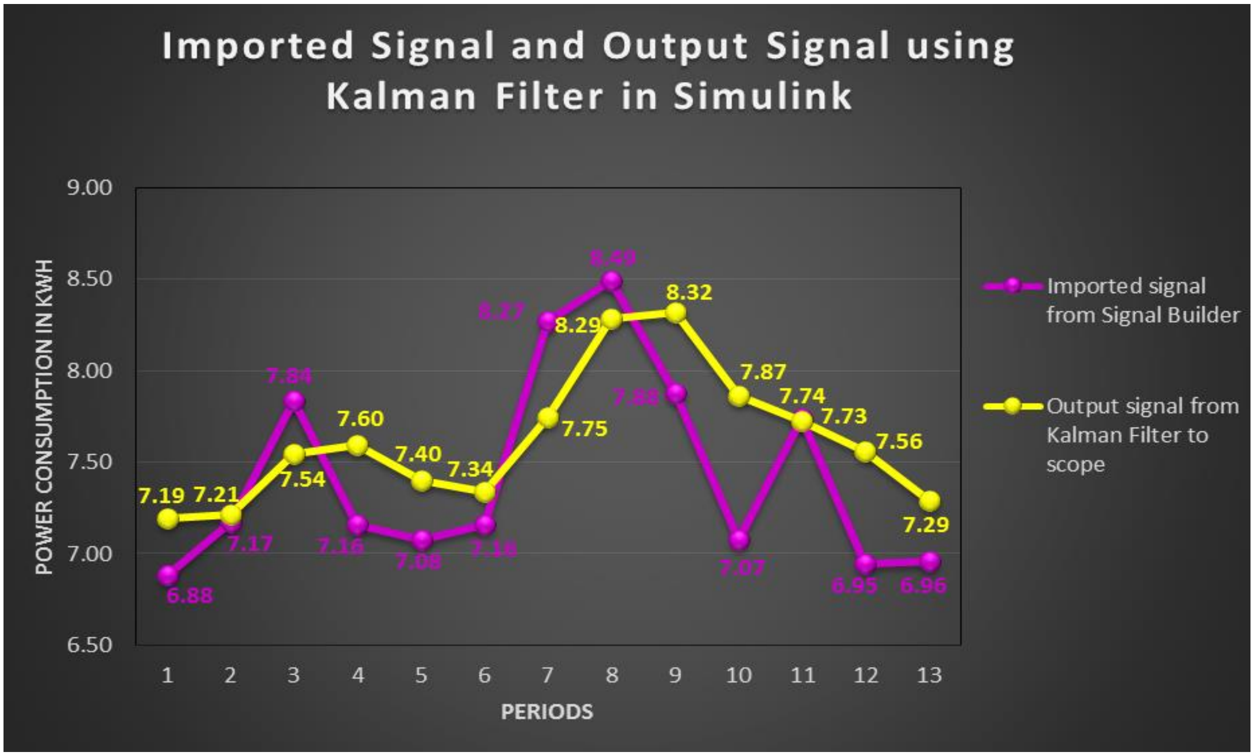

Figure 5.4 Imported Signal and Output Signal using Kalman Filter in Simulink

Kalman Filter method using Microsoft® *Excel*

By using the Kalman Filter method in Microsoft® Excel, the formulas 3.21 to 3.23 were used, as well as the initial power consumption data for Monday, 6 March 2017, as shown in Table 5.2, to predict the power consumption for the following Monday.

It was decided to take the previous reading as 7.435 kWh, as shown in red in Table 5.5. The value of 7.435 kWh is the average kWh per period for Monday, 6 March 2017. The error in measurement was taken as 4, which means that a reading can be four more or four less. The previous error estimate was initially taken as two, which means the reading can be two more or two less.

Table 5.5 Kalman Filter prediction for power consumption in kWh for Monday, 13 March 2017 in Microsoft® Excel

Kalman Filter Method					
Period	**Initial Measurement**	**Error in measurement**	**Current estimate**	**Kalman gain**	**Previous error in estimate**
t-1			**7.435**		2
t	6.880	4	7.250	0.33	1.33
t+1	7.173	4	7.231	0.25	1.00
t+2	7.836	4	7.352	0.20	0.80
t+3	7.160	4	7.320	0.17	0.67
t+4	7.077	4	7.285	0.14	0.57
t+5	7.159	4	7.269	0.13	0.50
t+6	8.273	4	7.381	0.11	0.44
t+7	8.495	4	7.492	0.10	0.40
t+8	7.876	4	7.527	0.09	0.36
t+9	7.074	4	7.489	0.08	0.33
t+10	7.738	4	7.509	0.08	0.31
t+11	6.947	4	7.468	0.07	0.29
t+12	6.962	4	7.435	0.07	0.27
Total initial comsumption in kWh	96.651	Total perdicted consumption in kWh	96.007		

Table 5.6 shows the prediction of the power consumption in kWh for Monday, 13 March 2017, by using Kalman Filter method in Microsoft® Excel. The prediction was also made for 13 periods from 07:55 in the morning until 17:40 in the afternoon.

The total predicted power consumption for the above period, using Kalman Filter in Microsoft® Excel was about ***96.007 kWh***, as shown in Table 5.6.

Table 5.6 Kalman Filter prediction for power consumption in kWh for Monday, 13 March 2017

Prediction for power consumption in kWh (Kalman Filter) - Monday, 13 March 2017														
Date & Time	**Date & Time**	**Period**	**CT1: Red phase Lights [kWh]**	**CT2: White phase Lights [kWh]**	**CT3: Blue phase Lights [kWh]**	**CT4: Red phase Plugs [kWh]**	**CT5: White phase Plugs [kWh]**	**CT6: Blue phase Plugs [kWh]**	**CT7: Red phase Dedicated plugs [kWh]**	**CT8: White phase Dedicated plugs [kWh]**	**CT9: Blue phase Dedicated plugs [kWh]**	**CT10: Red phase Special points [kWh]**	**CT11: White phase Special points [kWh]**	**CT12: Blue phase Special points [kWh]**
2017-03-13 07:55	2017-03-13 08:40	1	0.34677	1.611486	0.449909	0.47085	0.084246	0.315795	1.152469	0.90177	1.0881	0.01584	0.180912	0.631577
2017-03-13 08:40	2017-03-13 09:25	2	0.34762	1.560295	0.440635	0.44718	0.080339	0.32501	1.166996	0.908923	1.079974	0.016493	0.184856	0.672287
2017-03-13 09:25	2017-03-13 10:10	3	0.347828	1.525239	0.435057	0.45209	0.078053	0.322823	1.178297	0.908206	1.074118	0.01661	0.187072	0.826352
2017-03-13 10:10	2017-03-13 10:55	4	0.347632	1.5011	0.431279	0.43973	0.078154	0.337172	1.175522	0.906663	1.070841	0.013921	0.188192	0.829501
2017-03-13 10:55	2017-03-13 11:40	5	0.347304	1.485081	0.430512	0.45077	0.078967	0.331739	1.159661	0.897509	1.068077	0.013987	0.188711	0.832709
2017-03-13 11:40	2017-03-13 12:25	6	0.347016	1.489282	0.43062	0.45214	0.078883	0.351802	1.140387	0.884342	1.06976	0.017731	0.18907	0.818296
2017-03-13 12:25	2017-03-13 13:10	7	0.346694	1.575539	0.430749	0.45889	0.081832	0.35598	1.171753	0.885909	1.06884	0.020984	0.189385	0.794288
2017-03-13 13:10	2017-03-13 13:55	8	0.346437	1.644839	0.430901	0.4487	0.082748	0.352788	1.194199	0.882764	1.066541	0.023923	0.189615	0.828782
2017-03-13 13:55	2017-03-13 14:40	9	0.346073	1.677823	0.431087	0.4443	0.084146	0.34983	1.176823	0.875806	1.063241	0.022055	0.189642	0.866326
2017-03-13 14:40	2017-03-13 15:25	10	0.34585	1.658426	0.431226	0.43725	0.086461	0.345049	1.165825	0.87961	1.078898	0.021605	0.189681	0.849512
2017-03-13 15:25	2017-03-13 16:10	11	0.345774	1.703551	0.431304	0.4283	0.090645	0.341151	1.148894	0.880402	1.09374	0.022198	0.189794	0.832778
2017-03-13 16:10	2017-03-13 16:55	12	0.346097	1.728016	0.431273	0.42225	0.093732	0.339972	1.13272	0.878265	1.102215	0.021373	0.187034	0.785507
2017-03-13 16:55	2017-03-13 17:40	13	0.346673	1.70934	0.468192	0.42042	0.096676	0.334693	1.121596	0.876306	1.103608	0.021195	0.174595	0.761395
			4.507766	**20.87002**	**5.672744**	**5.77287**	**1.094881**	**4.403806**	**15.08514**	**11.56648**	**14.02795**	**0.247913**	**2.42856**	**10.32931**
			31.051			**11.272**			**40.680**			**13.006**		
			96.007											

Figure 5.5 shows the initial power consumption (Imported Signal) for Monday, 6 March 2017, the predicted power consumption (Output Signal) for Monday, 13 March 2017, using Kalman Filter in Simulink in *Matlab*® as well as the prediction for Monday, 13 March 2017, using Kalman Filter in *Microsoft*® Excel.

As can be seen in Figure 5.5, the prediction of the Kalman Filter method in Microsoft® Excel is the most accurate prediction of the two methods obtained.

For this reason, it was decided to henceforth use the readings obtained in Microsoft® Excel for further calculations and predictions in this study.

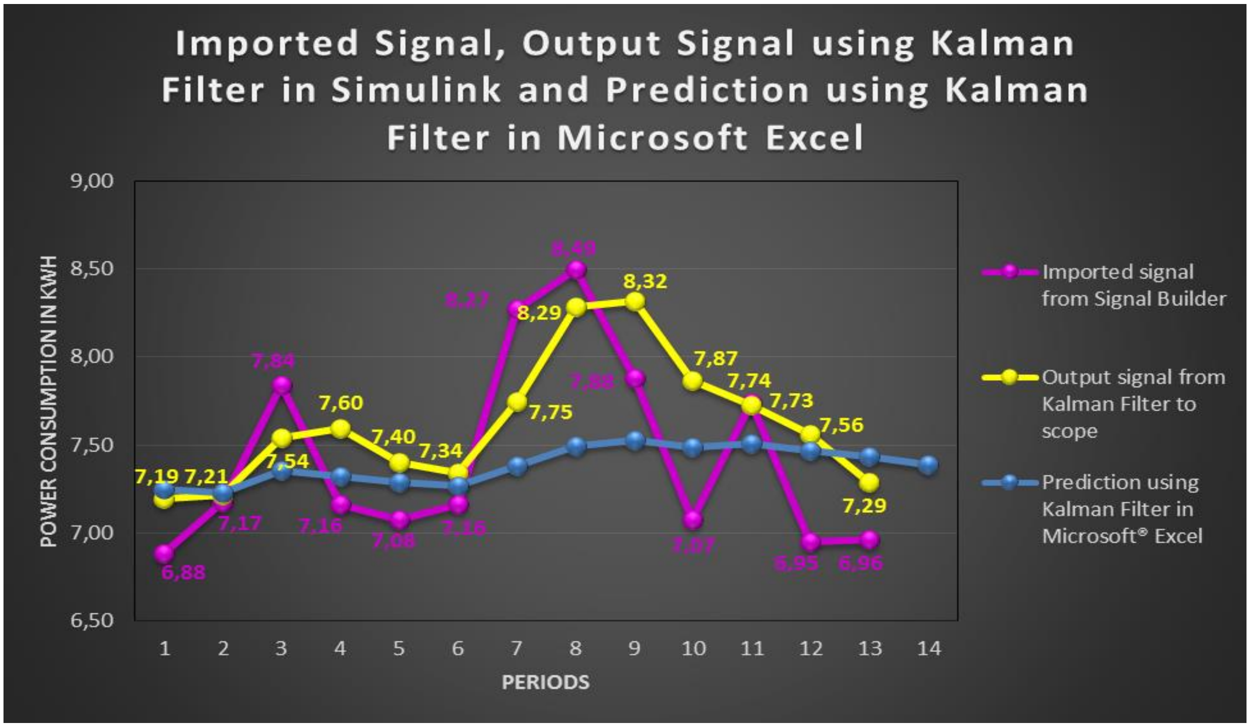

Figure 5.5 Imported Signal, Output Signal using Kalman Filter in Simulink and prediction using Kalman Filter in Microsoft® Excel.

5.2.5 Actual consumption

Table 5.7 shows the actual total power consumption in kWh for Monday, 13 March 2017. The power consumption was also monitored from 07:55 in the morning until 17:40 in the afternoon. The total actual power consumption for the above-mentioned period was about ***98.279 kWh****,* as shown in the Table 5.7.

Table 5.7 Actual power consumption in kWh for Monday, 13 March 2017

Actual power consumption in kWh - Monday, 13 March 2017														
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]
2017-03-13 07:55	2017-03-13 08:40	1	0.34835	1.39216	0.0001	0.58635	0.13276	0.377534	1.169064	0.904433	0.87313	0.000747	0.194766	0.384176
2017-03-13 08:40	2017-03-13 09:25	2	0.346531	1.394139	8.53E-05	0.60108	0.131202	0.510662	1.17329	0.922039	0.871175	0.00388	0.193358	0.703238
2017-03-13 09:25	2017-03-13 10:10	3	0.345601	1.392073	0.154673	0.51582	0.140834	0.454563	1.218446	0.888195	0.867483	0.002047	0.192691	0.930502
2017-03-13 10:10	2017-03-13 10:55	4	0.3442	1.390172	0.427709	0.62321	0.144268	0.469512	1.127092	0.794568	0.869191	0.022213	0.191111	0.820934
2017-03-13 10:55	2017-03-13 11:40	5	0.343188	1.404875	0.429276	0.499	0.144879	0.438998	1.052961	0.797431	0.87541	0.009208	0.189956	0.807755
2017-03-13 11:40	2017-03-13 12:25	6	0.342797	1.526704	0.430163	0.33435	0.141367	0.446253	1.021102	0.733186	0.86652	0.022277	0.190186	0.858752
2017-03-13 12:25	2017-03-13 13:10	7	0.343363	2.263985	0.426638	0.62858	0.177988	0.455993	1.432506	0.951144	1.049905	0.012927	0.192363	0.7036
2017-03-13 13:10	2017-03-13 13:55	8	0.348859	2.245545	0.420932	0.65479	0.230777	0.592526	1.538731	0.959158	1.100294	0.022242	0.1963	0.494621
2017-03-13 13:55	2017-03-13 14:40	9	0.345591	2.259063	0.418941	0.44392	0.191909	0.455956	1.656468	0.966606	1.103624	0.03446	0.194296	0.792988
2017-03-13 14:40	2017-03-13 15:25	10	0.346163	2.228442	0.41768	0.42447	0.109242	0.412616	1.210873	0.906216	1.120857	0.019041	0.194739	1.147314
2017-03-13 15:25	2017-03-13 16:10	11	0.349935	2.272729	0.416851	0.49607	0.113675	0.437844	1.026375	0.896408	1.113765	0.03163	0.197471	0.713259
2017-03-13 16:10	2017-03-13 16:55	12	0.354764	1.952319	0.412583	0.42608	0.110135	0.611895	0.928329	0.860532	1.111309	0.005207	0.155883	0.695051
2017-03-13 16:55	2017-03-13 17:40	13	0.358271	0.809759	0.970484	0.29742	0.101688	0.442813	0.922812	0.866906	1.099213	0.016534	0.000459	0.408968
			4.517612	**22.53196**	**4.926114**	**6.53114**	**1.870724**	**6.107166**	**15.47805**	**11.44682**	**12.92188**	**0.202412**	**2.283579**	**9.461159**
			31.976			**14.509**			**39.847**			**11.947**		
			98.279											

5.2.6 Power consumption and prediction profiles for all twelve outgoing circuits

Figures 5.6 to 5.17 show the initial power consumption, predicted consumption using the Straight Line method, Moving Average method and the Kalman Filter method in Microsoft® Excel, as well as the actual power consumption for all twelve outgoing circuits.

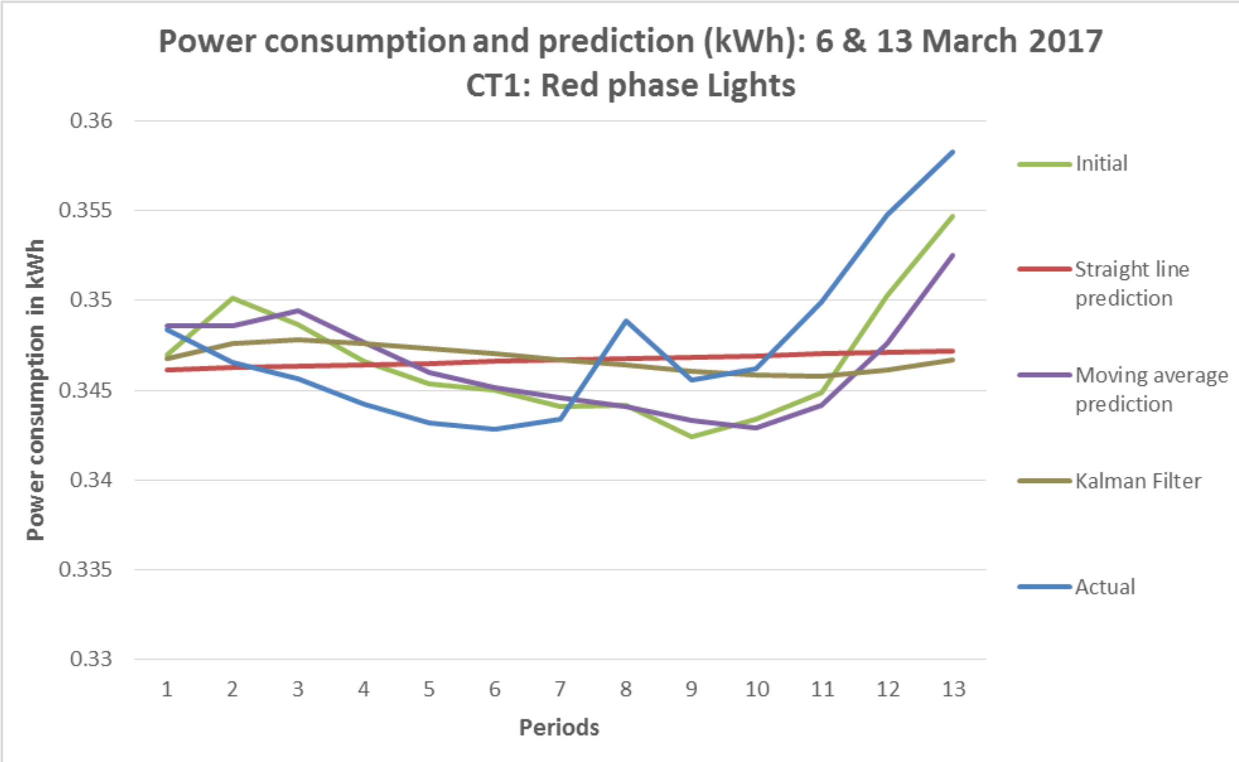

Figure 5.6 Power consumption and prediction for CT1: Red Phase Lights

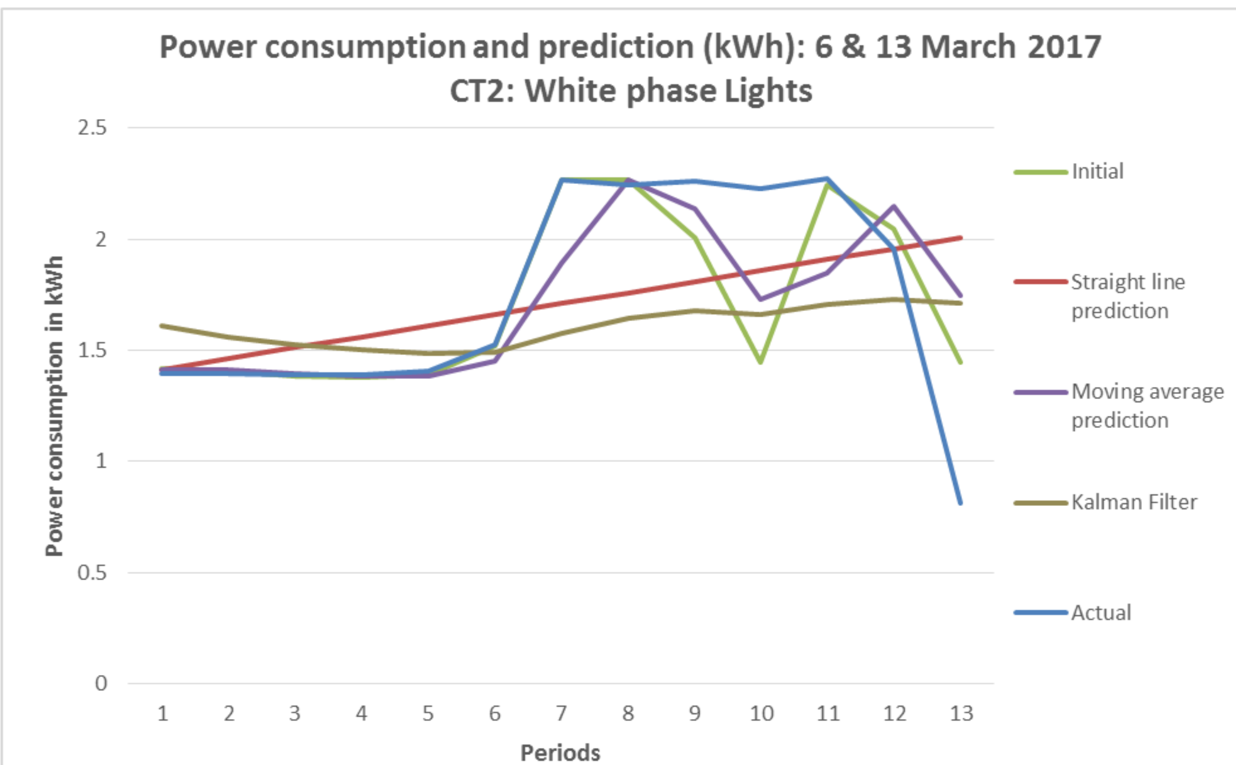

Figure 5.7 Power consumption and prediction for CT2: White Phase Lights

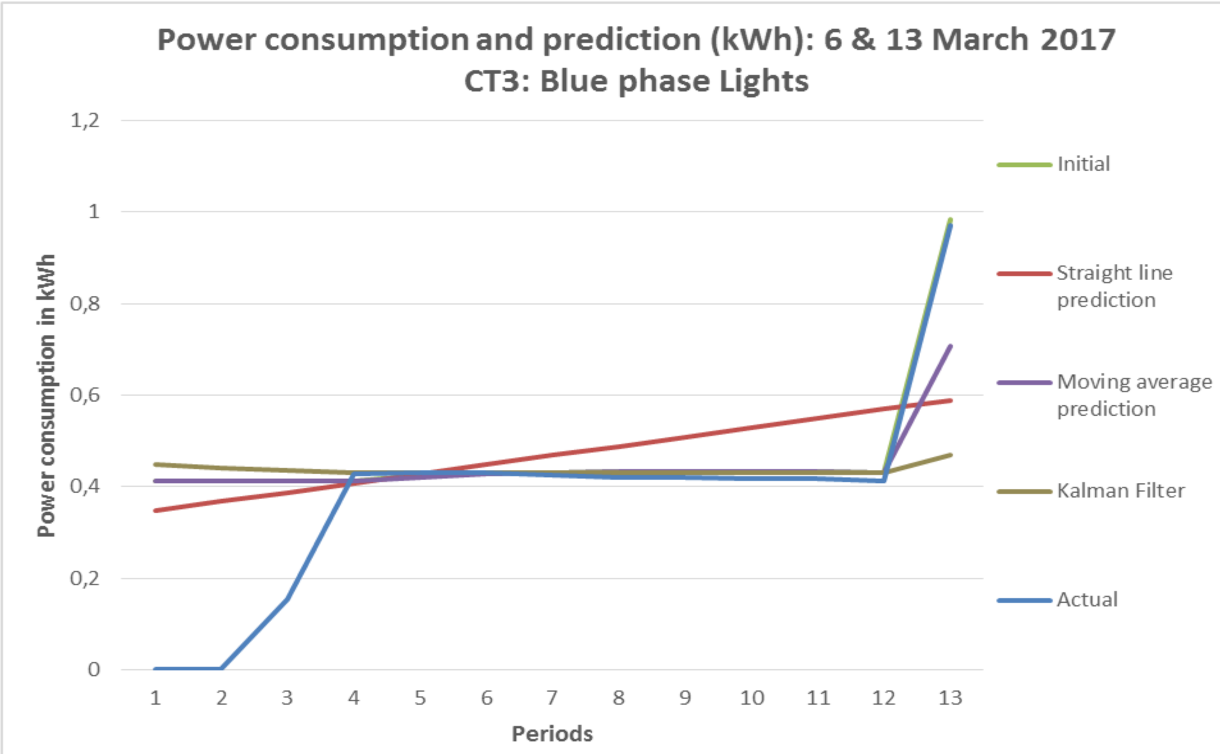

Figure 5.8 Power consumption and prediction for CT3: Blue Phase Lights

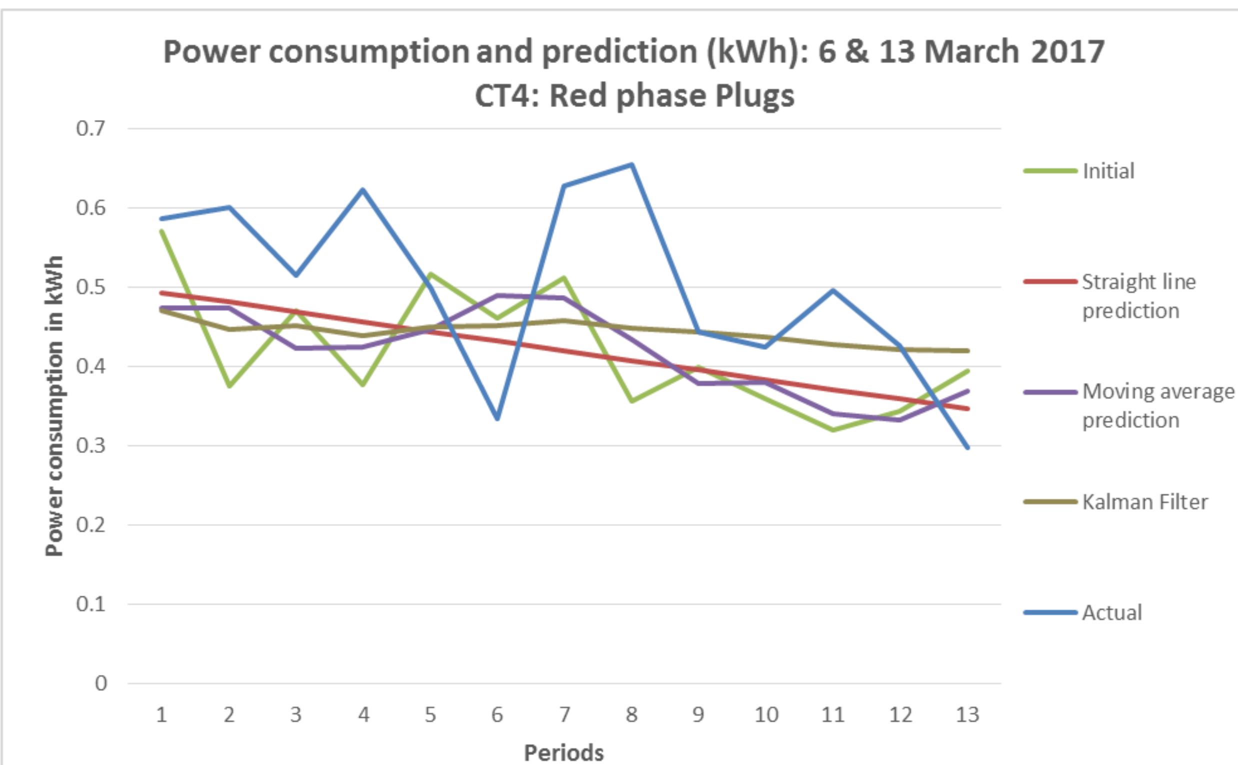

Figure 5.9 Power consumption and prediction for CT4: Red Phase Plugs

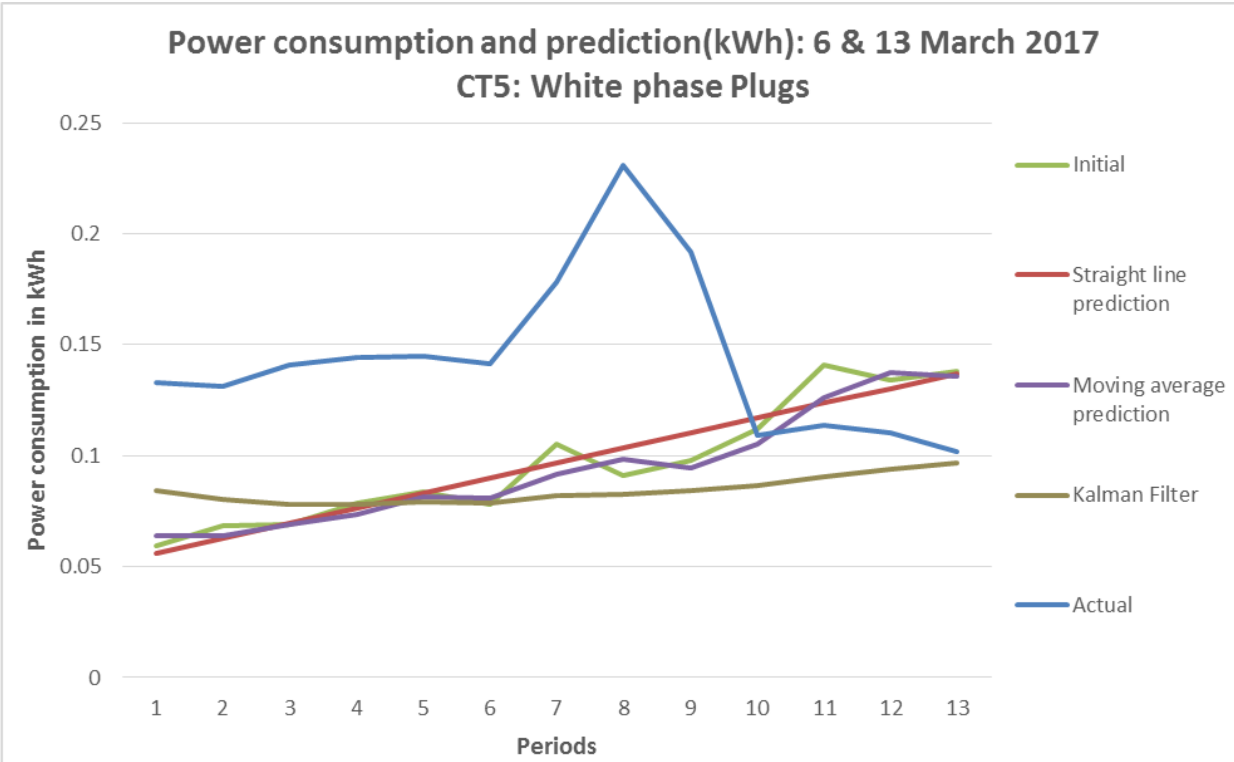

Figure 5.10 Power consumption and prediction for CT5: White Phase Plugs

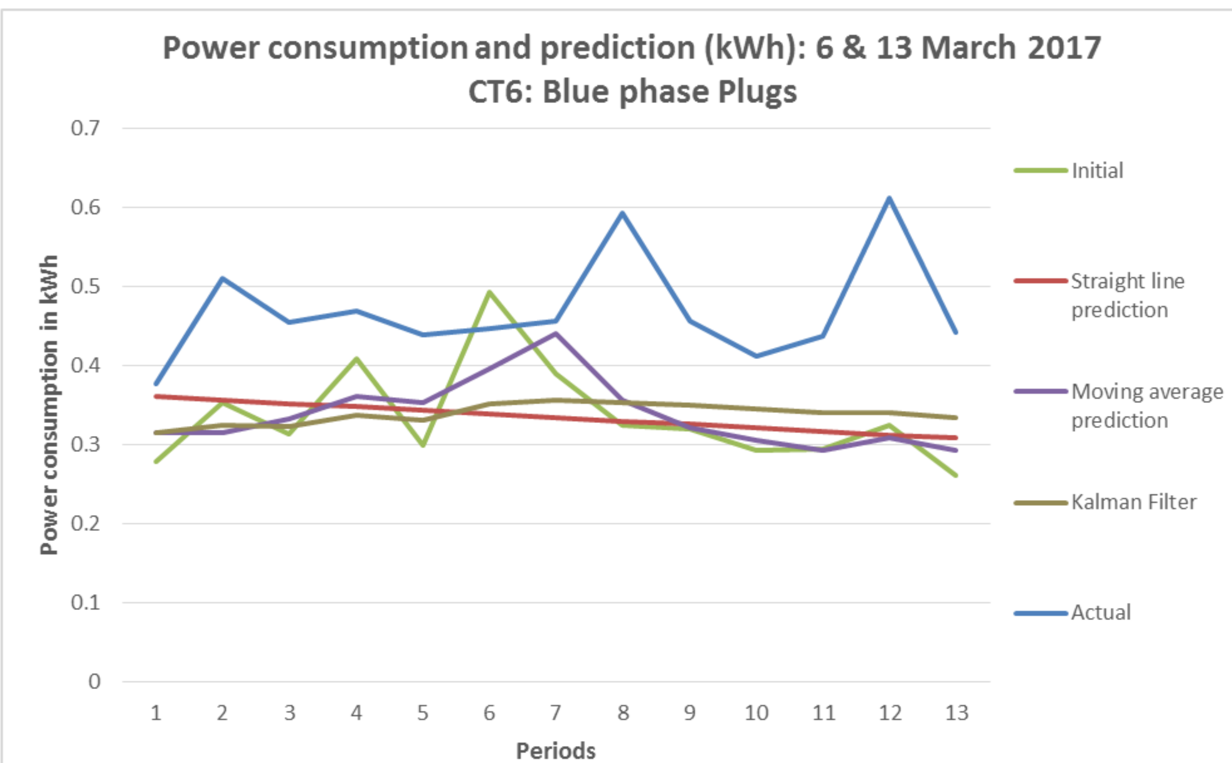

Figure 5.11 Power consumption and prediction for CT6: Blue Phase Plugs

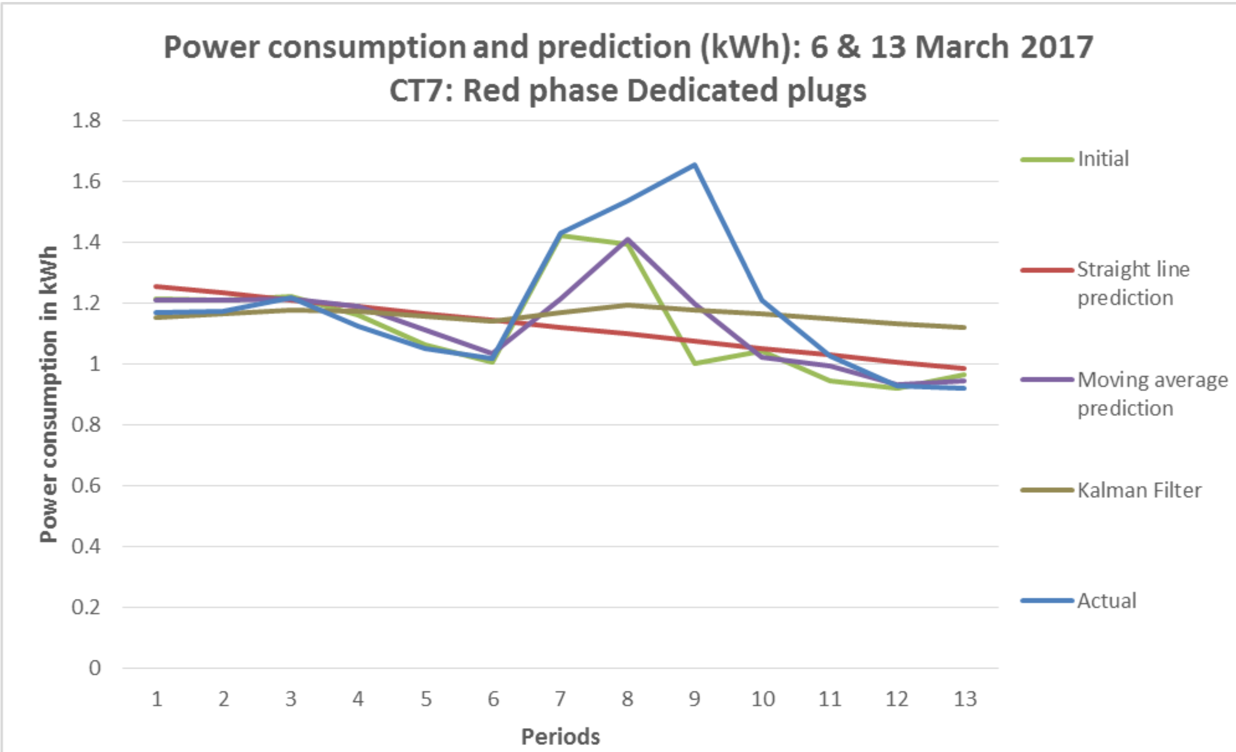

Figure 5.12 Power consumption and prediction for CT7: Red Phase Dedicated Plugs

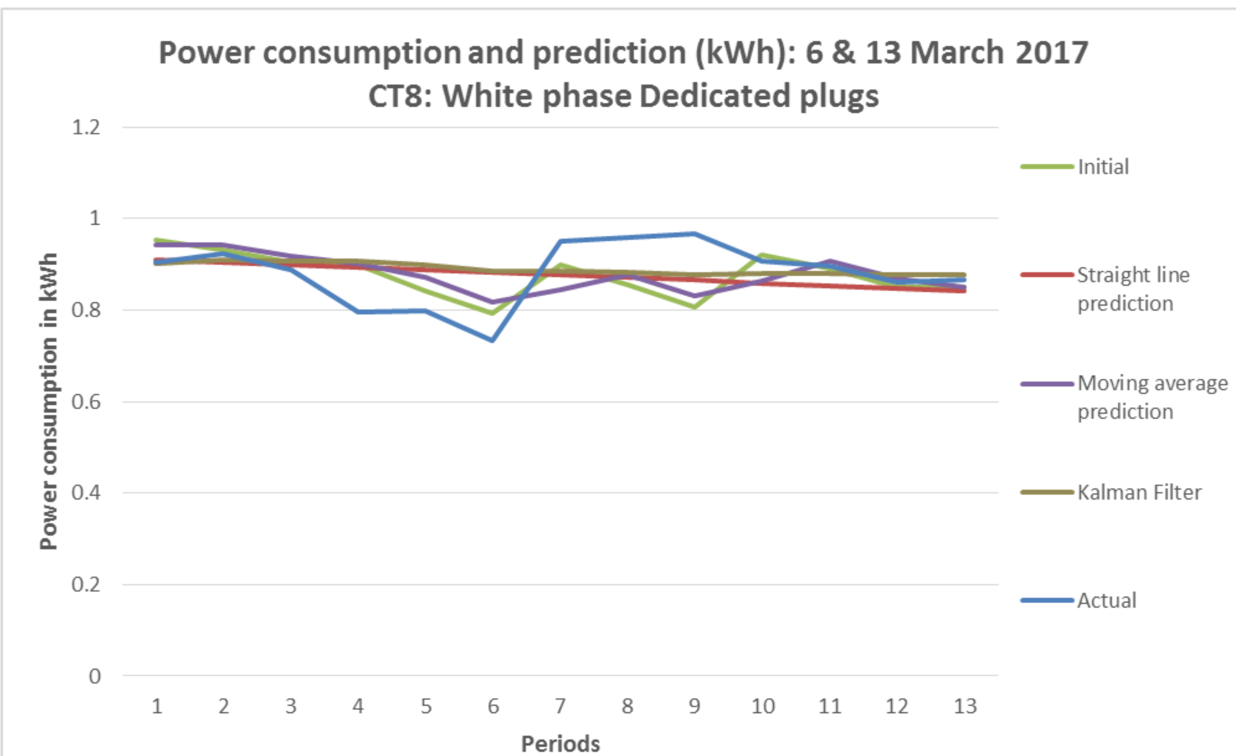

Figure 5.13 Power consumption and prediction for CT8: White Phase Dedicated Plugs

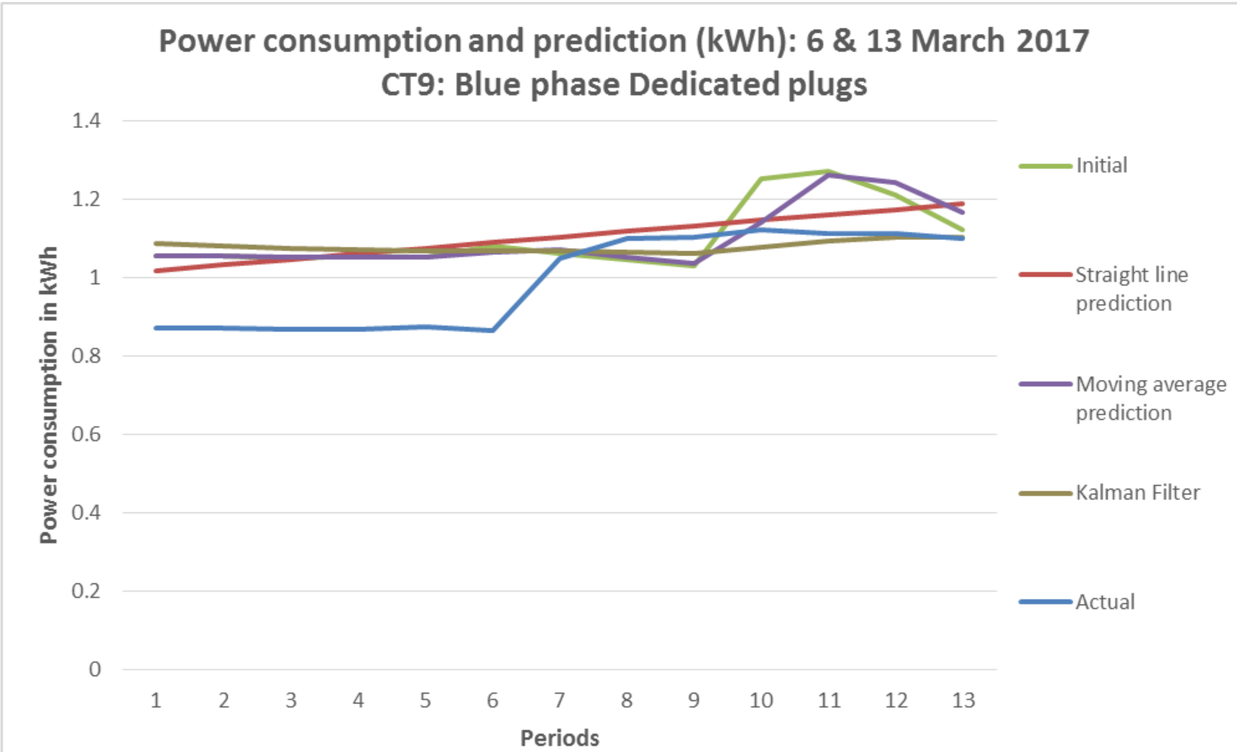

Figure 5.14 Power consumption and prediction for CT9: Blue Phase Dedicated Plugs

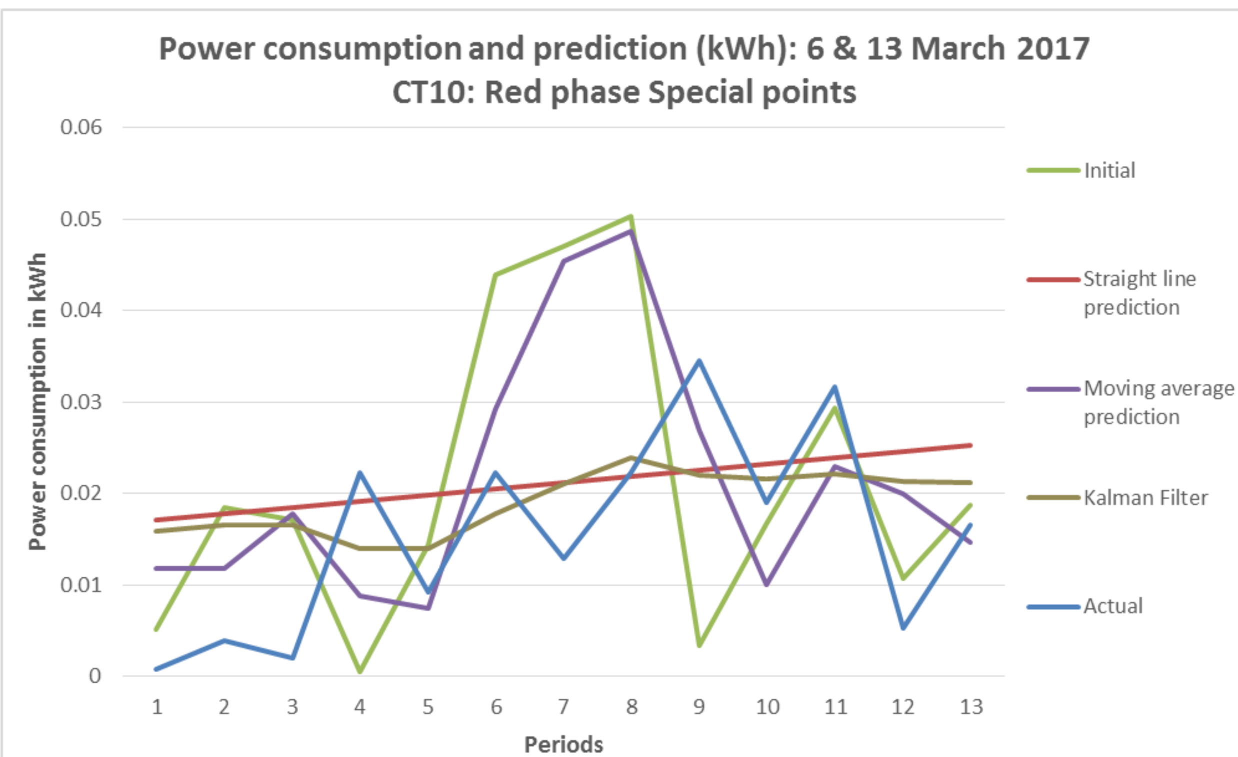

Figure 5.15 Power consumption and prediction for CT10: Red Phase Special points

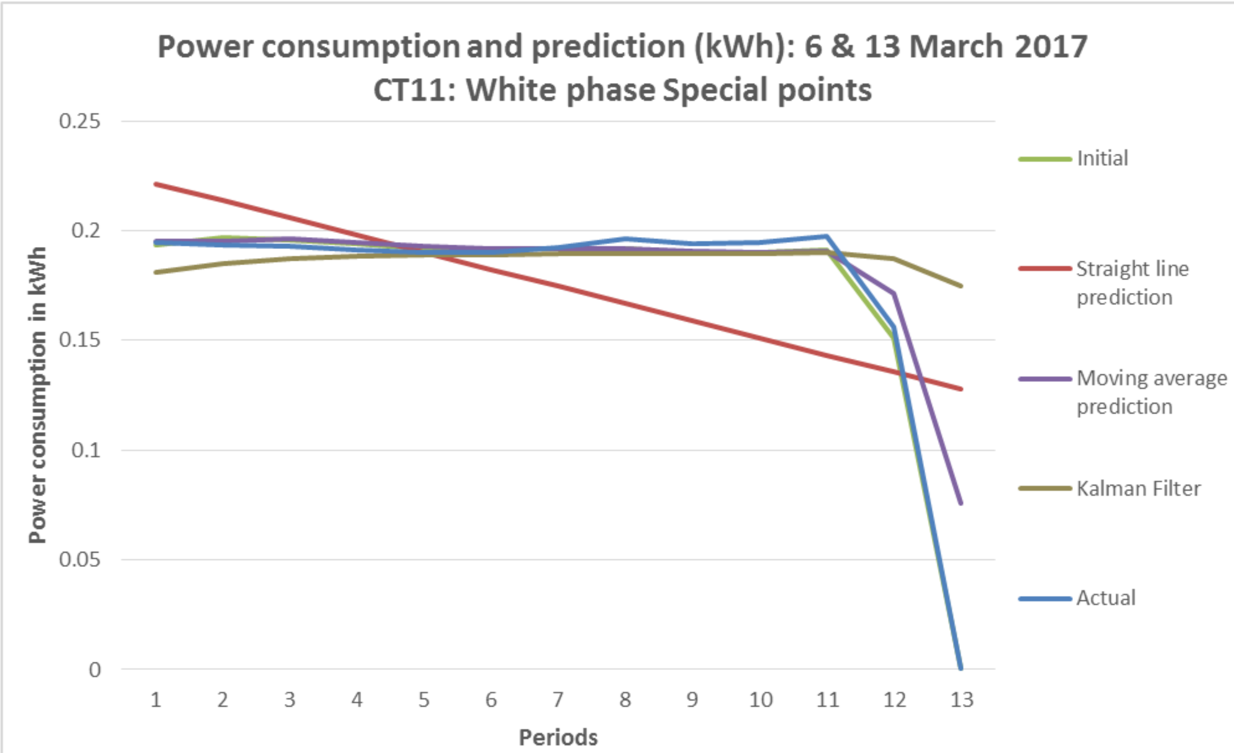

Figure 5.16 Power consumption and prediction for CT11: White Phase Special points

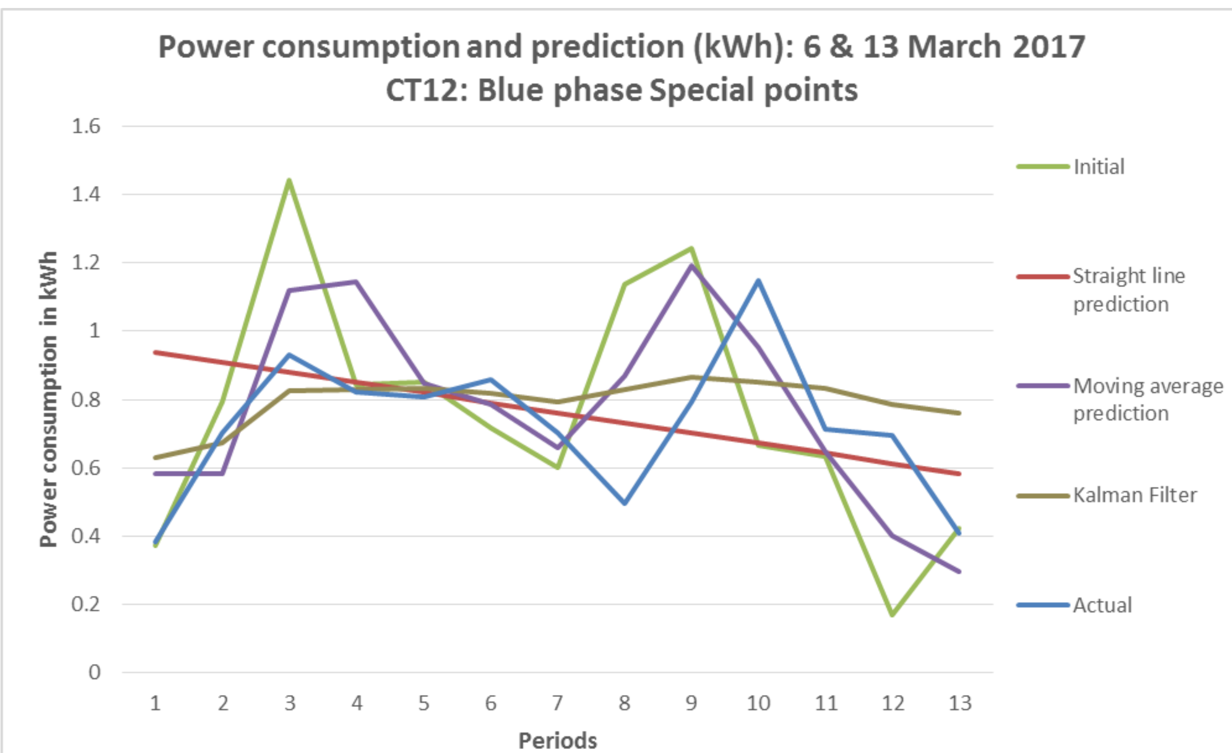

Figure 5.17 Power consumption and prediction for CT12: Blue Phase Special points

5.2.7 Total power consumption and prediction profiles for light circuits

Figure 5.18 shows the total initial power consumption for Monday, 6 March 2017, for all three light circuits as shown in green.

The prediction using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel for Monday, 13 March 2017, for the three light circuits are also shown on the graph in red, purple and olive green, respectively.

The actual total power consumption for the same day is shown in blue on the graph.

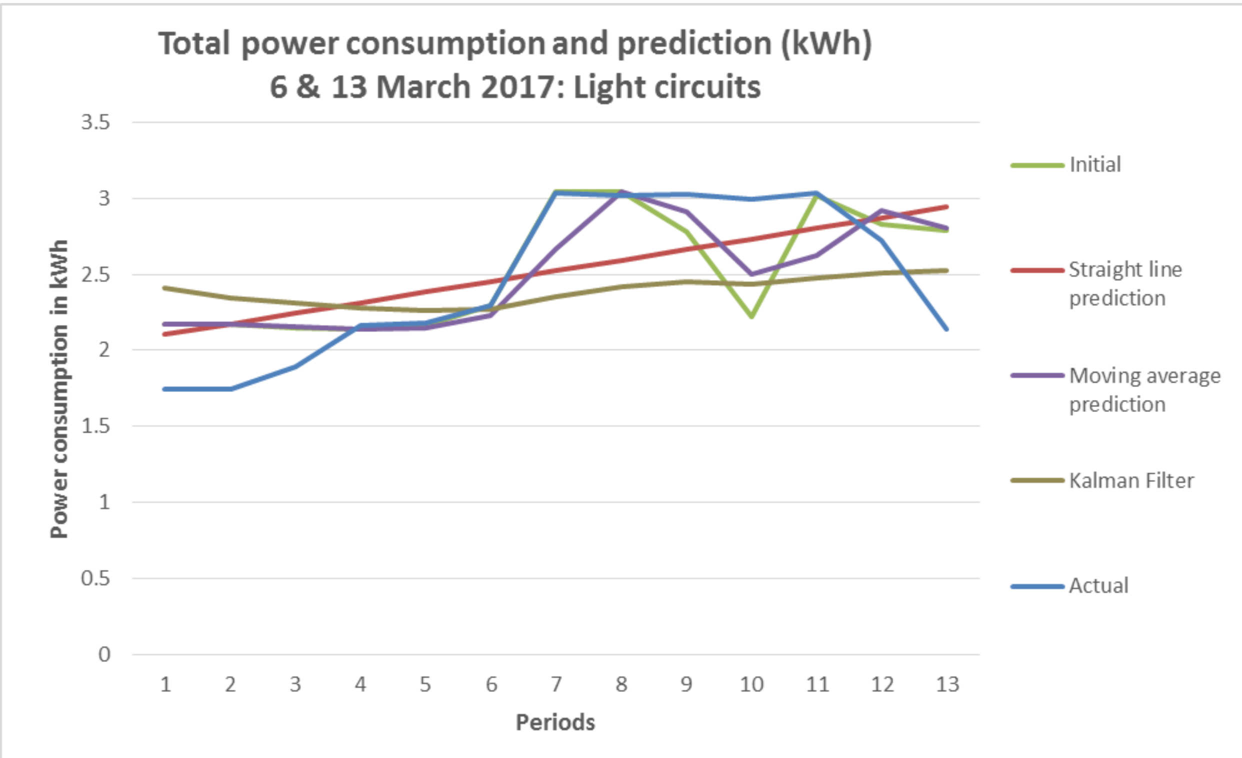

Figure 5.18 Total power consumption and prediction profiles for light circuits

In Figure 5.19, it can be observed that the initial power consumption for the light circuits for Monday, 6 March 2017, amounts to approximately ***32.815 kWh***.

The prediction was made for the following Monday using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel. The predicted consumption using the three methods was ***32.815 kWh, 32.596 kWh*** and ***31.051 kWh,*** respectively.

The actual power consumption for the light circuits for Monday, 13 March 2017, was approximately ***31.976 kWh***.

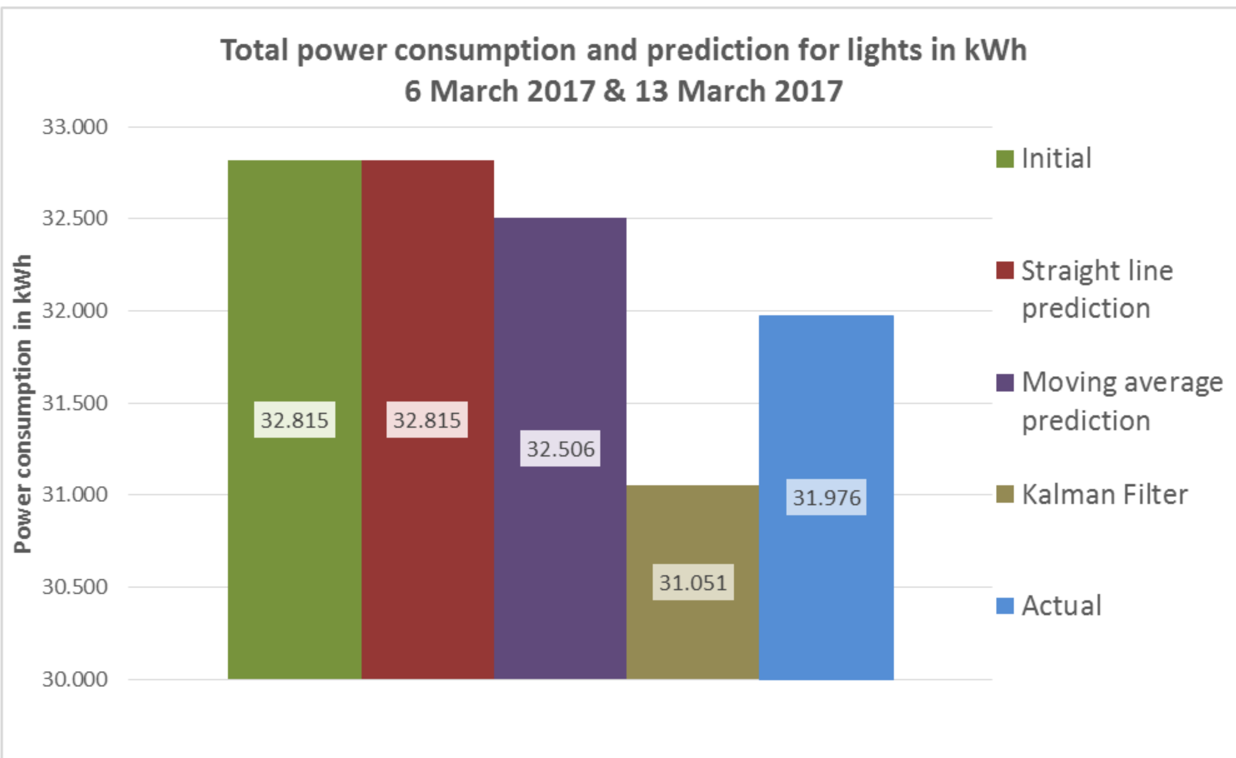

Figure 5.19 Total power consumption and prediction for light circuits

As shown in Table 5.8, the percentage predicted accuracy using the Straight Line method ranges from ***98.62%*** to ***123.56%*** for the three light circuits. This gives a total predicted accuracy of ***102.62%*** for the accumulated power consumption for the light circuits.

The percentage predicted accuracy using the Moving Average method ranges from ***98.53%*** to ***117.75%***. This gives a total predicted accuracy of ***101.66%*** for the accumulated power consumption for the light circuits.

The percentage predicted accuracy using the Kalman Filter method in Microsoft® Excel ranges from ***92.62%*** to ***115.16%***. This gives a total predicted accuracy of ***97.11%*** for the accumulated power consumption for the light circuits.

Table 5.8 Percentage accuracy of predicted power consumption for each light circuit

Percentage accuracy for light circuits				
Lights	**CT1**	**CT2**	**CT3**	**Total for Lights**
Initial consumption	4.507	22.221	6.086	32.815
Prediction: Straight line	4.507	22.221	6.086	32.815
Prediction: Moving average	4.504	22.201	5.800	32.506
Prediction: Kalman Filter	4.508	20.870	5.673	31.051
Actual consumption	4.518	22.532	4.926	31.976
% Accuracy: Straight line	**99.76%**	**98.62%**	**123.56%**	**102.62%**
% Accuracy: Moving average	**99.71%**	**98.53%**	**117.75%**	**101.66%**
% Accuracy: Kalman Filter	**99.78%**	**92.62%**	**115.16%**	**97.11%**

5.2.8 Total power consumption and prediction profiles for plug circuits

Figure 5.20 shows the total initial power consumption for Monday, 6 March 2017, for all three plug circuits, as shown in green.

The prediction using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel for Monday, 13 March 2017, for the three plug circuits are also shown on the graph in red, purple and olive green, respectively.

The actual total power consumption for the same day is shown on the graph in blue.

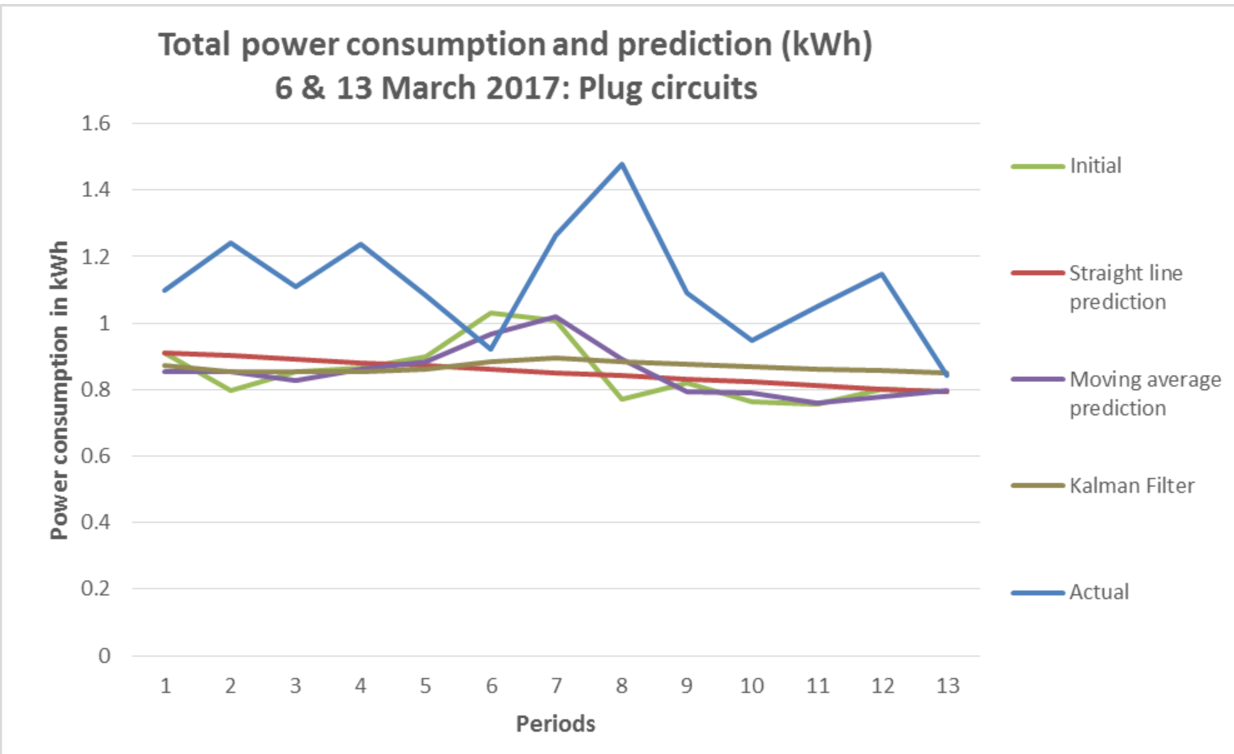

Figure 5.20 Total power consumption and prediction profiles for plug circuits

In Figure 5.21, it can be observed that the initial power consumption for the plug circuits for Monday, 6 March 2017, amounts to approximately ***11.073 kWh***.

The prediction was made for the following Monday using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel. The predicted consumption using the three methods was ***11.073 kWh, 11.075 kWh*** and ***11.272 kWh***, respectively.

The actual power consumption for the plug circuits for Monday, 13 March 2017, was approximately ***14.509 kWh***.

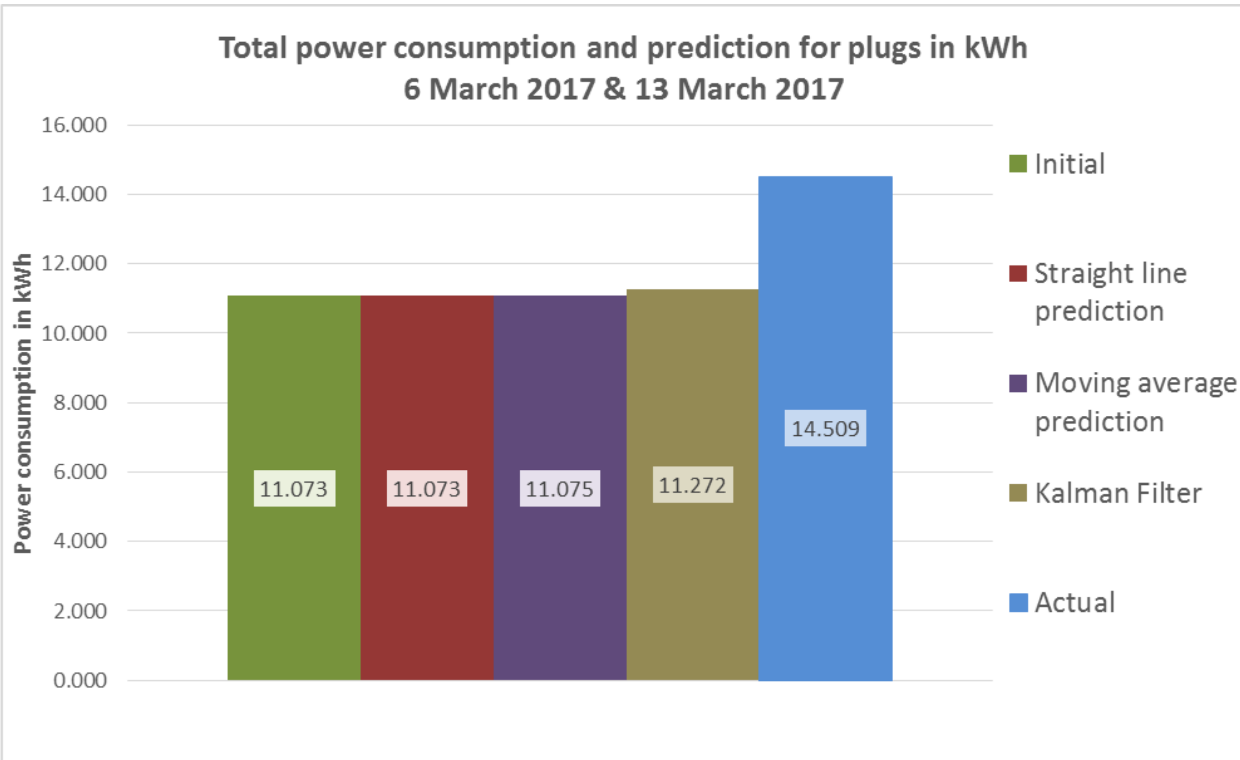

Figure 5.21 Total power consumption and prediction for plug circuits

As shown in Table 5.9, the percentage predicted accuracy using the Straight Line method ranges from ***67.18%*** to ***83.68%*** for the three plug circuits. This gives a total predicted accuracy of ***76.32%*** for the accumulated power consumption for the plug circuits.

The percentage predicted accuracy using the Moving Average method ranges from ***65.33%*** to ***83.54%***. This gives a total predicted accuracy of ***76.33%*** for the accumulated power consumption for the plug circuits.

.The percentage predicted accuracy using the Kalman Filter method in Microsoft® Excel ranges from ***58.53%*** to ***77.69%.*** This gives a total predicted accuracy of ***77.69%*** for the accumulated power consumption for the plug circuits.

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Table 5.9 Percentage accuracy of predicted power consumption for each plug circuit

Percentage accuracy for plug circuits				
Plugs	**CT4**	**CT5**	**CT6**	**Total for Plugs**
Initial consumption	5.465	1.257	4.351	11.073
Prediction: Straight line	5.465	1.257	4.351	11.073
Prediction: Moving average	5.456	1.222	4.397	11.075
Prediction: Kalman Filter	5.773	1.095	4.404	11.272
Actual consumption	6.531	1.871	6.107	14.509
% Accuracy: Straight line	**83.68%**	**67.18%**	**71.24%**	**76.32%**
% Accuracy: Moving average	**83.54%**	**65.33%**	**72.00%**	**76.33%**
% Accuracy: Kalman Filter	**88.39%**	**58.53%**	**72.11%**	**77.69%**

5.2.9 Total power consumption and prediction profiles for dedicated plug circuits

Figure 5.22 shows the total initial power consumption for Monday, 6 March 2017, for all three dedicated plug circuits as shown in green.

The prediction using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel for Monday, 13 March 2017, for the three dedicated plug circuits are also shown on the graph in red, purple and olive green, respectively.

The actual total power consumption for the same day is shown on the graph in blue.

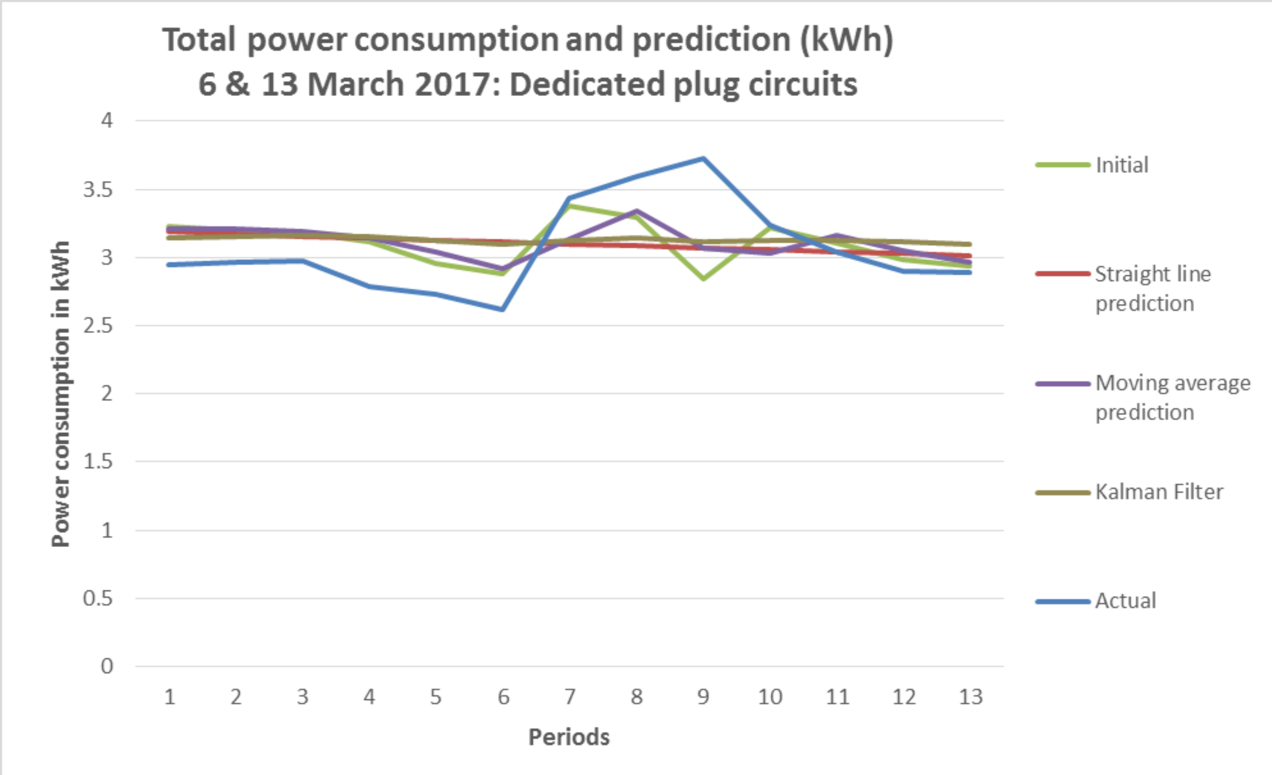

Figure 5.22 Total power consumption and prediction profiles for dedicate plug circuits

In Figure 5.23, it can be observed that the initial power consumption for the dedicated plug circuits for Monday, 6 March 2017, amounts to approximately ***40.32 kWh***.

The prediction was made for the following Monday using the Straight Line method, Moving Average method, as well as Kalman Filter method in Microsoft® Excel. The predicted consumption using the three methods was ***40.32 kWh, 40.449 kWh*** and ***40.680 kWh**,* respectively.

The actual power consumption for the dedicated plug circuits for Monday, 13 March 2017, was approximately ***39.847 kWh***.

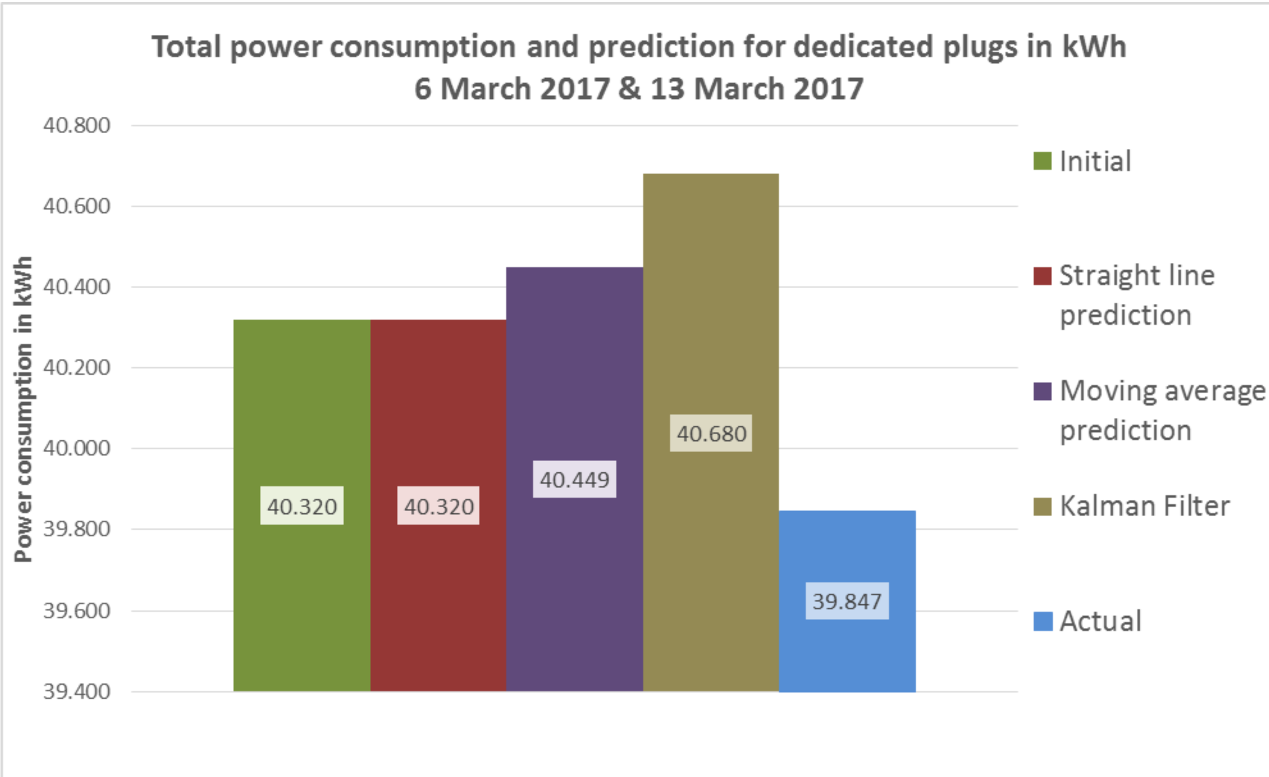

Figure 5.23 Total power consumption and prediction for dedicated plug circuits

As shown in Table 5.10, the percentage predicted accuracy using the Straight Line method ranges from ***94.20%*** to ***111.03%*** for the three dedicated plug circuits. This gives a total predicted accuracy of ***101.19%*** for the accumulated power consumption for the dedicated plug circuits.

The percentage predicted accuracy using the Moving Average method ranges from ***94.99%*** to ***110.77%***. This gives a total predicted accuracy of ***101.51%*** for the accumulated power consumption for the dedicated plug circuits.

The percentage predicted accuracy using the Kalman Filter method in Microsoft® Excel ranges from ***97.46%*** to ***108.56%***. This gives a total predicted accuracy of ***102.09%*** for the accumulated power consumption for the dedicated plug circuits. .

Table 5.10 Percentage accuracy of predicted power consumption for each dedicated plug circuit

Percentage accuracy for dedicated plug circuits				
Dedicated plugs	**CT7**	**CT8**	**CT9**	**Total for Dedicated plugs**
Initial consumption	14.581	11.392	14.347	40.320
Prediction: Straight line	14.581	11.392	14.347	40.320
Prediction: Moving average	14.703	11.433	14.313	40.449
Prediction: Kalman Filter	15.085	11.566	14.028	40.680
Actual consumption	15.478	11.447	12.922	39.847
% Accuracy: Straight line	**94.20%**	**99.52%**	**111.03%**	**101.19%**
% Accuracy: Moving average	**94.99%**	**99.88%**	**110.77%**	**101.51%**
% Accuracy: Kalman Filter	**97.46%**	**101.05%**	**108.56%**	**102.09%**

5.2.10 Total power consumption and prediction profiles for special point circuits

Figure 5.24 shows the total initial power consumption for Monday, 6 March 2017, for all three special point circuits as shown in green.

The prediction using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel for Monday, 13 March 2017, for the three special point circuits are also shown on the graph in red, purple and olive green, respectively.

The actual total power consumption for the same day is shown on the graph in blue.

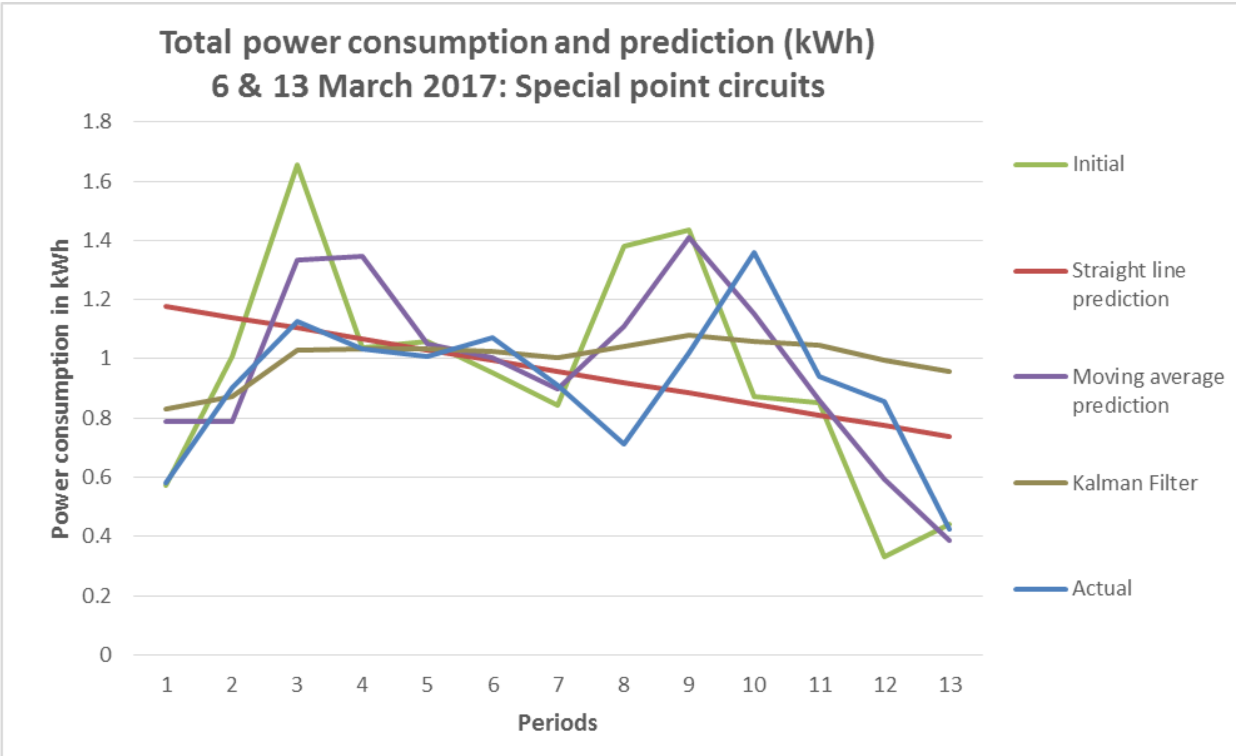

Figure 5.24 Total power consumption and prediction profiles for special point circuits

In Figure 5.25, it can be seen that the initial power consumption for the special point circuits for Monday, 6 March 2017, amounts to approximately ***12.8443 kWh***.

The prediction was made for the following Monday using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel. The predicted consumption using the three methods was ***12.443 kWh, 12.727 kWh*** and ***13.006 kWh,*** respectively.

The actual power consumption for the special point circuits for Monday, 13 March 2017, was approximately ***11.947 kWh***.

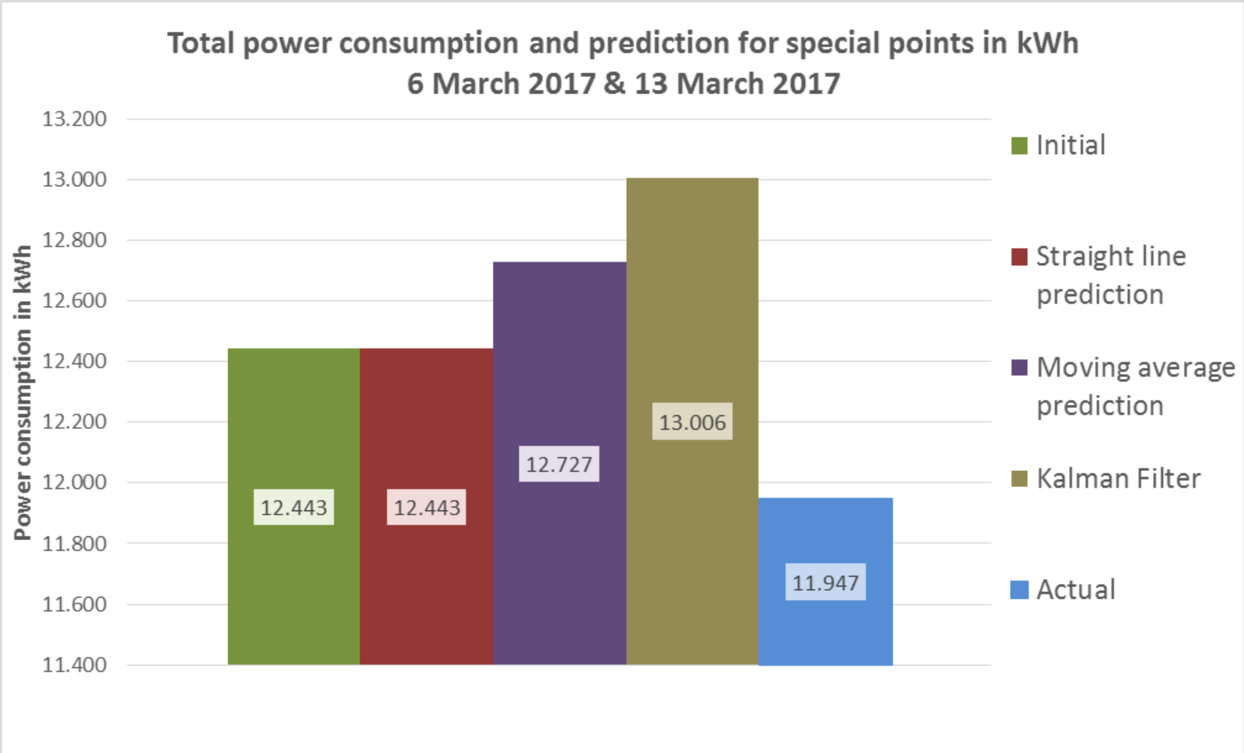

Figure 5.25 Total power consumption and prediction for special point circuits

As shown in Table 5.11, the percentage predicted accuracy using the Straight Line method ranges from ***99.39%*** to ***136.13%*** for the three special point circuits. This gives a total predicted accuracy of ***104.15%*** for the accumulated power consumption for the special point circuits.

The percentage predicted accuracy using the Moving Average method ranges from ***103.69%*** to ***136.06%***. This gives a total predicted accuracy of ***106.52%*** for the accumulated power consumption for the special point circuits.

The percentage predicted accuracy using the Kalman Filter method in Microsoft® Excel ranges from ***106.35%*** to ***122.48%***. This gives a total predicted accuracy of ***108.86%*** for the accumulated power consumption for the special point circuits.

Table 5.11 Percentage accuracy of predicted power consumption for each special point circuit

Percentage accuracy for special point circuits				
Special points	**CT10**	**CT11**	**CT12**	**Total for Special points**
Initial consumption	0.276	2.270	9.898	12.443
Prediction: Straight line	0.276	2.270	9.898	12.443
Prediction: Moving average	0.275	2.368	10.083	12.727
Prediction: Kalman Filter	0.248	2.429	10.329	13.006
Actual consumption	0.202	2.284	9.461	11.947
% Accuracy: Straight line	**136.13%**	**99.39%**	**104.62%**	**104.15%**
% Accuracy: Moving average	**136.06%**	**103.69%**	**106.58%**	**106.52%**
% Accuracy: Kalman Filter	**122.48%**	**106.35%**	**109.18%**	**108.86%**

5.2.11 Total overall power consumption and prediction profiles

Figure 5.26 shows the total initial power consumption for Monday, 6 March 2017, as shown in green.

The prediction using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel for Monday, 13 March 2017, are also shown on the graph in red, purple and olive green, respectively.

The total actual power consumption for the same day is shown on the graph in blue.

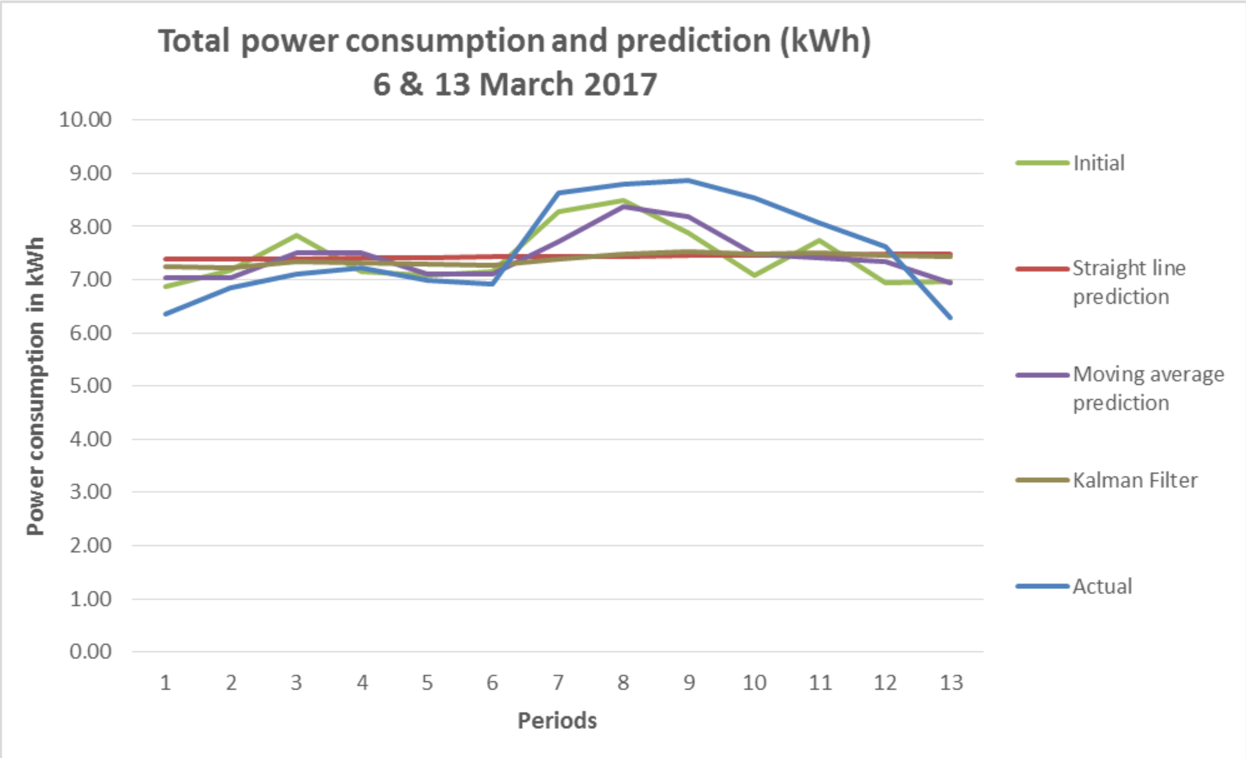

Figure 5.26 Total power consumption and prediction profiles

In Figure 5.27, it can be observed that the total initial power consumption for all twelve circuits for Monday, 6 March 2017, amounts to approximately ***96.651 kWh***.

The prediction was made for the following Monday using the Straight Line method, Moving Average method and Kalman Filter method in Microsoft® Excel. The total predicted consumption using the three methods was ***96.651 kWh, 96.757 kWh*** and ***96.007 kWh***, respectively.

The total actual power consumption for the all twelve circuits for Monday, 13 March 2017, was approximately ***98.279 kWh***.

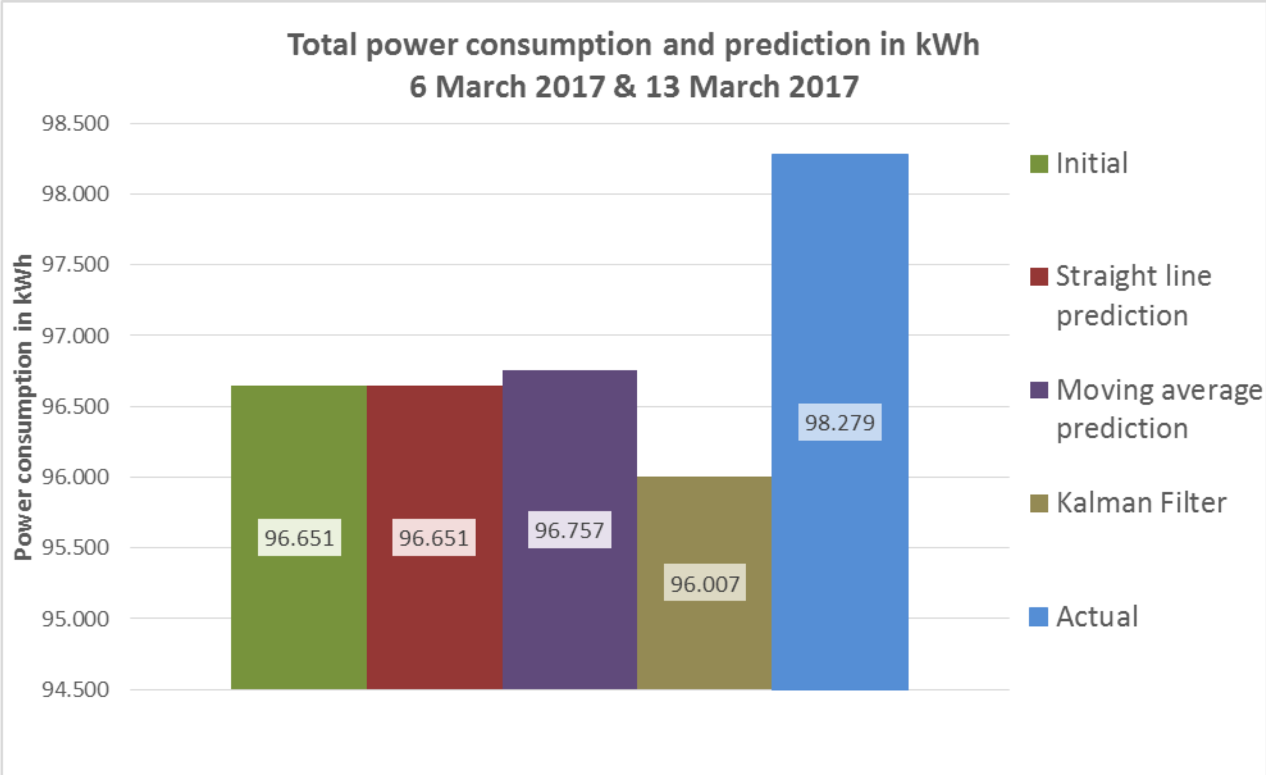

Figure 5.27 Total power consumption and prediction

As shown in Table 5.12, the percentage predicted accuracy using the Straight Line method ranges from ***76.32%*** to ***104.15%*** for all twelve outgoing circuits. This gives a total predicted accuracy of ***98.34%*** for the accumulated power consumption for all the circuits.

The percentage predicted accuracy using the Moving Average method ranges from ***76.33%*** to ***106.52%***. This gives a total predicted accuracy of ***98.45%*** for the accumulated power consumption for all the circuits.

The percentage predicted accuracy using the Kalman Filter method in Microsoft® Excel ranges from ***76.33%*** to ***106.52%***. This gives a total predicted accuracy of ***97.69%*** for the accumulated power consumption for all the circuits.

Table 5.12 Percentage accuracy of total predicted power consumption

Overall percentage accuracy of the predicted power consumption					
	Total for Lights in kWh	Total Plugs usage in Kwh	Total Dedicated plugs usage in kWh	Total Special points usage in kWh	Total consumption in kWh
Initial consumption	32.815	11.073	40.320	12.443	**96.651**
Prediction: Straight line forecast	32.815	**11.073**	**40.320**	**12.443**	**96.651**
Prediction: Moving average	32.506	**11.075**	**40.449**	**12.727**	**96.757**
Prediction: Kalman Filter	31.051	**11.272**	**40.680**	**13.006**	**96.007**
Actual comsumption	31.976	14.509	39.847	11.947	**98.279**
% Accuracy: Straight line	**102.62%**	**76.32%**	**101.19%**	**104.15%**	**98.34%**
% Accuracy: Moving average	**101.66%**	**76.33%**	**101.51%**	**106.52%**	**98.45%**
% Accuracy: Kalman Filter	**97.11%**	**77.69%**	**102.09%**	**108.86%**	**97.69%**

From the above results, it can be seen that the three predicted values are very close to each other. Overall, the Moving Average prediction was the most accurate prediction, followed by the Straight Line prediction and then the Kalman Filter prediction. The difference between the Moving Average prediction and the Kalman Filter prediction was only **0.75 kWh** or **0.76%**.

5.3 Total Power Consumption and Prediction Profiles for a Month

The total initial power consumption in kWh of the second floor has been monitored for three months. All twelve outgoing circuits that include all the light circuits, plug circuits, dedicated plug circuits and the special point circuits were monitored for 24 hours a day for March, April and May.

5.3.1 Initial power consumption for March 2017, predicted power consumption for March 2018 and actual power consumption for March 2018

As shown in Figures 5.28 and 5.29, the total initial power consumption for the second floor for March 2017 was **5029.67 kWh** for all the outgoing circuits and the initial average consumption per hour for the same period was **7.268 kWh**.

The Straight Line, Moving Average and Kalman Filter in Microsoft® Excel predictions for March 2018 were **5029.67 kWh**, **5030.53 kWh** and **4944.89 kWh**, respectively. The average consumption per hour for the Straight Line, Moving Average and Kalman Filter predictions for the same period was **7,368 kWh**, **7.270 kWh** and **7.146 kWh**, respectively.

The actual power consumption for March 2018 was **4350.24 kWh** and the average actual consumption per hour for the same period was **6.286 kWh**.

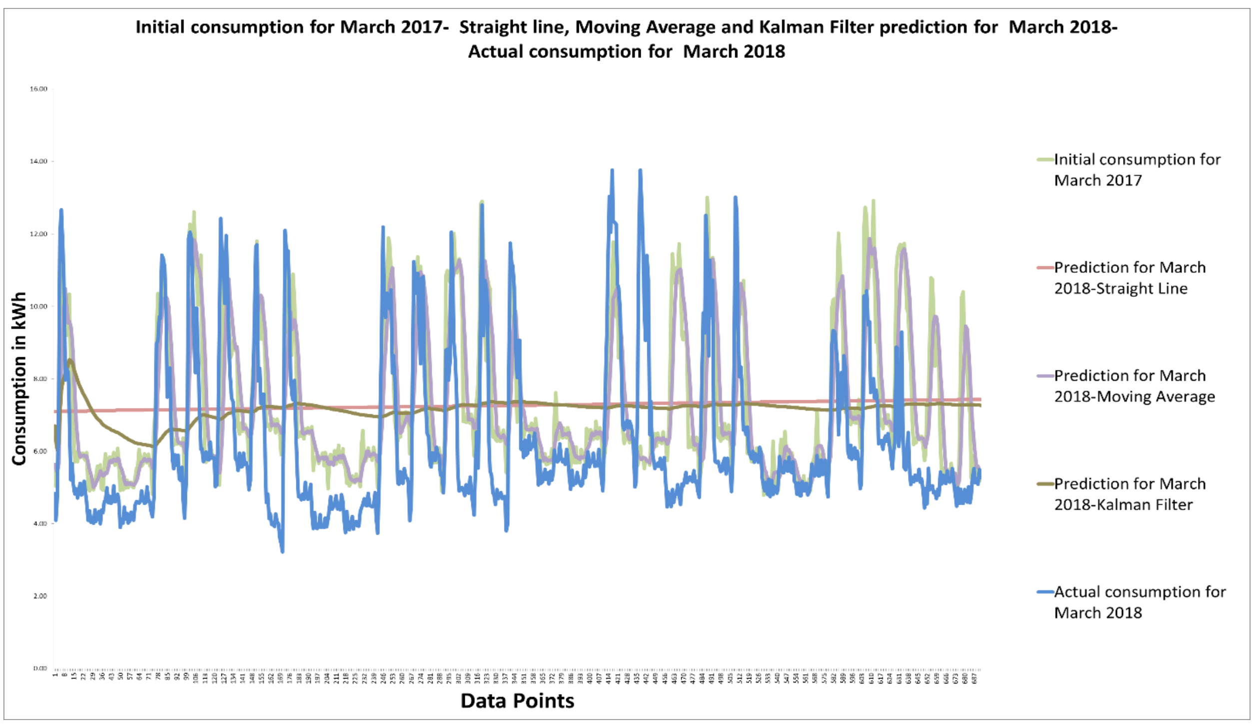

Figure 5.28 Initial power consumption profiles for March 2017, predicted and actual consumption profiles for March 2018

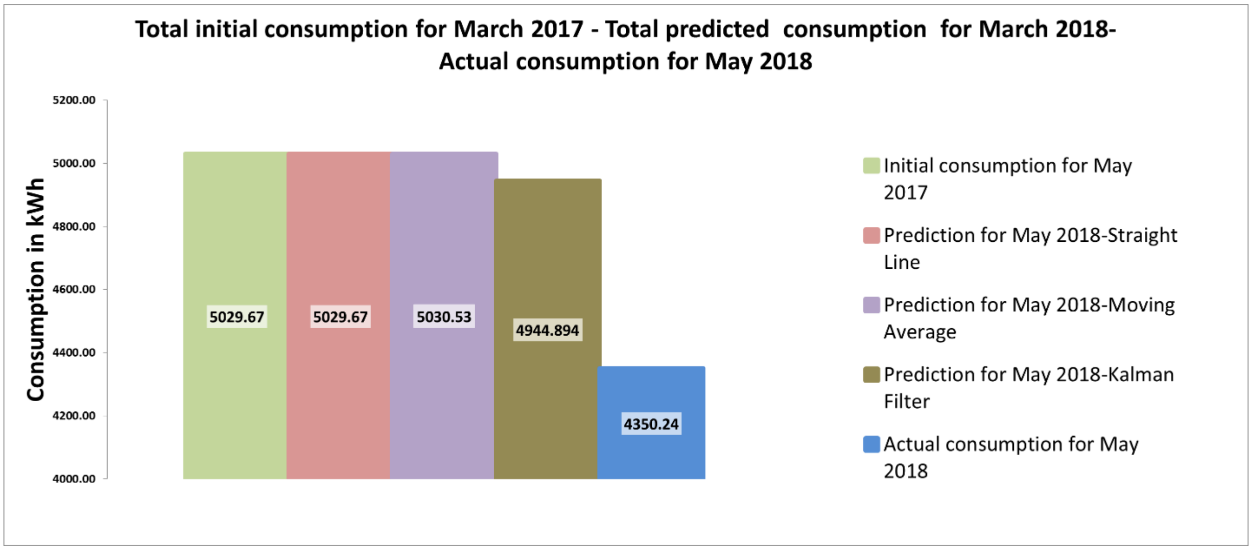

Figure 5.29 Total initial power consumption for March 2017, total predicted and actual consumption for March 2018

5.3.2 Initial power consumption for April 2017, predicted power consumption for April 2018 and actual power consumption for April 2018

As shown in Figures 5.30 and 5.31, the total initial power consumption for the second floor for April 2017 was **3416.74 kWh** for all the outgoing circuits and the initial average consumption per hour for the same period was **4.937 kWh**.

The Straight Line, Moving Average and Kalman Filter in Microsoft® Excel predictions for April 2018 were **3416.77 kWh**, **3515.40 kWh** and **3503.56 kWh**, respectively. The average consumption per hour for the Straight Line, Moving Average and Kalman Filter predictions for the same period was **4,938 kWh**, **4.936 kWh** and **5.063 kWh**, respectively.

The actual power consumption for April 2018 was **4075.31 kWh** and the average actual consumption per hour for the same period was **5.889 kWh**.

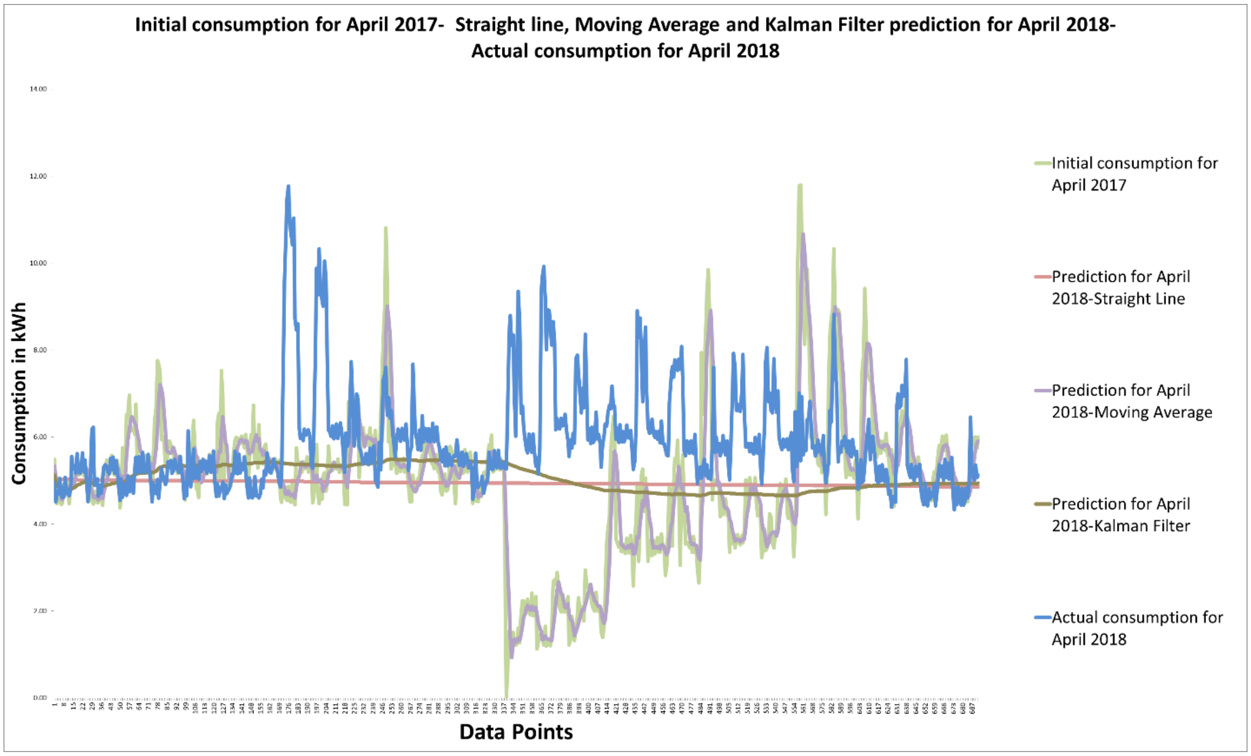

Figure 5.30 Initial power consumption profiles for April 2017, predicted and actual consumption profiles for April 2018

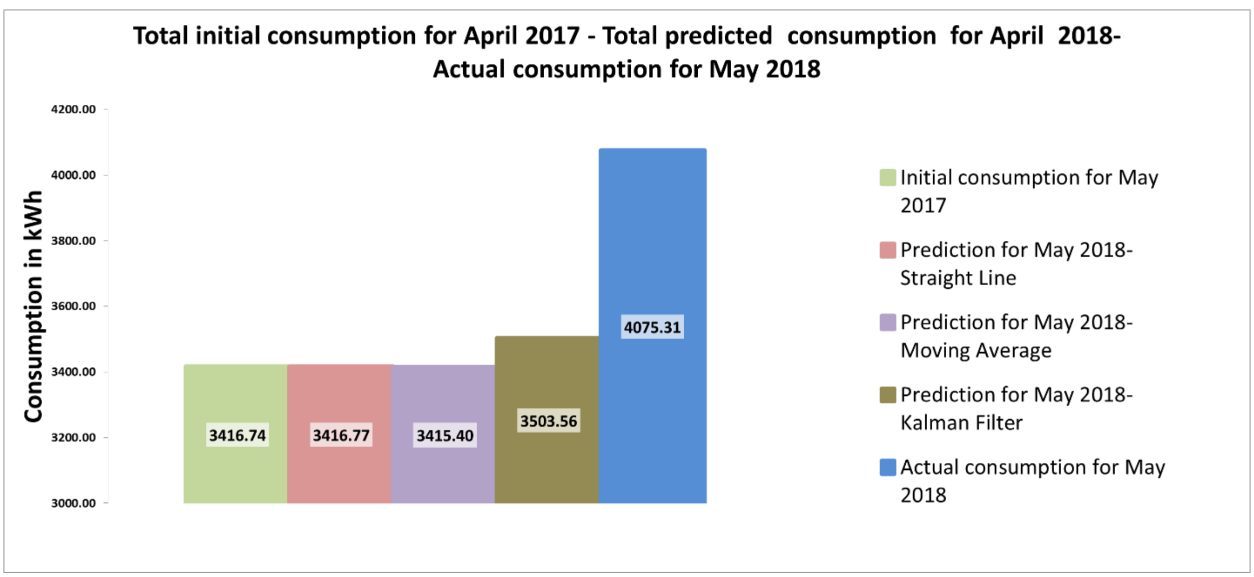

Figure 5.31 Total initial power consumption for April 2017, total predicted and actual consumption for April 2018

5.3.3 Initial power consumption for May 2017, predicted power consumption for May 2018 and actual power consumption for May 2018

As shown in Figures 5.32 and 5.33, the total initial power consumption for the second floor for May 2017 was **3549.51 kWh** for all the outgoing circuits and the initial average consumption per hour for the same period was **5.129 kWh**.

The Straight Line, Moving Average and Kalman Filter in Microsoft® Excel predictions for May 2018 were **3549.51 kWh**, **3549.51 kWh** and **4241.54 kWh**, respectively. The average consumption per hour for the Straight Line, Moving Average and Kalman Filter predictions for the same period was **5.129 kWh**, **5.129 kWh** and **6.129 kWh**, respectively.

The actual power consumption for May 2018 was **4041.54 kWh** and the average actual consumption per hour for the same period was **5.840 kWh**.

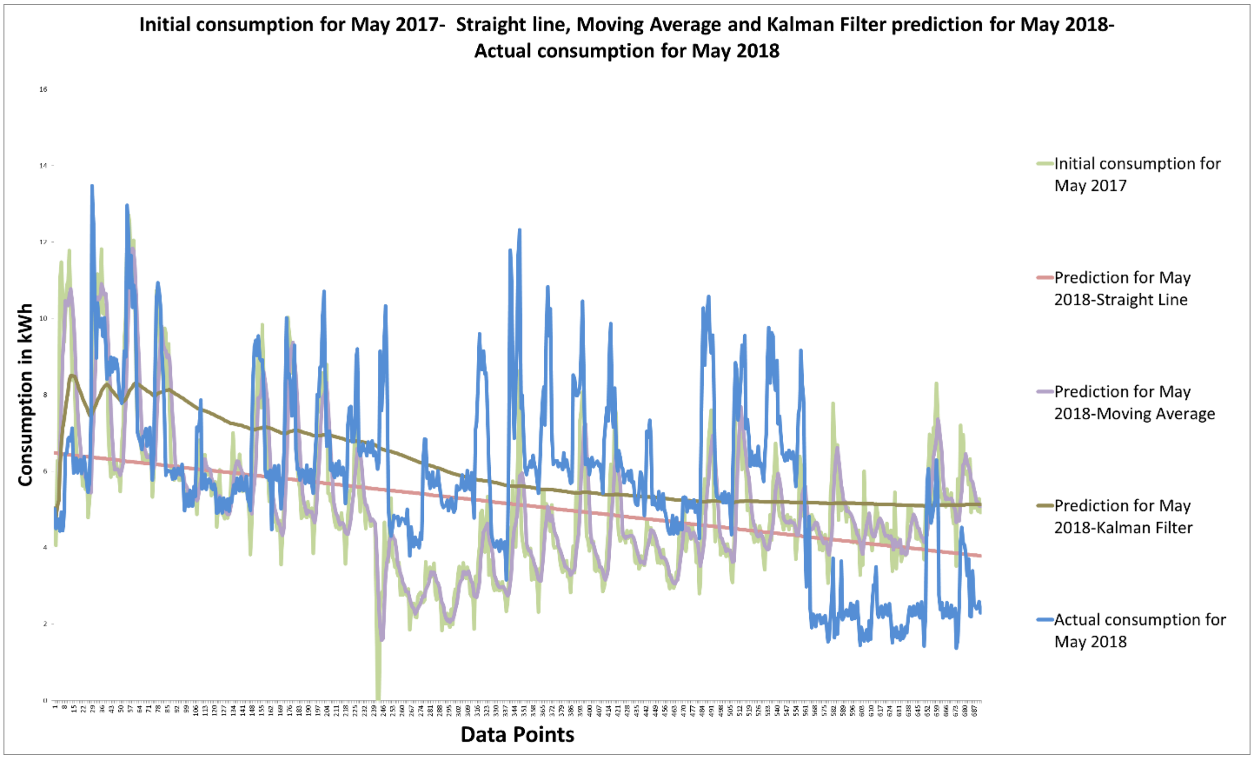

Figure 5.32 Initial power consumption profiles for May 2017, predicted and actual consumption for May 2018

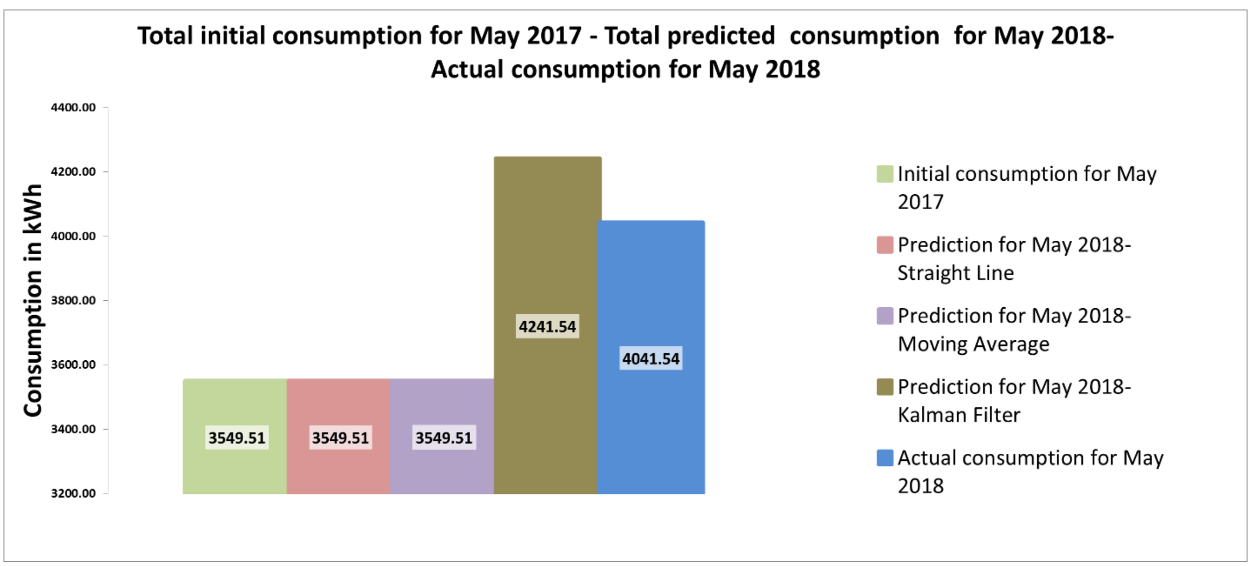

Figure 5.33 Total initial power consumption for May 2017, total predicted and actual consumption for May 2018

Table 5.13 shows the overall percentage accuracy of the predicted consumption for each month, as well as a total overall percentage accuracy for the three months.

Table 5.13 Percentage accuracy of total predicted power consumption for three months

Overall percentage accuracy of the predicted power consumption				
	March	April	May	Total consumption for three months
Initial consumption 2017	5029.67	3416.74	3549.51	11995.92
Prediction: Straight Line method 2018	5029.67	3416.77	3549.51	11995.95
Prediction: Moving Average method 2018	5030.53	3415.40	3549.51	11995.44
Prediction: Kalman Filter method 2018	4944.89	3503.56	4241.54	12690.00
Actual comsumption 2018	4350.24	4075.31	4041.54	12467.10
% Accuracy: Straight line	115.62%	83.84%	87.83%	96.22%
% Accuracy: Moving average	115.64%	83.81%	87.83%	96.22%
% Accuracy: Kalman Filter	113.67%	85.97%	104.95%	101.79%

As can be seen in Table 5.13, the predictions of power consumption of the three methods used for March are very close to each other. The difference between the best and worst prediction was only **1.97%**.

The predicted power consumption for April was also very close to each other and the difference between the best and worst prediction was **2.16%.**

However, the predicted power consumption for May differs greatly. The difference between the best and worse prediction was **17.12%.**

It can also be seen that there were power outages in April 2017 and May 2017 and that some of the circuits were OFF during the power outages. As a result of the power outage, the predicted power consumption for April 2018 and May 2018 was quite different from the actual power consumption for the two months.

Another reason for the difference between initial consumption and actual consumption is that the numbers of the class groups differ from semester to semester, which means that the class occupancy will also differ. As stipulated in paragraph 5.1 on page 129, there is a fairly good correlation between power consumption and building occupants.

Overall, the Kalman Filter prediction was the most accurate prediction for the three months, followed by the Straight Line prediction and then the Moving Average prediction.

5.4 Switching of Certain Distribution Board Circuits

To evaluate the prediction of power savings on the overall consumption and to prevent usage over baseline settings, certain distribution board circuits needed to be switched to achieve this. Before the actual switch control could be implemented, it was necessary to determine the initial power consumption for a specific pre-recorded event and Monday, 6 March 2017 was selected in order to determine an average value for the power consumption per period and then use it for the baseline setting.

A priority list had to be compiled to determine which circuits should be turned off first, without causing any inconvenience during the day, especially during lectures.

A prediction was also made to determine what the power consumption would be for Monday, 13 March 2017, and to compare it to the actual consumption for the same day.

5.4.1 Initial power consumption

Table 5.14 shows the initial power consumption for all thirteen periods for Monday, 6 March 2017, to be implemented for the prediction for Monday, 13 March 2017. The total power consumption for all the circuits was 96,651 kWh, which gives an average of 7.43 kWh per period.

Table 5.14 Total initial power consumption for all thirteen periods for Monday, 6 March 2017

Initial power consumption in kWh - Monday, 6 March 2017															
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]	Total usage for each period
2017-03-06 07:55	2017-03-06 08:40	1	0.346965	1.415779	0.413345	0.571712	0.059388	0.277999	1.214217	0.952698	1.057083	0.005131	0.193547	0.371940	**6.880**
2017-03-06 08:40	2017-03-06 09:25	2	0.350169	1.406719	0.412811	0.376184	0.068618	0.352657	1.210577	0.930385	1.055596	0.018450	0.196689	0.794417	**7.173**
2017-03-06 09:25	2017-03-06 10:10	3	0.348660	1.385015	0.412746	0.471745	0.068905	0.314072	1.223499	0.905336	1.050693	0.017078	0.195935	1.442613	**7.836**
2017-03-06 10:10	2017-03-06 10:55	4	0.346652	1.380406	0.412391	0.377912	0.078660	0.408921	1.161646	0.898951	1.054455	0.000476	0.193793	0.845246	**7.160**
2017-03-06 10:55	2017-03-06 11:40	5	0.345341	1.388966	0.425908	0.517035	0.083848	0.299137	1.064494	0.842582	1.051492	0.014386	0.191823	0.851956	**7.077**
2017-03-06 11:40	2017-03-06 12:25	6	0.344994	1.518689	0.431378	0.461728	0.078293	0.492248	1.005470	0.792176	1.081545	0.043937	0.191582	0.717403	**7.159**
2017-03-06 12:25	2017-03-06 13:10	7	0.344118	2.265592	0.431779	0.512905	0.105421	0.389406	1.422687	0.898444	1.061479	0.047007	0.191909	0.602226	**8.273**
2017-03-06 13:10	2017-03-06 13:55	8	0.344124	2.268538	0.432266	0.356907	0.090997	0.324059	1.396207	0.854458	1.045853	0.050372	0.191684	1.139227	**8.495**
2017-03-06 13:55	2017-03-06 14:40	9	0.342433	2.007669	0.432950	0.400288	0.098119	0.320249	1.003063	0.806222	1.030236	0.003376	0.189909	1.241766	**7.876**
2017-03-06 14:40	2017-03-06 15:25	10	0.343404	1.445063	0.432750	0.359696	0.111935	0.292455	1.044853	0.921461	1.251124	0.016653	0.190116	0.664555	**7.074**
2017-03-06 15:25	2017-03-06 16:10	11	0.344855	2.245051	0.432237	0.320916	0.140847	0.294380	0.945723	0.889909	1.271841	0.029319	0.191149	0.631969	**7.738**
2017-03-06 16:10	2017-03-06 16:55	12	0.350293	2.046051	0.430875	0.343669	0.133863	0.324638	0.922451	0.850474	1.212390	0.010644	0.151149	0.170988	**6.947**
2017-03-06 16:55	2017-03-06 17:40	13	0.354736	1.447884	0.985051	0.394709	0.137890	0.260788	0.965854	0.848877	1.123120	0.018706	0.000448	0.423837	**6.962**
Total usage in kWh per CT			**4.506743**	**22.221423**	**6.086490**	**5.465406**	**1.256785**	**4.351008**	**14.580742**	**11.391973**	**14.346909**	**0.275534**	**2.269733**	**9.898141**	
Total usage in kWh for lights, plugs, dedicated plugs & special special points			**32.815**			**11.073**			**40.320**			**12.443**			
Total usage in kWh for period 1 to 13			**96.651**												**96.651**
Average usage in kWh per period			**7.43**												

5.4.2 Priority list of accessories and baseline setting

A priority list has been compiled, as shown in Table 5.15. The reason why this was done is to switch OFF certain circuits if the power consumption goes above a certain baseline setting without interfering too much with day-to-day operation. Although it will have a minor impact on daily operations, especially without hot water, air-conditioning and lighting, daily tasks can still be continued without these so-called luxury.

The average power consumption for all thirteen periods for Monday, 6 March 2017, was approximately 7.43 kWh per period, as shown in Table 5.14.

It was decided to make the baseline setting 7.43 kWh in order to switch OFF certain circuits, according to the priority list as shown in Table 5.15.

Table 5.15 Baseline setting and priority list of electrical accessories

Maximum Baseline Setting in kWh	Minimum Baseline Setting in kWh	Priority	Priority list	Current Transformer	Electrical accessories
7,43	4	1	Special Points	CT10	Geyser
		2	Special Points	CT11	Aircon
		3	Special Points	CT12	Aircon
		4	33.3% Lights	CT1	Lights: Passage, Toilets
		5	66.7% Lights	CT3	Lights:Passage, Toilets, Offices, Post Graduates Cubicles, Balcony
		6	All lights	CT2	Lights:Passage, Toilets, Offices, Post Graduates Cubicles, Balcony, Laboratory 1 & 2
		7	30% Plugs	CT4	Plugs: Offices, Part of Laboratory 1
		8	60% Plugs	CT5	Plugs: Offices, Laboratory 1, Part of Laboratory 2
		9	All plugs	CT6	Plugs: Offices, Laboratory 1, Laboratory 2, Post Graduates Cubicles
		10	33.3% Dedicated plugs	CT8	Dedicated plugs: Part of Laboratory 1, Part of Laboratory 2
		11	66.7% Dedicated plugs	CT7	Dedicated plugs: Rest of Laboratory 1
		12	All Dedicated plugs	CT9	Dedicated plugs: Rest of Laboratory 2

5.4.3 Predicted power consumption

Table 5.16 shows the predicted power consumption for Monday, 13 March 2017. The total predicted power consumption using the Moving Average method, was 96,757 kWh which gives an average of 7.44 kWh per period.

The reason why the Moving Average method was implemented for this test phase, was that it was the most accurate prediction between the three methods that were used in this dissertation, namely the Straight Line method, the Moving Average method and the Kalman Filter method. See Table 5.12.

Table 5.16 Total predicted power consumption for all thirteen periods for Monday, 13 March 2017

Prediction of power consumption in kWh (Moving average) - Monday, 13 March 2017															
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]	Total usage for each period
2017-03-13 07:55	2017-03-13 08:40	1	0.348567	1.411249	0.413078	0.473948	0.064003	0.315328	1.212397	0.941541	1.056340	0.011790	0.195118	0.583179	**7.027**
2017-03-13 08:40	2017-03-13 09:25	2	0.348567	1.411249	0.413078	0.473948	0.064003	0.315328	1.212397	0.941541	1.056340	0.011790	0.195118	0.583179	**7.027**
2017-03-13 09:25	2017-03-13 10:10	3	0.349414	1.395867	0.412779	0.423965	0.068762	0.333364	1.217038	0.917860	1.053145	0.017764	0.196312	1.118515	**7.505**
2017-03-13 10:10	2017-03-13 10:55	4	0.347656	1.382711	0.412569	0.424829	0.073783	0.361496	1.192572	0.902143	1.052574	0.008777	0.194864	1.143929	**7.498**
2017-03-13 10:55	2017-03-13 11:40	5	0.345996	1.384686	0.419150	0.447474	0.081254	0.354029	1.113070	0.870766	1.052973	0.007431	0.192808	0.848601	**7.118**
2017-03-13 11:40	2017-03-13 12:25	6	0.345168	1.453828	0.428643	0.489382	0.081070	0.395692	1.034982	0.817379	1.066518	0.029162	0.191703	0.784679	**7.118**
2017-03-13 12:25	2017-03-13 13:10	7	0.344556	1.892140	0.431579	0.487317	0.091857	0.440827	1.214079	0.845310	1.071512	0.045472	0.191746	0.659815	**7.716**
2017-03-13 13:10	2017-03-13 13:55	8	0.344121	2.267065	0.432023	0.434906	0.098209	0.356732	1.409447	0.876451	1.053666	0.048689	0.191797	0.870727	**8.384**
2017-03-13 13:55	2017-03-13 14:40	9	0.343278	2.138104	0.432608	0.378597	0.094558	0.322154	1.199635	0.830340	1.038045	0.026874	0.190797	1.190497	**8.185**
2017-03-13 14:40	2017-03-13 15:25	10	0.342918	1.726366	0.432850	0.379992	0.105027	0.306352	1.023958	0.863841	1.140680	0.010014	0.190013	0.953161	**7.475**
2017-03-13 15:25	2017-03-13 16:10	11	0.344129	1.845057	0.432494	0.340306	0.126391	0.293417	0.995288	0.905685	1.261483	0.022986	0.190632	0.648262	**7.406**
2017-03-13 16:10	2017-03-13 16:55	12	0.347574	2.145551	0.431556	0.332292	0.137355	0.309509	0.934087	0.870192	1.242116	0.019982	0.171149	0.401478	**7.343**
2017-03-13 16:55	2017-03-13 17:40	13	0.352515	1.746968	0.707963	0.369189	0.135877	0.292713	0.944153	0.849676	1.167755	0.014675	0.075798	0.297412	**6.955**
Total usage in kWh per CT			**4.504**	**22.201**	**5.800**	**5.456**	**1.222**	**4.397**	**14.703**	**11.433**	**14.313**	**0.275**	**2.368**	**10.083**	
Total usage in kWh for lights, plugs, dedicated plugs & special special points				**32.506**			**11.075**			**40.449**			**12.727**		
Total usage in kWh for period 1 to 13								**96.757**							**96.757**
Average usage in kWh per period								**7.44**							

5.4.4 Actual power consumption

Table 5.17 shows the actual power consumption for Monday, 13 March 2017. As evident in Table 5.17, the actual power consumption was approximately 98,279 kWh. This gives an average power consumption of about 7.56 kWh per period.

The difference between the predicted power consumption and the actual power consumption was approximately 1,522 kWh. This gives an accurate prediction of about 98.45%, as shown in Table 5.12.

Table 5.17 Total actual power consumption for all thirteen periods for Monday, 13 March 2017

Actual power consumption in kWh - Monday, 13 March 2017															
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]	Total usage for each period
2017-03-13 07:55	2017-03-13 08:40	1	0.348350	1.392160	0.000100	0.586349	0.132760	0.377534	1.169064	0.904433	0.873130	0.000747	0.194766	0.384176	**6.364**
2017-03-13 08:40	2017-03-13 09:25	2	0.346531	1.394139	0.000085	0.601082	0.131202	0.510662	1.173290	0.922039	0.871175	0.003880	0.193358	0.703238	**6.851**
2017-03-13 09:25	2017-03-13 10:10	3	0.345601	1.392073	0.154673	0.515819	0.140834	0.454563	1.218446	0.888195	0.867483	0.002047	0.192691	0.930502	**7.103**
2017-03-13 10:10	2017-03-13 10:55	4	0.344200	1.390172	0.427709	0.623208	0.144268	0.469512	1.127092	0.794568	0.869191	0.022213	0.191111	0.820934	**7.224**
2017-03-13 10:55	2017-03-13 11:40	5	0.343188	1.404875	0.429276	0.499005	0.144879	0.438998	1.052961	0.797431	0.875410	0.009208	0.189956	0.807755	**6.993**
2017-03-13 11:40	2017-03-13 12:25	6	0.342797	1.526704	0.430163	0.334345	0.141367	0.446253	1.021102	0.733186	0.866520	0.022277	0.190186	0.858752	**6.914**
2017-03-13 12:25	2017-03-13 13:10	7	0.343363	2.263985	0.426638	0.628576	0.177988	0.455993	1.432506	0.951144	1.049905	0.012927	0.192363	0.703600	**8.639**
2017-03-13 13:10	2017-03-13 13:55	8	0.348859	2.245545	0.420932	0.654791	0.230777	0.592526	1.538731	0.959158	1.100294	0.022242	0.196300	0.494621	**8.805**
2017-03-13 13:55	2017-03-13 14:40	9	0.345591	2.259063	0.418941	0.443925	0.191909	0.455956	1.656468	0.966606	1.103624	0.034460	0.194296	0.792988	**8.864**
2017-03-13 14:40	2017-03-13 15:25	10	0.346163	2.228442	0.417680	0.424465	0.109242	0.412616	1.210873	0.906216	1.120857	0.019041	0.194739	1.147314	**8.538**
2017-03-13 15:25	2017-03-13 16:10	11	0.349935	2.272729	0.416851	0.496073	0.113675	0.437844	1.026375	0.896408	1.113765	0.031630	0.197471	0.713259	**8.066**
2017-03-13 16:10	2017-03-13 16:55	12	0.354764	1.952319	0.412583	0.426083	0.110135	0.611895	0.928329	0.860532	1.111309	0.005207	0.155883	0.695051	**7.624**
2017-03-13 16:55	2017-03-13 17:40	13	0.358271	0.809759	0.970484	0.297416	0.101688	0.442813	0.922812	0.866906	1.099213	0.016534	0.000459	0.408968	**6.295**
Total usage in kWh per CT			**4.517612**	**22.531965**	**4.926114**	**6.531137**	**1.870724**	**6.107166**	**15.478048**	**11.446823**	**12.921876**	**0.202412**	**2.283579**	**9.461159**	
Total usage in kWh for lights, plugs, dedicated plugs & special points				**31.976**			**14.509**			**39.847**			**11.947**		
Total usage in kWh for period 1 to 13			98.279												98.279
Average usage in kWh per period			7.56												

5.4.5 Controlling circuit breakers in distribution board

To realise the "Switch OFF", as indicated in Table 5.18, a specific program was implemented in Microsoft® Excel. The hardware was achieved using an Arduino UNO and a program written for controlling the alternating current (AC) circuit breakers.

Table 5.18 Power consumption while baseline setting is 7.43 kWh and certain CTs are OFF

Action 1	CT10: Red phase Special points [kWh]	New Total 1 prior	Action 2	CT11: White phase Special points [kWh]	New Total 2 prior	Action 3	CT12: Blue phase Special points [kWh]	New Total 3 prior	Action 4	CT1: Red phase Lights [kWh]	New Total 4 prior	Action 5	CT3: White phase Lights [kWh]	New Total 5 prior
	0.000747	6.363570		0.194766	6.363570		0.384176	6.363570		0.348350	6.363570		0.000100	6.363570
	0.003880	6.850682		0.193358	6.850682		0.703238	6.850682		0.346531	6.850682		0.000085	6.850682
	0.002047	7.102926		0.192691	7.102926		0.930502	7.102926		0.345601	7.102926		0.154673	7.102926
	0.022213	7.224177		0.191111	7.224177		0.820934	7.224177		0.344200	7.224177		0.427709	7.224177
	0.009208	6.992944		0.189956	6.992944		0.807755	6.992944		0.343188	6.992944		0.429276	6.992944
	0.022277	6.913651		0.190186	6.913651		0.858752	6.913651		0.342797	6.913651		0.430163	6.913651
Switch OFF		8.626061	Switch OFF		8.433699	Switch OFF		7.730099	Switch OFF		7.386735		0.426638	7.386735
Switch OFF		8.782534	Switch OFF		8.586234	Switch OFF		8.091613	Switch OFF		7.596992	Switch OFF		7.176060
Switch OFF		8.829366	Switch OFF		8.635070	Switch OFF		7.842082	Switch OFF		7.049095		0.418941	7.049095
Switch OFF		8.518608	Switch OFF		8.323869	Switch OFF		7.176554		0.346163	7.176554		0.417680	7.176554
Switch OFF		8.034385	Switch OFF		7.836913	Switch OFF		7.123654		0.349935	7.123654		0.416851	7.123654
Switch OFF		7.618882	Switch OFF		7.462999	Switch OFF		6.767949		0.354764	6.767949		0.412583	6.767949
	0.016534	6.295321		0.000459	6.295321		0.408968	6.295321		0.358271	6.295321		0.970484	6.295321
	0.077	**91.016**		**1.153**	**91.016**		**4.914**	**91.016**		**3.480**	**91.016**		**4.505**	**91.016**

The setup code and controlling code can be seen in Figure 5.34. To be able to accomplish the "Switch OFF" indicated in Tables 5.18 for CT10 for example, the Microsoft Visual Basic code in Figure 5.34 was implemented.

```
Private Sub Switch_ON_CT10()
  Port$ = "mode.com " + Range("D49").Value + ":9600,N,8,1"     'create port number string with settings
  Shell Port$
  Application.Wait (Now + TimeValue("0:00:02"))
  Open Range("D49").Value For Binary Access Read Write As #1   'Com port value
  Application.Wait (Now + TimeValue("0:00:01"))
  Put #1, , " Relay1ON" + Chr(10) + Chr(13)
  Application.Wait (Now + TimeValue("0:00:01"))
  Close #1
End Sub
```

Figure 5.34 Setup code and controlling code for port

The Microsoft® Excel code in Figure 5.35 first declares the universal serial bus (USB) port, depiction in cell D49, with the baud rate, parity and character length. It then opens the relative USB port and sends a serial text “Relay1ON” to instruct the Arduino to switch on the relative relay to break the relative alternating current (AC) circuitry.

To be able to reset the “Switch OFF” in the circuit, the code in Figure 5.35 was used.

```
Private Sub Switch_OFF_CT10()
  Port$ = "mode.com " + Range("D49").Value + ":9600,N,8,1"     'create port number string with settings
  Shell Port$
  Application.Wait (Now + TimeValue("0:00:02"))
  Open Range("D49").Value For Binary Access Read Write As #1   'Com port value
  Application.Wait (Now + TimeValue("0:00:01"))
  Put #1, , " Relay1OFF" + Chr(10) + Chr(13)
  Application.Wait (Now + TimeValue("0:00:01"))
  Close #1
End Sub
```

Figure 5.35 Microsoft® Excel code used in resetting the circuits

Figure 5.35 is exactly the same code as Figure 5.34, with the difference being the receiving of the string, "Relay1OFF" resetting the relative alternating circuit.

The Arduino hardware can be seen in Figure 5.36.

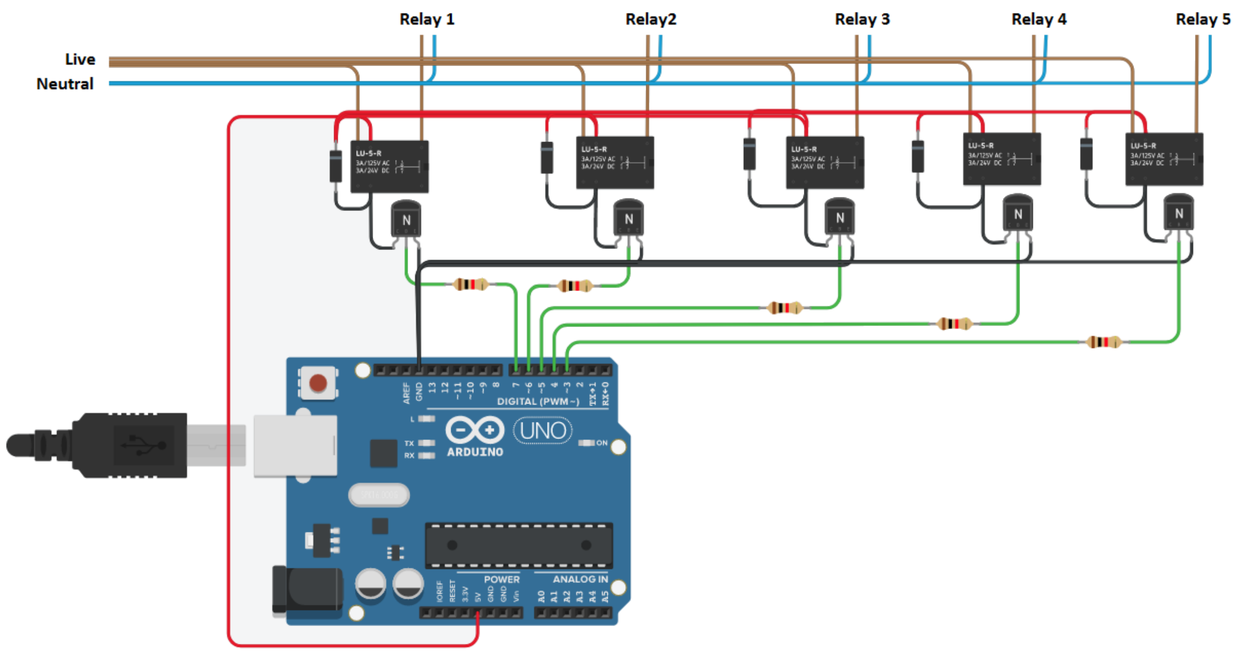

Figure 5.36 Circuit used to switch OFF selected circuit breakers (Relay)

The Arduino circuits connect serially via the USB port of the personal computer (PC) with the prediction software running in Microsoft® Excel.

In Figure 5.37, the code used in the Arduino circuit can be investigated, controlling the circuit breakers in the distribution board. As only five circuits were controlled initially, only five relays were being initialised in a low state meaning no circuits were switched OFF. On receiving a text string serially, the program in Figure 5.37 decides which relay is to be switched ON or OFF, as seen in the loop() function of Figure 5.37. Thus, the total program summary of the code and hardware could be explained through Figure 5.38.

```
/*
  Switch Relay circuit breakers with serial command
*/

int Relay1 = 7;  //define relay port pins
int Relay2 = 6;
int Relay3 = 5;
int Relay4 = 4;
int Relay5 = 3;

void setup()
{
  pinMode(Relay1, OUTPUT);    //define ports as outputs
  pinMode(Relay2, OUTPUT);
  pinMode(Relay3, OUTPUT);
  pinMode(Relay4, OUTPUT);
  pinMode(Relay5, OUTPUT);
  digitalWrite(Relay1, LOW);  //switch all relays OFF
  digitalWrite(Relay2, LOW);
  digitalWrite(Relay3, LOW);
  digitalWrite(Relay4, LOW);
  digitalWrite(Relay5, LOW);
  Serial.begin(9600);
}
String testString;

void loop()
{

 // Test if command received on serial port
    if(Serial.available()){       // test serial data received
      testString = Serial.readString();
      delay(500);
      if (testString == "Relay1ON" ) {  // test which relay to switch
        digitalWrite(Relay1, HIGH);
      }
      if (testString == "Relay1OFF" ) {
        digitalWrite(Relay1, LOW);
      }
      if (testString == "Relay2ON" ) {
        digitalWrite(Relay2, HIGH);
      }
      if (testString == "Relay2OFF" ) {
        digitalWrite(Relay2, LOW);
      }
      if (testString == "Relay3ON" ) {
        digitalWrite(Relay3, HIGH);
      }
      if (testString == "Relay3OFF" ) {
        digitalWrite(Relay3, LOW);
      }
      if (testString == "Relay4ON" ) {
        digitalWrite(Relay4, HIGH);
      }
      if (testString == "Relay4OFF" ) {
        digitalWrite(Relay4, LOW);
      }
      if (testString == "Relay5ON" ) {
        digitalWrite(Relay5, HIGH);
      }
      if (testString == "Relay5OFF" ) {
        digitalWrite(Relay5, LOW);
      }
    }
}
```

Figure 5.37 Program on ARDUINO controlling the contact breakers in distribution board

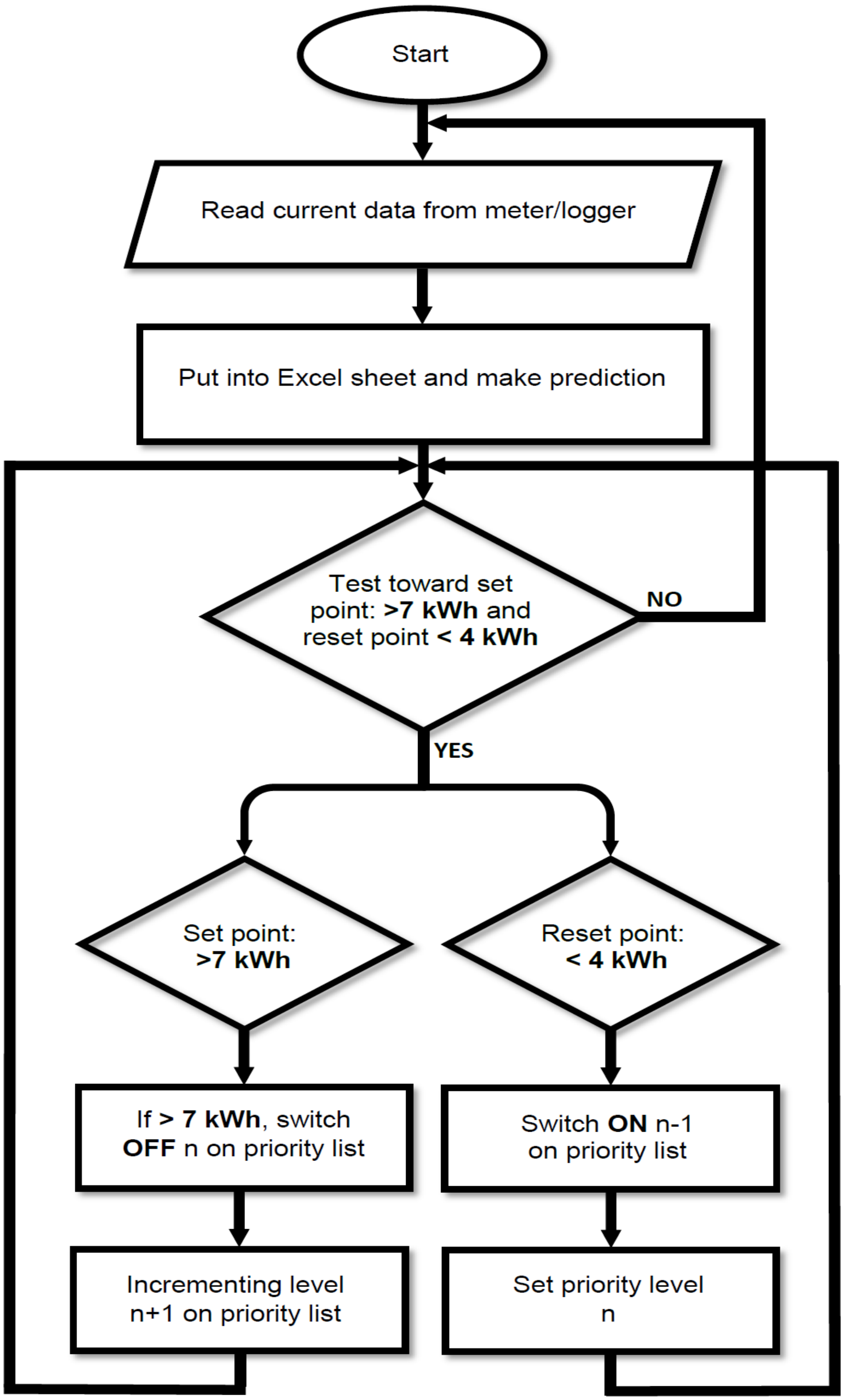

Figure 5.38 Flowchart of switching certain circuits

An initial reading is obtained from the CTs and eGauge meter. The next period usage is then predicted. On the prediction, it is decided if the usage is going to be above the maximum threshold or below the minimum threshold.

If it is higher, it starts switching off circuits, starting with the lowest priority until suitable threshold level is reached. The cycle is repeated, starting from reading the actual values and performing the whole process over again.

The same is done for the lower threshold but only switching the circuit ON or resetting the circuits.

Table 5.18 shows that certain circuits were switched OFF, as some of the readings were above the baseline setting of 7.43 kWh.

In this case, CT 10, CT 11 and CT 12 are turned OFF for six periods, since the readings for those periods were above the baseline of 7.43 kWh. CT 1 is turned OFF for three periods and CT 3 for only one period.

By setting the baseline to 7.43 kWh, the total power consumption was approximately 91.016 kWh, as shown in Table 5.19. The average usage was 7 kWh per period.

Table 5.19 New power consumption while baseline setting is 7.43 kWh and certain CTs are OFF

New power consumption in kWh with certain circuits switched off - Monday, 13 March 2017															
Date & Time	Date & Time	Period	CT1: Red phase Lights [kWh]	CT2: White phase Lights [kWh]	CT3: Blue phase Lights [kWh]	CT4: Red phase Plugs [kWh]	CT5: White phase Plugs [kWh]	CT6: Blue phase Plugs [kWh]	CT7: Red phase Dedicated plugs [kWh]	CT8: White phase Dedicated plugs [kWh]	CT9: Blue phase Dedicated plugs [kWh]	CT10: Red phase Special points [kWh]	CT11: White phase Special points [kWh]	CT12: Blue phase Special points [kWh]	Total usage for each period
2017-03-13 07:55	2017-03-13 08:40	1	0.348350	1.392160	0.000100	0.586349	0.132760	0.377534	1.169064	0.904433	0.873130	0.000747	0.194766	0.384176	**6.364**
2017-03-13 08:40	2017-03-13 09:25	2	0.346531	1.394139	0.000085	0.601082	0.131202	0.510662	1.173290	0.922039	0.871175	0.003880	0.193358	0.703238	**6.851**
2017-03-13 09:25	2017-03-13 10:10	3	0.345601	1.392073	0.154673	0.515819	0.140834	0.454563	1.218446	0.888195	0.867483	0.002047	0.192691	0.930502	**7.103**
2017-03-13 10:10	2017-03-13 10:55	4	0.344200	1.390172	0.427709	0.623208	0.144268	0.469512	1.127092	0.794568	0.869191	0.022213	0.191111	0.820934	**7.224**
2017-03-13 10:55	2017-03-13 11:40	5	0.343188	1.404875	0.429276	0.499005	0.144879	0.438998	1.052961	0.797431	0.875410	0.009208	0.189956	0.807755	**6.993**
2017-03-13 11:40	2017-03-13 12:25	6	0.342797	1.526704	0.430163	0.334345	0.141367	0.446253	1.021102	0.733186	0.866520	0.022277	0.190186	0.858752	**6.914**
2017-03-13 12:25	2017-03-13 13:10	7		2.263985	0.426638	0.628576	0.177988	0.455993	1.432506	0.951144	1.049905				**7.387**
2017-03-13 13:10	2017-03-13 13:55	8		2.245545		0.654791	0.230777	0.592526	1.538731	0.959158	1.100294				**7.322**
2017-03-13 13:55	2017-03-13 14:40	9		2.259063	0.418941	0.443925	0.191909	0.455956	1.656468	0.966606	1.103624				**7.496**
2017-03-13 14:40	2017-03-13 15:25	10	0.346163	2.228442	0.417680	0.424465	0.109242	0.412616	1.210873	0.906216	1.120857				**7.177**
2017-03-13 15:25	2017-03-13 16:10	11	0.349935	2.272729	0.416851	0.496073	0.113675	0.437844	1.026375	0.896408	1.113765				**7.124**
2017-03-13 16:10	2017-03-13 16:55	12	0.354764	1.952319	0.412583	0.426083	0.110135	0.611895	0.928329	0.860532	1.111309				**6.768**
2017-03-13 16:55	2017-03-13 17:40	13	0.358271	0.809759	0.970484	0.297416	0.101688	0.442813	0.922812	0.866906	1.099213	0.016534	0.000459	0.408968	**6.295**
Total usage in kWh per CT			**3.480**	**22.532**	**4.505**	**6.531**	**1.871**	**6.107**	**15.478**	**11.447**	**12.922**	**0.077**	**1.153**	**4.914**	
Total usage in kWh for lights, plugs, dedicated				**30.517**			**14.509**			**39.847**			**6.144**		
Total usage in kWh for period 1 to 13			**91.016**												**91.016**
Average usage in kWh per period			**7.00**												

There was a total saving of approximately 5.635 kWh. This resulted in a saving of about 5.83% for Monday, 13 March 2017. This proved to work well and a greater percentage of savings could be achieved by switching another circuit breaker. The effect on classes was non-invasive in these tests, but minor discomfort was experienced during the day by staff and students.

Chapter 6

Conclusion

The aim of this study was to determine and evaluate the energy performance of the Engineering Technology Building (ETB) at the Central University of Technology (CUT). These evaluations were achieved by analysing real-time measured data for energy consumption, using an inverse approach. Due to the limited number of current transformers (CTs) available, the building was monitored one floor at a time, each floor for specific time periods.

Collected information of the building's energy consumption was used to create a projection model. This model of energy use may help in future building planning, it may provide useful information about most probable energy consumption for similar buildings, or predict energy use under different conditions in current buildings.

Also, it can be used to show impacts of possible energy saving measures and help in finding an optimal way of reducing energy costs. A summary of the building's electricity supply demand and equipment was compiled in order to make informed choices.

This study differs from a normal load analysis in that it provides useful information in terms of the day-to-day operation of the building in question. Emphasis is placed on mapping the pattern of measured daily electrical consumption of the case study building against the daily room activities and occupancy. Carrying out a mapping in this way helps to identify the potential electricity savings that can be achieved.

Building energy consumption improvement options were identified in this study. One of the primary reasons identified for the poor energy performance of the actual building is the designed lighting density. The cause of the high lighting power density in the actual building may partially be attributed to the fact that all the lighting circuits in the building are manually triggered and in some zones, for example the lecture halls, multiple lighting circuits are installed to cater for different lighting requirements. Both these lighting design properties have negative impacts on the overall energy consumption of the building. The reason for this is that all the lights in the room are switched on manually, every time a person walks into the room, and no intelligence lighting control is installed.

The HVAC energy consumption in the actual building was also identified as one of the components that can significantly influence the annual energy consumption of the building. To ensure significant changes in energy consumption, the primary focus should be on reducing the lighting power density and improving the efficiency of the HVAC system of the actual building.

An annual energy performance improvement for the actual building can be accomplished by only reducing the lighting density of the building and marginally improving the energy efficiency of the HVAC system.

It was noted that the dedicated circuitry, especially in the computer laboratories on the second floor, also takes up a significant amount of the total power usage. This circuit is dedicated to technical instruments and equipment, as well as computer and monitor sets.

The reasons for the high power consumption is the high occupancy of the computer laboratories during the day, as well as the fact that the computers are not switched OFF after use. It has also been found that a substantial amount of power is consumed on weekends when it is assumed that no people are in the building and no classes are offered either.

From the study, there were various actions identified that can be taken to yield nearly immediate returns for the plan.

These include:

- Installation of smart energy management tools for computers and appliances.
- Replacing existing lighting with more energy-efficient bulbs.
- Eliminating the number of bulbs lit, as well as the wattage of each bulb. Testing actual lumens in the classrooms before changing the lighting.
- Regulating temperature without risk of human tampering (e.g. installing thermostats in the ceiling).
- Keeping doors and windows closed, installing sensors.
- Reviewing maintenance procedures and making efficiency part of maintenance policy.
- Scheduling power on/off cycles.
- Installing outdoor lighting sensors.

Contributions of the study also include a prediction model based on Linear Regression (Straight Line) prediction, Moving Average prediction and Kalman Filter prediction. This was also extended to an smart management system simulated in Matlab®, Simulink, and implemented in Microsoft® Excel and controlled using an Arduino UNO board.

In terms of long-term plans, the institution may consider performance contracts after they have addressed what can be done in-house. Building a comprehensive maintenance program into the plan can save a huge amount of money that otherwise might go to outside contractors. Effective energy plans will include ongoing preventive maintenance and long-term capital planning.

Future studies may include finding data for additional buildings, enabling a more complete database to be set up, or expanded with additional building information. The more data are available, the more accurate the model, and the more effectively energy use may be predicted.

It is proposed that similar if not the same meters should be installed in the rest of the building(s) for a more efficient system, which can help in defining the breakdown of energy use. Increasing the number of meters provides a better image of real-time energy consumption and shows possible deficiencies in the system. It can improve the capability of accurately tracking energy use.

Additionally, installed meters can be used to track loads of individual buildings, providing valuable information about the energy costs associated with specific functions, such as the operation of laboratories. It can assist in calculating energy use for different consumers: air-conditioning, heating, domestic hot water, lighting, and so forth.

In further studies, alternative energy resources may also be investigated to minimise the electricity demand from traditional sources.

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Appendix A

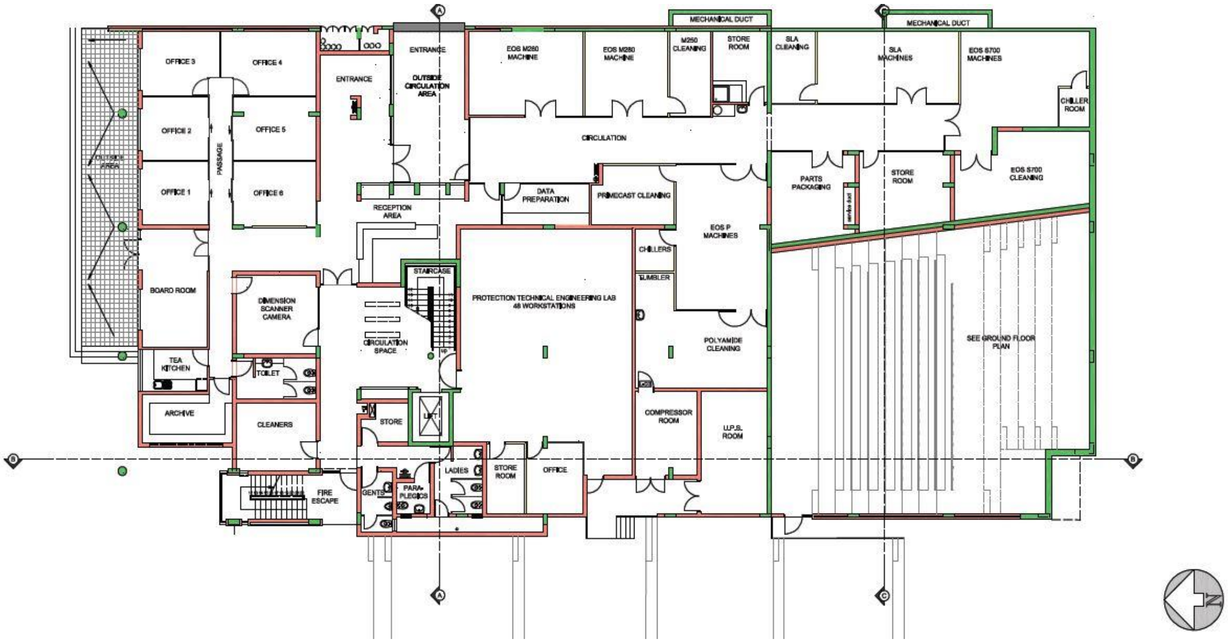


Figure A.1 Lower Ground Floor Plan of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

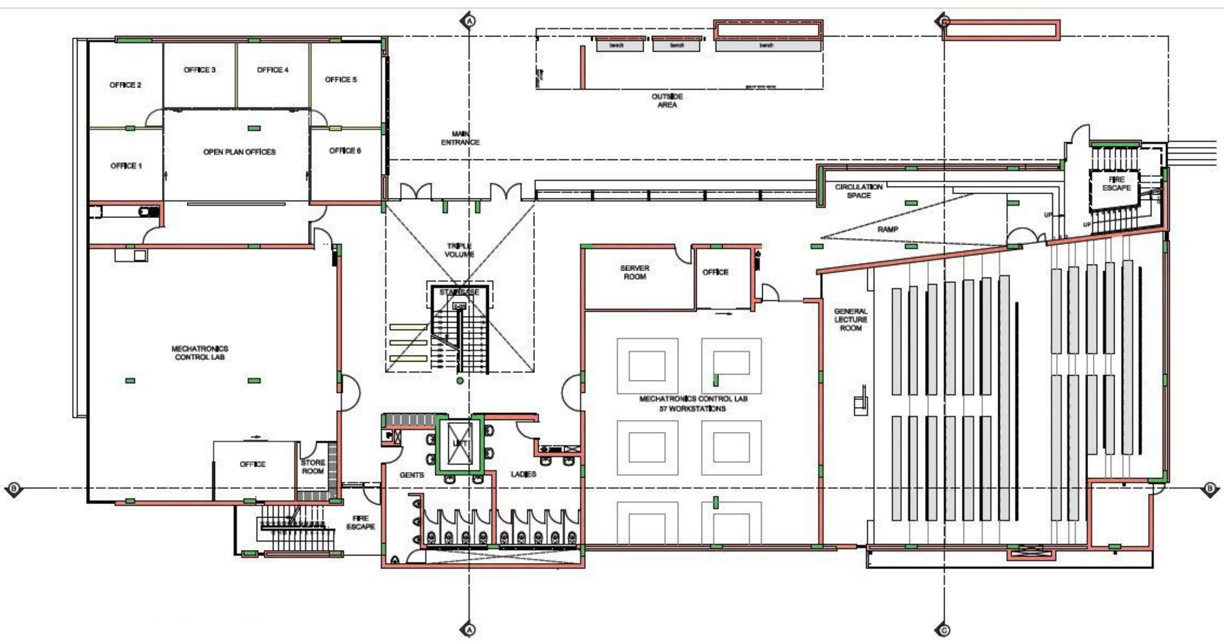


Figure A.2 Ground Floor Plan of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

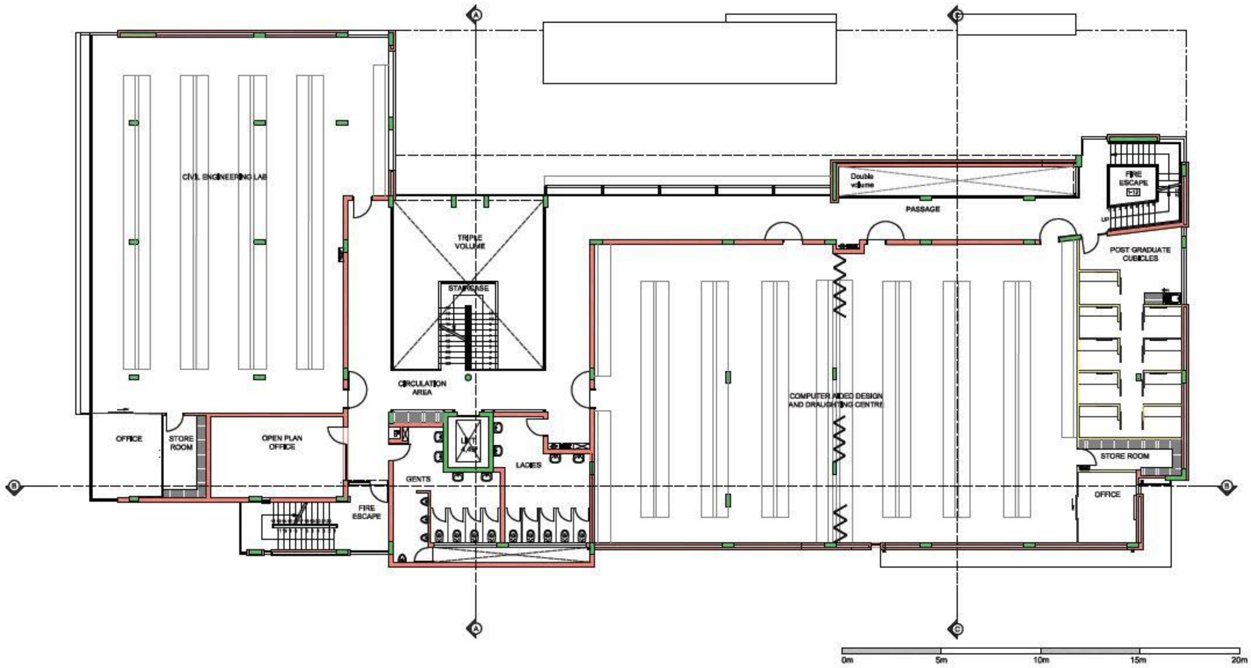


Figure A.3 First Floor Plan of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

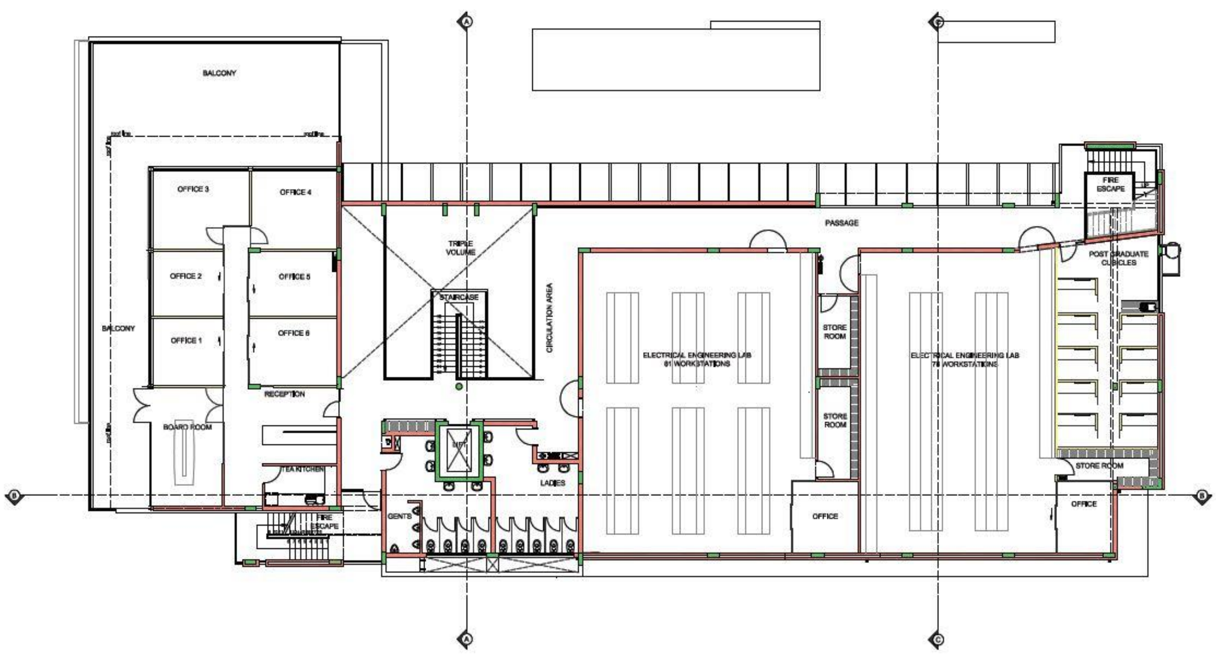


Figure A.4 Second Floor Plan of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

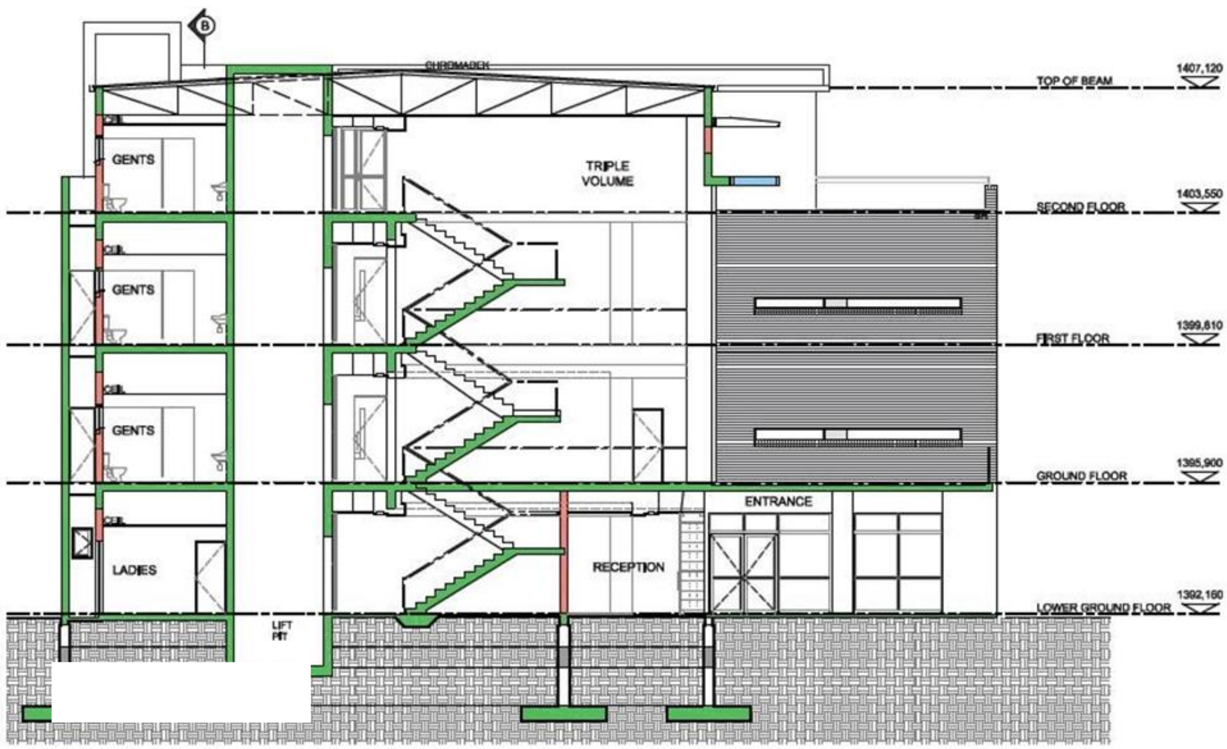
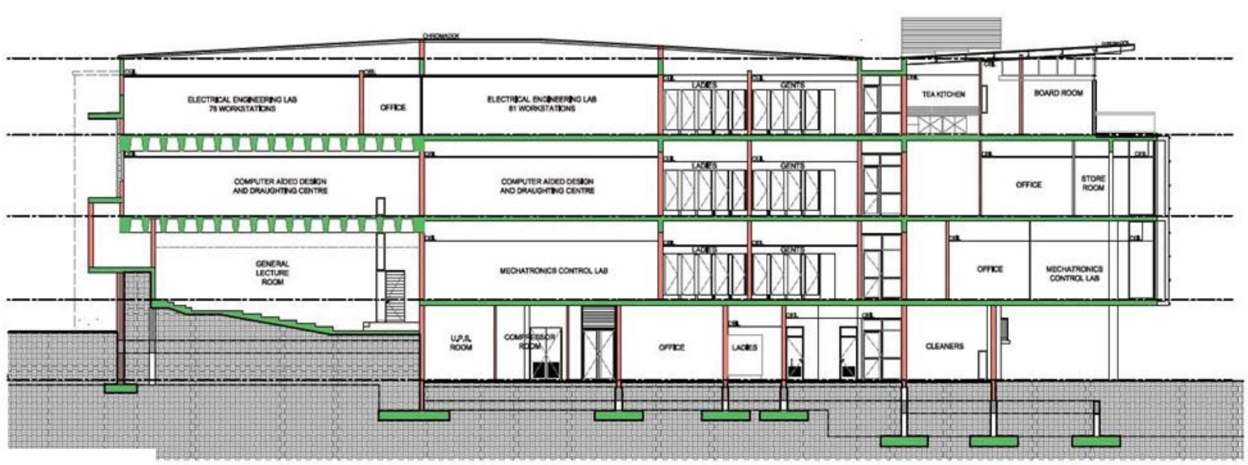


Figure A.5 *Section AA of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein*



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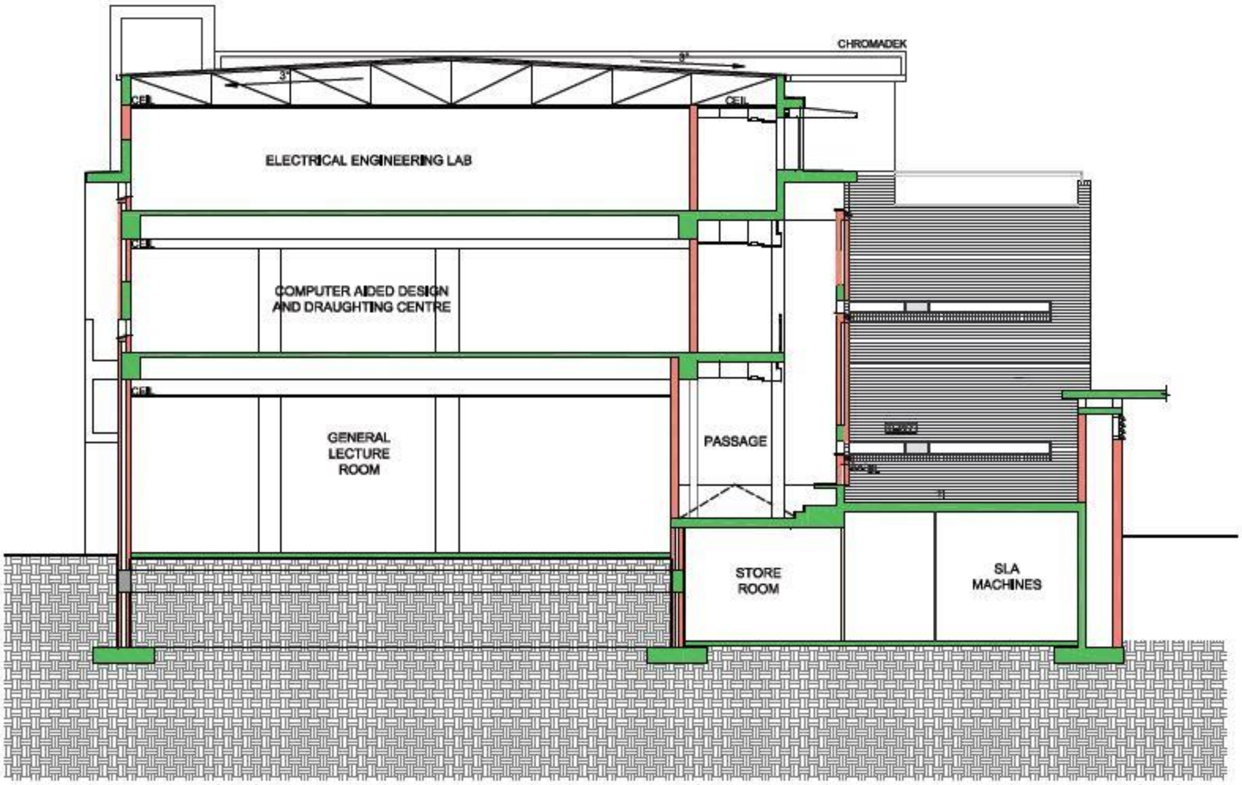


Figure A.7 Section CC of the Engineering Technology Building (ETB) on the Central University of Technology (CUT) campus in Bloemfontein

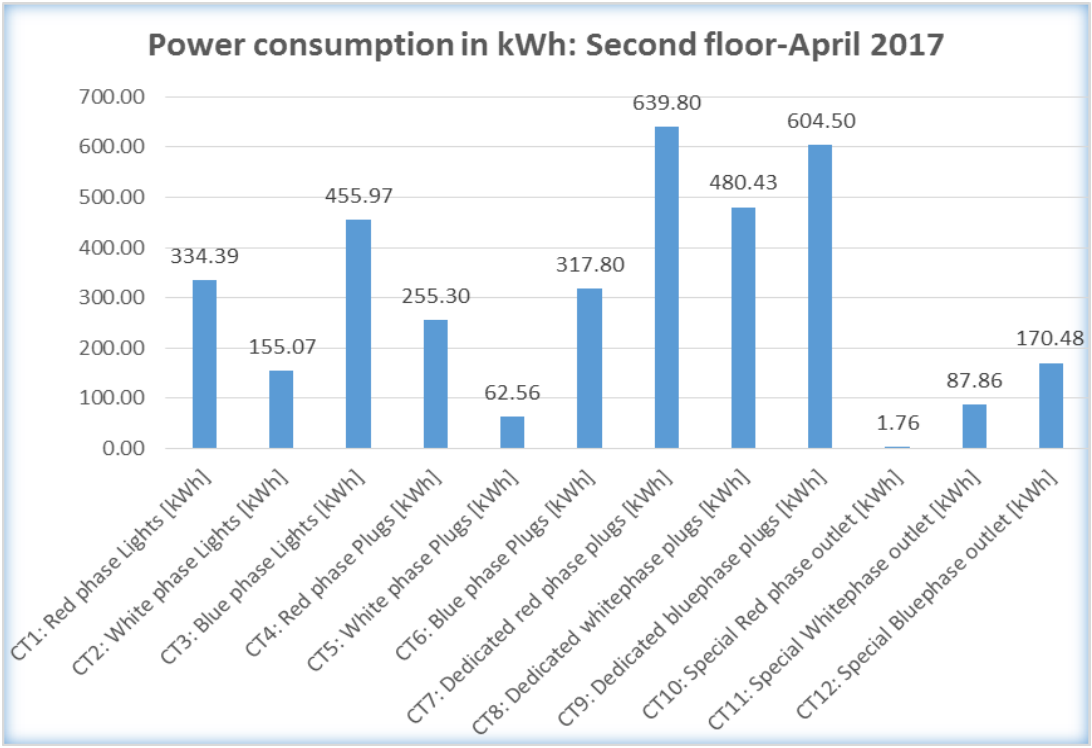


Figure A.8 Power consumption in kWh of the second floor – April 2017

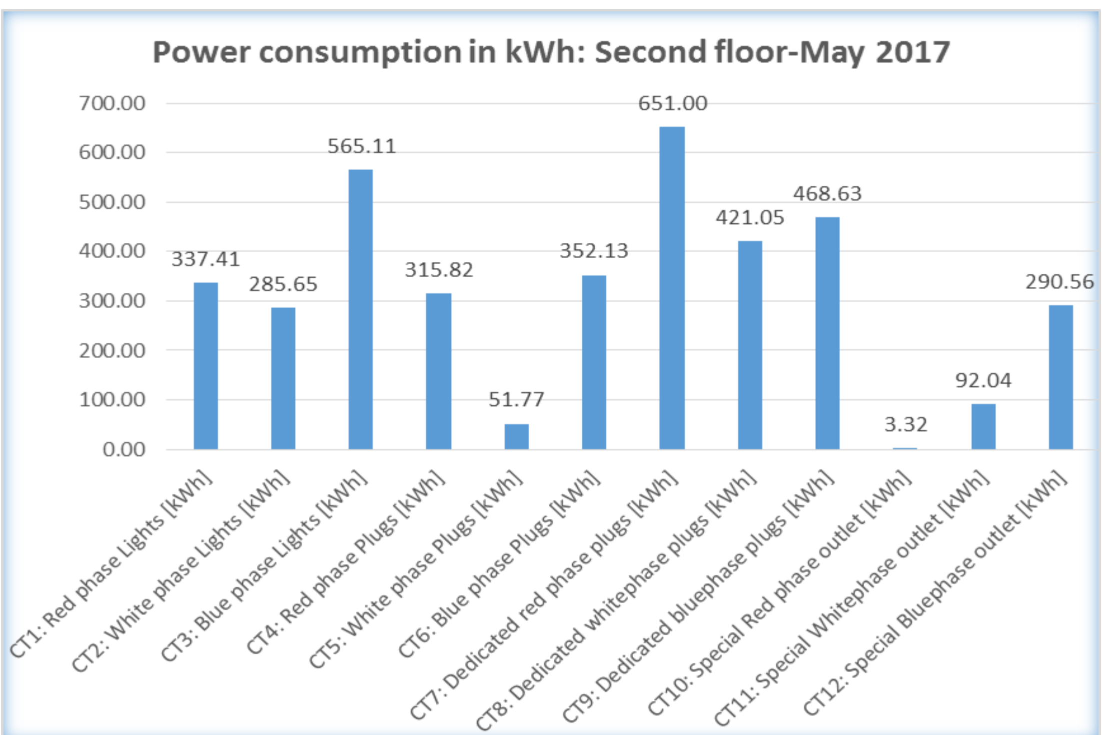


Figure A.9 Power consumption in kWh of the second floor – May 2017

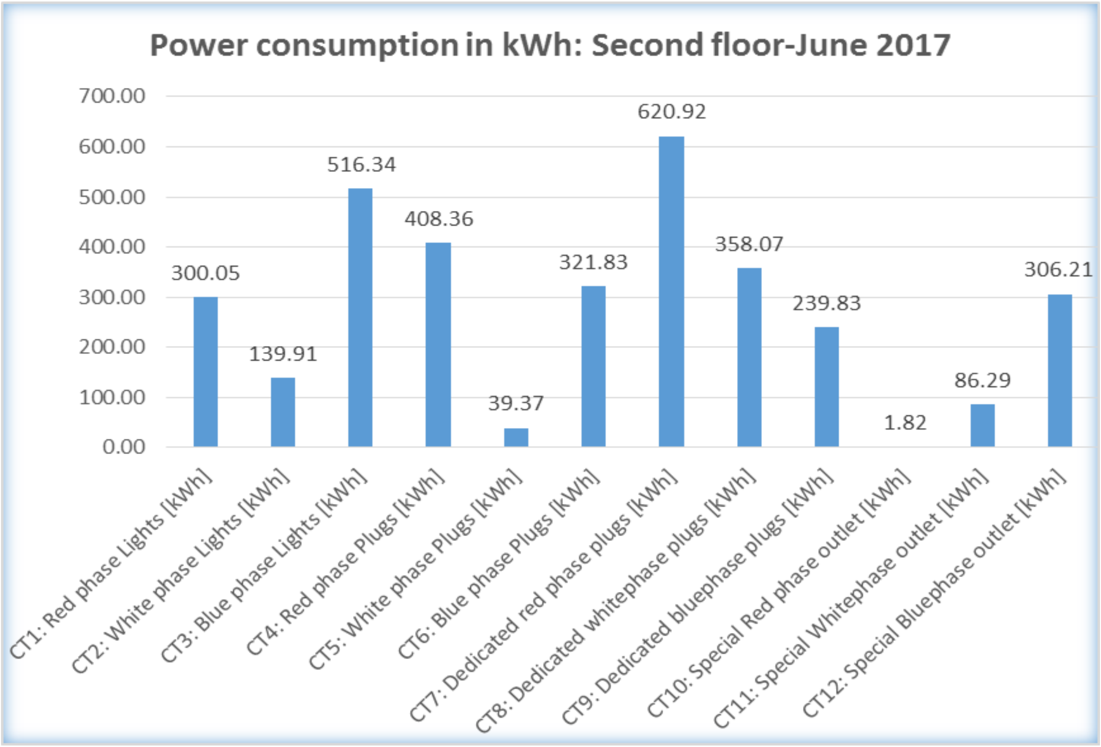


Figure A.10 Power consumption in kWh of the second floor – June 2017

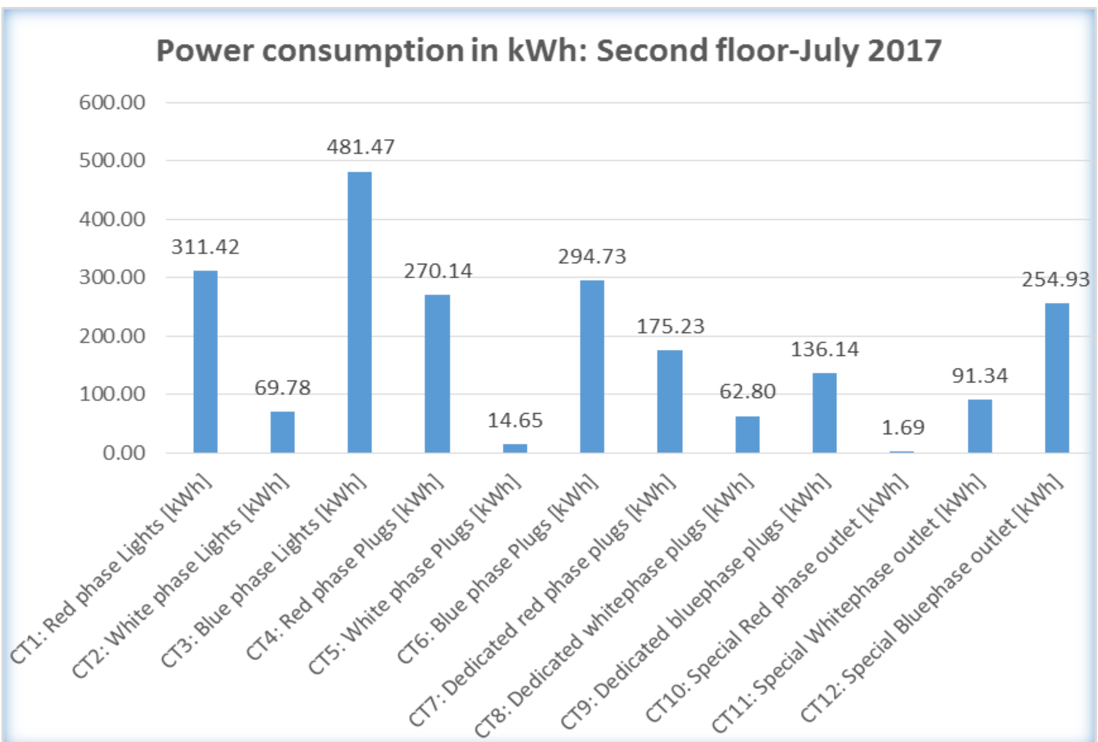


Figure A.11 Power consumption in kWh of the second floor – July 2017

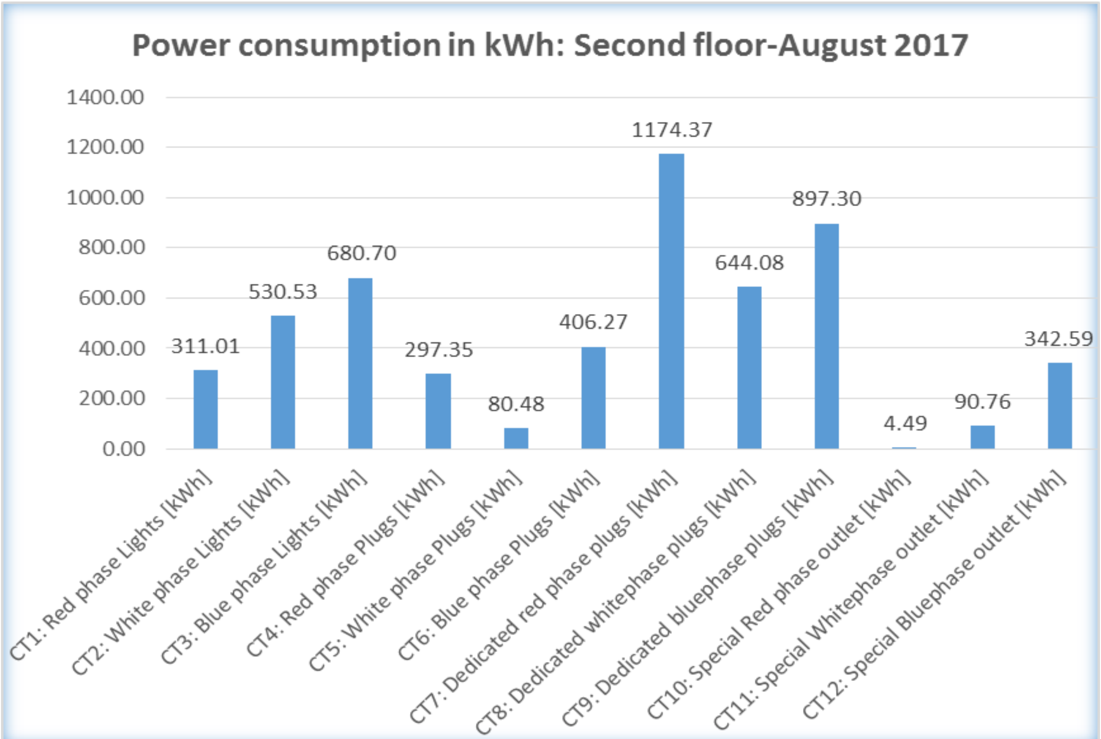


Figure A.12 Power consumption in kWh of the second floor – August 2017

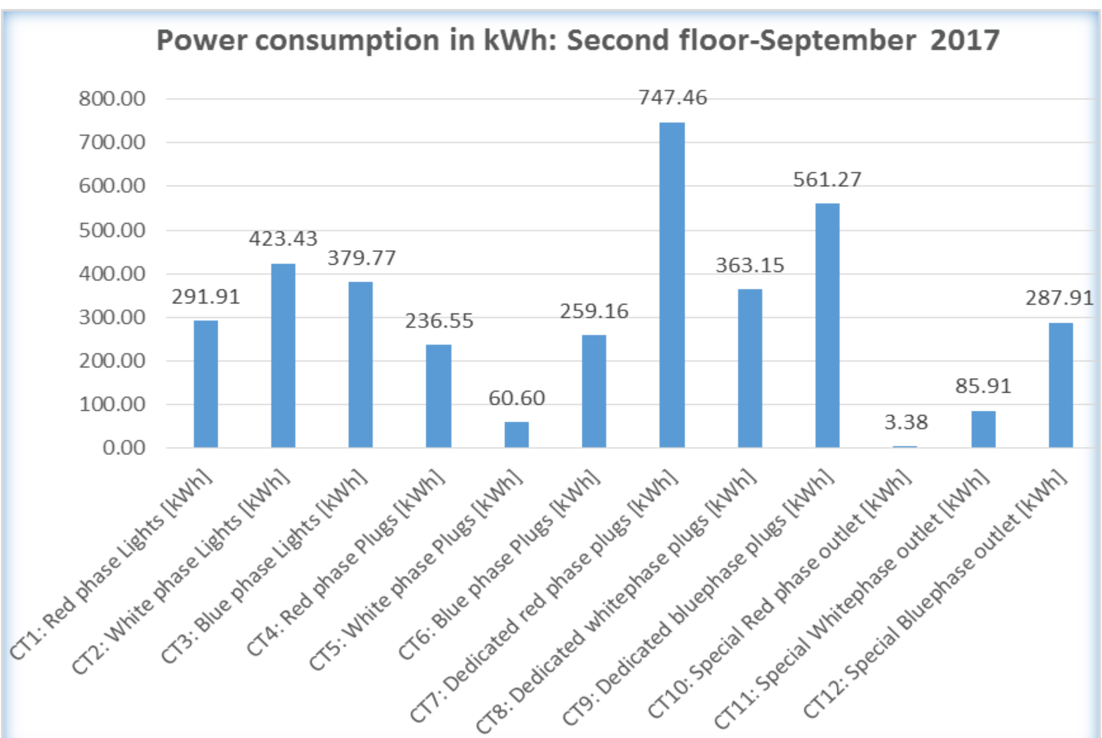


Figure A.13 Power consumption in kWh of the second floor – September 2017

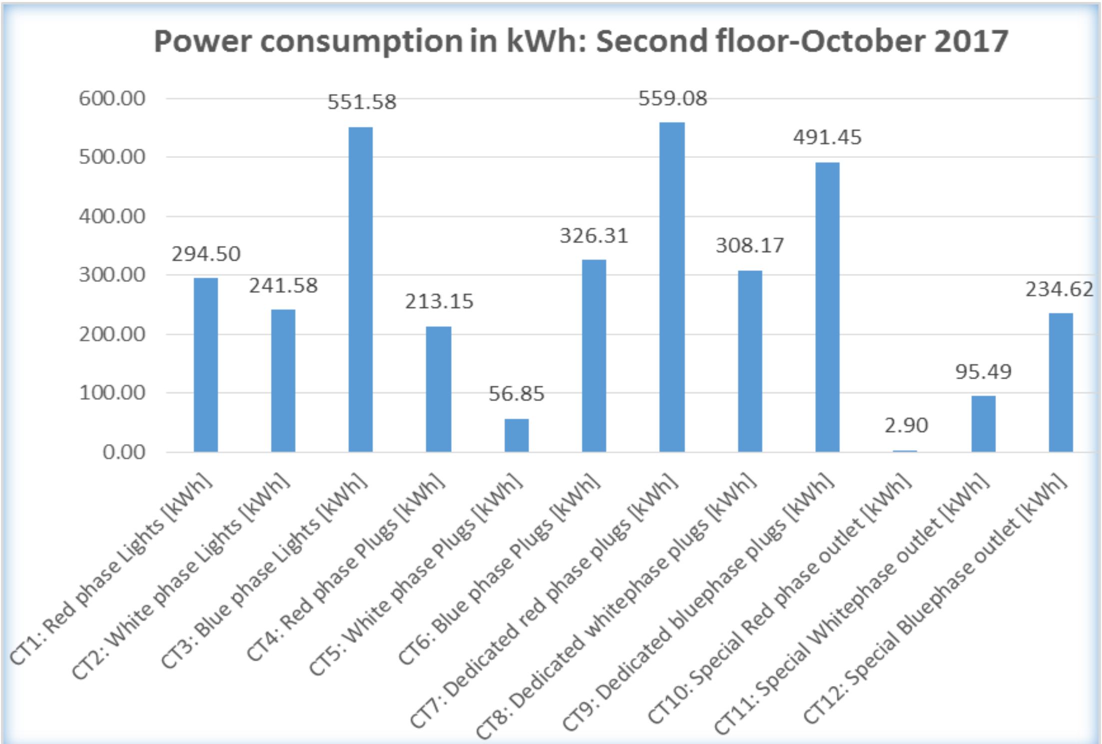


Figure A.14   Power consumption in kWh of the second floor – October 2017

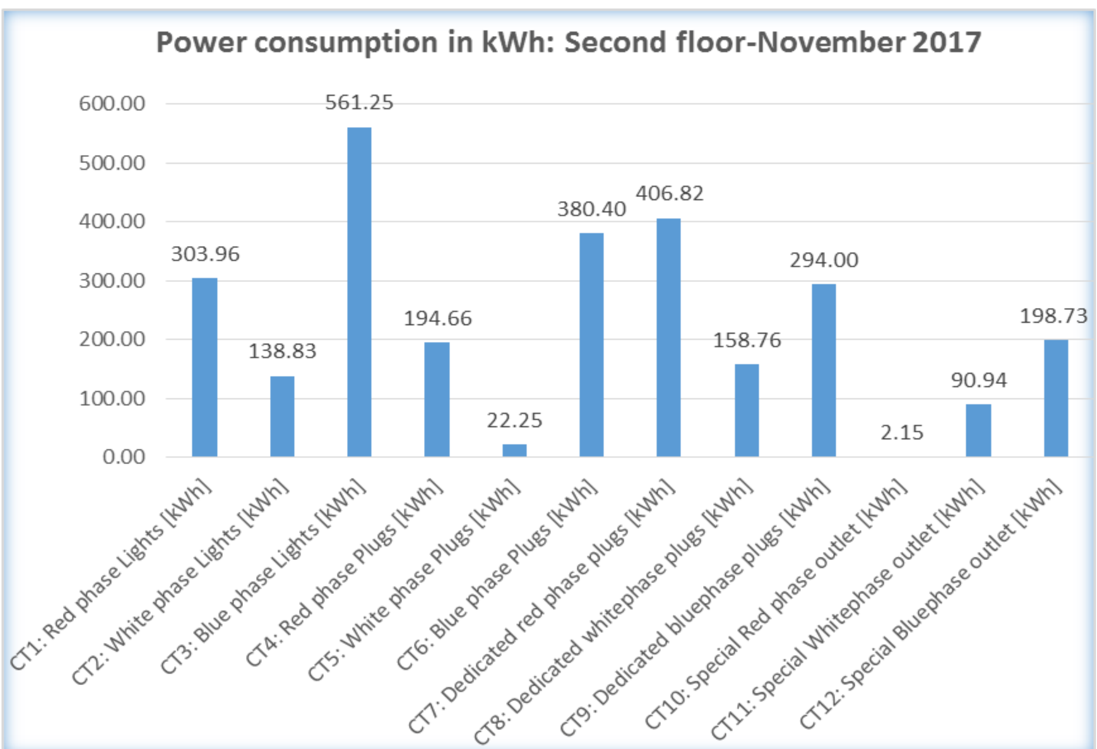


Figure A.15   Power consumption in kWh of the second floor – November 2017

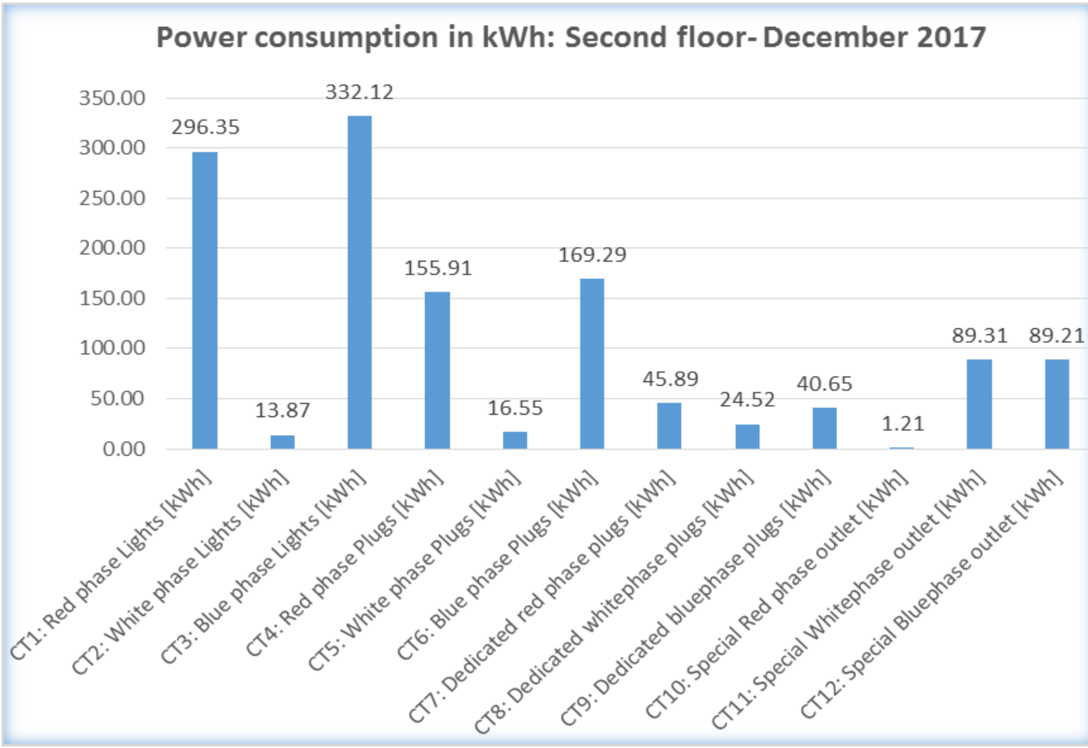


Figure A.16 Power consumption in kWh of the second floor – December 2017

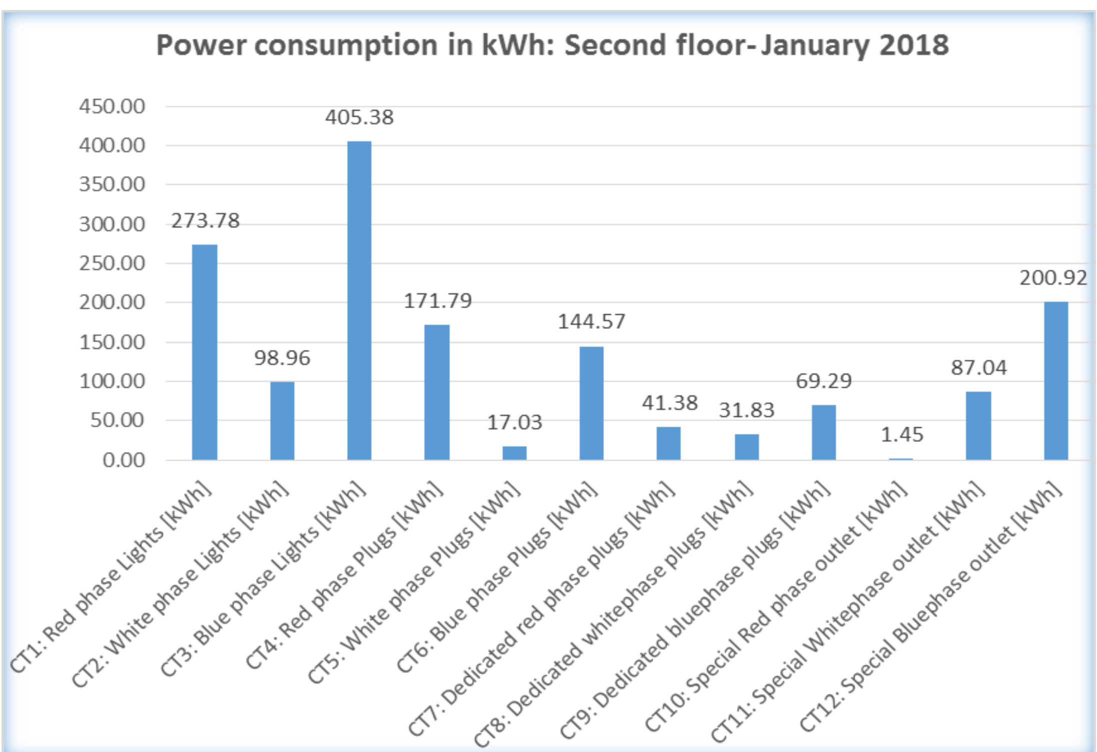


Figure A.17 Power consumption in kWh of the second floor – January 2018

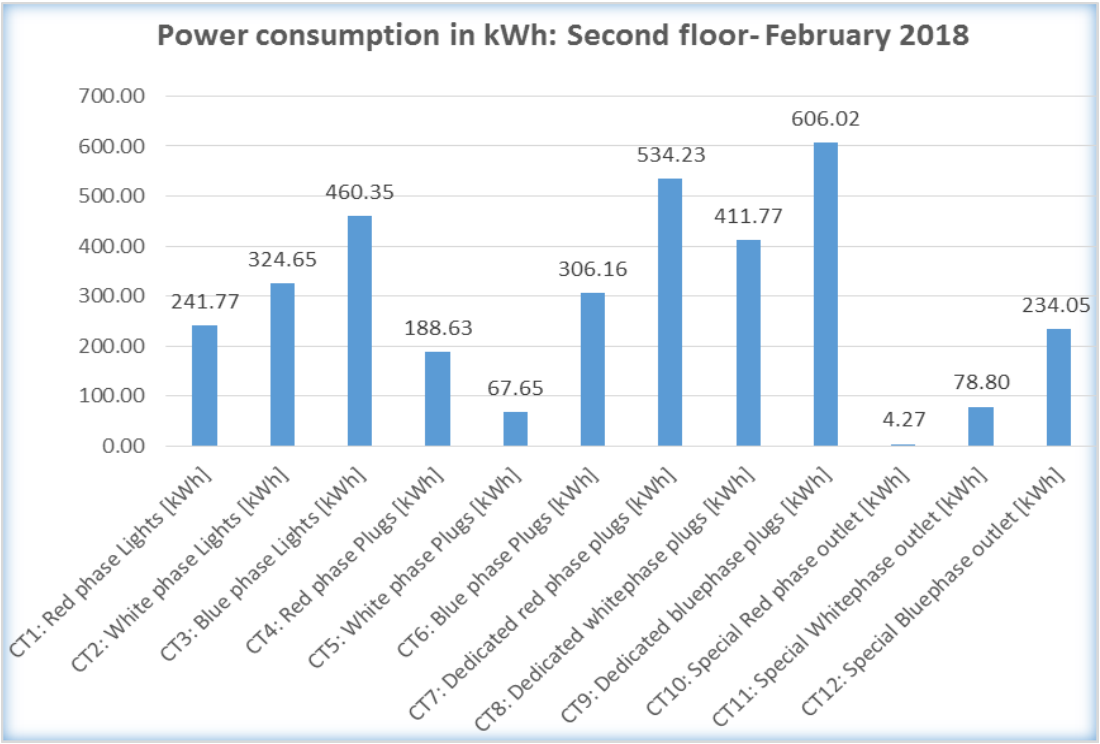


Figure A.18 Power consumption in kWh of the second floor – February 2018

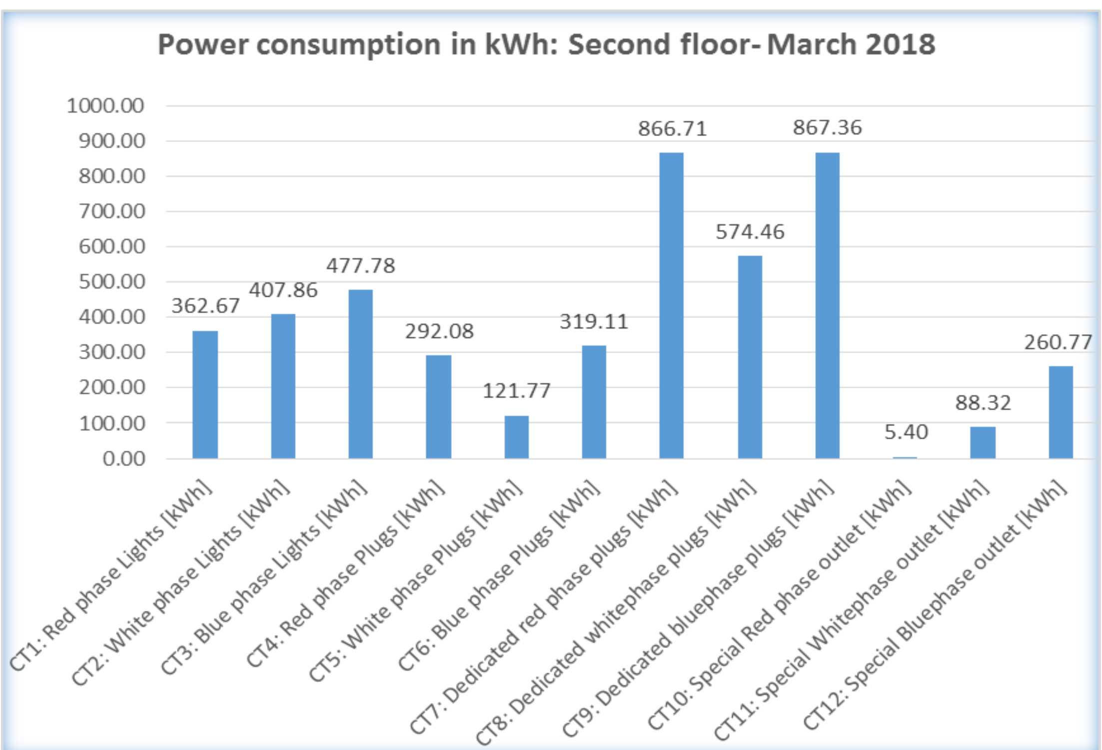


Figure A.19 Power consumption in kWh of the second floor – March 2018

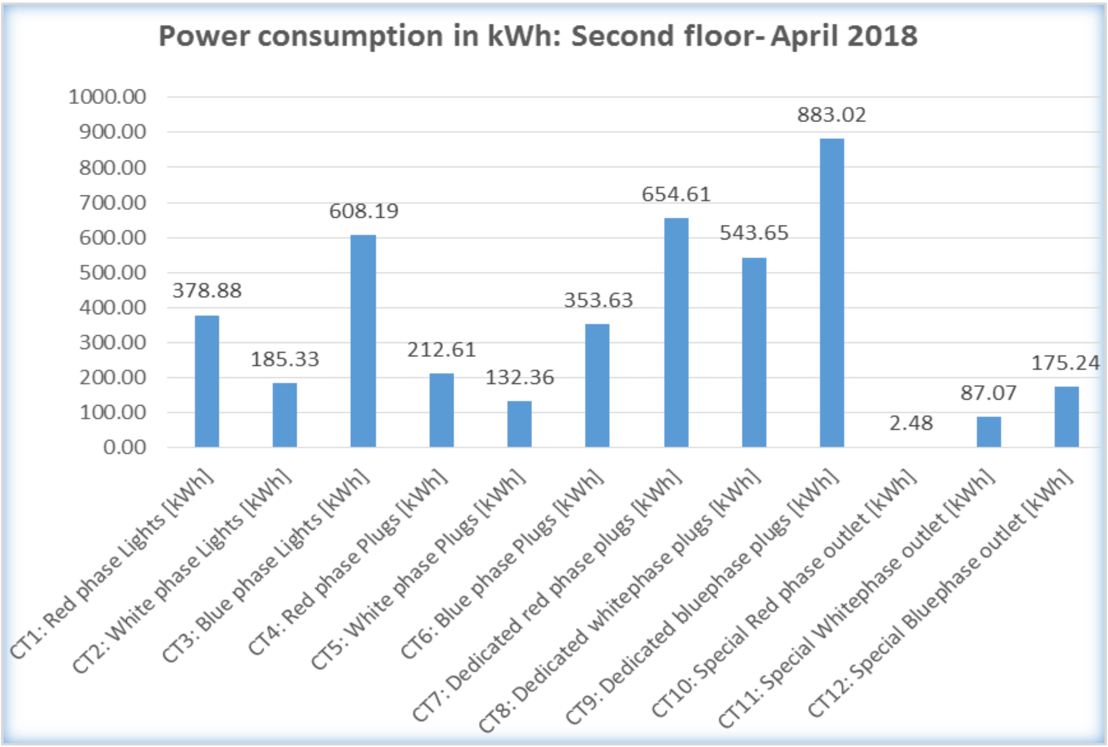


Figure A.20 Power consumption in kWh of the second floor – April 2018

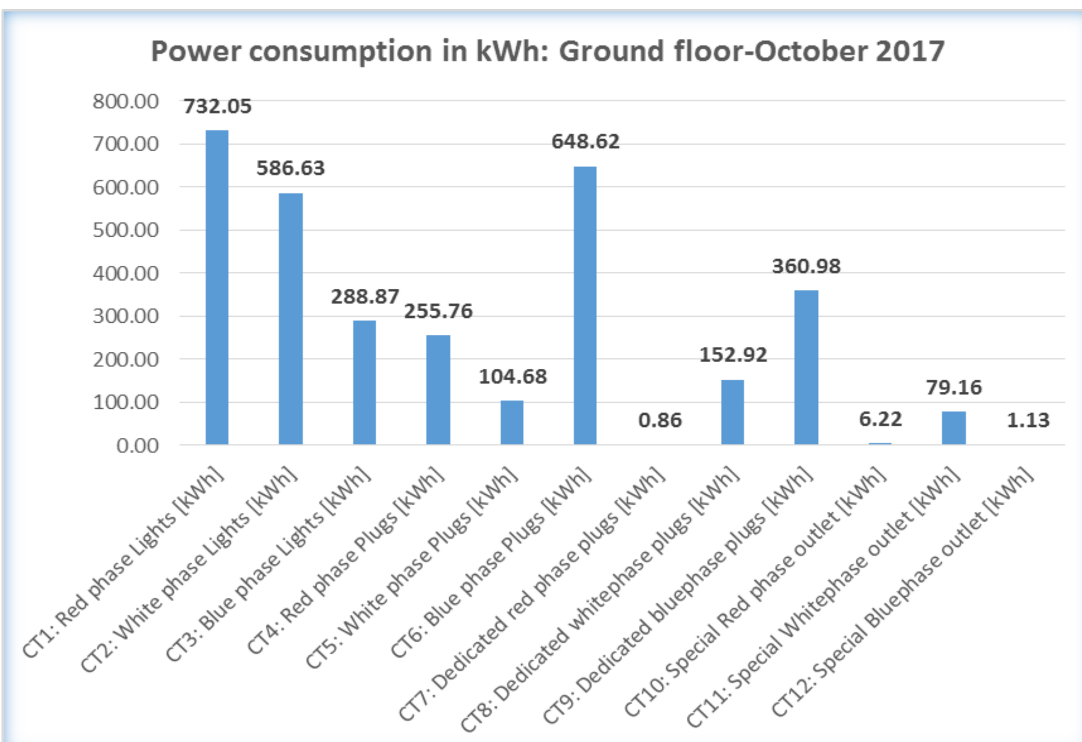
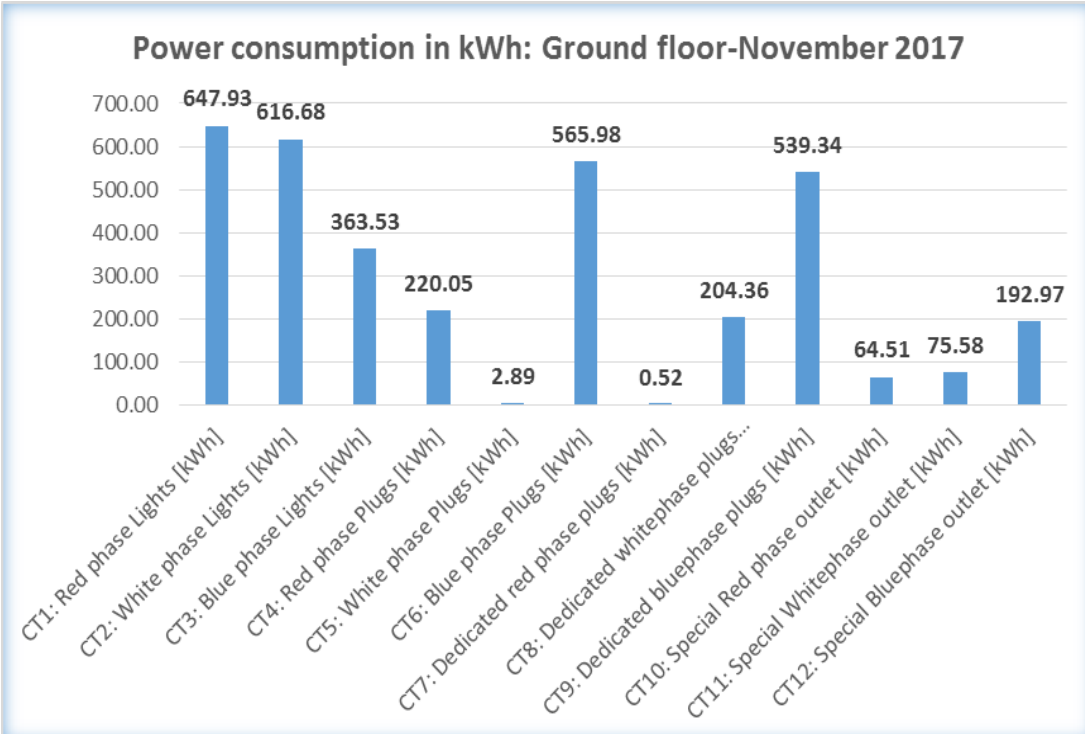


Figure A.21 Power consumption in kWh of the ground floor – October 2017



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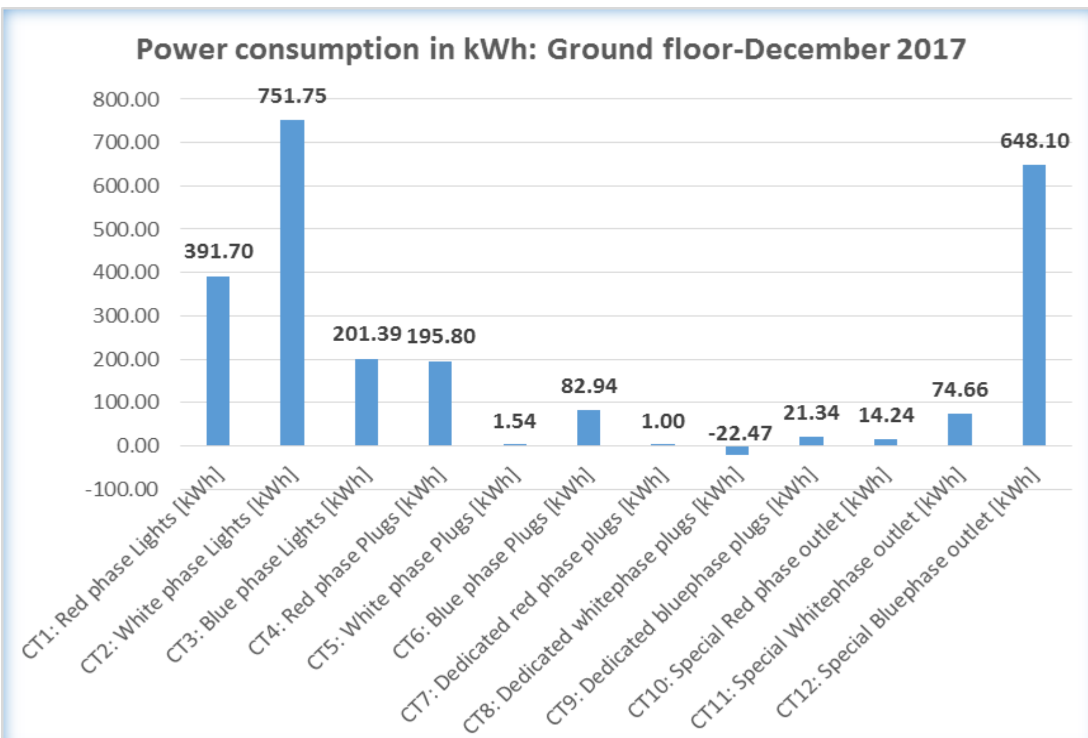

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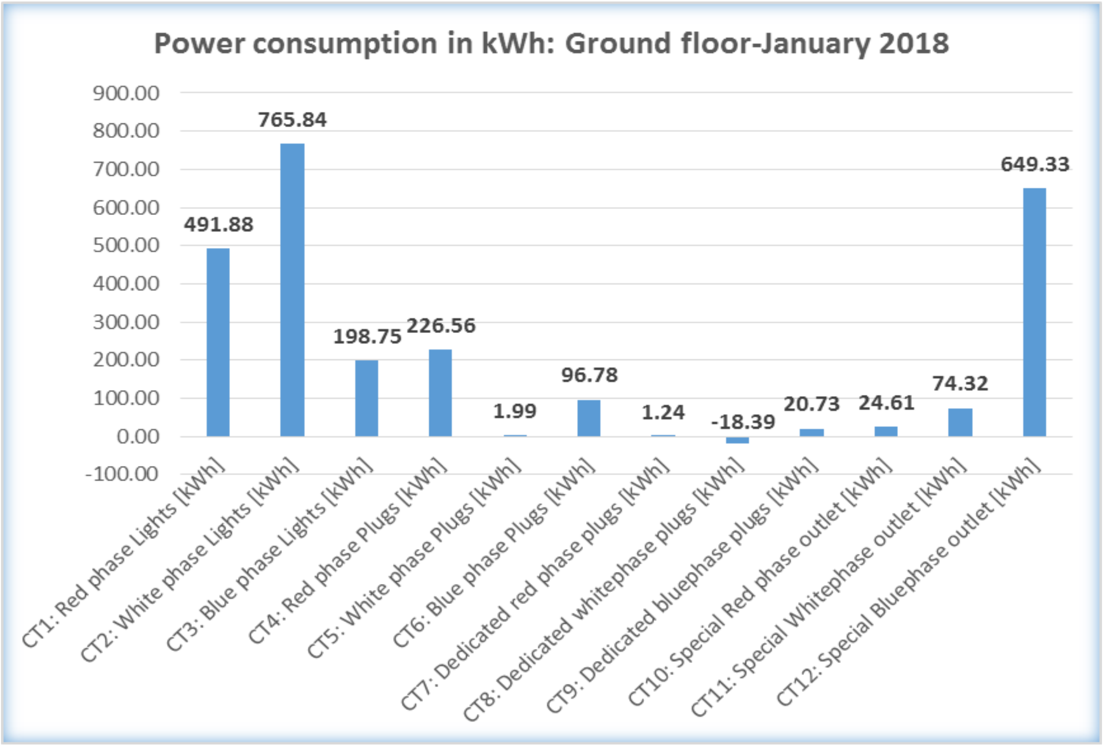

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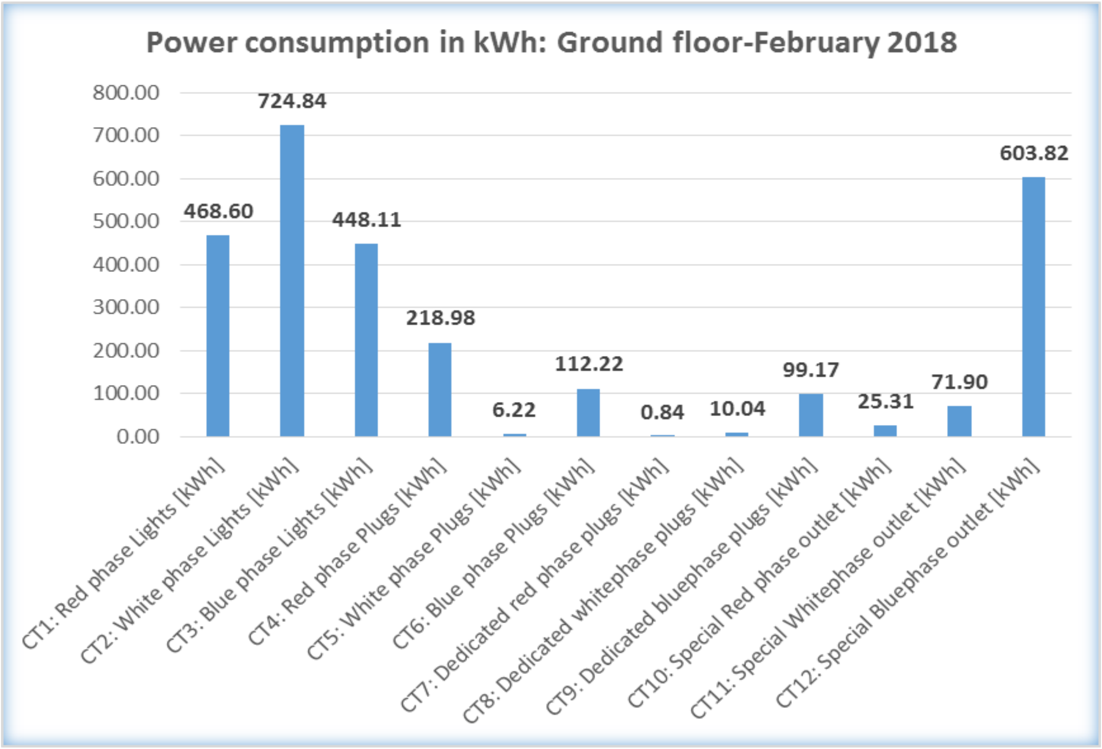

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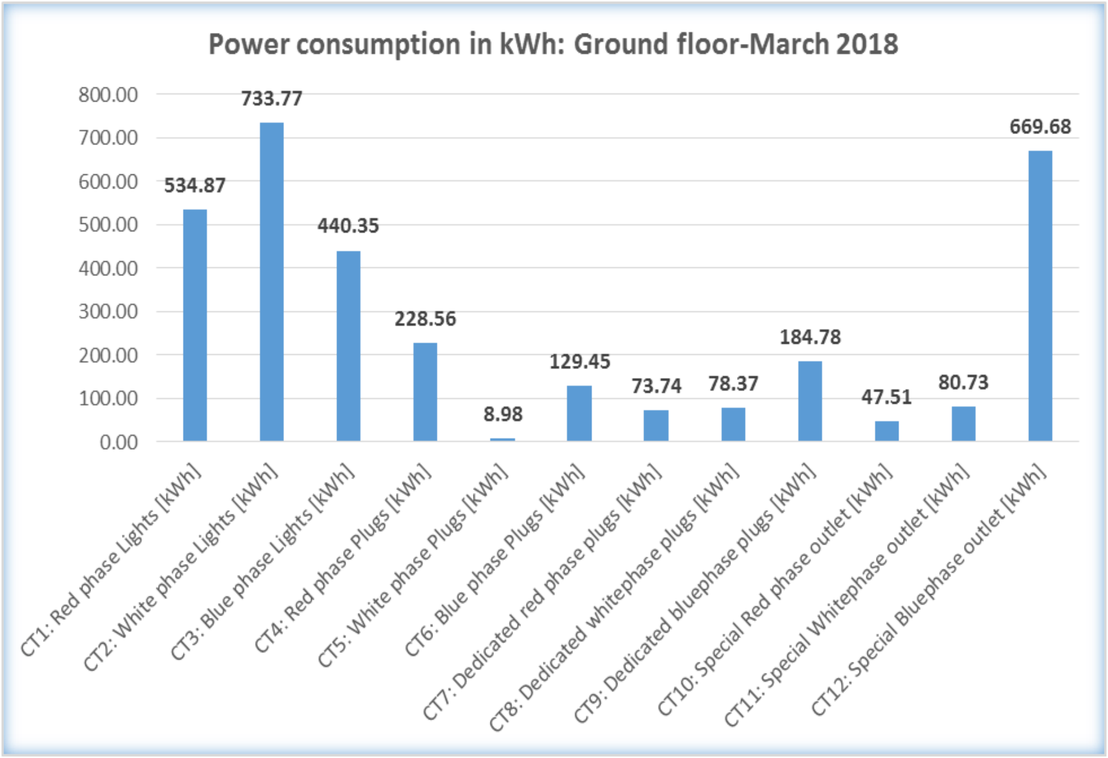

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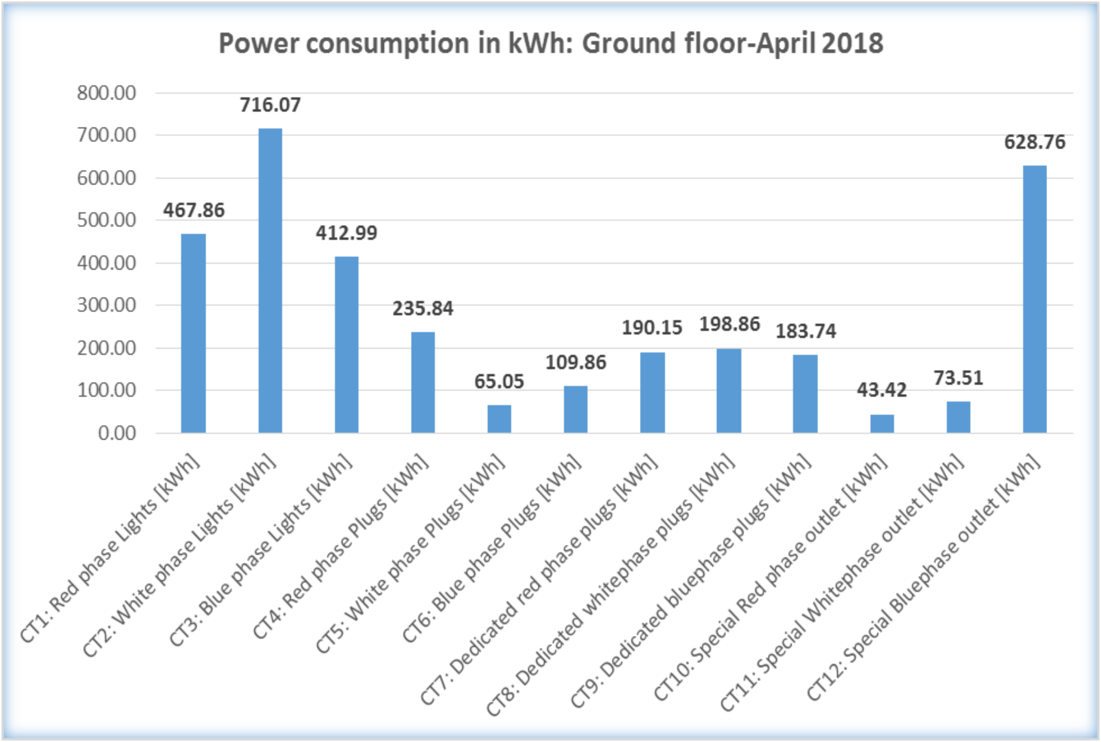

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