DEVELOPMENT OF A SOLID STATE DISTRIBUTED LIGHTING SYSTEM FOR RURAL ENERGY EFFICIENT APPLICATIONS

by

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DECLARATION

I, WILFRED LESLIE OWEN FRITZ, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed .... 17 December 2006

ABSTRACT

The electrical supply utility, ESKOM, cannot cope with the growing demand in South Africa. This results in load shedding and power outages. This capacity can be augmented, by conducting energy audits, retrofitting government buildings, designing and installing cost-effective lighting systems, and using renewable energy sources in rural areas. Households in rural areas depend on candles and paraffin lamps to supply light at night. Solar panels as renewable energy sources are very expensive in conventional lighting systems. The problem is that a cost-effective, affordable lighting system has not yet been designed. The following four projects have been completed by the author:

- Software development for a lighting design in general
- Efficient high bright light emitting diode (HB-LED) lighting system
- Energy audit and retrofit of the Nuwe Hoop School in Worcester
- Optimization of hybrid solar–diesel system

Firstly, the author wrote a program that is used in lighting designs. This illumination software is utilized for educational purposes. A manual step-by-step lighting design procedure was compiled. The JAVA object-oriented programming language was used to write the code of the design software. Real life design parameters are fed to the program, to confirm proper implementation. The software package will perform illuminance calculations to display relevant Isolux diagrams for educational purposes.

In the second project, the author heads the Service Learning and Development (SLD) unit. This unit delivers a service to the community, to improve their standard of living and to provide training to students registered at the institution. The members of the unit are students and lecturers who work in collaboration with government organizations and private companies in industry. The SLD unit performs energy audits, retrofitting and installations for the abovementioned role players. The pilot

project was contracted to the SLD unit to do an energy audit at a school in Worcester. This was done in collaboration with ESKOM. The author compiled an Energy Audit with recommendations for the Nuwe Hoop School for the deaf in Worcester, about 100 km from the university. The aim of the project was to reduce the school's electricity consumption significantly.

Thirdly, a low cost HB-LED lamp was designed that is relatively cheap to manufacture. The bulk of the problem is the high cost per HB-LED. This low cost lighting system is to be established in a rural community near Stellenbosch. The low voltage building reticulation network of an HB-LED lighting system is fed from photo-voltaic (PV) panels. Solid state lighting luminaires and driving circuits were designed, simulated, developed, installed and commissioned. The simulation was done with the PSIM and TINA software, to obtain optimal operating parameters. Ideally operating conditions of the system should be remotely monitored.

Finally, recommendations were made to optimize an inefficient hybrid solar–diesel system on a farm in Calvinia. A new high voltage regulator was designed to be installed.

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GLOSSARY

AC (Alternating Current): The commonly available electric power supplied an AC generator and is distributed in single or three-phase forms. AC current changes its direction of flow (cycles).

British Thermal unit (Btu): One British thermal unit is the amount of energy used to increase the temperature of one pound of water by one degree Fahrenheit.

Capacitor: A device which, when connected in an alternating-current circuit, causes the current to lead the voltage in time phase. The peak of the current wave is reached ahead of the peak of the voltage wave. This is the result of the successive storage and discharge of electric energy.

CFL: Compact fluorescent lamp. The integral CFL has the lamp and control gear built-in into a single unit. This fits into an existing light socket. In the modular unit the lamp and control gear is separate, with a dedicated lamp holder.

Conductor: A material, such as copper or aluminium, which offers low resistance or opposition to the flow of electric current.

CRI (colour rendering index): A quantitative measure of the accuracy of colour rendering is the colour-rendering index (CRI). This measure is based on comparing the colours rendered by a LEDs light source to the colours rendered by a “perfect” reference light source. As the maximum luminous efficacy decreases, the maximum CRI increases, as the wavelengths move further to the extremes of the visible spectrum.

Current: The time rate of flow of electrical charge and is measured in amperes (A).

DC (Direct Current): A current that flows only in one direction in an electric circuit. It may be continuous or discontinuous and it may be constant or varying.

Demand Side Management (DSM): DSM is when a utility or local authority that supplies electricity put measures or activities in place that influence the way it is used by the customers. Two main opportunities are targeted namely Energy Efficiency and Load Management

ECG (electronic control gear): lamps that are driven by electronic devices.

Efficacy (η) [lumen/watt or lm/W]: The efficiency of a light source by converting the electrical input power to light or the luminous flux to power intake ratio of a lamp.

Efficiency: A measure of the useful light output in lumens against the total amount of lumens generated by the light source.

Energy Efficiency: The wise use of energy or electricity to save resources and money. The installation of more energy efficient equipment will lead to electricity or energy savings whenever the relevant equipment is used.

Frequency: The rate at which alternating current makes a complete cycle of reversals. It is expressed in cycles per second. In the U.S. 60 cycles (Hz) is the standard while in other countries 50 Hz (cycles) is more common.

Hertz (HZ): One cycle per second (as in 50 Hz, which is 50 cycles per second).

High Bright LED (HB-LED): High Bright Light emitting diodes are PN junction devices that give off light radiation when biased in the forward direction. In a HB-LED electrons and holes are injected into a solid-state semiconductor, which emits light.

Iluminance or Illumination (E) [lux or lx or lm/m^2]: The luminous flux density at a point on a surface or $E = \frac{\Phi}{A}$

Inductance: The characteristic of an electric circuit by which varying current in it produces a varying magnetic field which causes voltages in the same circuit or in a nearby circuit.

Inverter: An electronic device that converts fixed frequency and fixed voltages to variable frequency and voltage.

Kilowatt: Since the watt is a relatively small unit of power, the kilowatt (kW) or 1,000 watts, is used where larger units of power measurements are desirable.

Lamp life: the time at which 50% of the test samples have failed or the time it took the lamp to maintain 50% of its initial brightness

Load Factor: The ratio of the average power to the maximum demand specified over a period (monthly or annually etc.).

Load Management: The implementation of load control options. With load control the time of energy use is shifted without a change in the overall energy use.

Luminaire: an apparatus (support, circuit auxiliaries and protection) that distributes, filters or transform light form a lamp/s. It excludes the lamp/s. Circuit auxiliaries are the components needed to operate the light source directly from the mains supply.

Luminous flux (Φ) [lumen or lm]: Light energy / waves radiated (received) by a source (surface)

Luminous intensity or Candle power (I) [Candela or lm/sr]: Solid angular flux density of a source in a specified direction.
Thus $\Phi = \omega I$.

Maintenance Factor (MF): Illuminance deterioration is caused by the lamp lumen maintenance factor (LLMF), luminaire maintenance factor (LMF) and room surface maintenance factor (RSMF). Thus MF = LLMF*LMF*RSMF.

MBOE: million barrels of oil equivalent

Outage: Unexpected or unplanned Blackout / Electrical power failure for long period.

Phase: Indicates the space relationships of windings and changing values of the recurring cycles of AC voltages and currents. Due to the positioning (or the phase relationship) of the windings, the various voltages and currents will not be similar in all aspects at any given instant. Each winding will lead or lag another, in position. Each voltage will lead or lag another voltage, in time. Each current will lead or lag another current, in time. The most common power supplies are either single or three-phase (with 120 electrical degrees between the 3 phases).

Reactance (inductive): The characteristic of a coil, when connected to alternating current, which causes the current to lag the voltage in time phase. The current wave reaches its peak later than the voltage wave reaches its peak.

Renewables: Renewable energy sources like solar generated electricity through photovoltaics or thermal methods, wind energy, wave energy conversion, electricity production with fuel cells and alcohol production from agricultural products.

Resistance: The degree of obstacle presented by a material to the flow of electric current is known as resistance and is measured in ohms.

Solid State Lamp (SSL): SSLs are High Bright Light Emitting Diodes with their driving circuitry as a compact unit.

Specific gravity: The specific gravity of a substance is a comparison of its density to that of water (1.000)

Utilisation Factor (UF): A measure of the efficiency of installation or percentage of flux that reaches the work plane.

UV: Ultraviolet

Voltage: The force that causes a current to flow in an electrical circuit. Analogous to pressure in hydraulics, voltage is often referred to as electrical pressure

Watt: The amount of power required to maintain a current of one ampere at a pressure of one volt.

CHAPTER ONE

INTRODUCTION

One of the main aims of this thesis is to recommend energy consumption reduction methods. The research objective of this thesis was to investigate the feasibility to:

- develop software to verify lighting design results of a general, elementary lighting design;
- retrofit a lighting system at a school in Worcester, after an energy audit is done;
- design, install and commission a prototype of a low cost energy efficient, renewable solid state lighting system to be installed in a rural community in Stellenbosch and
- optimise an existing inefficient off-grid hybrid solar–diesel system on a farm in Calvinia.

This Chapter is elaborating about the research problem. It gives a statement of the problem and the background to the research problem. A literature review of Energy Audits and Solid State Lighting is given. The literature review is expanded on Energy Audits in Chapter 3 and on Solid State Lighting in Chapter 4. This chapter also asks the research question, states the objectives of the research, discusses the research design and methodology and the limitations of the research. The significance of the research, expected outcomes and results of the research are summarised. Chapter 2 describes the development of software with JAVA, to compile an illumination software package to calculate the design parameters and to display the relevant isolux diagrams of a lighting design. Chapter 3 discusses energy management and the energy audit of a school for the deaf in Worcester. Chapter 4 covers the development of a solid state distributed lighting system. Simulation is done on various LED driver circuits to asses its viability. In Chapter 5 the optimization of an inefficient hybrid solar-diesel system on a farm in Calvinia in researched and recommendations are made. Chapter 6 is about the conclusion.

1.1 Statement of Research Problem

The driving force in Energy Management is the development of new energy efficient technologies to reduce the combustion of fossil fuels and to provide standard energy services, viz. heat, air-conditioning and lighting and process equipment for industry. The problem is worsened by the fact that the South African government committed itself to make electrification available to informal settlements and rural areas. A further problem is that the electrical supply utility, ESKOM cannot cope with the growing demand and it results in load shedding and outages. This capacity can be augmented, by conducting energy audits, retrofitting government buildings, designing and installing cost effective lighting systems, driven by renewable energy sources in rural areas. Households in rural areas depend on candles and paraffin lamps to supply light at night. Solar panels as renewable energy sources in these areas are very expensive in conventional lighting systems. The problem is that a cost effective, affordable lighting system has not yet been designed. A low cost high bright light emitting diode (HB-LED) lamp is still to be designed that is relatively cheap to manufacture. The bulk of the problem is the high cost per HB-LED. A school in Worcester needs to be energy audited, a rural community is to be established with a low cost proper lighting system and an inefficient hybrid solar–diesel system on a farm in Calvinia is to be optimised.

1.2 Background to Research Problem

The interest of the author lies in the development of sustainable energy sources, especially in the lighting field. Energy efficiency is promoted and implemented firstly for the sake of saving energy for the same economic output, and secondly for reducing greenhouse gas emissions. The background to the research problem is as follows:

1.2.1 Worldwide Awareness of sustainable energy

The World Summit on Sustainable Development (WSSD) was attended by approximately 21000 international delegates in Johannesburg, South Africa in 2002. On 14 February 2006 UK delegates visited Cape Town on a renewable Energy Mission to promote renewable energy technologies and to form partnerships with South Africans. The author and his supervisor attended the workshop. The director of the Environmental Planning of the City of Cape Town announced that the International Council of Local Environmental Initiatives (ICLEI) World Congress 2006 will be hosted by Cape Town in Cape Town from 27 February to 3 March 2006, to emphasize the importance of renewable energy conversion. The ICLEI is an international network supporting sustainable development in local government. It strives to achieve improvements in global sustainability and environmental conditions. It aims to provide technical support services and consultancy to aid the implementation of local sustainable development and environmental policies and programs. More than 400 local government associations worldwide are currently members of ICLEI. ICLEI is involved in a number of programmes where local authorities can exchange good practice and receive practical training in sustainability management and climate protection [ICLEI, 2005]. The fifth Southern African Regional International Council on Large Electric Systems (CIGRE) was held in Somerset West from 24-28 October 2005, where the emphasis was on bottlenecks in electrical networks and rapid growing demand.

The aim of all these programs and events is to institute ecologically sound environmental management; since fossil fuel and coal fired power plants are the major causes of air pollution in electricity generation. Many new renewable energy technologies have been innovated and implemented to reduce environmental impacts of electricity production. These technologies have been actively and vigorously researched overseas.

Rahman addresses national energy efficiency experiences to reduce energy usage per unit of economic output, in four major economies in the world – in the industrializing and industrialized world, namely China, India, the United States and the European Union (EU) [Rahman, 2006:13-17]. He provides several websites on energy efficiency strategies and experiences and discusses and emphasizes the enormous energy savings by implementation of energy consumption reduction plans put in place as follows:

- The National Energy Conservation and Efficiency 20 year plan in China
- The National Energy Conservation and Efficiency program in India
- The Energy Star program and Appliance and Equipment efficiency Standards in the USA
- The Promotional Energy Efficient Initiatives (Green Light and Electric Motor Challenge Voluntary program), Intelligent Energy program and the Lisbon Agenda in the EU.

Among the four economies compared in the paper, the EU provides the highest level of energy efficiency in their residential, commercial and industrial sectors, with highly visible programs to encourage energy efficient behaviour on to its users. China, with its heavy industries, presently uses more than five times as much energy as the EU, to produce one unit of GDP in dollars. The USA uses 50% more than the EU. In South Africa we should strive to do more with less, i.e., reducing or maintaining the energy intensity as demand increases, as in the EU.

1.2.2 Importance of renewable energy

The world's economies are dependent on energy. However, coal fired power plants are the major cause of air pollution. This leads to environmental destruction in the form of acid rain, greenhouse and global warming. Carbon dioxide traps heat in the earth's atmosphere. About 70% of the increase in CO_2 concentrations have occurred in the last 50 years, and have been attributed to coal and other fossil fuel burning for energy generation [Morgan & Keith, 1995]. This percentage is increasing and the CO_2 will remain in the atmosphere for about a century.

The growth in population develops a growth in residential density and in industrialised countries a growth in the economy that augments energy consumption. This leads to more environmental damage. Only renewable energy technologies can reduce CO_2 emission, to the demand with fewer environmental consequences. Figure 1.2.2 shows the carbon dioxide levels in countries that are industrialised [Morgan & Keith, 1995:468-476]. These technologies also need to be advocated and researched in Africa.

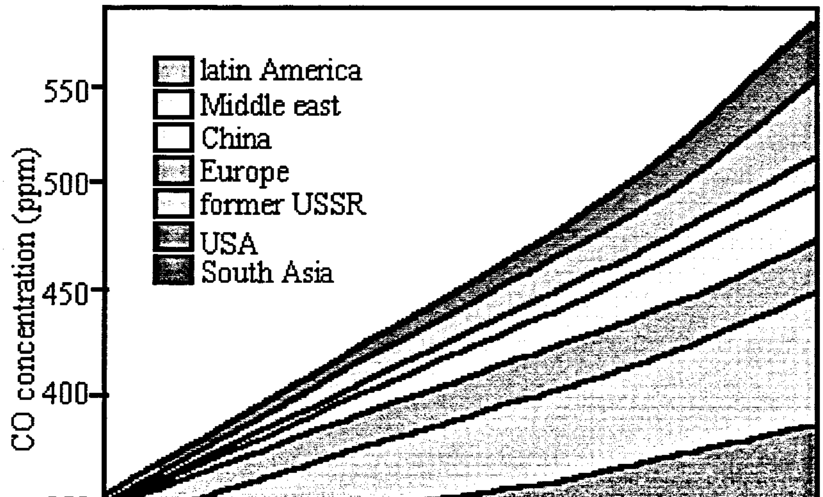


Figure 1.2.2: Carbon dioxide levels in industrialised countries

1.2.3 What is the availability of new sustainable technology?

Markets typically under-invest in what Branscomb calls basic technology research [Branscomb, 1997:41-48]. Electricity accounts for about 40% of total global energy consumption [Davis, 1991:1-10] and is considered to be a good indicator of economic progress. The growth of developing countries of Asia, Latin America and Africa, as well as the expected population increase present a huge environmental challenge to humanity. This challenge is very acute in the power generation, transmission and distribution sector. In China, for example, it is expected that about 70 percent of the rising demand is met by burning coal [Morgan & Keith, 1995:468-476]. Countries are to invest in new and existing technologies to prevent the expansion of the hole in the ozone layer. Planning for the delivery of affordable modern energy services is vital to socio-economic development. New energy generation designs, producing eco-friendly electric power with the least possible contribution of fossil fuels, will improve the dreary situation. [Fuggle,1989]

1.2.4 Renewable energy technologies

There is no doubt that the use of new and renewable energy sources should be supported in building a worldwide sustainable energy sector. However, some technical assistance agencies and developing countries government's strict policies of dealing exclusively with renewable energy technologies have resulted in renewables being chosen for projects in which they were clearly inappropriate and considerably more expensive than conventional options. The incremental costs born by the continent due to these experiments have been very high in the 70s and 80s.

This is not to say that new renewable energy technologies should not be applied. On the contrary, more knowledge of the conditions under which these technologies are the most suitable is needed. But renewables should be subject to the same technical, financial and social analysis as the commercial options are being subjected to. Only in this way can a commercial market and trust in the new technologies be attained [Levine,1993].

When introducing modern energy services one has to look further than the energy source and the technology used. The whole fuel chain from source and generation to distribution should be seen as a package with technical and regulatory mechanisms and institutional frameworks as integral components. The success stories of rural electrification co-operatives is an example of innovative approaches when addressing small and fragmented markets, while also recognising the need to mobilise citizens to fully participate in the implementation of programs.

1.2.5 Environmental impact assessments

A broader use of environmental impact assessments is certainly welcome in African countries. However, the boundaries of responsibilities in an under-organized context require a continuous research effort that is not usually built into environmental impact assessments being made today. Supporting joint research between academics, policy makers, industries and the public is another area to be considered in the energy sector support. In the early 1970's there were several attempts to formulate a series of steps that should be followed in technology assessment but no formal procedure has received universal acceptance. A study of 24 technology assessments (mainly done by teams at universities or consulting firms under the sponsorship of the national science foundation in the USA) [Hopper, 1988] finds considerable diversity among the methodologies actually employed but the study indicates that the assessment process in all cases could be described functionally under two headings.

Below is a summary of these findings:

1.2.5.1 Technology description

Each technology assessment team first assembled data on the current state of technology and the patterns that its future development might take. Typically this was done by interviews with a series of technological experts and an extrapolation of current trends; with some allowance for forces that might alter these trends. Since both the technological development and its impacts would be affected by the future social context; some social forecasting had to be included; implicitly if not explicitly. Usually a basic continuity was assumed and past social trends were projected; for example; it was assumed that lifestyles and social institutions would not change significantly. In some cases; more varied alternative futures were visualised by the presentation of scenarios imagined and plausible sequences of events reflecting a wider range of assumptions.

1.2.5.2 Environmental impact

It is astonishing that the USA with only 5% of the world's population, consumes 25% of the total energy consumed worldwide [Capehart *et al,* 2003]. This leads to environmental problems due to the combustion of fossil fuels. To decrease this problem various energy consumption reduction methods are being researched and put to practice, viz.

- solar generated electricity through photo-voltaics or thermal methods,
- wind energy,
- wave energy conversion
- electricity production with fuel cells and
- alcohol production from agricultural products.

These methods can be used as distributed power systems to generate electricity during peak electricity demand periods (early mornings and evenings). By generating electricity with these renewable energy sources, which coincides with the maximum demand of the grid, the electricity demand from the utility can be reduced.

Environmental, economic, political and social impacts on critically affected population segments were listed. Secondary and higher order impacts then were traced from each of these primary impacts. Typically this was done by a series of checklists and by reliance on experts in several disciplinary fields (though social scientists were not strongly represented; except for economists). A preference for the use of mathematical models to predict quantifiable impacts was evident in these technology assessments. There were difficult judgements in bounding each study, establishing its temporal horizon, geographical scope, and the impacts selected for detailed analysis. Uncertainties in estimating impacts created other problems; sometimes at least upper and lower limits could be given, or a range of estimates or probabilities could be agreed on.

1.2.5.3 South African state of affairs

In general we would have to look at regional and sub-regional approaches to tackle the problem. Africa has more than 50 countries that need integrated policies particularly in the energy sector. The development assistance support should take both the regional and sub-regional reality into account. Unfortunately, even climate change mitigation policies in which trans-boundary aspects are evident are mainly treated within the narrow national context [International Energy Agency, 1993]. Sub-regional support should be designed to promote more cooperation among countries, regional technology transfer, and the formation of regional markets for alternative energy utilization. Most northern continents have already moved far in this direction or are in the process of doing so.

We need to promote the development of African dynamic regions to promote active research and development in reduced energy consumption and alternative energy applications.

Of the 45 million South Africans, about 34 percent did not have access to electricity in 2001. This is 1.3 times greater than the world average. In rural areas 51 percent of the households did not have access to electricity. This is more than twice the world average [NER, 2001]. About 77% of this country's primary energy source is provided by coal [ESKOM, 2004]. This leads to emission of greenhouse gases, causing global climate change [DME, 2003]. To promote the application of renewable energy sources and sustainable development and to utilize the unharnessed sources of energy, the South African Department of Minerals and Energy released the Draft White Paper on Renewable Energy on 23 August 2002. Despite coal being environmentally the least desirable fossil fuel, it will continue to be South Africa's most important resource in power generation. The National Utility, ESKOM, has developed indicators to quantify the amount of emissions produced by their generators. This is illustrated in Table 1.2.5.3.

Table 1.2.5.3: Environmental implications of using 1MW of power

	Unit per MW Power in 2001	**Amount**
Water usage	Litres	1 260
Coal burnt	Kilograms	500
Ash produced	Kilograms	139.78
Ash emitted	Kilograms	0.31
SO_2 emissions	Kilograms	7.91
No_x emissions	Kilograms	3.61
CO_2 emission	Kilograms	890

ESKOM tries to reduce these negative emissions at their power stations in compliance with the Constitution of the Republic of South Africa (act 108 of 1996) [Lisa, 2003:181-185]. This act states that the people of South Africa have the right to a clean environment.

To promote rural electrification where the grid is inaccessible, the government encourages the installation of standalone mini grid hybrid systems. This is a non-grid service where wind generators, micro-hydro power and solar power are fed to the same 230V AC bus. This is being done under the auspices of the DME at the Hluleka Game reserve in the Wild Coast [Lisa, 2003:181-184].

In a study done in Mmabatho in 1991 [Holm, 1991:4-7] it was found that people in the lower income communities aspire to live in homes similar to the higher income level groups. It is the high-income homeowner who has the capital to implement these renewable technologies, and not the poor. Therefore, it is important to implement renewable technologies in the high-income market to create awareness and aspiration by the rest, to own the same. With time it should be well promoted, affordable to all and aspired by the lower income groups [Holm, 1991:4-7].

1.2.6 Western Cape electricity supply shortfall

Closer to home, the Western Cape was severely hit by blackouts or power outages and experienced load shedding since November 2005. It unexpectedly lasted for three months. ESKOM was in a crisis and had to put a recovery plan in place for the Koeberg power station near Cape Town, to restore the electricity supply to the Western Cape. Some of the following recovery plan steps were put in place by ESKOM [Anon, 2006:8]:

- During peak periods, the estimated 300MW shortfall will be addressed through a Demand Side Management (DSM or energy efficiency) programme.
- 500 DSM teams will implement Efficient Light Programmes and provide information on the conservation of electricity in residential areas (geyser temperature adjustments, pool pump settings etc.)
- ESCOM is busy engaging with potential independent power producers for assistance and have obtained an additional 80MW at R115 million.
- A number of mobile generation plants have been procured, to supply an additional 100MW for the winter peak period.
- A subsidy programme for energy efficient lighting has been put in place.

The Cape Argus reported on 9 March 2006, on the outages in the Western Cape as follows: [Anon, 2006:8]

"More than two weeks after rolling blackouts first become a part of everyday life, suppliers of gas, gas equipment and portable generators are still doing a roaring trade. Gas appliances and generators disappeared from shop floors like hot cakes, as people desperate to find alternative sources of cooking and lighting rushed to suppliers. The only aspect that dampened business was, in same cases, a shortage of stock."

1.3. Energy Management

According to Capehart energy management is the judicious and effective use of energy to maximise profits (minimise costs) and enhance competitive positions [Capehart *et al*, 2003:1]. Besides energy conservation, other means of energy consumption reduction can be done viz. load shedding, power factor correction, efficient lighting systems etc. The driving force in Energy Management is the development of new energy efficient technologies to reduce the combustion of fossil fuels and to provide standard energy services, viz. heating, lighting, air-conditioning and process equipment for industry.

The amount of energy dissipated in converting mechanical or chemical energy to electrical energy in the generation process must be kept in mind when designing an efficient lighting system. One British thermal unit (Btu) is the amount of energy used to increase the temperature of one pound of water by one degree Fahrenheit. One kWh of electrical energy is equivalent to 3412 Btu. One should be aware of the fact that the steam turbines and boilers used to generate electrical energy, dissipate more than 10 000 Btu of primary fuel to produce one kWh of electrical energy [Capehart *et al*, 2003]. This excludes losses due to inefficiencies when used by the end user.

In 1950 the total annual energy consumption in the USA was 16 million barrels of oil equivalent (MBOE) per day. Their imported crude oil amounted to $3 billion crude oil in 1970. In 2000 the figure increased to $119 million. In 2000 they consumed almost 50 MBOE. Worldwide more than 200 MBOE per day is consumed. Worldwide lighting dissipates about 30% to 70% of the total overall energy consumption

[Capehart *et al*, 2003]. Proper lighting designs would reduce annual energy consumption.

In the previous century renewable energy technologies were developed with the depletion of natural resources. More South Africans rely on electricity for heating of living space, hot water supply systems, lighting systems, stoves for cooking etc. However, the electricity grid does not exist in remote rural areas. Here the natural resources are being depleted. There is a need for reliable and affordable electrical energy in these remote rural areas, to conserve precious natural resources namely wood, coal, paraffin and gas. One of the technologies available to implement in rural areas are solar system installations. One of ESKOM's Demand Side Management (DSM) recovery plan steps was the establishment of a subsidy programme for energy efficient lighting. DSM is when a utility or local authority that supplies electricity put measures or activities in place that influence the way it is used by the customers. Two main opportunities are targeted namely [Grobler *et al*, 2005:47-51]:

- Energy Efficiency – The installation of more energy efficient equipment will lead to electricity or energy savings whenever the relevant equipment is used.
- Load Management – The implementation of load control options. With load control the time of energy use is shifted without a change in the overall energy use.

The first DSM plan was introduced by ESKOM in 1994.

1.3.1 Energy Audits

Proper lighting designs would reduce annual energy consumption.

Energy Audits revealed that the most common mistakes leading to the waste of energy in a lighting design are as follows: [Anderson, 2003:103-109]

- Inefficient luminaires; when the lamp demands more power to produce the same illumination than necessary
- Over lighting; when the output illumination is more than necessary
- Excessive heat generation; when heat produced by artificial lighting needs to be offset by air conditioning
- Transmission loss; if luminaires are installed far from work surfaces, light intensity will be lost.

The following projects, being commissioned in South Africa, emphasize the significance of energy audits [Kreuger, 2005]:

- *Energy efficient streetlight network for Cape Town*

In October 2005 a private company TFMC conducted an energy audit and has been awarded a contract to design, construct, operate and maintain an energy efficient streetlight network for the City of Cape Town. The invested capital would eventually exceed R60 million. The contract entails the removal of the existing inefficient luminaries that uses mercury vapour and low-pressure sodium lamps. It will be replaced with new standardised luminaries using energy efficient high-pressure sodium lamps. The agreement is open to an option to extend the contract to other areas. Beside the increased road safety factor, the financial benefits to the City of Cape Town, over the ten-year contract period, will be millions of Rands. TFMC is already negotiating with other municipalities to promote the benefits of retrofitting existing public lighting networks.

- *Retrofit of FNB Bank City*

Lemay Electrical concluded the retrofit of more than 18 000 luminaires at FNB

Bank City, in Johannesburg, resulting in a saving of 2.2 MW. They replaced:

- 75W fluorescent tubes with 58W ECG, which resulted in the same light output.
- 250w high bays fittings with 120W ECG lamps and reflector, which resulted in the same light output.
- 25, 3x36W fittings (average 500 lux) with 30, 2x28W fittings (average 517 lux), resulting in a 52W saving per fitting.

- Energy efficient ECG lamps are designed in Europe and uses triphospher lamps with reflectors that reduces energy consumption significantly.

1.3.2 Solid State Lighting

The most recent technology in lighting is Solid State Lighting (SSL) or LED technology and is vigorously being researched. In SSL electrons and holes are injected into a solid-state semiconductor. These electron-hole re-combinations emit a narrow spectrum of light in the visible spectrum. Its wavelength can be adjusted to increase the efficiency to convert the narrow spectrum to semi-broadband emissions

Table 1.3.2: SSL-LED Lamp Targets

TECHNOLOGY	SSL-LED 2002	SSL-LED 2007	SSL-LED 2012	INCANDES-CENT	FLUORES-CENT
Efficiency (lm/W)	>25	>75	>150	16	85
Lifetime (khr)	20	>20	>100	1	10
Input Power (W/lamp)	1	27	6,7	75	40
Colour Rendering Index (CRI)	75	80	>80	95	75
Market Penetration	Low flux	Incandescent	Fluorescent	x	x

that cover the entire visible light spectrum. This cannot be achieved in incandescence and florescence technology. A semiconductor High Bright light emitting diode (HB-LED) is pyramid shaped and emits light in a wide angle. Built-in reflectors enhance maximum light emission.

1.4 Research Questions

Conventional lighting technology (candles and paraffin lamps) is the main rural domestic lighting source in SA. Unfortunately this state of affairs will be prolonged, as it will take decades before an electrification network is established in all rural areas. The first research question asked was how to develop software to verify lighting design results of a general, elementary lighting design. The next question was what would the payback period of a lighting retrofit be? This was motivated by the current lighting system installation in the City of Cape Town and FNB Bank City. It determined what the payback period of a lighting system retrofit at a school in Worcester would be, after an energy audit was done? The third research question asked was whether a low cost energy efficient, renewable solid-state lighting system could be designed, installed and implemented for a rural community? Finally research was done and recommendations given on how much an existing inefficient off-grid hybrid solar–diesel system can be optimised.

1.5 Objectives of the Research

The first research aim is to develop an illumination software package to provide parameters for lighting design. The software should also cater HB-LED lamps.

Secondly, an energy audit and retrofit of the Nuwe Hoop School in Worcester was conducted. The Cape Peninsula University of Technology (CPUT), Electrical Engineering Department in Bellville, established a Service Learning and Development (SLD) unit. The author heads the SLD unit. This unit is to compile an Energy Audit at the Nuwe Hoop School in Worcester and made recommendations to put energy consumption reduction methods in place, by means of energy efficient, cost effective electrical installations.

The third aim was to develop an efficient HB-LED lighting system, driven by a renewable energy source (solar panels, battery controllers and batteries). An infrastructure or reticulation system to supply a few houses in a rural community in the Stellenbosch / Kraaifontein area with proper energy efficient lighting, was developed. A cost-effective stand-alone streetlight system is also to be developed.

Finally, recommendations were given to optimize an inefficient off-grid hybrid solar–diesel system on a farm in Calvinia. The feasibility of implementing HB-LED lamps as part of the optimization were investigated.

1.6 Research Design and Methodology

1.6.1 Software development for lighting design

A need arose for a software package to perform illuminance calculations to display relevant Isolux diagrams for educational purposes. A manual step-by-step design procedure was compiled. The JAVA object-oriented programming language is to be used to write the code of the design software, according to the manual steps. The design parameters of an example are fed to the program, to confirm proper calculations. A design with HB-LED lamps can also be done.

Parameters calculated in lighting design are confirmed by an Isolux diagram plot. These illuminances on horizontal planes are used in conjunction with a tutorial to confirm whether calculations have been done properly. The user is then prompted by the software to enter the relevant data in order to compute the required parameters. The results are verified with the software-generated diagrams.

First the appropriate recommended standard SABS illuminance (in lux) is determined. After the type of luminaire is chosen, the total amount of lumens is calculated. This formula utilises data such as the illuminance, the area of the working plane, the utilisation factor and the lamp lumen maintenance factor, the lamp survival factor, the luminaire maintenance factor and the room surface maintenance factor. In the layout the lamp mounting height is decided on, and the lamp wattage, minimum number of lighting points and spacing of the luminaries are calculated. These calculated tutorial values are then entered in the software package (developed by the author) to check the horizontal illuminance patterns.

This chapter seeks to highlight the importance of energy efficient, cost effective lighting designs.

1.6.2 Efficient HB-LED lighting system,

The prototype of a HB-LED lighting system was designed and is fed from photo-voltaic (PV) panels. This is to be installed on a farm for a community in the Kraaifontein / Stellenbosch area, approximately 20 km from the university's Bellville campus. Solid state lighting luminaires and driving circuits was designed, simulated, developed and an prototype was installed.

Deep cycle lead acid batteries were charged by solar panels. Battery conditioning or regulating circuitry was designed and constructed to obtain optimal battery operating conditions. An inverter for a 220V AC CFL stand-alone streetlamp was designed and built.

1.6.3 Energy audit and retrofit of the Nuwe Hoop School in Worcester

The Cape Peninsula University of Technology, Electrical Engineering Department in Bellville, has established a Service Learning and Development (SLD) unit. The SLD unit delivers a service to the community, to improve their standard of living and to provide training to the students registered at the institution. The SLD unit delivers a service to the community, to improve their standard of living and to provide training to students registered at the institution. The unit members are students and lecturers, and are in collaboration with government organisations, and private companies in the industry. The SLD unit performs certain functions to the abovementioned role players, on a contract basis. As an incentive, the students are compensated at a decent remuneration. A need arose for lecturers in the SLD to provide training to students and community members to conduct energy audits, retrofits and installations etc.

The first project contracted to the SLD unit was in Worcester, in collaboration with ESCOM and a company called Innovative Energy Projects. The SLD unit compiled an Energy Audit at the "Nuwe Hoop" centre for the deaf in Worcester. The centre is about 100 km from the university. This centre has 3 schools and 3 hostels to cater for pre-primary, junior and senior learners with impaired hearing. There is also an extensive laundry and kitchen on the premises, which had a great contribution to the centre's energy consumption. The aim of the project was to reduce the centre's electricity consumption to promote energy saving amongst the community. This project can be used as a case study, to highlight the importance of energy efficient, cost effective electrical installations. The viability of the implementation of HB-LEDs was investigated.

1.6.4 Optimisation of hybrid solar–diesel system

A new high voltage regulator was designed to be implemented on a farm in Calvinia. This regulator serves the purpose of a battery controller. Recommendations were made to optimise the system. Appliances should be connected to a timer to perform load shedding.

1.7 Limitations of Research

The illumination software is limited to:

- rectangular rooms only
- a selection of twenty different lamp types
- even lamp spacing,

but any type of lamp should be able to be used in the design; as long as its photometric data is available.

The energy audit was done only at the Nuwe Hoop School. Reference is made to another audit that the team did in Langa. An analysis was made and savings forecasted and recommendations were made.

The following is relevant to the lighting design of the community project:

- An inverter (12V DC input to 220 – 240V AC output) was constructed.
- Off the shelf PV panels, batteries and were used in the design.

Topics not to be included in the scope of the project are:

- Modelling of the HB-LED
- Modelling of solar panels
- Rural emergency equipment (traffic and railway signalling SSL-solar applications etc.) design and implementation.
- Retrofitting of lamps and electrical circuits at the Nuwe Hoop School is to be outsourced to a private company
- Diesel generator design

Future research would be the synchronising of the designed renewable energy systems to the existing ESKOM grid or any distributed energy generation or hybrid system. Another area of research would be driving the HB-LEDs with both DC and AC sources and setting LV and HV lighting and reticulation standards. This should be Installed in rural areas.

1.8 Significance of Research

This research was important since ESKOM's current generation capacity issue requires a limitation to the demand of the system. The Nuwe Hoop energy audit and retrofit and the Kraaifontein and Calvinia renewable energy source implementation can be used as pilot projects to encourage other implementations to limit ESKOM customers' daily demand for electricity. One of ESKOM's DSM recovery plan steps is the establishment of a subsidy programme for energy efficient lighting. HB-LED can augment energy saving in future lighting designs.

The following stakeholders benefited from the research:

- The Kraaifontein / Stellenbosch rural community will have a lighting system installed
- CPUT students obtained training in energy auditing
- Part of the Worcester community received training and employment during the retrofit.
- The Nuwe Hoop School has lower energy consumption and a lower electricity account.
- ESKOM will has DSM implementation

1.9 Expected Outcomes, Results and Contributions of the Research

The expected outcomes that were wished to be achieved are:

- Software to verify lighting design results
- A new solid state lamp with driver circuitry as prototype
- A photovoltaic reticulation system
- A stand alone streetlamp
- A remote monitoring system of lighting system parameters
- An energy audit and recommendations of the school in Worcester
- Construction of new battery regulation circuitry
- Recommendations to optimise the inefficient off-grid hybrid solar–diesel system
- The viability of implementing HB-LEDs in all four projects done in this thesis.

CHAPTER TWO

ILLUMINATION SOFTWARE DEVELOPMENT

2.1 Introduction

A need arose for a software package to perform illuminance calculations to display relevant Isolux diagrams for educational purposes. Parameters calculated in lighting design needs to be confirmed by an Isolux diagram plot. An Isolux diagram illuminances on horizontal planes are to be used in conjunction with a tutorial to confirm whether calculations have been done properly. The user will be prompted by the software to enter relevant data in order to compute the required parameters.

There are two methods of designing a general lighting layout. One method is to select the type of luminaire first, then use its specific photometric data in the design. The other method determines design needs by using a computer program. Luminares can then be selected to fit these requirements. In this chapter the approach will be to use the abovementioned first method, then verify the results with software generated diagrams.

First the appropriate recommended standard SABS illuminance in lux is determined. After the type of luminaire is chosen, the total amount of lumens is calculated. This formula utilises data such as the illuminance, the area of the working plane, the utilisation factor and the lamp lumen maintenance factor, the lamp survival factor, the luminaire maintenance factor and the room surface maintenance factor. In the layout the lamp mounting height is decided on, and the lamp wattage, minimum number of lighting points and spacing of the luminaries are calculated. These calculated tutorial values are then entered in the software package to be developed, to check the horizontal illuminance pattern. This chapter also seeks to highlight the importance of energy efficient, cost effective lighting designs.

A 100-watt common incandescent lamp produces an efficacy of 17.5 lumens per watt (1750 lumens) compared with the 100-watt halogen lamp, which produces 18.8 lumens per watt. These differences are much smaller than the comparison with the compact fluorescent, but the typical cost of a halogen light is 5 times higher compared to a compact fluorescent. In Figure 2.1 the LEDs efficacy vary from 10 to 50 lumens / watt depending on the colour. [Drennen *et al.* 2000:1-20]

Solid-State technology will change the way lighting systems and buildings are designed and used. It will be possible to mount solid state devices in any pattern or shape of floors, walls, ceilings or furniture, providing either point or diffused light that can be turned to the shade or intensity desired by the occupants. In this chapter a general, elementary lighting design technique is presented in detail with software developed to verify the design results.

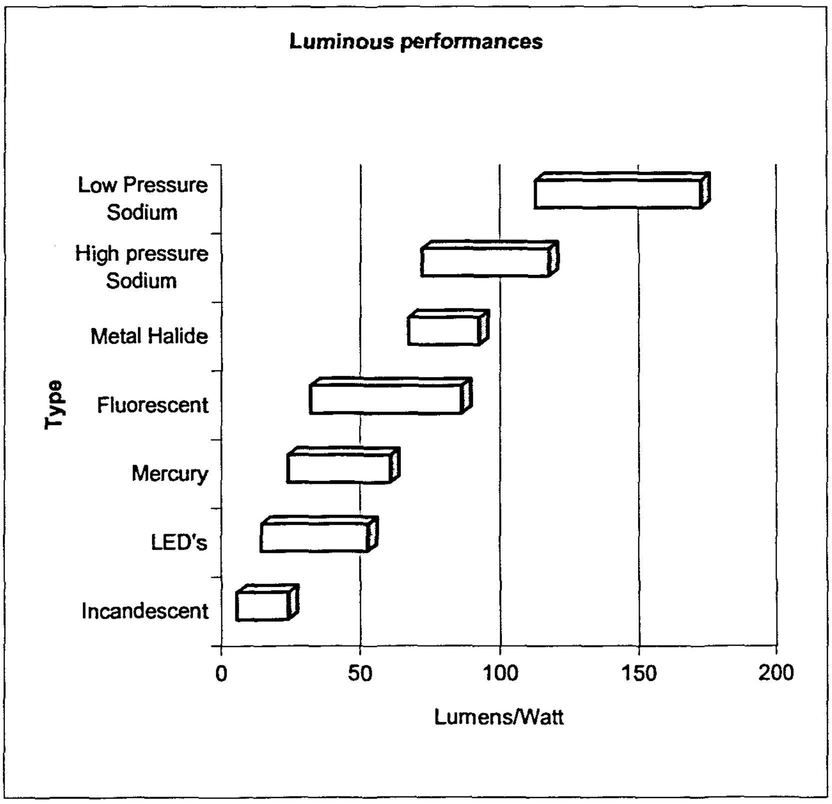


Figure 2.1: Efficacy of various conventional and semiconductor light sources.

2.2 Design of a General Lighting System

A good design is the application of the most appropriate equipment in an economical but effective manner. The illuminance of a new installation will deteriorate from day one, due to the maintenance factor (MF). This factor varies with the type of lamp, luminaire, location and frequency of cleaning. In the following example a lighting system is to be installed in a 30 x 20m medical store room, with an 8m ceiling height and 5m mounting height. The subsequent steps are followed to establish an acceptable illuminance on the working plane:

1) The appropriate recommended standard illuminance is determined as 150 lux from Table 2.2.2 [Prichard, 1999:89], sourced from the Chartered Institution of Building Services Engineers, CIBSE 1994 Interior Lighting Code.
2) The type of luminaire is, unwisely chosen as tungsten incandescent with photometric data listed in Table 2.2.1 [Prichard, 1999:89].
3) A utilization factor (UF) of 0,6 and a maintenance factor (MF) of 0,75 are used.

4) The total luminous flux of the room is calculated as:

$$\Phi = \frac{E*A}{UF*MF} = \frac{150*30*20}{0{,}6*0{,}75} = 200000 \text{ lm}$$

5) The space to height ratio is chosen as unity, $\frac{S}{H} = 1$, resulting in a 5m lamp spacing.
6) The number of lamps are calculated in Table 2.2.1 as:

Table 2.2.1: Calculation of Number of Lamps

Lamp rating (W)	Φ per lamp (lm)	No of lamps (Φtotal / Φper lamp)
60	710	281
150	2180	92
500	8300	24

7) The twenty four 500W lamps can only be arranged in 4 rows of 6 lamps each with a spacing of 5m as shown in Figure 2.2.1.

8) The displayed pattern of illuminance lines on a plane as a series of illuminance contours forms an Isolux diagram (see Figure 2.2.2).

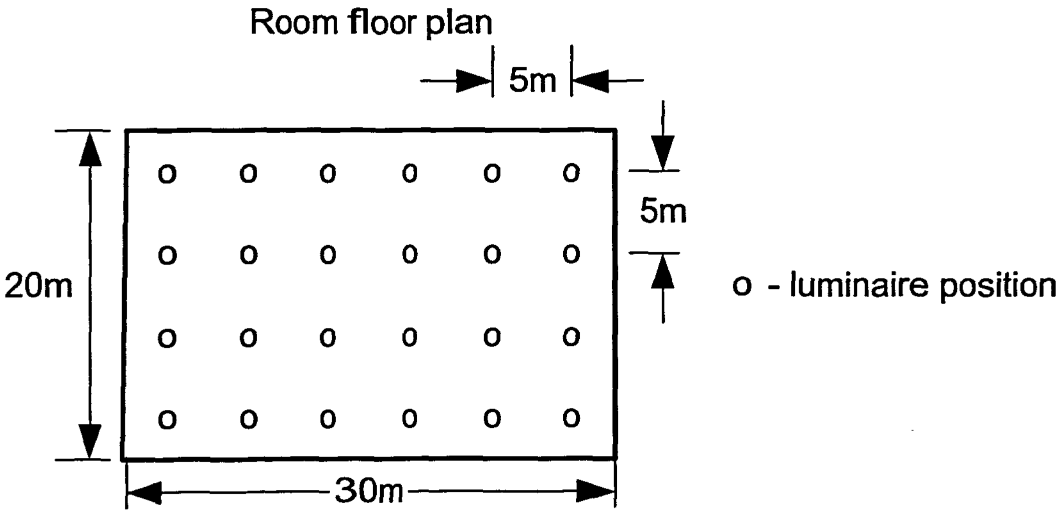


Figure 2.2.1: Luminaire layout diagram

An Isolux diagram is useful for lighting applications where no reflected light is considered.

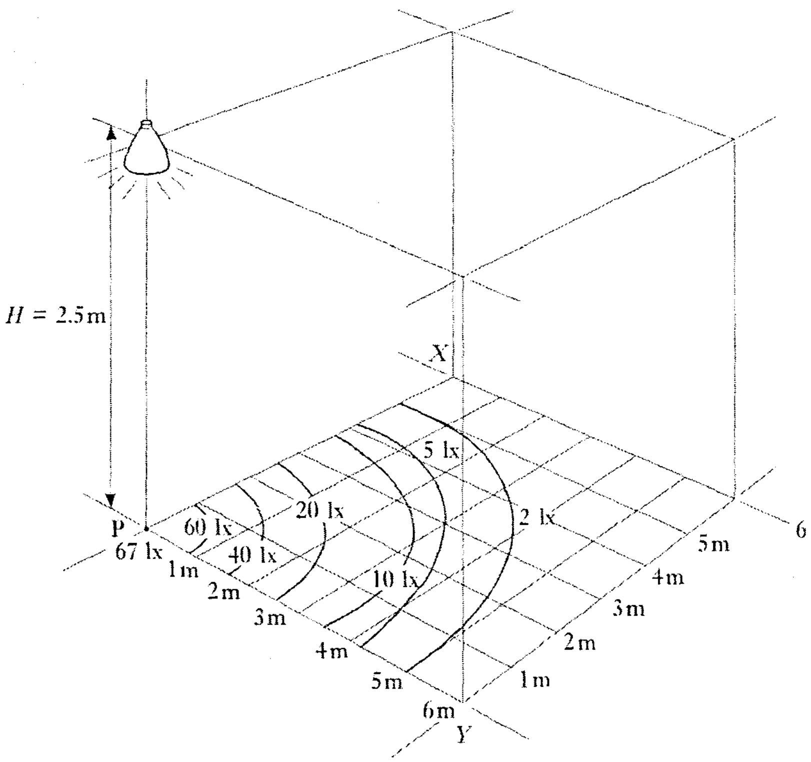


Figure 2.2.2: An Isolux diagram

Table 2.2.2: Standard Maintained Illuminance Table

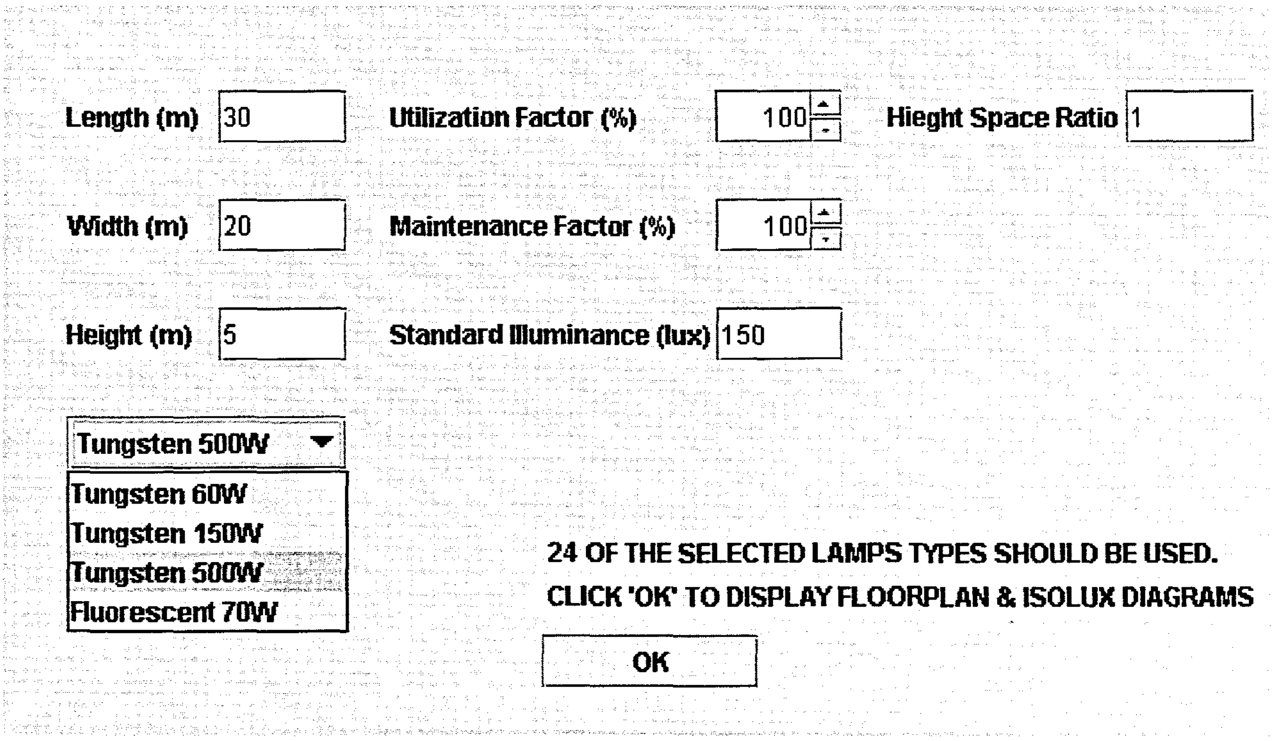
Standard maintained illuminance (lx)	Characteristics of the activity/interior	Representative activities/ interiors
50	Interiors used rarely with visual tasks confined to movement and casual seeing without perception of detail	Cable tunnels, indoor storage tanks, walkways
100	Interiors used occasionally with visual tasks confined to movement and casual seeing calling for only limited perception of detail	Corridors, changing rooms, bulk stores, auditoria
150	Interiors used occasionally with visual tasks requiring some perception of detail or involving some risk to people, plant or product	Loading bays, medical stores, switchrooms, plant rooms
200	Continuously occupied interiors, visual tasks not requiring perception or detail	Foyers and entrances, monitoring automatic processes, casting concrete, turbine halls, dining rooms
300	Continuously occupied interiors, visual tasks moderately easy, i.e. large details (> 10 minutes arc) and/or of high contrast	Libraries, sports and assembly halls, teaching spaces, lecture theatres, packing
500	Visual tasks moderately difficult, i.e. details to be seen are of moderate size (5–10 minutes of arc) and may be of low contrast. Also colour judgement may be required	General offices, engine assembly, painting and spraying, kitchens, laboratories, retail shops
750	Visual tasks difficult, i.e. details to be seen are small (3–5 minutes of arc) and of low contrast. Also good colour judgements may be required	Drawing offices, ceramic decoration, meat inspection, chain stores
1000	Visual tasks very difficult, i.e. details to be seen are very small (2–3 minutes of arc) and can be of very low contrast. Also accurate colour judgements may be required	General inspection, electronic assembly, gauge and tool rooms, retouching paintwork, cabinet making, supermarkets
1500	Visual tasks extremely difficult, i.e. details to be seen extremely small (1–2 minutes of arc) and of low contrast. Visual aids and local lighting may be of advantage	Fine work and inspection, hand tailoring, precision assembly
2000	Visual tasks exceptionally difficult, i.e. details to be seen exceptionally small (< 1 minute of arc) with very low contrasts. Visual aids and local lighting will be of advantage	Assembly of minute mechanisms, finished fabric inspection

2.3 Software Development

The author developed the software with the object-oriented language, JAVA. The code listing can be seen in Appendix A.

2.3.1 Inputs

The user is prompted to enter the relevant data of the lighting scheme as shown in the PC screen display in Figure 2.3.1.1. In this specific example both the Utilization Factor and Maintenance Factor is 100%.

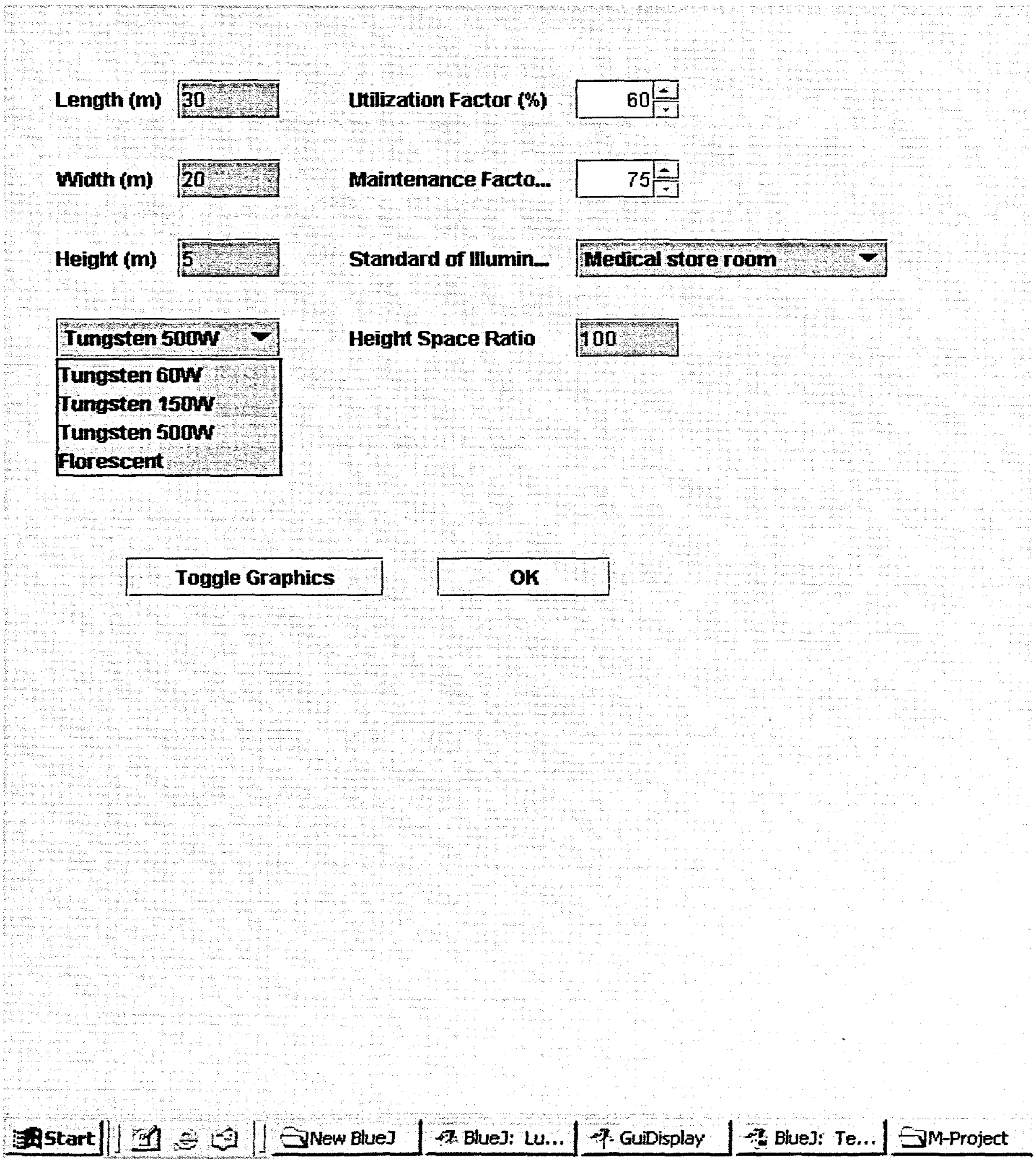


Length (m) 30
Utilization Factor (%) 100
Hieght Space Ratio 1
Width (m) 20
Maintenance Factor (%) 100
Height (m) 5
Standard Illuminance (lux) 150
Tungsten 500W

24 OF THE SELECTED LAMPS TYPES SHOULD BE USED.
CLICK 'OK' TO DISPLAY FLOORPLAN & ISOLUX DIAGRAMS

Figure 2.3.1.1: Software Input Output Window

The PC screen display in Figure 2.3.1.2. displays another example with design parameters of a 60% Utilization Factor and a 75% Maintenance Factor.



Length (m) 30

Width (m) 20

Height (m) 5

Tungsten 500W

Utilization Factor (%) 60

Maintenance Facto... 75

Standard of Illumin... Medical store room

Height Space Ratio 100

Figure 2.3.1.2: PC screen displaying different Input parameters entered by user.

The parameters of the example are entered as follows:

1) STANDARD ILLUMINANCE OF ROOM (lux): 150

2) SELECT ONE OF THE LISTED LAMP TYPES IN THE LAMP PHOTOMETRIC DATA Table 2.3.1.1: These tables are available from lamp manufacturers.

Table 2.3.1.1: Lamp photometric data

LAMP TYPE	RATING (W)	LUMINOUS FLUX (lm)
Tungsten:	60	710
	150	2180
	500	8300
Fluorescent tubes (White)	70	5740
	58	4600
	36	2850
Compact fluorescent lamp (CFL)	15	900
	23	1500
Low pressure sodium (SOX)	35	4800
	180	3300
High pressure sodium (SON +)	150	16000
	250	28500
	400	54000
High Pressure Mercury (MBF)	50	2000
	125	6500
	400	22000
HB-LED	3	20

3) ROOM SIZE:
a) LENGTH (m) = 30
b) WIDTH (m) = 20
c) HEIGHT FROM WORK SURFACE TO LAMP (m) = 5

4) $\frac{S}{H}=1$

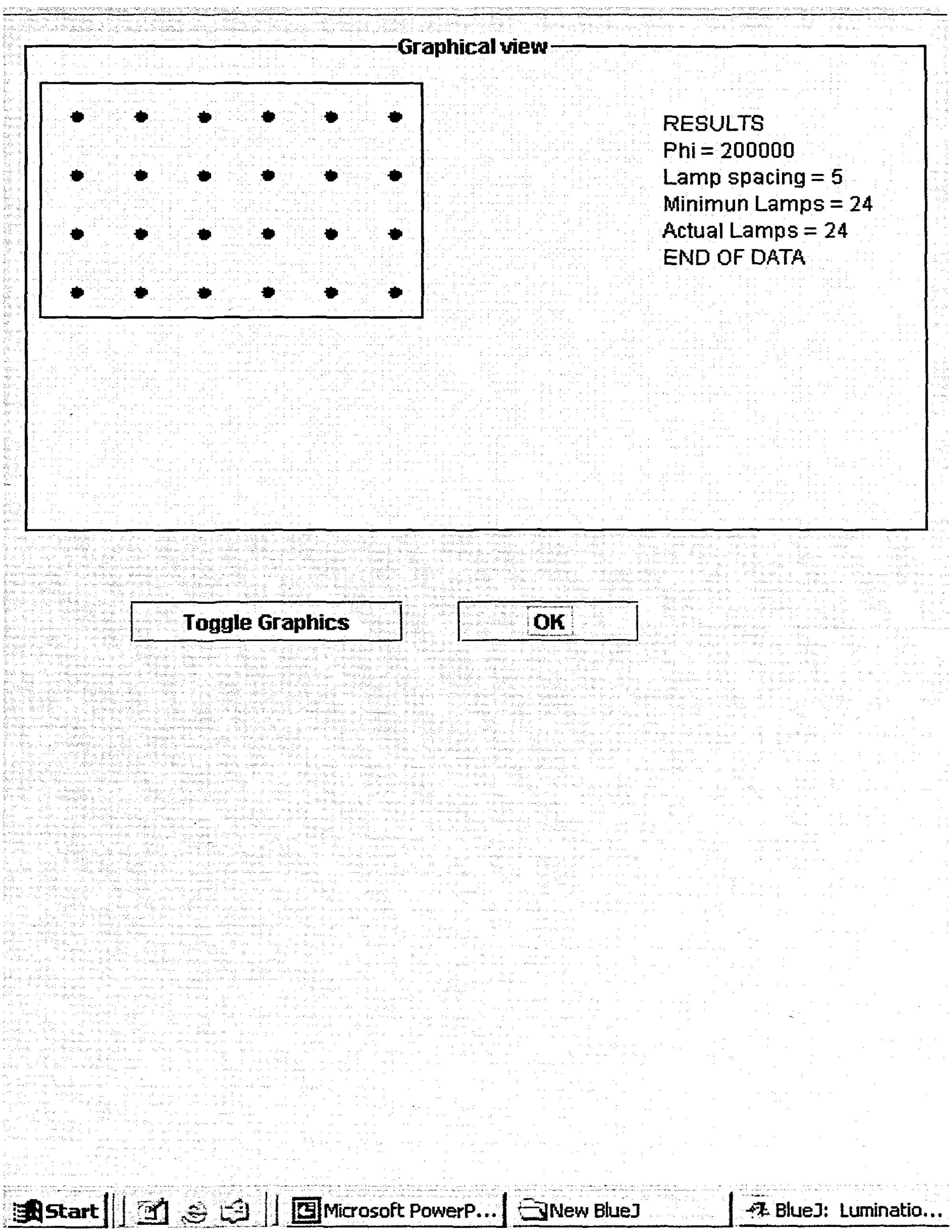
5) UF = 0.6

6) MF = 0.75

2.3.2 Outputs

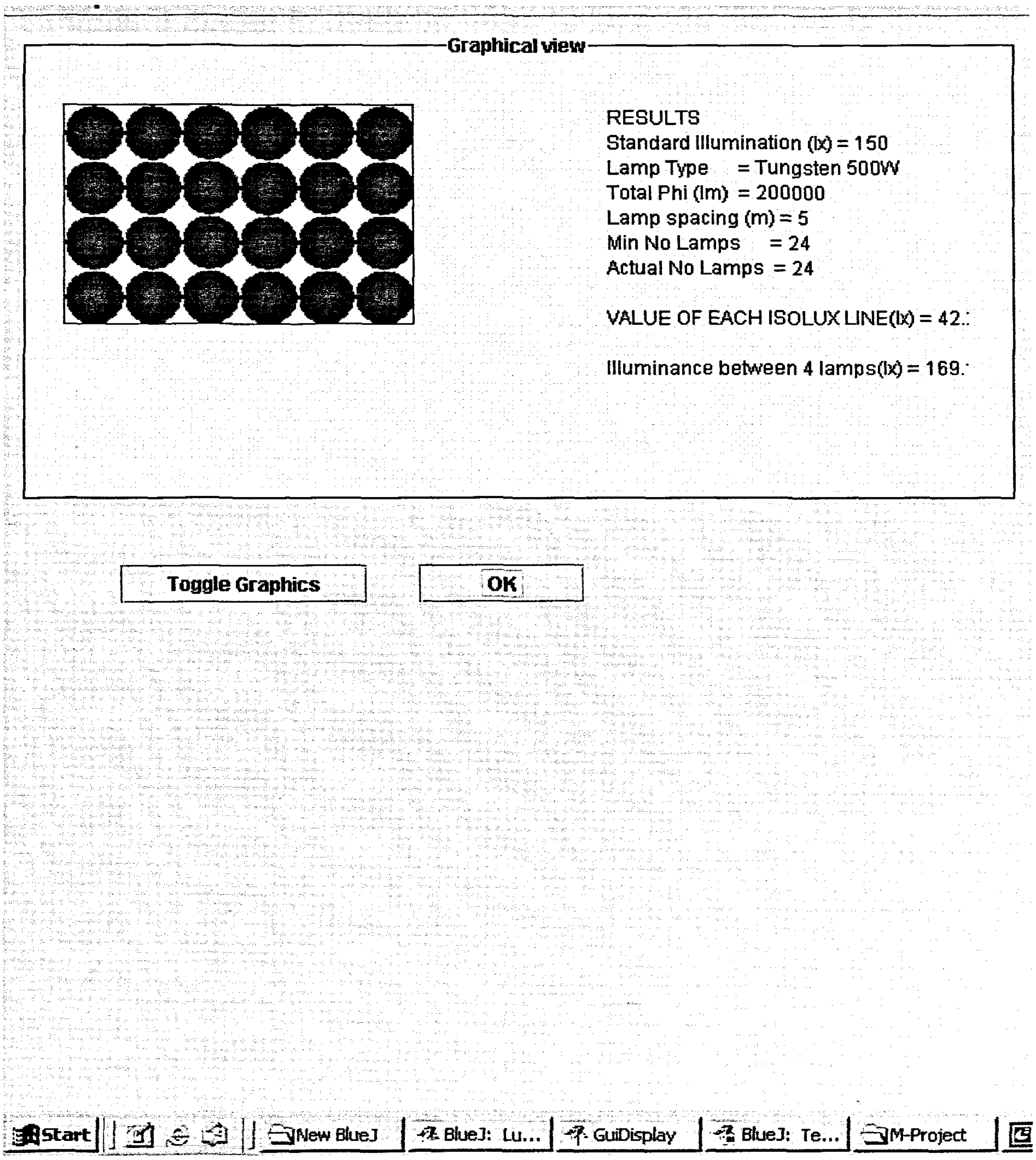
The following outputs are displayed on the screen as shown in Figures 2.3.2.1 and 2.3.2.2:

1) NUMBER OF LAMPS & LAMP RATINGS.
2) THE FLOORPLAN WITH LUMINAIRE ARRANGEMENTS
3) THE FLOORPLAN WITH ISOLUX DIAGRAMS.



RESULTS
Phi = 200000
Lamp spacing = 5
Minimun Lamps = 24
Actual Lamps = 24
END OF DATA

Figure 2.3.2.1: Floor plan layout screen



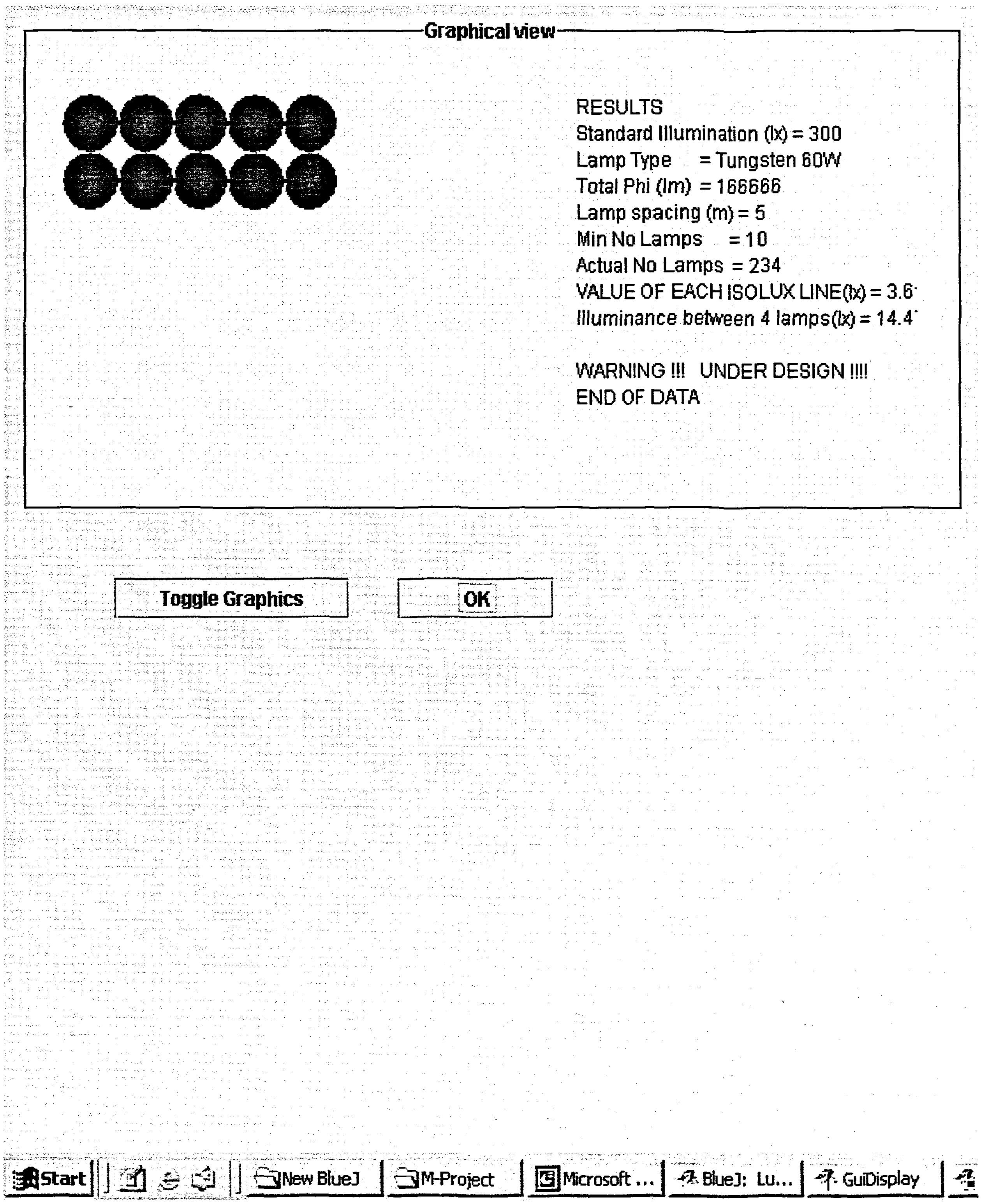
RESULTS
Standard Illumination (lx) = 150
Lamp Type = Tungsten 500W
Total Phi (lm) = 200000
Lamp spacing (m) = 5
Min No Lamps = 24
Actual No Lamps = 24

VALUE OF EACH ISOLUX LINE(lx) = 42.

Illuminance between 4 lamps(lx) = 169.

Figure 2.3.2.2: Floor plan with 500W lamps, displaying Isolux diagrams

Figure 2.3.2.3 displays the floor plan of a different example where 60W lamps are used. This resulted in a design where the user is warned that it is a faulty design. The illumination of the design is 14.4 lux instead of the desired 300 lux.



```
RESULTS
Standard Illumination (lx) = 300
Lamp Type     = Tungsten 60W
Total Phi (lm) = 166666
Lamp spacing (m) = 5
Min No Lamps     = 10
Actual No Lamps = 234
VALUE OF EACH ISOLUX LINE(lx) = 3.6
Illuminance between 4 lamps(lx) = 14.4

WARNING !!!  UNDER DESIGN !!!!
END OF DATA
```

Figure 2.3.2.3: Floor plan with 60W lamps, displaying Isolux diagrams of another design

2.4 Conclusion

It is important that the minimum lighting level standards of the Illuminating Engineering Society (IES) be followed when designing or retrofitting a lighting system. This is to insure worker productivity and safety. [Capehart et al, 2003:155]. The developed software displayed the desired graphics properly. Students can now verify whether their calculations were done correctly. The current software is user friendly and warns the user when the chosen data will result in a faulty design. This can be seen on the display in Figure 2.3.2.3. The software can be upgraded and grown into an expanded educational package, where lighting systems can be designed immediately on site. The software also accommodates designs with HB-LEDs.

CHAPTER THREE

ENERGY AUDIT AT SCHOOLS IN WORCESTER

3.1 Introduction

Energy management and the application of energy consumption reduction methods are high on the priority list of South Africa's electrical supply utility, ESKOM. One of ESKOM's Demand Side Management (DSM) recovery plan steps was the establishment of a subsidy programme for energy auditing and energy efficient lighting. A need arose to implement new lighting designs and to improve existing lighting systems. These improved lighting systems are used as recommendations in Energy Audits to achieve lighting efficiency and energy consumption reduction. It also highlights and promotes cost effective designs and energy management. New and better lighting methods are developed and researched to increase returns, domestically and in industry. This also highlights the importance of energy consumption reduction. This paper also discusses an Energy Audit conducted at a school in Worcester by the Service Learning and Development (SLD) unit of the Cape Peninsula University of Technology, Electrical Engineering Department in Bellville. The SLD delivers a service to the community, to improve their standard of living and to provide training to Electrical Engineering students.

3.2 ESKOM Recovery Plans in South Africa

The emission of greenhouse gas is augmented by the fact that the South African government committed itself to make electrification available to informal settlements and rural areas. A further problem is that the electrical supply utility, ESKOM cannot cope with the growing demand and it results in load shedding and outages. Conducting energy audits, retrofitting government and corporate buildings, designing and installing cost effective lighting systems, can increase capacity.

One of the recovery plan steps put in place by ESKOM that was discussed in 1.2.6 is a subsidy programme for energy efficient lighting. It was also forecasted in December 2006 that blackouts will cripple major cities in Gauteng in January 2007. As a safety precaution ESKOM made 95 billion Rand available to upgrade its network in 2007. Maintenance on the network will increase the consumer's electricity bill significantly. [e-TV, 2006].

3.3 Incandescence vs Fluorescence

In 1999, 21% of the USA electricity consumption was used for lighting. Ninety one percent of this electrical lighting technology used was conventional incandescence and fluorescence [Steigerwald, *et al,* 2002]. Significant improvements in lighting efficiency will have a major impact on worldwide energy consumption reduction.

Incandescent light is broadband of which most lies outside the visible light spectrum. To be effective the metal-filament of the lamp must be heated (to the incandescence temperature). Tungsten is used because it has a very high melting point; most filaments operate at temperatures in the region of 2 700 °C. Because of this incandescence is very inefficient. At this high temperature the surface of the filament evaporates until it eventually fractures under its own weight. This reduces its lamp life. The incandescent bulb is very inefficient, since it dissipates about 90% of energy in the form of heat. This energy is in the invisible infrared part of the spectrum. The ambient temperature of a room with many installed incandescent lamps is much higher than under conditions where these lamps are switched off. This results in an increased use of air conditioning and an increase in energy consumption.

The second technology is fluorescence, where low pressure gas is excited rather than heated, resulting in narrowband atomic line emissions. This is re-emitted by fluorescent materials. The discharged light is narrowband in the visible light spectrum. Fluorescence is initiated by a discharge in mercury vapour, causing radiation in the ultraviolet region of the spectrum. Its efficiency is much higher than that of the incandescent lamp.

Table 3.3.1: Lamp Specifications

TECHNOLOGY	**INCANDESCENCE**	**FLUORESCENCE**
Efficacy (lm/W)	16	85
Lifetime (khr)	1	10
Input Power (W/lamp)	75	40
Colour Rendering Index (CRI)	95	75

Up to now fluorescence technology with its better efficacy, has provided remarkable energy savings. By replacing the incandescent lamps with fluorescent lamps or compact fluorescent lamps (CFLs), the ambient temperature of the room will be lowered, since the latter operate at a cooler temperature. This results in huge energy consumption reduction, firstly due to the higher efficacy of the CFLs, as can be seen in Table 3.3.1, and secondly due to the elimination of additional air conditioning [Kendall & Scholand M, 2001]. A CFL has a lifetime much higher than that of an incandescent lamp. Lamp life is defined as the time at which 50% of the test samples have failed or the time it took the lamp to maintain 50% of its initial brightness.

Kendall M and Scholand M illustrates that a 100-watt typical incandescent lamp has an efficacy of 17.5 lumens per watt and produces 1750 lumens, whereas a 100W fluorescent lamp produces between 3000 and 9000 lumens depending on the colour type.

It shows that the efficacy of fluorescent lamps is 2 to 6 times better than that of incandescence. Solid-State or LED technology is another lighting technology that is vigorously being researched. Solid-State lamps will become available as a white light source, competing with incandescence and fluorescence, in the near future.

3.4 Types of lighting systems

The fluorescent tube, CFL and solid-state lamps are lighting technologies promoted to replace conventional incandescence in new lighting designs. Energy efficient, cost effective lighting designs are being implemented worldwide. The first parameter to establish in a lighting design is the Standard maintained Illuminance (lx), according to the application or activity being performed, as listed in Table 2.2.2. The unit of illuminance is lux or lx.

The next step of the design is to determine the lamp Efficacy, Luminous flux, Luminous intensity, Iluminance, Utilisation Factor and Maintenance Factor (MF) in order to calculate the number of lamps and its ratings. The design can then be verified by plotting the floor-plan with luminaire arrangements and isolux diagrams [Fritz, 2004:23-24]. The displayed pattern of illuminance lines on a plane as a series of illuminance contours forms an Isolux diagram as shown in Figure 2.2.2 [Prichard, 1999:89].

Lighting technology is very dynamic, with new lamps being developed constantly. A lighting design can be one of the following three or a combination of them [Raissen, 2000:4-5]:

- General lighting replaces natural sunlight, when the sun sets. This is achieved by using an indirect light source, viz. wall mounted fittings, ceiling suspended luminaries and lamp stands. The primary light beam must shine upwards to be reflected by the ceiling, and the secondary one(s) beams directly downward. Indirect lighting systems result in an evenly distributed light output, with fewer shadows and less glare. Fluorescent, tungsten halogen or metal halide light sources are recommended for general lighting. Fluorescence is the most energy efficient, where metal halide is very expensive.

- Task lighting is purpose-designed and installed for specific tasks to be performed. These tasks vary from reading, writing, cooking, sewing, computing and TV watching. This design makes use of desk lamps, table lamps, study lamps and sunken ceiling or floor fixtures. Compact fluorescent and incandescent lamps are recommended. Task lighting can also be achieved by controlling general lighting by means of dimmers, enhanced by a desk lamp. Solid state lamps are used extensively for torches and flashlights.

- Accent lighting accentuates or highlights objects. These objects can be anything from plants, pictures, statues, garden walkways or displayed retail merchandise. Variable low voltage light sources are recommended. Four ceiling mounted antiglare 50W, 12V metal halide down lighters per $12m^2$ will be adequate to illuminate displayed merchandise. The more expensive merchandise should be lit more than that of the cheaper ones. The customer's eye will be attracted to the brightest light level.

3.5 Energy Audit of Lighting system of Nuwe Hoop School in Worcester

The energy audit that was conducted by the SLD team at the Nuwe Hoop school in Worcester was motivated by the current lighting system installation in the City of Cape Town and FNB Bank City. The audit of the school in Worcester determined what the payback period of a lighting system retrofit would be.

The SLD unit compiled an Energy Audit at the "Nuwe Hoop" centre for the deaf in Worcester, approximately 100 km from the university. The author was also a team member of the Energy Research Unit (ERU) when a school in Langa was energy audited in 2002. See report in Appendix G. Figure 3.5.1 shows some of the SLD unit student members in front of the Nuwe Hoop School. This centre has three schools and three hostels that cater for pre-primary, junior and senior learners with impaired hearing. There is also a laundry and kitchen on the premises; its electrical appliances had a great contribution to the energy consumption of the centre. Figures 3.5.1 to 3.5.10 are pictures taken on site.

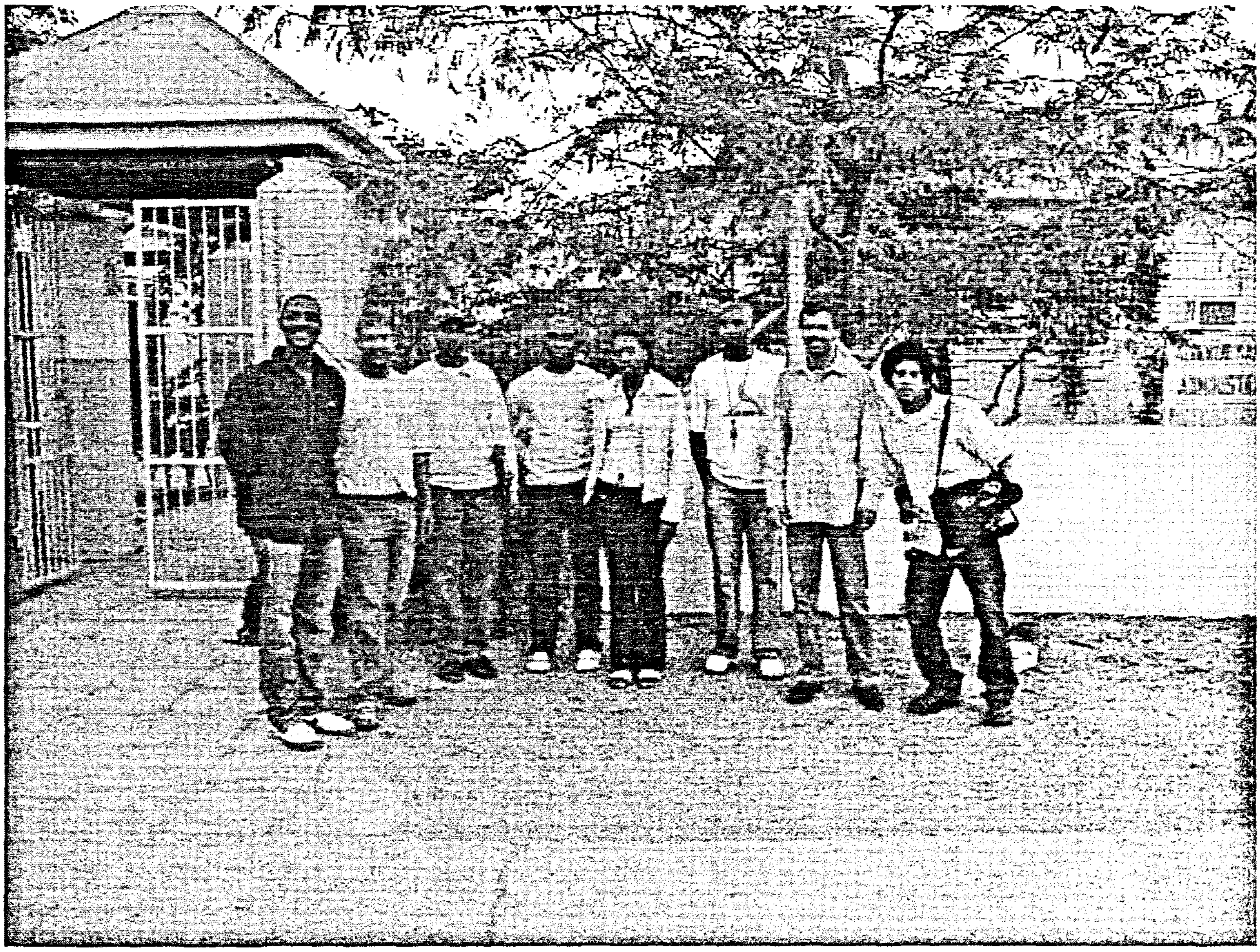


Figure 3.5.1: The author and the SLD unit student members at the entrance to the Nuwe Hoop School.

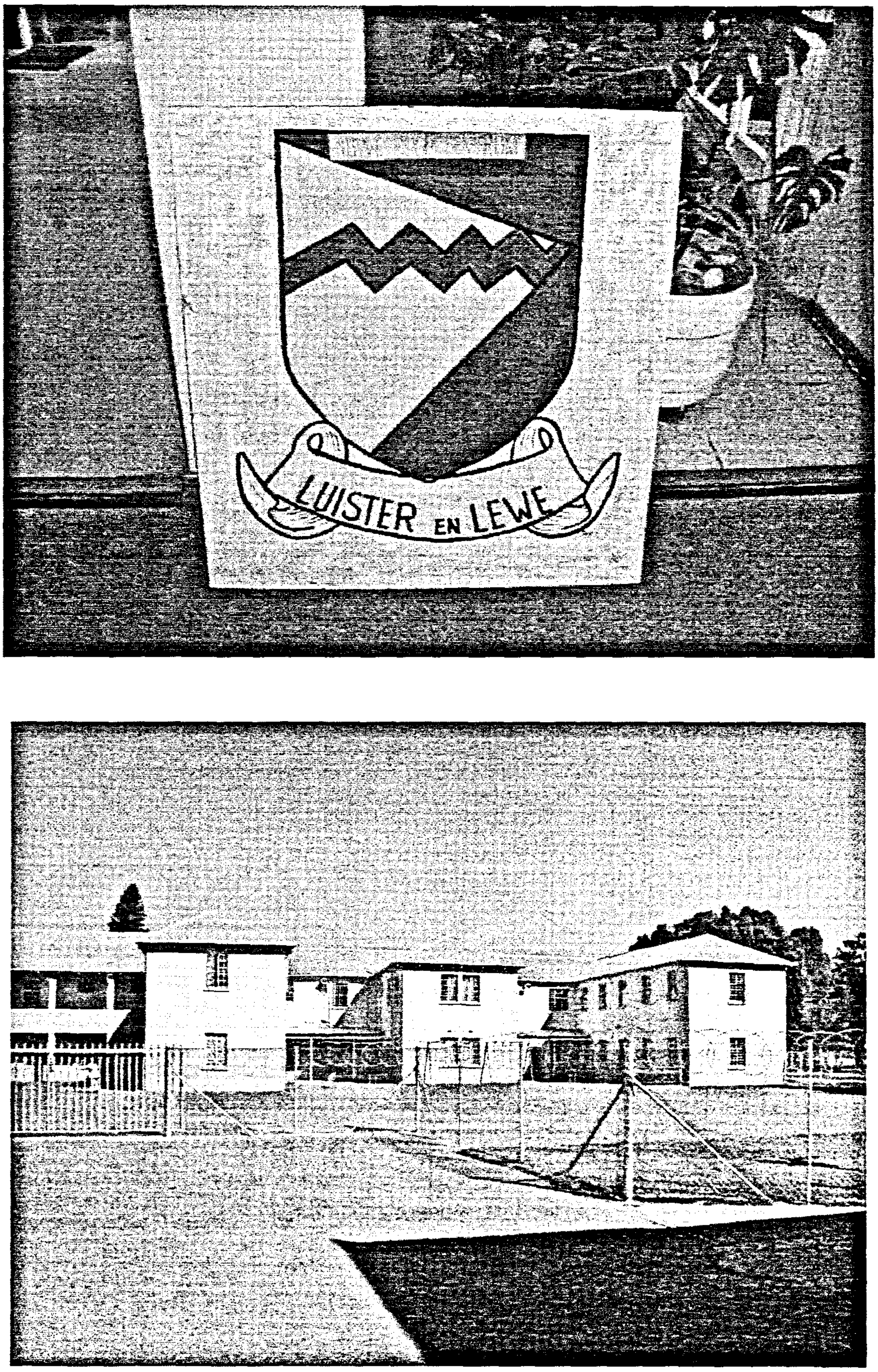


Figure 3.5.2: One of the school buildings and their emblem

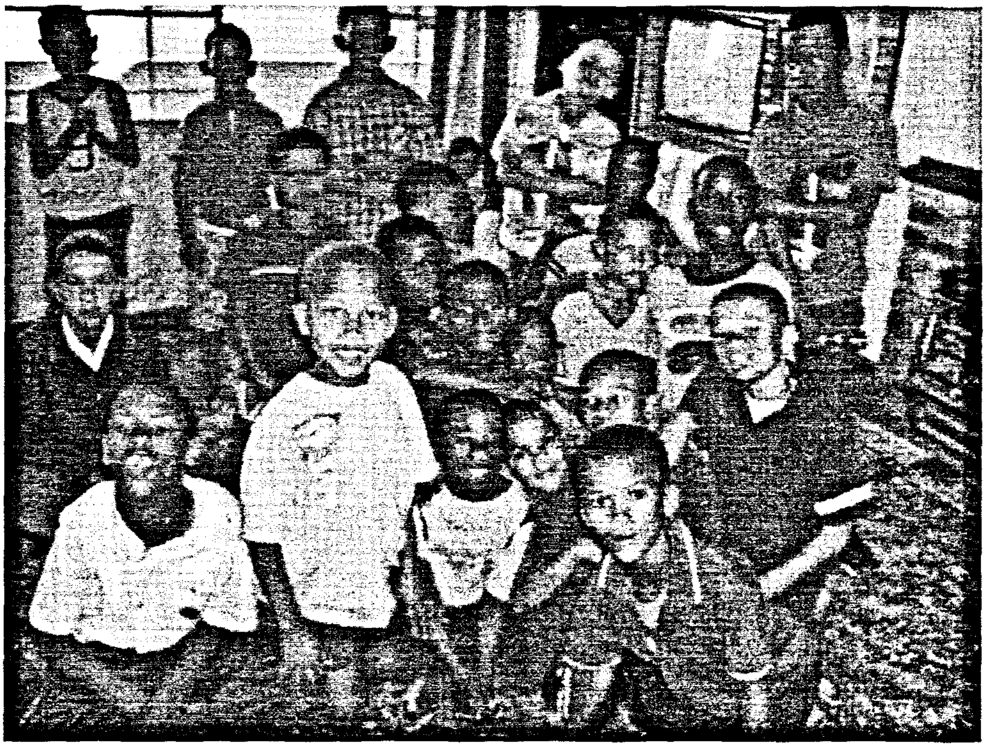


Figure 3.5.3: Primary school children in their hostel and laundry staff

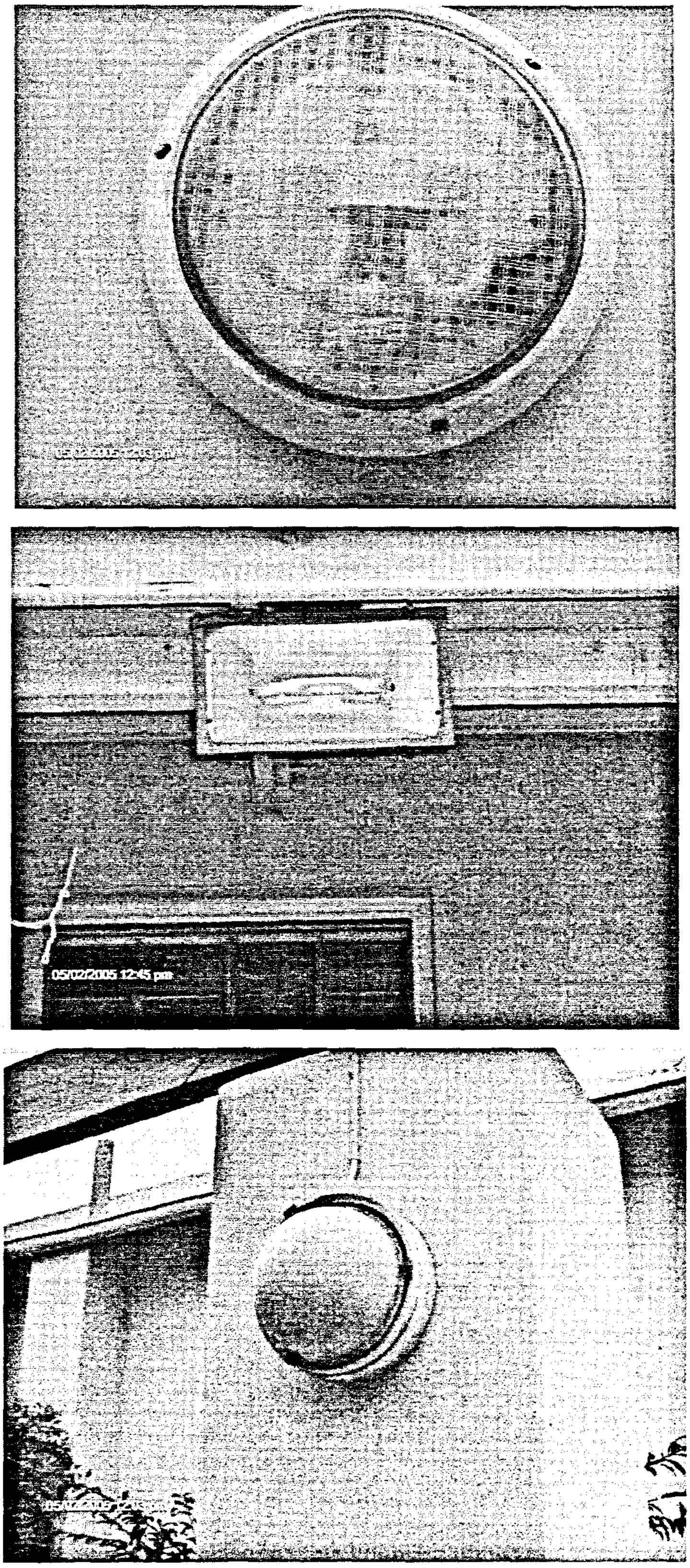


Figure 3.5.4: Various lamps and lamp-fittings installed on the premises

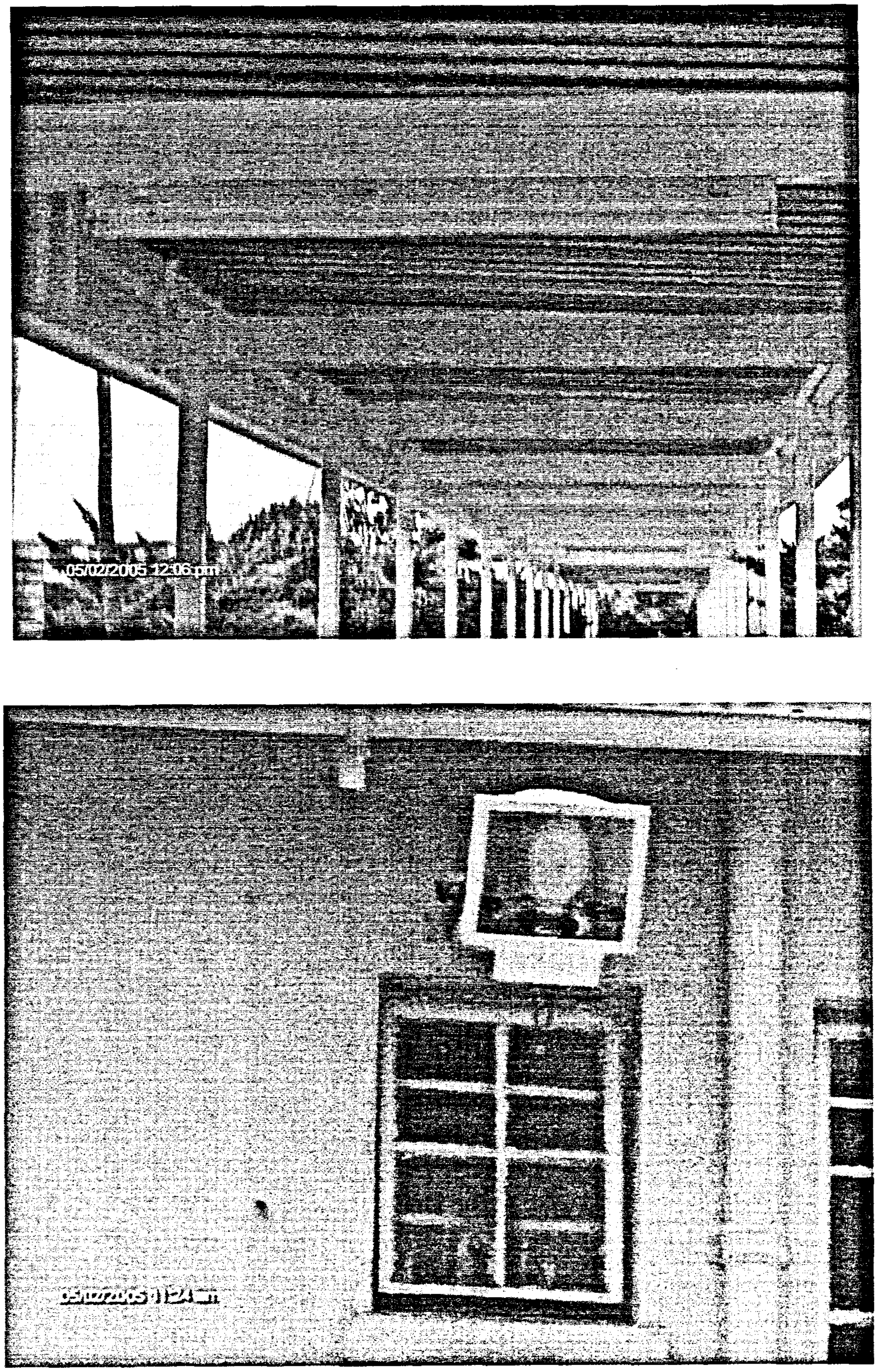


Figure 3.5.4: Various lamps and lamp-fittings installed on the premises (cont...)

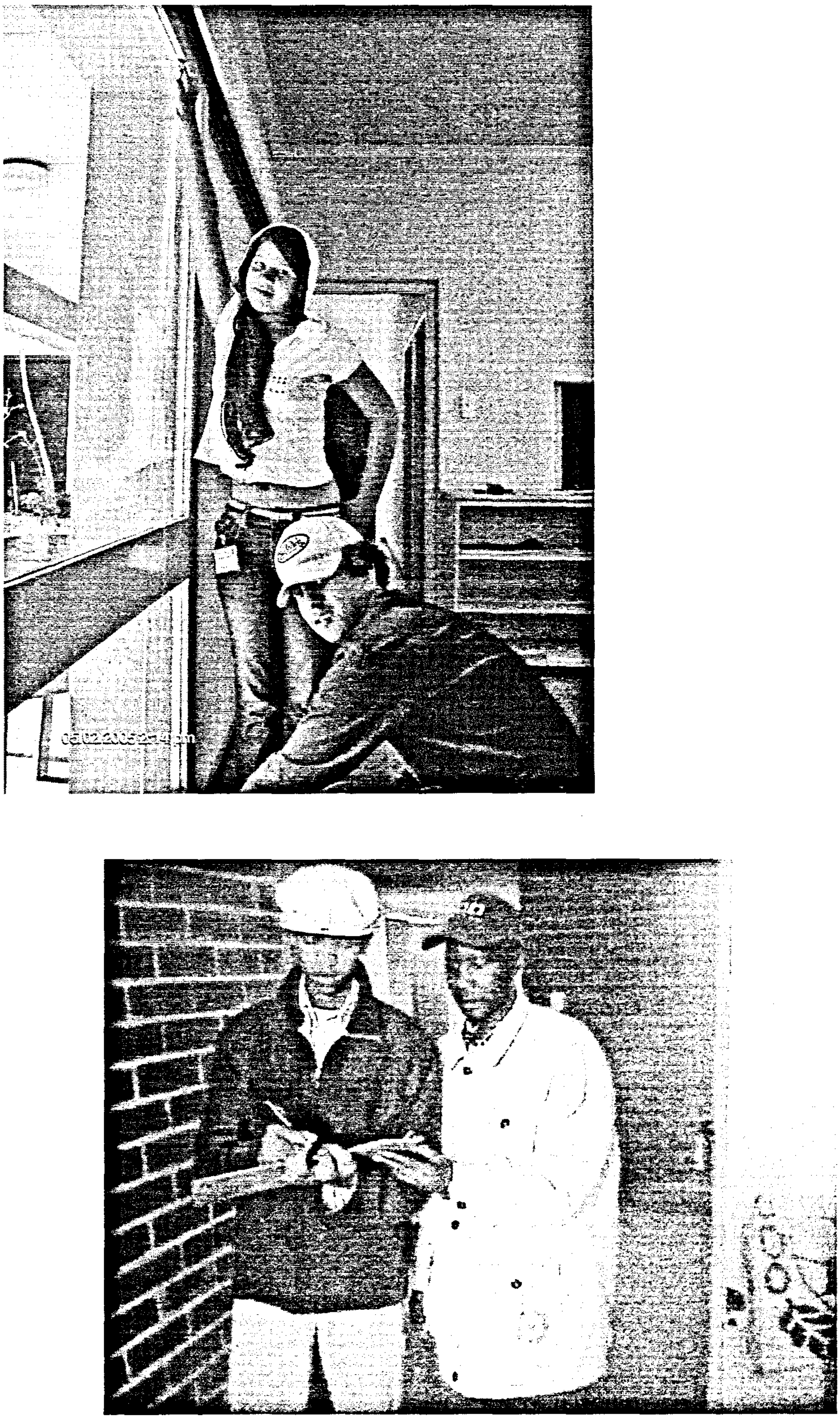


Figure 3.5.5: SLD team members recording measurements

Figure 3.5.6: SLD team members recording light meter readings in the kitchen

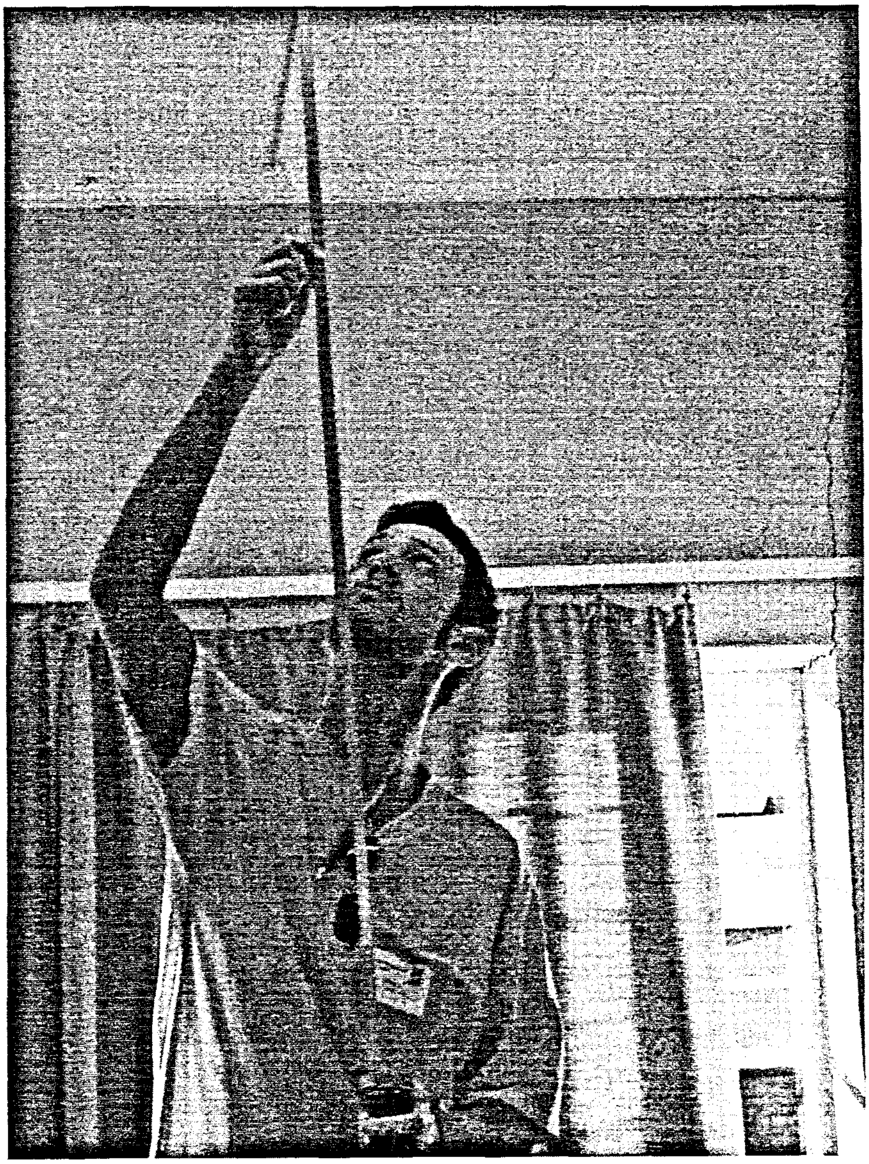


Figure 3.5.7: Another team member, Jason Witkowsky busy with measurements in a classroom

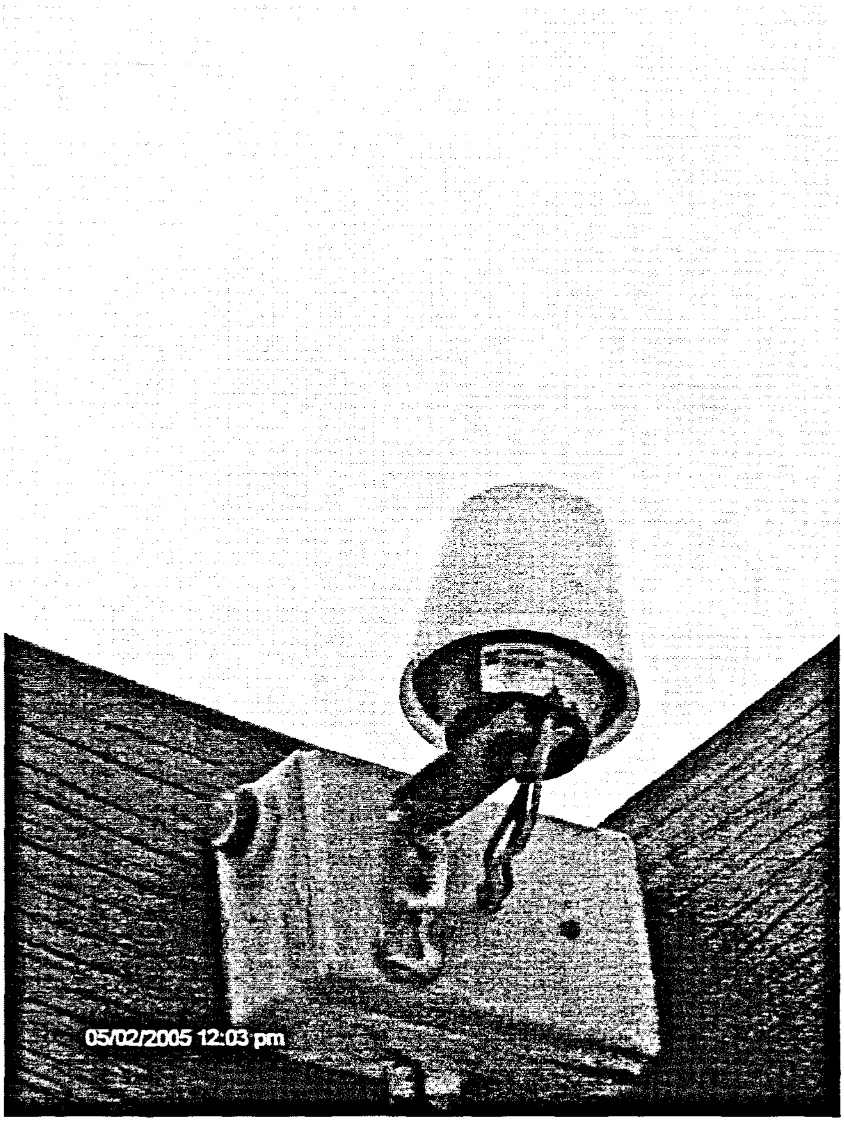


Figure 3.5.8: A light sensor for the outdoor lamps

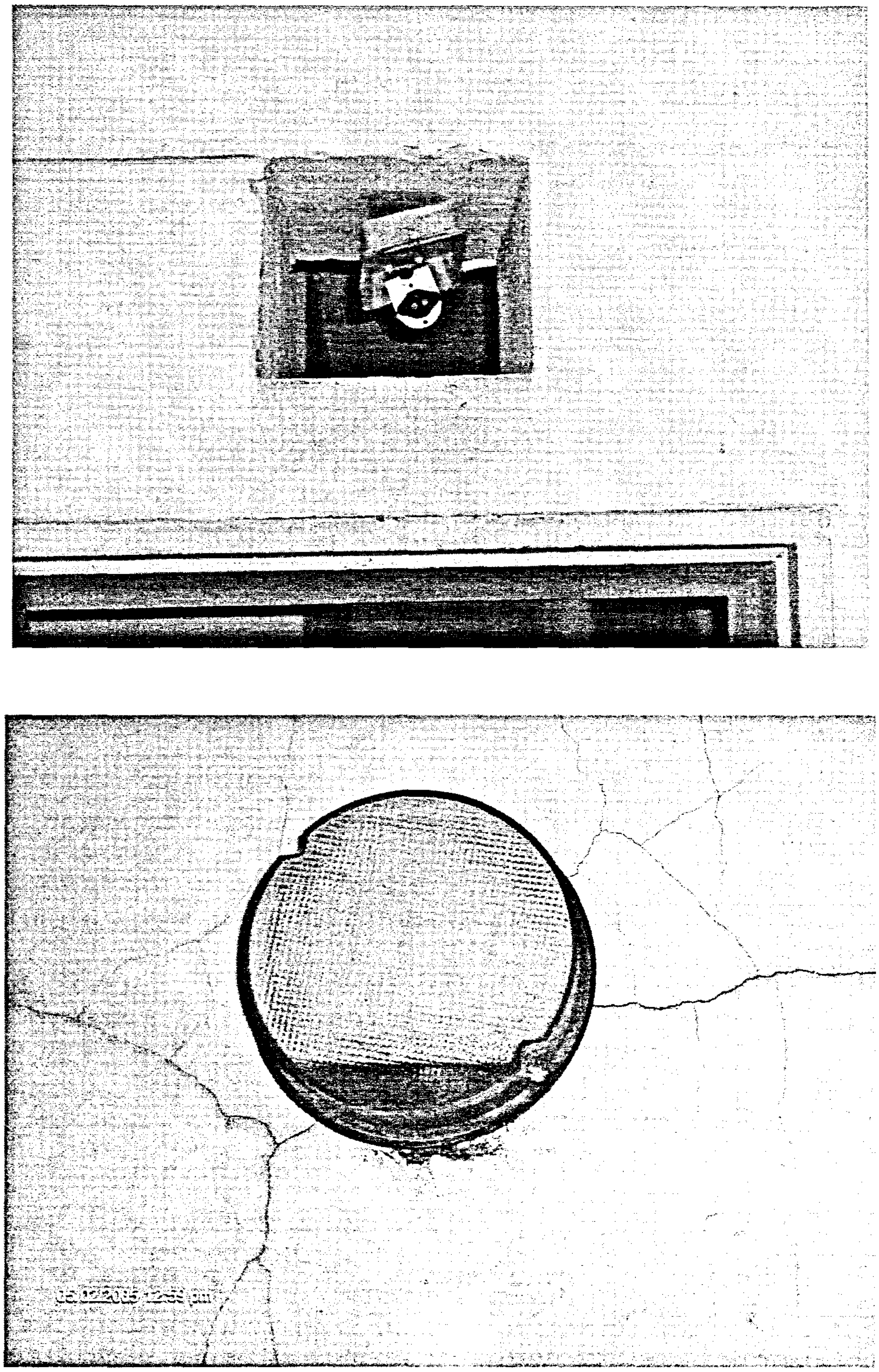


Figure 3.5.9: Damaged lamps on site

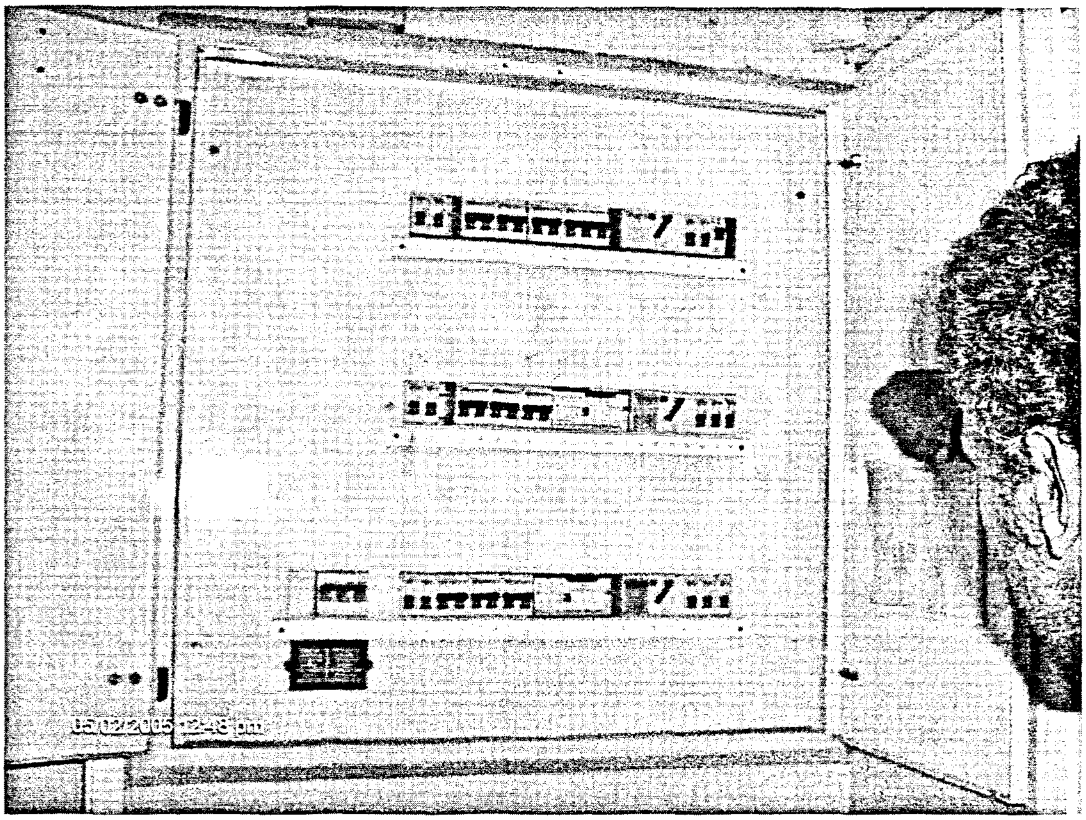


Figure 3.5.10: The author investigates the lighting circuits

3.6 Problems encountered while conducting the Audit

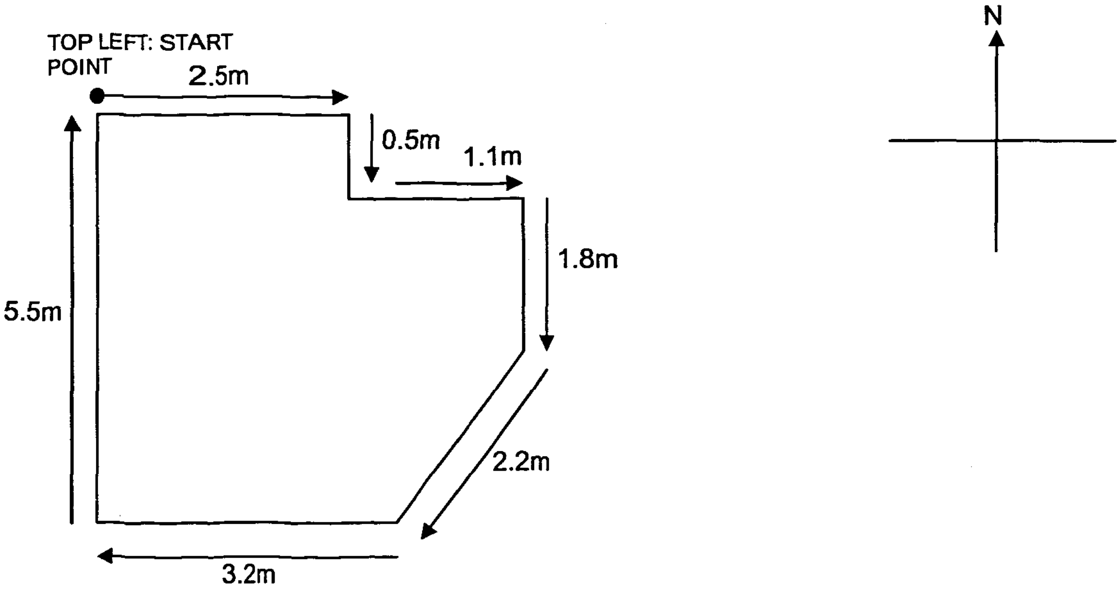
The biggest problems encountered while conducting the audit were:

- unavailability of lighting plans, floor plans or updated floor plans
- unmarked room numbers
- the inaccessibility of certain areas
- fused lamps
- missing lamps
- new installations in progress
- manpower shortage (unavailability of students).

3.7 Findings

The specification and differences between T8 and T12 fluorescent tubes are listed in Appendix B.

The installation was done with the help of community members for ESKOM's account. On each Audit Form (see Appendix C) the team member had to draw a diagram of the room dimension as shown in Figure 3.7.



Would read as: 2.5E, 0.5S, 1.1E, 1.8S, 2.2SW, 3.2W, 5.5N

Figure 3.7: Example of a room floor plan layout with dimensions, as drawn on an Audit Form

Some of the lamp information gathered in the audit is categorized in Table 3.7.1 and Table 3.7.2. Also see Appendix D.

Figure 3.7.1: Lighting Summary: Nuwe Hoop Junior School

Location	Installed Fittings												Installed Wattage
	T8				T12				CFL	Incandescent			
	1.5		1.2		1.5		1.2			60W	75W	100W	
	D	S	D	S	D	S	D	S					
Block A17 - A27 (top floor)	0	1			54	8	12	0	6	0	0	0	8624
Admin / D / E Blocks	0	0			151	16	0	0	0	0	0	13	21970
Girls Hostel: Gnd & 1st Flr	0	0			14	1	0	0	0	61	0	12	6745
Admin / Classrooms / D Block	10	6			92	2	0	0	0	4	0	17	15538
Junior Classrooms A & B	1	0			80	5	11	0	0	0	0	0	11721
Boys Hostel Ground Floor	1	0			2	0	0	0	0	0	0	52	5460
Boys Hostel Admin Block	0	0			9	18	0	1	0	0	0	56	7980
Laundry	0	0			28	0	1	0	0	0	0	9	4620
Pre-Primary School	2	0			17	6	0	1	1	16	0	0	3843
Pre-Primary Apartment	0	0			0	0	0	0	0	12	0	0	720
Sub-Total	14	7	0	0	447	56	24	2	7	93	0	159	87221

Table 3.7.2 Pre-Primary School Indoor lamps

Room No.	Lamp Type														Total Wattage
	T8			T12					CFL	Wattage	IL			Wattage	
	1.5 (58W)		Wattage	1.5 (65W)		1.2 (40W)		W			60	75	100		
	D	S		D	S	D	S								
Office 1			0				1	40		0				0	40
Office 2			0		2			130		0				0	130
Classroom			0	3				390		0				0	390
Bronne Sentrum			0					0		0	1			60	60
Toilet			0					0		0	1			60	60
			0					0		0	1			60	60
Kitchen			0		2			130		0				0	130
Classroom 1			0	3				390		0				0	390
Classroom 2			0	3				390		0				0	390
Toilet			0					0		0	4			240	240
Classroom 3			0	4				520		0				0	520
Classroom 4	2		232					0		0				0	232
Classroom 5			0	4				520		0				0	520
Toilet			0					0		0	1			60	60
			0					0		0	1			60	60
			0					0		0	2			120	120
Corridor between classrooms			0					0		0	4			240	240
			0					0		0				0	0
			0					0		0				0	0
			0					0		0				0	0
Corridor at Office			0					0		0	1			60	60
Foyer			0					0	1	11				0	11
Storeroom			0		2			130		0				0	130
TOTALS	2	0	232	17	6	0	1	2640	1	11	16	0	0	960	3843

3.8 Recommendations

After the energy audit was conducted, the following energy consumption reduction methods were recommended;

- approximately 800 incandescent lamps to be replaced by energy efficient CFLs,
- 200 T8 fluorescent tubes, and
- 800 T12 fluorescent tubes be replaced by triphosphor lamps.

This would reduce the energy consumption of the interior lighting of the complex from 31MWh to 12.5MWh, for a unity power factor. At a cost of 52,17c/kWh, this is a massive saving per month. After the energy audit these recommendations were to be implemented by Innovative Energy Projects and community members.

The simple payback period can be calculated by dividing the lamp costs by the annual energy cost savings.

The saving per annum is 18.5 MWh*52,17c/kWh = R 9 651

Assuming the price of a triphosphor fitting at R50,00 and that of a CFL at R5,00, results in a simple payback period of

$$\frac{54000}{9651} = 5.595 \text{ years}$$

Although a light sensor was used to control some of the outdoor lamps, it was recommended that some of the outdoor lamps be switched on and off consecutively by means of a timer. It was also recommended that a delayed-off light switch with a programmable on-timer be installed in some areas inside the buildings. A LS7338 programmable timer was recommended. This proposed programmable timer is a MOS integrated circuit that turns a triac on and off. When activated the triac turns on and starts the timer. The timer is controlled by an external RC combination connected to an oscillator input. With time-out the power delivered by the triac is stepped down by a third and is slowly reduced to zero over a certain time. The output of the LS7338 drives the gate of a triac in series with the load (lamp).

It was too expensive at this stage to replace the lamps with HB-LED lamps, due to their high cost.

3.9 Conclusion

This project highlights the importance of energy efficient, cost effective electrical lighting installations. The standard of living of the community has been improved as follows:

- Most of the incandescent lamps were darkened as the tungsten was deposited on the lamp walls. With the retrofit the learner's productivity is increased, due to the proper lighting levels.
- The learners can benefit from the electricity bill the savings if the now available funds are utilized elsewhere at school.
- The unemployed that assisted with the lamp retrofits and cleaning of lamp covers, earned a wages for their input.
- The payback period is less than 6 years.

CHAPTER FOUR

DEVELOPMENT OF A SOLID STATE DISTRIBUTED LIGHTING SYSTEM

4.1 Introduction

Most countries currently rely on fossil fuels such as coal for energy. These fuels are non-renewable and will eventually dwindle or become too expensive or too environmentally damaging to use. In contrast, renewable energy resources, such as wind and solar energy, are constantly being replenished and will never run out. Rural and remote areas often have poor or inadequate illumination. Power from the National Grid is not established in these areas.

The electrical supply utility, ESKOM, cannot cope with the growing demand in South Africa. This results in load shedding and power outages. This capacity can be augmented, by conducting energy audits, retrofitting government buildings, designing and installing cost-effective lighting systems, and using renewable energy sources in rural areas. Households in rural areas depend on candles and paraffin lamps to supply light at night. HB-LEDs have become as bright as and more efficient than incandescent and fluorescent lamps. HB-LEDs have already begun to replace incandescent bulbs in many applications where durability, compactness, cool operation and directionality are required. Efficiencies of more than 50% have been achieved in infrared devices. Similar efficiencies in visible white light HB-LEDs would be ten times more than incandescent lamps and two times more than fluorescent lamps. SSL should be more competitive than conventional lamps (as shown in

Table 1.3.2) because of the following advantages: [Kendall & Scholand, 2001]:

- Efficient thermal management where electronics dynamically adjust the colour ratio to a constant white point at a specified temperature.
- Efficient optical engineering where wavelength conversion and colour mixing is independent of operating temperature.
- Electronic compensation for colour drift versus time.
- Reliability of 100 000 hours lifetime.
- Environmentally friendliness - disposable, non-toxic materials are mercury free.

Up to now the fluorescence technology has provided remarkable energy savings. SSL will significantly, further improve this energy saving in general lighting by 50%. As this technology advances, light quality and market penetration will increase and prices will fall. SSL market penetration and its energy saving potential in general lighting will be driven by economics. This will depend on how quickly SSL developments will occur.

If prices drop to that of incandescent lamps, SSL will achieve full market penetration in all lighting applications by 2020 as shown in Figure 4.1.1 [Kendall & Scholand, 2001]. This will result in enormous energy savings per annum. In Japan a SSL market penetration of 13%, with efficiency of 120 lm/W by 2010 is targeted [Tagutchi, 2001]. In the USA it is 50% by 2012 and 90% by 2020. If the technology performance targets are met, it will enable penetration of incandescent lighting by 2007 and that of fluorescent lighting by 2020. [Kendall & Scholand, 2001]. Solid-State lamps should become available as a white light source, competing with incandescence and fluorescence, in the near future.

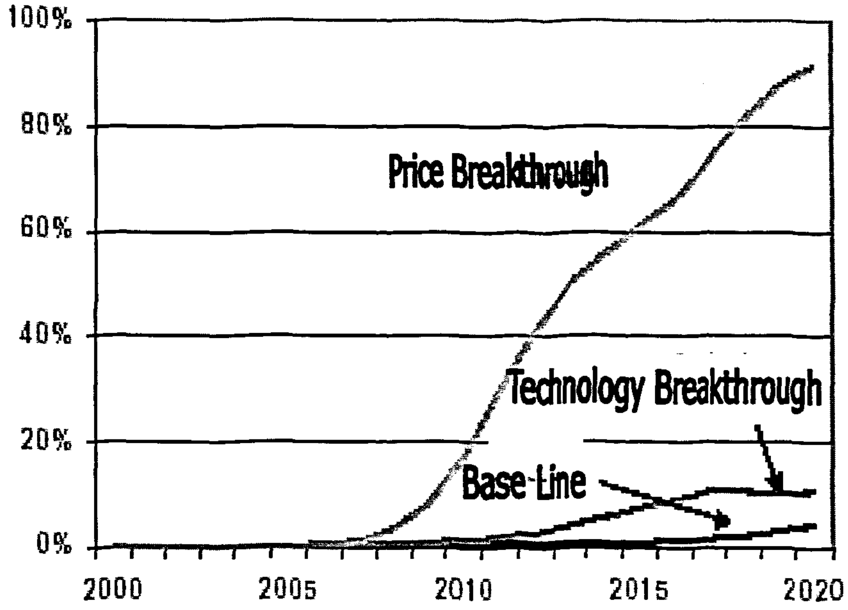


Figure 4.1.1: The Percentage Annual available lumen market captured by SSL.

4.2 White Light LEDs

Conventional lighting has nearly reached maximum efficiency but this is not the case with solid-state lighting. LEDs operate on entirely different principles, using crystalline layers that convert electrical input into an optical output, at a colour determined by composition of the material. The coloured LEDs are the main elements of white–light sources and it already made a big impact on this market. White itself is not actually a colour and producing what the eye perceives as a white light requires the generation of many hues together. The easiest way to make white is by using either blue or ultra violet LEDs and add phosphorous. Mixing LEDs to produce white light is a difficult task. This section looks into aspects regarding solutions and methods in generating white colour with LEDs for lighting.

Semiconductor Lighting technology has gained momentum at an unprecedented rate. Recent advances in the basic technology make it possible that these super-efficient, long life lights will soon be competing for the white light market. These lighting systems are covering a wide variety of disciplines, and encompassing everything beyond the photon creation device, including photon placement, integration into the environment, and interaction with humans. Therefore, our thinking about lighting systems is relatively immature. Basic concepts are often taken for granted, such as the Colour Rendering Index (CRI) or even the definition of the lumen that may need to be rethought with respect to Solid-State Lighting. Natural sunlight is the most acceptable "white light" to the human eye and thus has a baseline CRI of 100. Therefore, a LED with a CRI of 85 is closer better than one with a CRI of 60. Earlier white LEDs were closer to the other side of the scale, where ultraviolet light, for example, has a CRI of between 0 and 10. Another area where LEDs are strongly competing in is colour temperature. "Cool" white LEDs have a more bluish than red colour, with a Kelvin temperature of 5000 and above. The LED industry is quickly moving towards semiconductor replacement of true, natural, warm light sources. Currently, white solid-state light sources with high CRIs, colour temperatures in the 3200 range and light output of 22 lumens are available in bulk and are available off the shelf. This first semiconductor light engine is ready to replicate the glow of an incandescent bulb and will dramatically increase the appeal of LED illumination for indoor lighting applications.

4.2.1 White Light Technologies

When our eyes detect the colour of an object we normally take the process from when the incoming light enters it, up to when the brain recognises a certain colour, for granted. This is such a remarkable process that the following question should be asked: "How many different colours can be distinguished by the eye?" The astonishing answer is: "Thousands of different colours". It makes sense, since with computer generation thousand of different colours can be created, and these displayed colours looks different to the eye. Likewise, the eye can distinguish between many "white" colours, from cool white to warm yellow. The parts of the eye that is important for colour vision are displayed in Figure 4.2.1 [Fairchild, 1998]:

The cornea and lens focus the image onto the retina. The retina is the part that detects any incoming light. The iris adjusts in width to partially account for light levels. The fovea is the central focal point of the eye. The fovea is the area where we get most of the detail and colour in what we see. The optic nerve carries the visual information to the brain.

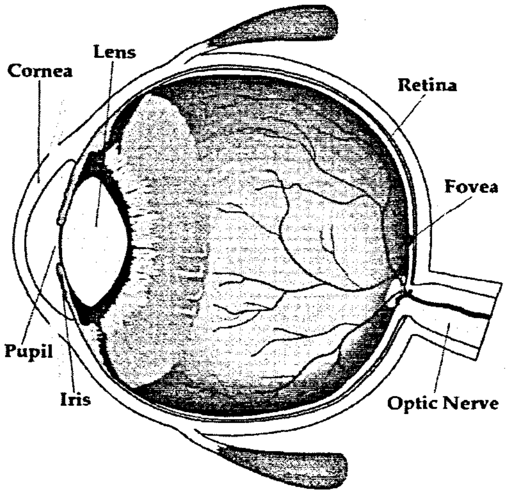


Figure 4.2.1 Parts of the eye

Another question to ask is: "What is a Solid State Light and what technology is used to achieve a solid-state white light device." At the heart of a solid state light (SSL) is a sandwich of semiconductor layers, built on a substrate. When the electrons and holes recombine, light is emitted in a narrow spectrum around the energy band gap of the material. Because the light is narrowband, and can be concentrated in the visible portion of the spectrum, it has, like Fluorescence, much higher light-emission efficiency than Incandescence. Therefore, Solid-State Lighting technology is overcoming similar challenges associated with converting the narrowband emission into semi-broadband emission that fills the visible spectrum to give the appearance of white light. Unlike in Fluorescence technology, the wavelength of the narrowband emission can be adapted relatively easily, by either maximizing the quantum efficiency, or to minimize the quantum energy inefficiency associated with its conversion. Consequently, this technology is potentially more efficient than Fluorescence.

Light trapped in the semiconductor chip is one of the problems encountered by this lighting technology. The problem is due to the high refractive index (over 3) of most semiconductors, which causes most of the light (>95%) to be internally trapped due to total internal reflection. The best external quantum efficiency reported to date for a visible LED is only around 55% while the theoretical maximum is 100%. Currently, three approaches exist for generating white light using solid-state devices, namely:

- Wavelength Conversion Approach
- Colour Mixing Approach.
- Hybrid Approach.

4.2.2 Wavelength Conversion Approach

This approach convert narrowband emission into broadband white light involves using UV LEDs to excite phosphors that emit light at down-converted wavelengths. This approach is likely to be the lowest cost, because of its low system complexity (only a single LED chip, and since the colours are created already blended, lamp-level optical and colour engineering is minimized). But it is also the least efficient, because of the power-conversion loss associated with the wavelength down-conversion; and the least flexible, since the colours are preset at the factory. The wavelength for the UV LED in this approach is possible to be determined by balancing:

- the efficiency of the LED
- the quantum efficiency of the phosphors (the shorter the wavelength the more efficient) and
- the phosphor conversion efficiency

Therefore, the challenge will be the development of UV (370-410nm) LEDs with high (>70%) external power-conversion efficiency and input power density, and multicolour phosphor blends with high (>85%) quantum efficiency. The phosphor quantum efficiency is likely better for this approach, since there is a wider range of available phosphors in the UV. The phosphor conversion efficiency, in contrast, will be low, since there is a larger energy difference between the UV and the red/green/blue light than between blue and the red/green light.

4.2.3 Colour Mixing Approach.

This approach transforms narrowband emission into broadband white light by combining light from multiple LEDs of different colours as shown in Figure 4.2.3 [Matei, 2004:607-608]. This approach is expected to be the most efficient, as there are no power-conversion losses associated with wavelength down-conversion.

It is also likely to be the most flexible, since the hue of the light can be controlled by varying the mix of primary colours, either in the lamp, or in the luminaire. For this approach, of course, there is no phosphor and therefore no phosphor-related losses.

However, it is also expected to be the most expensive, because of its high system complexity due to:

- multiple LED chips
- mixing of light from separate sources and
- innovative drive electronics

Therefore, the challenge will be in the development of red, green and blue LEDs with high (>50%) external power-conversion efficiencies and input power density, low-cost optics and control strategies for spatially uniform, and programmable colour-mixing either in the lamp or in the luminaire. The Efficiency of this approach depends on the difficulties in combining the separate sources of light.

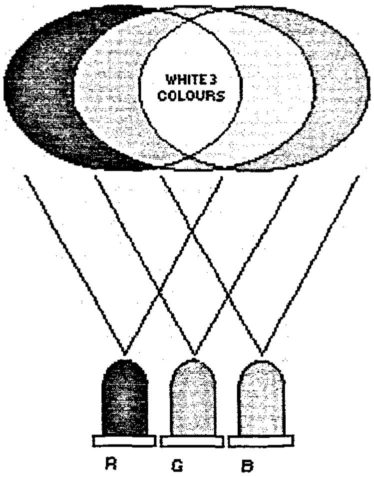


Figure 4.2.3: Mixing of multiple colours

4.2.4 Hybrid Approach.

This approach converts narrowband emission into broadband white light that involves Blue LEDs to excite a yellow or green and red phosphor (Figure 4.2.4) [Zukauskas *et al*, 2002]. The present generation of white LEDs, with luminous efficacies of 25 lm/W, is based on this approach. Primary light from a blue (460nm) InGaN-based LED is mixed with blue-LED-excited secondary light from a pale-yellow inorganic phosphor. The secondary light is centred at about 580 nm. The combination of partially transmitted blue and re-emitted yellow light gives the appearance of white light at a colour temperature of 8,000K and a luminous efficacy of about 25 lm/W. This combination of colours is similar to that used in black-and-white television. Since chip and phosphor efficiency may change with temperature, the ratio of the colours that are being blended will also change with temperature. [Matei, 2004:607-608]

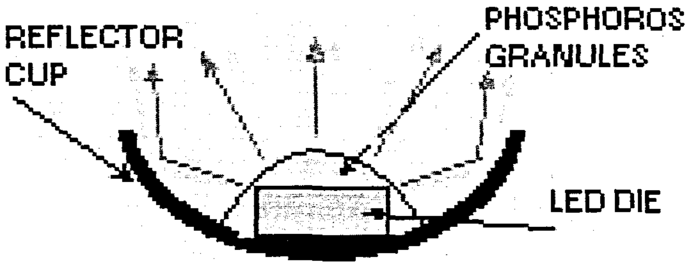


Figure 4.2.4: Blue LED chip plus yellow phosphors

4.2.5 Delivering light to the viewer

The final step for a semiconductor light source is to deliver the white light to that part of the environment that needs to be illuminated. SSL-LEDs have the advantage that they can deliver directed light more efficiently to small areas, because they are point sources. Their compactness enables more flexibility in the luminaire design. They are also very robust. When a white LED needs to be practically optimized it needs to attain the highest radiant efficiency and secondly the spectral power distribution optimization for the highest CRI and efficacy.

A Solid-State Light source has the ability to closely deliver the colours of non-white objects that it illuminates. One quantitative measure of the accuracy of colour rendering is the colour-rendering index (CRI). This measure is based on comparing the colours rendered by a LEDs light source to the colours rendered by a "perfect" reference light source. As the maximum luminous efficacy decreases, the maximum CRI increases, as the wavelengths move further to the extremes of the visible spectrum. The maximum CRI begins to saturate at 3 for a 2-colour source, at 85 for a 3-colour source, at 95 for a 4-colour source, and at 98 for a 5-colour source [Rea, 2001]. A tri-colour source can achieve the target CRI of 80 or greater and provide the best balance between CRI, luminous efficacy, and lamp complexity. Figure 4.2.5 illustrated the beam from a 5mm white LED (hybrid approach) with a 23° view angle [Zukauskas *et al*, 2002].

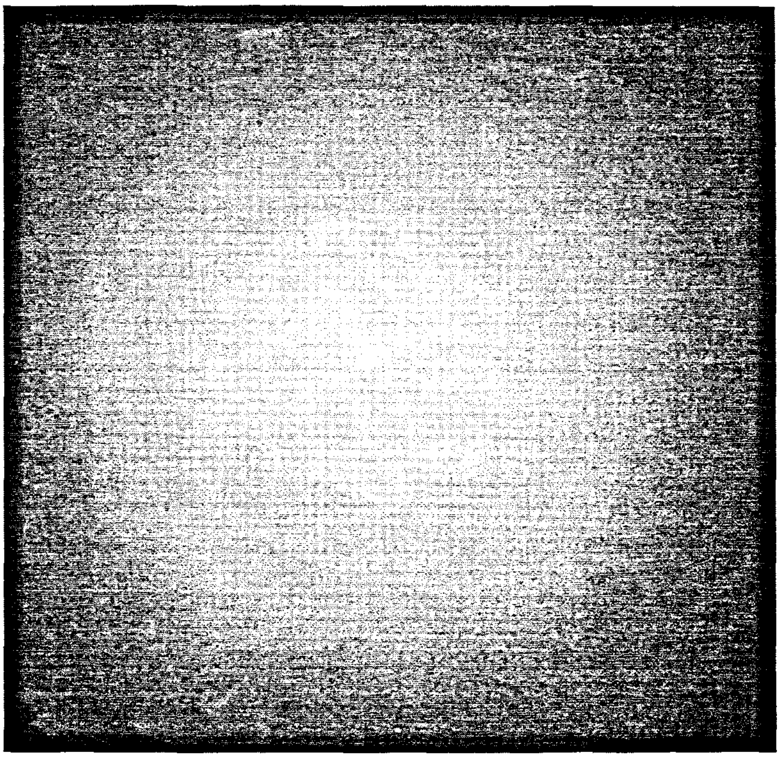


Figure 4.2.5: White LED beam

The non-white perimeter is brown or yellow and is an indication of some deficiency in the phosphor conversion method. The intensity of the white inner beam is approx 4000mcd at 20mA with a colour temperature of 5500K. Therefore, SSL-LED technology has advantages and disadvantages relative to fluorescence technology. The main advantage of SSL-LED is their initial narrowband light that is available in a much greater range of wavelengths, including the visible and near UV light, where as fluorescence is limited to the available emissions from a gas. [Matei, 2004:607-608].

4.2.6 SSL Lighting Systems

Besides the solid-state lighting chip, the rest of the lighting system is also critically important, with its own unique challenges, namely:

- Proper efficient driving circuits
- Supplying low-voltage high-current electricity in a world dominated by high-voltage low-current sockets.
- Integrating solid-state lighting into building architectures.
- Researching the ways in which solid-state lighting interacts with the human visual system to increase comfort and human productivity. [Haitz R, 2000]

Since solid-state (HB-LED) lighting lamps are essentially point sources of light, the optics required to collimate, focus and direct the light are relatively straightforward, and are ideally suited to directed "task-lighting" applications. For such applications, solid-state lighting is expected to have a huge advantage over traditional lighting. To use optics to create the uniform and homogeneous light output, necessary for large-area lighting applications, is very challenging. In future, optics is expected to make colour mixing and white light production available in a single lamp, with enough efficacy.

In conclusion of the case of white light LEDs, the most basic concept of colour rendering quality in is not yet well defined for solid-state lighting, where the visible spectrum is obtained primary light from chips and secondary light from phosphors.

Solid-state lighting technology is ideal for use in building and lighting architectures due to its compactness and environmental compatibility (rugged and vibration resistant). The programmability of SSL-LEDs makes it possible for lamps to be dimmed while maintaining high luminous efficacy, with colour selection. In buildings where lighting is a mix between artificial and natural (daylight) sources, programmable (dimmable) lighting can save significant amounts of energy. If both "hardware" and "software" features of SSL-LEDs are exploited, a new generation of more aesthetic and more energy-efficient buildings can be realised. Fluorescence technology has provided remarkable energy savings. Solid-state Lighting (SSL) will significantly, further improve this energy saving in general lighting, by 50%. As this technology advances, light quality and market penetration will increase and lamp prices will fall. [Kendall & Scholand, 2001]. Figure 4.2.6 displays examples of HB-LEDs. The one on the left is rated at 0.4W and the other one at 2W.

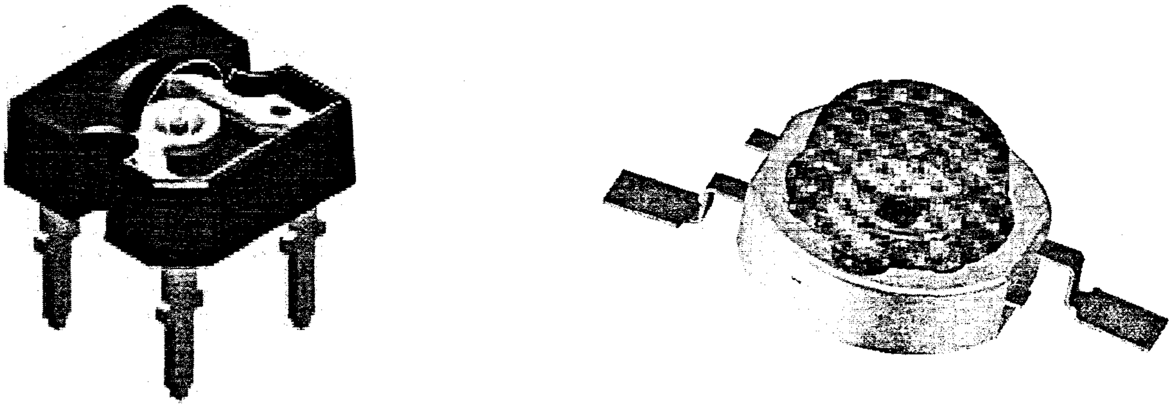


Figure 4.2.6: Examples of Typical HB-LEDs

4.3 Lighting Design

High lighting standards are important to illuminate a workspace effectively and the general surroundings sufficiently. A lighting load has a very poor load factor, as it is utilised over a very short period per day. This leads to the perception that its energy consumption has little impact on the maximum demand of a domestic, office or industrial installation. In 1999, 21% of the USA energy consumption was used for lighting. [Steigerwald *et al,* 2002] Worldwide patterns are the same. The fluorescent tube, compact fluorescent lamp and solid-state lamps are lighting technologies promoted to replace conventional incandescence. Energy efficient, cost effective lighting designs are being used worldwide.

The research question is whether a low cost energy efficient, renewable solid-state lighting system can be designed, installed and implemented for a rural community? The aim is to develop an efficient HB-LED lighting system, driven by a renewable energy source (solar panels, battery controllers and batteries). An infrastructure or reticulation system to supply a few houses in a rural community in the Stellenbosch / Kraaifontein area with proper energy efficient lighting, needs to be investigated. A cost-effective stand-alone streetlight system was also developed. The system could have remote monitoring of site operating conditions.

4.4 Research Design and Methodology

In this section a SSL prototype and a stand alone CFL streetlamp prototype is designed and built.

4.4.1 Efficient HB-LED lighting system

Solid state lighting luminaires and driving circuits are to be designed, simulated, developed and installed. Since semiconductor technologies are low DC voltage technologies, four different approaches can be adopted to supply SSL LEDs, viz. additional low-voltage building reticulation, built-in luminaire voltage regulation, built-in lamp voltage regulation and low-voltage output of solar cells. Application circuits and systems are to be designed and the most feasible one implemented.

The lighting dilemma in rural areas can be solved in applications where the low-voltage output of solar cells are utilized to drive HB-LEDs. This can be used with domestic, traffic and railway signalling applications. A 40W solar panel supplying three SSLs should be able to provide sufficient light in a rural home, which is remarkable compared to one incandescent lamp dissipating 60W. It would be affordable enough to ensure full ownership to the homeowner. Rural emergency equipment (traffic and railway signalling SSL-solar applications etc.) can be integrated with data communication devices. This will enable automatic remote fault reporting to ensure minimum downtime in the event of a breakdown. The biggest problem however was the design of an efficient driver circuit to the HB-LED. This will be a very challenging part of the project. Lead acid batteries were utilised. Battery conditioning or regulating circuitry was designed and constructed to obtain optimal battery operating conditions.

4.4.2 Simulation of LED drivers

The simulation of the driver circuit was done with the PSIM simulation software, to obtain optimal operating parameters.

The HB-LED test circuit shown in Figure 4.4.2 was simulated with PSIM.

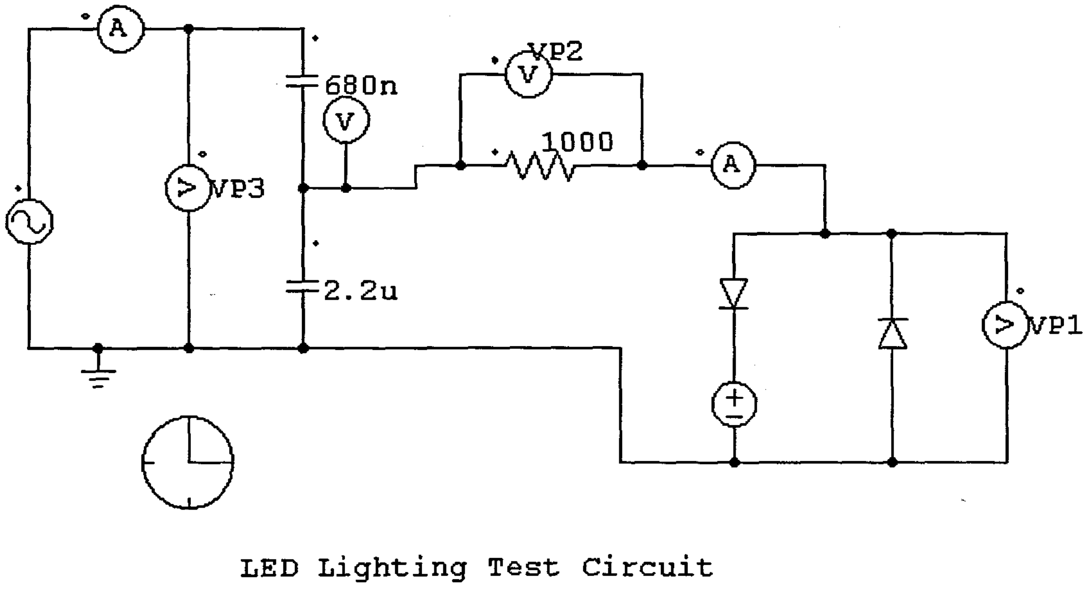


Figure 4.4.2: Schematic diagram of the HB-LED test circuit

4.4.3 Calculations and design of an LED Driver for DC Systems

LEDs generally require series resistance in order to drive it from DC or AC sources. This so-called current limiting resistor is a major drawback to efficiency of an otherwise perfect light source (LEDs are the most efficient electricity to light conversion source).

The following calculations were done:

To drive 24 LEDs from 12V DC requires the following standard design technique as shown in Figure 4.4.3.1.

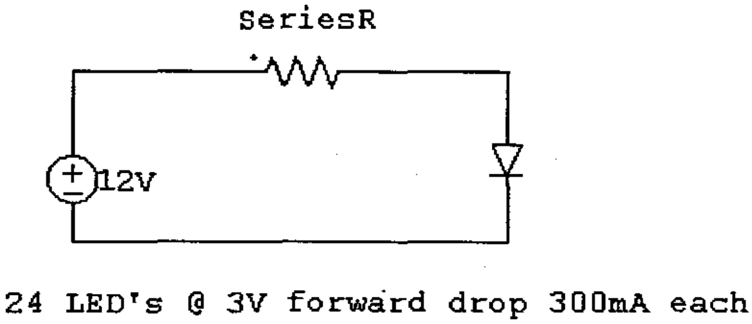


Figure 4.4.3.1: Schematic diagram of conventional LED circuit

The series resistance is calculated as follows:

24 x 300mA = 7.2A total current

a total of 12-3 = 9V must be dropped across the resistor

Ohms Law tells us that R should be $V/I = 9/7.2 = 1.25\ \Omega$.

This means a power dissipation in the series resistance of $V^2/R = 81/1.25 = 64W$. The total power dissipated by 24 LEDs at 300 mA is only 21W. The circuit efficiency is therefore only 25%.

A energy efficient electronics driver without any series resistance for the LEDs was sought after. Theoretically the circuit efficiency would then be almost 100%.

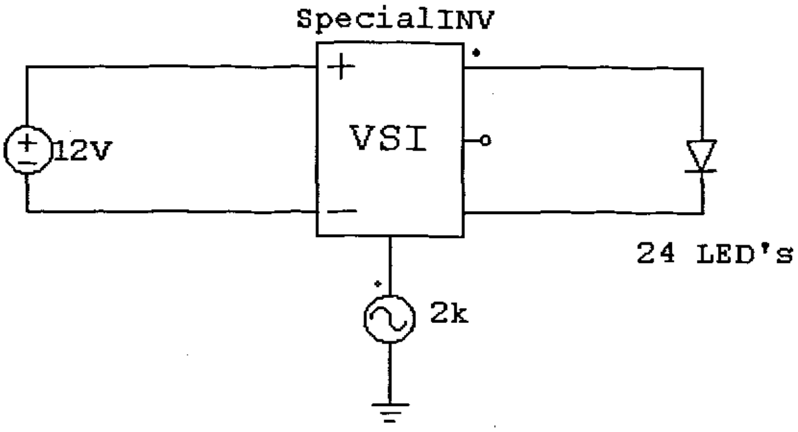


Figure 4.4.3.2: LED Driver for DC systems

With this specially designed driver circuit shown in Figure 4.4.3.2 it would be possible to supply 24 LEDs with 20 Watts at almost 98% efficiency.

4.4.4 Calculations and design of LED Driver for AC Systems

The lamp described in this section can be used in any typical industrial or domestic environment. The lamp can be inserted into a standard light fitting or socket without any modification. The motivation for the device is linked to energy consumption reduction methods.

The AC LED lamp operates on an AC supply voltage of up to 230V. The circuitry and PCB are fitted into a housing. The LEDs protrude from the top of the housing. The housing is terminated into a benchmark bayonet or screw-in type connecter used by standard incandescent or CFL lamps. The AC supply is fed through a standard lamp socket or fitting. To alter the intensity of the lamp any amount of up to 30 LEDs can be connected to the circuit. The circuit values must then be altered however. Any AC voltage up to 230V can be used. Again only the circuit values are to be altered.

Part of the AC LED Circuit is patented by the author and his supervisor. A circuit diagram of the device is shown in Figure 4.4.4.1. The lamp utilises a few components and a number of HB-LEDs. The problem with this circuit was the fact that the LEDs blew frequently when the lamp was powered up.

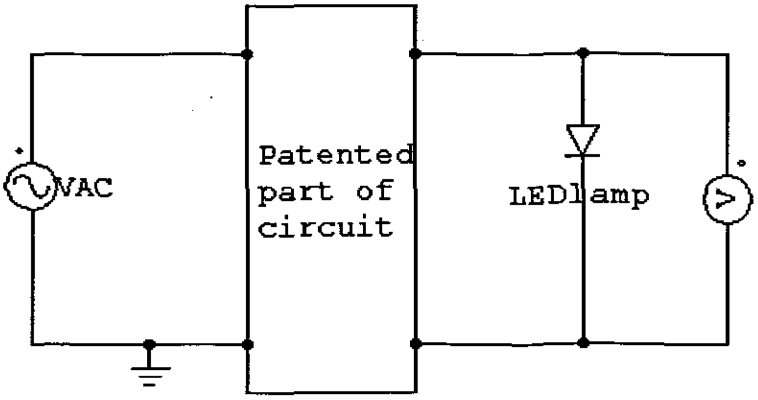


Figure 4.4.4.1: AC LED lamp circuit

It can be seen from the output waveforms in Appendix F, that when power is switched on surges on the supply lines produced large currents of up to 60A to flow through lamp, to flow through the LED lamp. This blew the LEDs. Transorbs or thermistor were installed in the supply line which dissipate power for a fraction of a second with switch on, to protect the LEDs from any surges or spikes. This improvement is shown in Figure 4.4.4.2. The transorb was suppose to protected the LEDs from the high currents with switch-on of the lamp. Occasionally the LEDs still blew. In the displayed circuit only 10 HB-LEDs are shown, but up to 30 can be used depending on the application. The electrical current through the circuit is determined by the sum of the peak forward current of each LED (20 – 250mA). The typical forward voltage of these HB-LEDs is approximately 3.5V. For example, say 8 HB-

LEDs specified at 250mA, 3.4V are used with 230V AC as supply. The peak current drawn by the HB-LEDs is 2A. The minimum power dissipated in the LEDs is (2/√2)(3.4V) =4.76W. The other components dissipate a fraction of the 4.76W and are negligible.

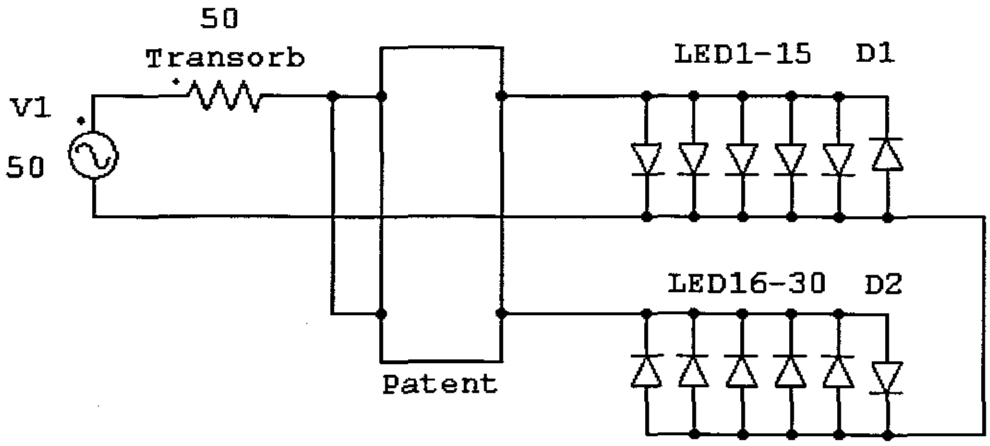


Figure 4.4.4.2: Improved AC LED circuit.

An advanced circuit was designed to prevent damage to the LEDs when it is swithched on. In the simulation of Figure 4.4.4.3 the noise generator output represents unwanted spikes. The supply voltage had a peak AC voltage of 300V with a 10V peak to peak noise source.

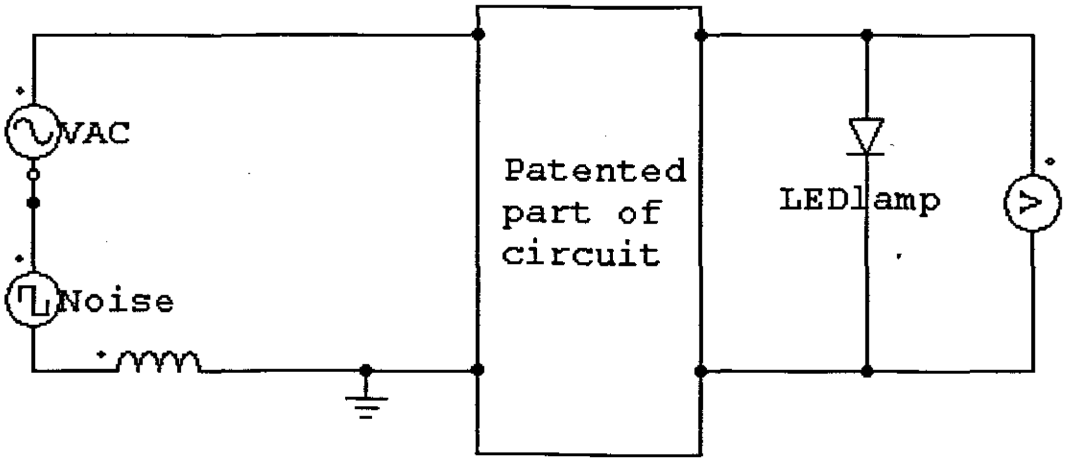


Figure 4.4.4.3: AC LED circuit with surge simulation

4.4.5. Test Results of AC LED circuit

The displayed waveforms of the circuit in Figure 4.4.4.2 are shown in Figure 4.4.5.1. The high generated currents and voltages can clearly be seen and are detrimental to the LEDs.

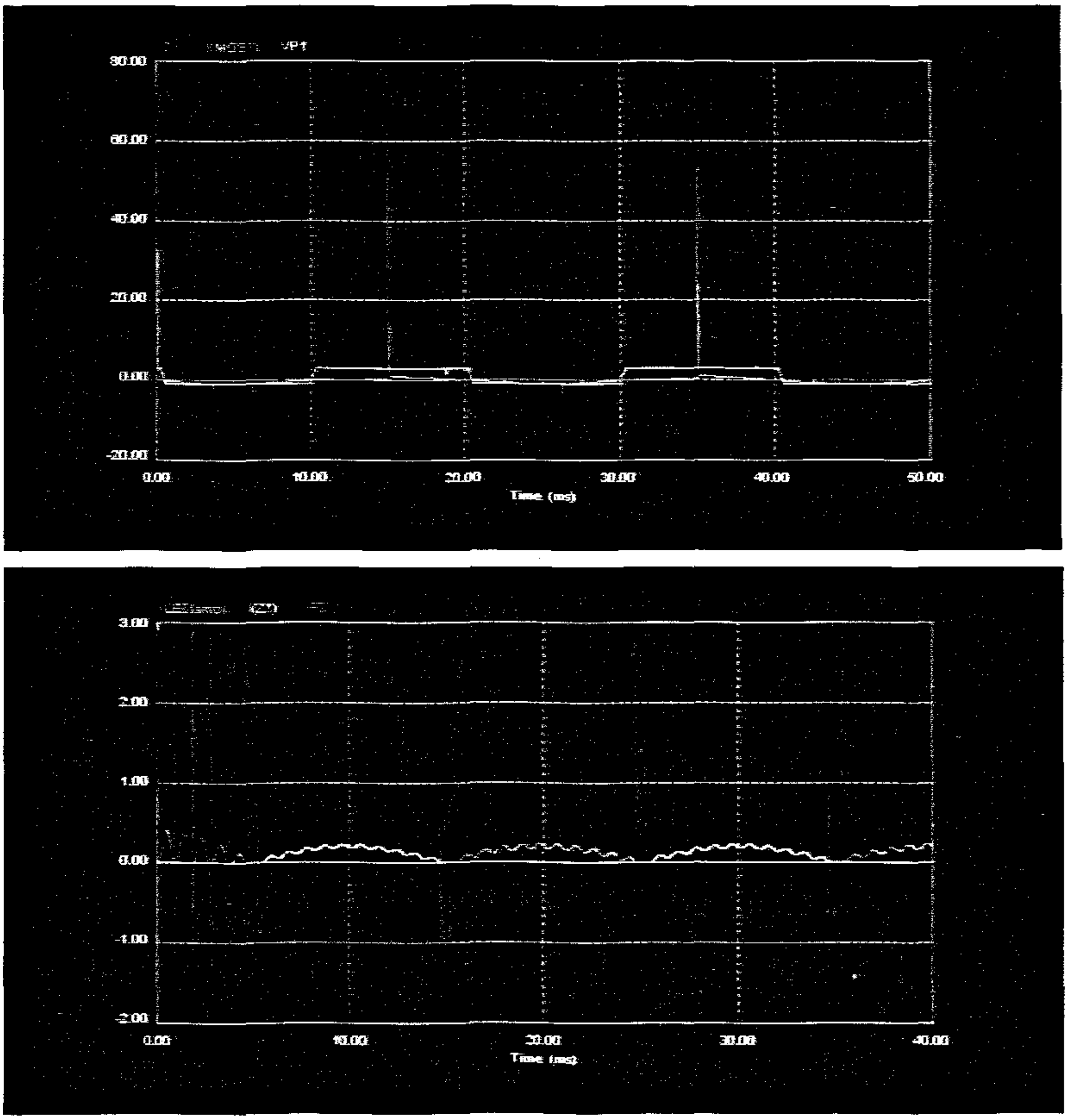


Figure 4.4.5.1: Simulated lamp waveforms of circuit without filter

The output of waveforms of an improved circuit with filtering is shown in Figure 4.4.5.2. The current flowing through the LED is less than 0.4A.

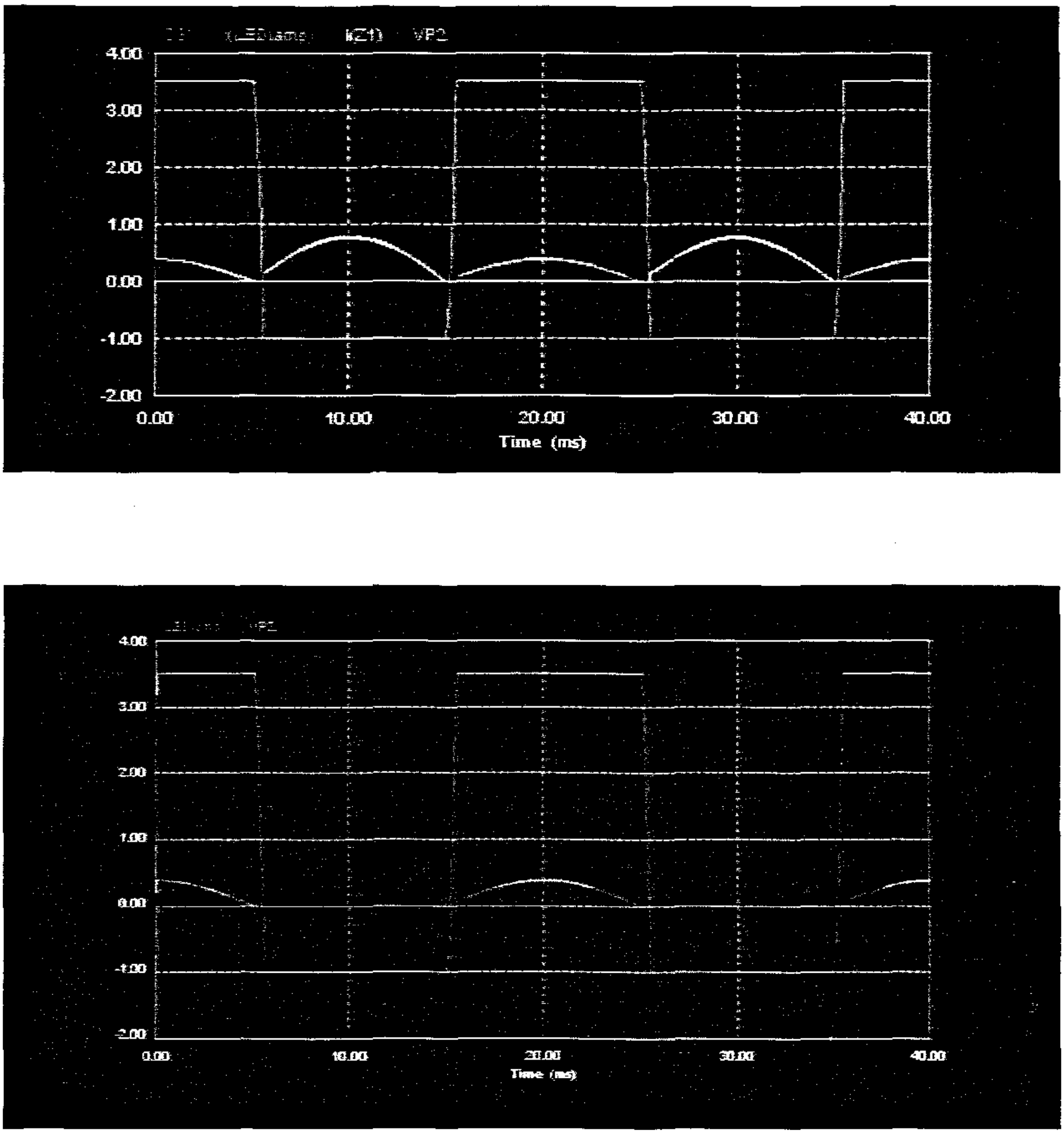


Figure 4.4.5.2: Simulated lamp waveforms of circuit with filter

4.4.6 Prototypes and Possible Configurations

The prototypes can be used in one of the following configurations:

1. Standard 230V AC application: In this configuration, the lamp is screwed into the standard conventional 230V lamp socket.
2. Any other AC supply voltage below 230V: In this configuration, the lamp components are altered to operate at that specific AC voltage below 230V.

Figure 4.4.6.1 shows the first AC HB-LED lamp prototype and Figure 4.4.6.2 displays the improved version.

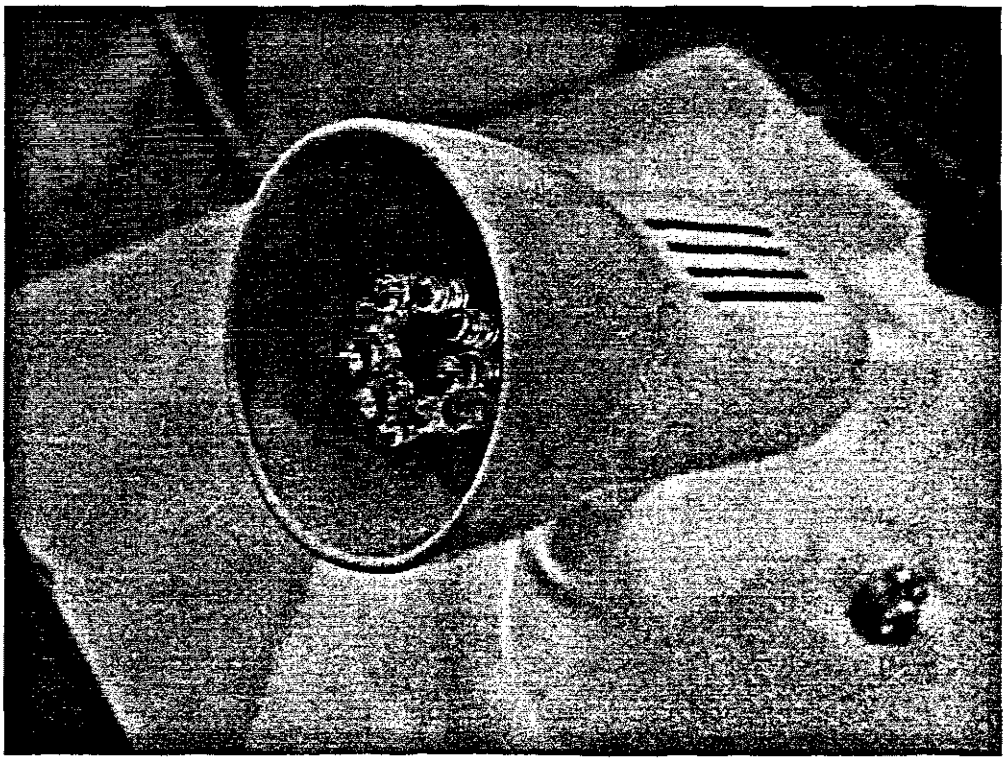


Figure 4.4.6.1: First AC HB-LED lamp prototype

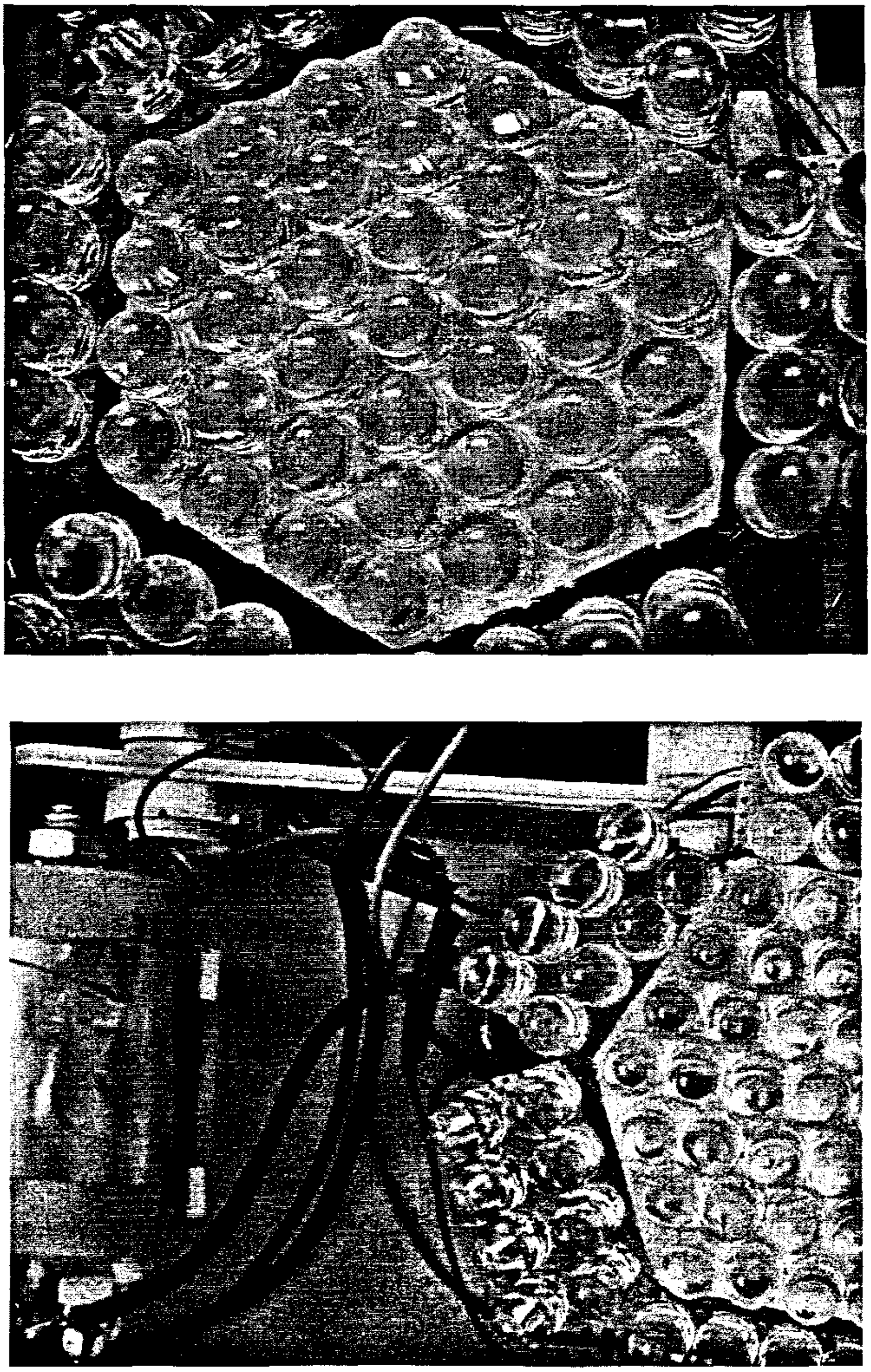


Figure 4.4.6.2: Improved AC HB-LED lamp prototype

4.4.7 The case of the stand-alone light system

An inverter for a 220V AC CFL outdoor stand-alone street light system is designed and built, to complement the indoor HB-LED system. Off the shelf CFLs were used as the lamp source. This project is aimed at collecting the sun light energy through the solar panel to provide lighting for pedestrians using walkways in rural and remote areas after dark. This stand-alone streetlamp should be easy to install on site. The conceptual idea is to provide adequate illumination with a compact fluorescent lamp (CFL) driven by a rechargeable battery. In this case solar energy is used to charge a battery with a solar panel via a control circuit. Lighting is supplied for a certain period of time after dark only (and not for the entire night). A light level detector is used for this purpose. During the daylight hours the battery is recharged to full capacity through a solar panel. The solar panel is positioned on a lamp pole. The solar panel is small so that it is not unsightly on the rural landscape. The battery output is used as the supply to an inverter. A prototype low cost inverter was built and implemented. The output of the inverter was used to drive a 220V CFL in a custom made street lamp unit.

4.4.7.1 Design Configurations of stand-alone lighting system

Since conventional incandescent lamps are very inefficient CFLs provided a cost effective solution. The street lamp consists of a solar panel, a lamp pole, the CFL, the inverter and a battery. The battery is charged in daytime by storing energy from the solar panel via a charger controller circuit. The fully charged battery would in return provide direct current to the input of a low cost inverter. Figure 4.4.7.1 illustrates a block diagram of circuit functionality of the AC supply of the design. The solar panel is connected to the batteries, feeding the inverter that supplies the load.

In the prototype a battery charging circuit was constructed and inserted in-between the solar panel and batteries, to prevent the batteries from overcharging or being run completely down.

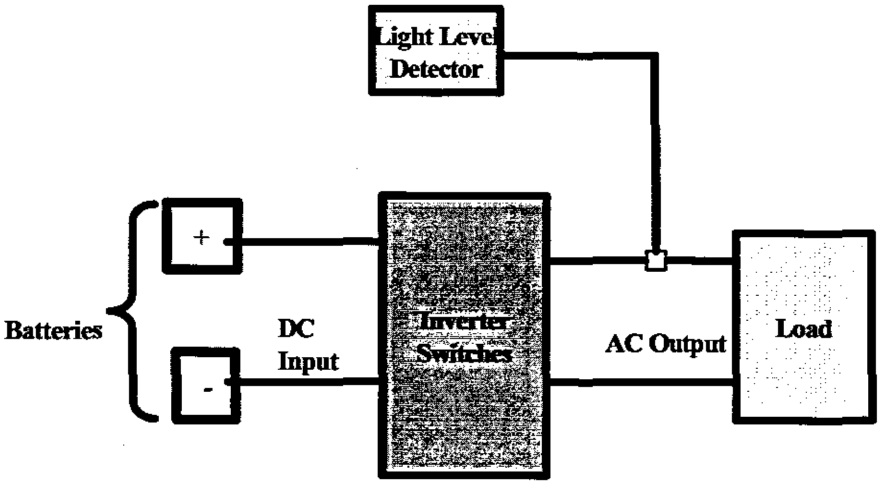


Figure 4.4.7.1: System Block Diagram

4.4.7.2 System Operation and Specification

The stand alone lighting system consists of:

The Solar Panel - Photo-voltaic cells of the panel absorb the sunlight energy during daylight and and even overcast weather conditions. The peak voltage of the solar panel used was 16.97V, The rated current was 3 A. The rated power was 50W.

The Battery - Deep cycle lead acid batteries are used. This is due to the fact that that it must sustain the luminaire source for a stipulated period at a specific discharge rate. The Amp-Hour rating of the battery shall be no less than 18 Amp-Hr.

The Battery Charging Circuit - Another essential component of the system is the battery charge controller. The charge controller is used to regulate the charging of the battery and allows the battery to be charged to a preset voltage without overheating the electrolyte. The charge controller extends the life expectancy of the battery tremendously by setting the operating voltage within specific limits. The schematic diagram of a Solar Panel Charge Controller is shown in Appendix E.

The Inverter - This is a device that converts a 12V DC voltage of the battery to 220V AC. The DC is converted to a square wave pulse train by the NAND gates, used as inverters. The output voltage is stepped up by the transformer. The 30VA inverter is designed to power an 18 W energy saver compact fluorescent bulb. Figure 4.4.7.2.1 shows the schematic diagram of the inverter [http://www.eklektrix.com/solar, 2006] and Figure 4.4.7.2.2 displays the constructed inverter in a metal casing. Figure 4.4.7.2.3 displays the complete unit and the circuitry inside the box of the prototype.

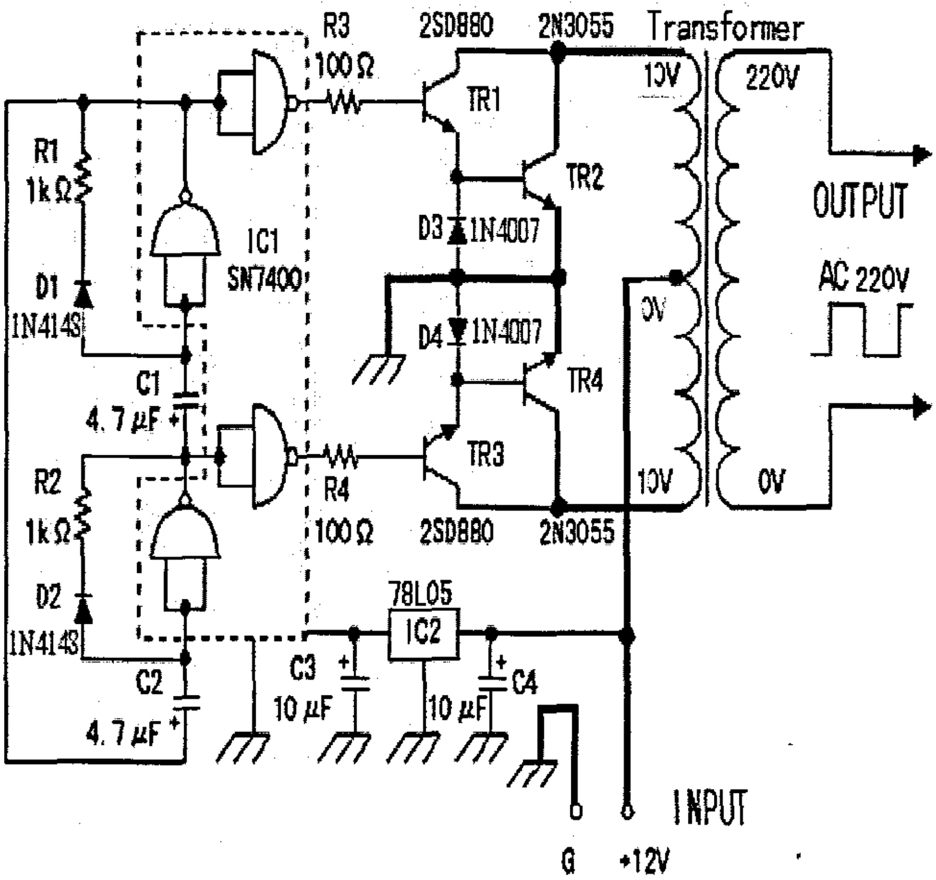


Figure 4.4.7.2.1: The Inverter Schematic Diagram

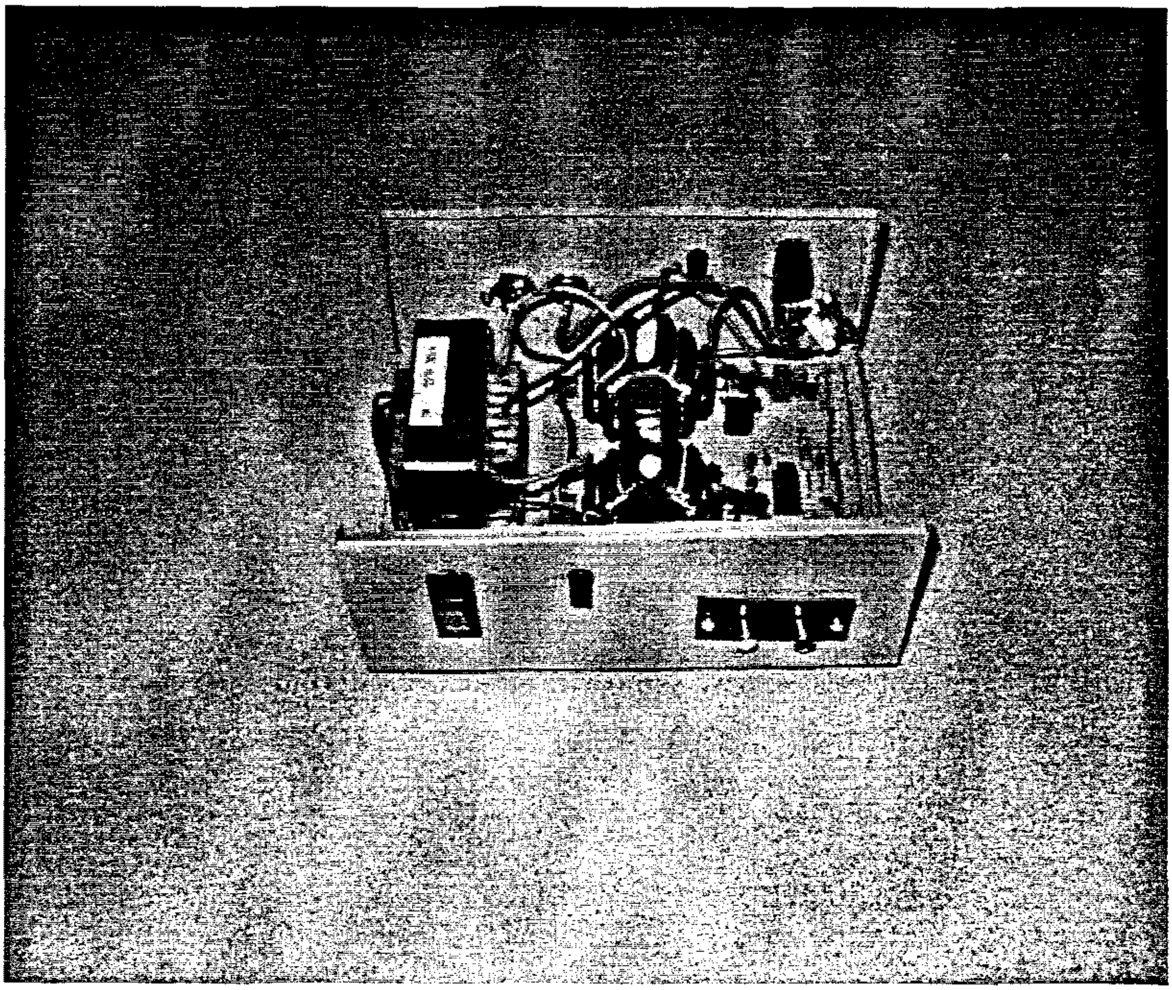


Figure 4.4.7.2.2: The 30VA Inverter prototype

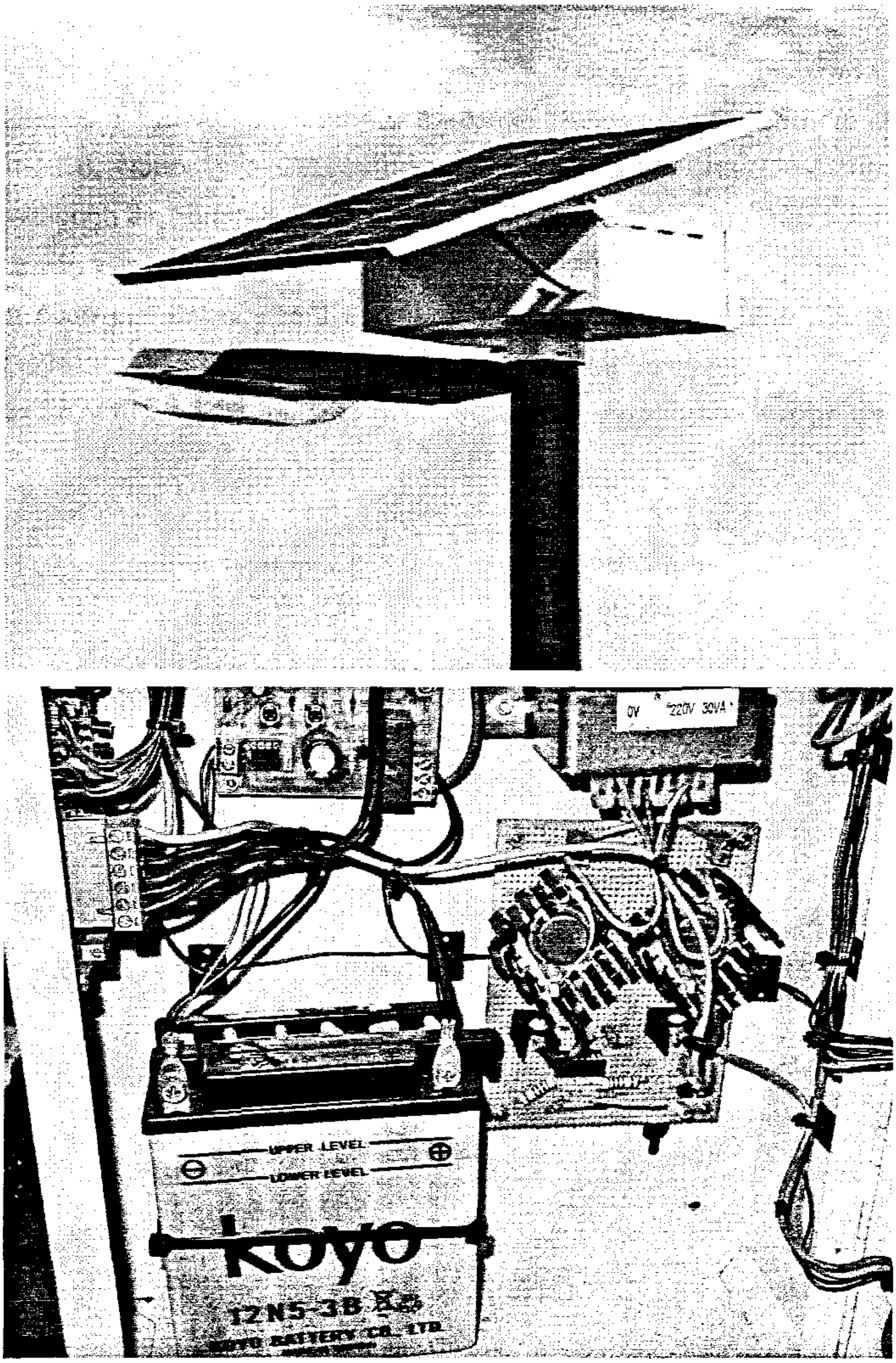
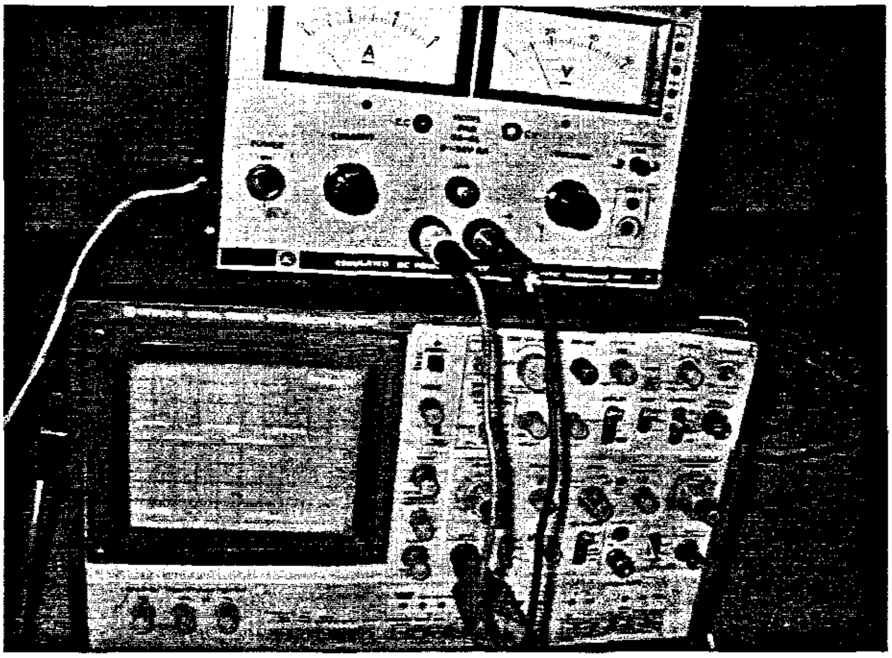


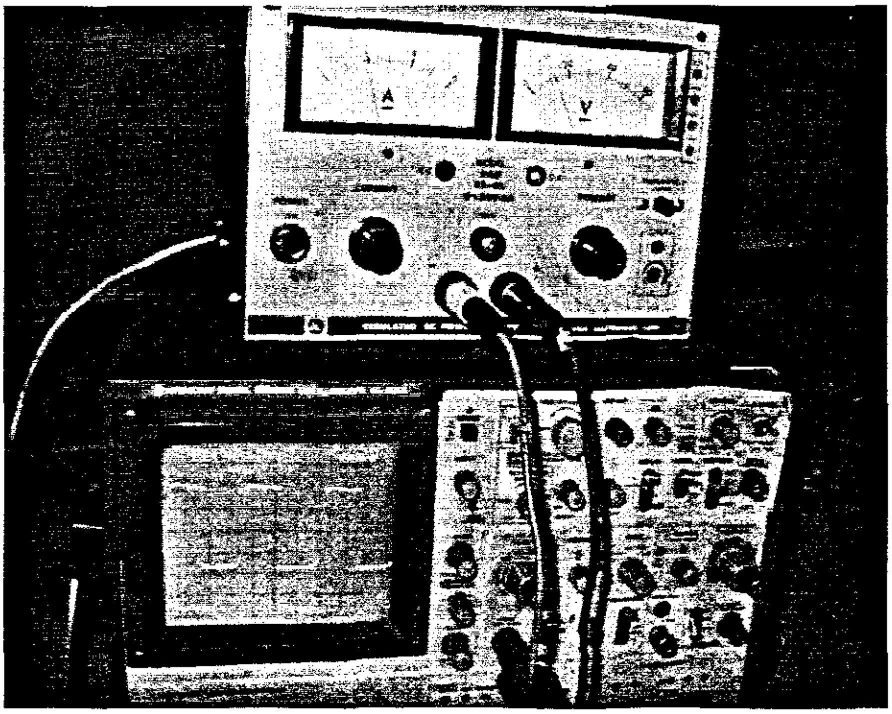
Figure 4.4.7.2.3 Photograph of complete unit (top) and circuitry inside the box (bottom)

4.4.7.3 Test Results

The output waveforms of the oscillator with and without a load are shown in Figure 4.4.7.3. Normally a CFL is driven by the mains 50Hz 220V supply sine wave. Although the inverter output is a rectangular waveform, the CFL operated as if it was driven with a mains input. The inverter was designed by using low cost transistors in a push pull arrangement and a single oscillator circuit. The oscillator rectangular waveform drives the push pull transistors, and is then stepped up by the transformer to 220V AC. A 50Hz output waveform at rated specification was produced.



Inverter Output Waveform without load



Inverter Output Wave Form with 18W CFL Load

Figure 4.4.7.3: Inverter Output waveforms

4.4.8 Conclusion

Although the supply voltage to the lamp was rectangular and not a sine wave, the lamps operated well. The lux-levels increased drastically when a reflector was installed. The 20 HB-LED dc lamp dissipated 21W (7.2A & 3V). The 8 HB-LED AC LED lamp dissipated 4.76W. These lamps have the following advantages. It:

- uses less power (21W compared to a 60W incandescent lamp)
- is protected against surges and spikes from the AC supply.
- has a longer lifespan
- runs at a very low temperature
- is more efficient
- still operates if some of the LEDs blow.
- directly replaces 230V conventional lamps without modifying lamp socket / fitting
- is environment friendly – no glass, no mercury etc.
- LEDs stimulate cytochromes in the body that increases the energy metabolism of cells [Matei, 2004:607]. Cytochromes convert sugar into instant energy that is required by the body to perform its functions.

CHAPTER FIVE

OPTIMIZATION OF AN INEFFICIENT HYBRID SOLAR–DIESEL SYSTEM ON A FARM IN CALVINIA

5.1 Introduction

A farm in a rural part of the Northern Cape is situated very far from the national electricity grid. Farms in that area (Niewoudtville near Calvinia) are supplied with electricity by wind turbines, solar panels, diesel generators or a combination of two or three of them. Calvinia is about 300 km from Cape Town. A big problem was the fact that the outputs from these devices were connected directly to the batteries, without any voltage regulation. This specific farm had an inefficient hybrid solar–diesel system. Figure 5.1 displays the equipment with the author and farmer in the foreground, on the farm.

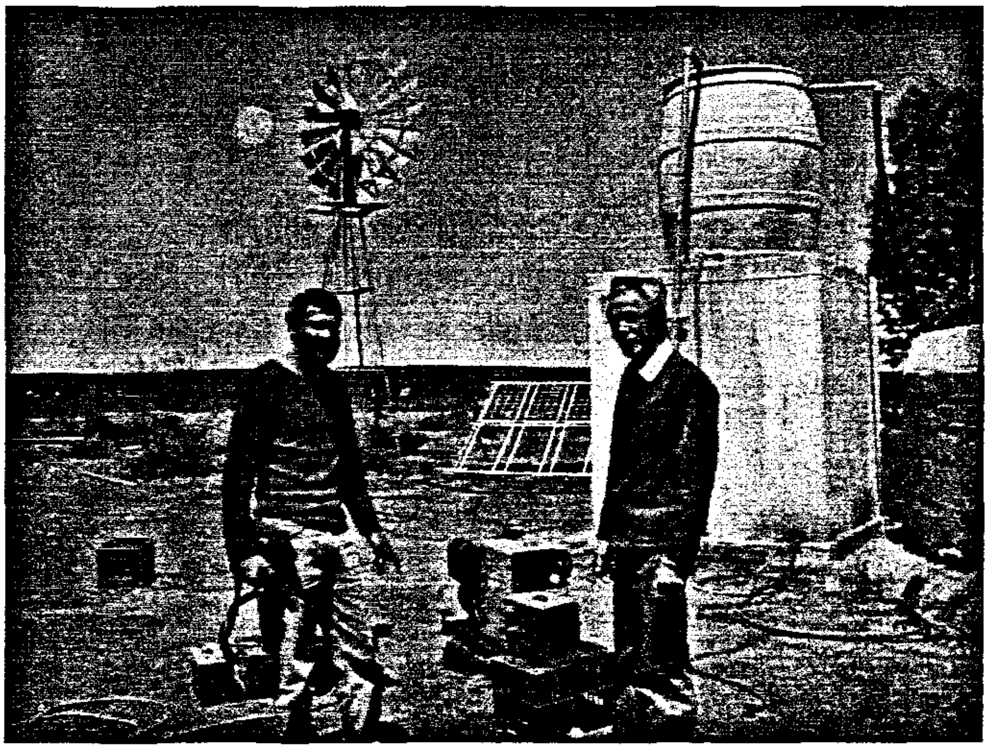


Figure 5.1: Hybrid solar–diesel system on Nieuwoudtville farm.

The electrical supply utility, ESKOM, cannot cope with the growing demand in South Africa. This results in load shedding and power outages. This capacity can be augmented, by conducting energy audits, retrofitting government buildings, designing and installing cost-effective lighting systems, and using renewable energy sources in rural areas. Households in rural areas depend on candles and paraffin lamps to supply light at night. The author is a member of the Centre for Distributed Power Electronic Systems (CDPeS) at the CPUT. CDPeS specializes in contract research and works in collaboration with government organizations, private companies in industry, the community and students. This chapter discusses the optimization of an inefficient hybrid solar–diesel system on a farm in Calvinia. Power from the National Grid is not established in this area. The farmer is supplied with electricity by solar power and a diesel generator. A new high voltage regulator was designed to protect the batteries on site, from overcharging. Recommendations were made to optimize the system.

5.2 Existing Solar-Diesel System

5.2.1 Solar Panels

The farmer uses six solar panels (two banks of three) rated at 80Wp each, as shown in Figure 5.2.1.1. The PV panels are mounted on a frame with wheels. The farmer also manually rotates the PV panels to follow the movement of the sun, to maximise direct sunlight on the solar panel coverage area as shown in Figure 5.2.1.2.

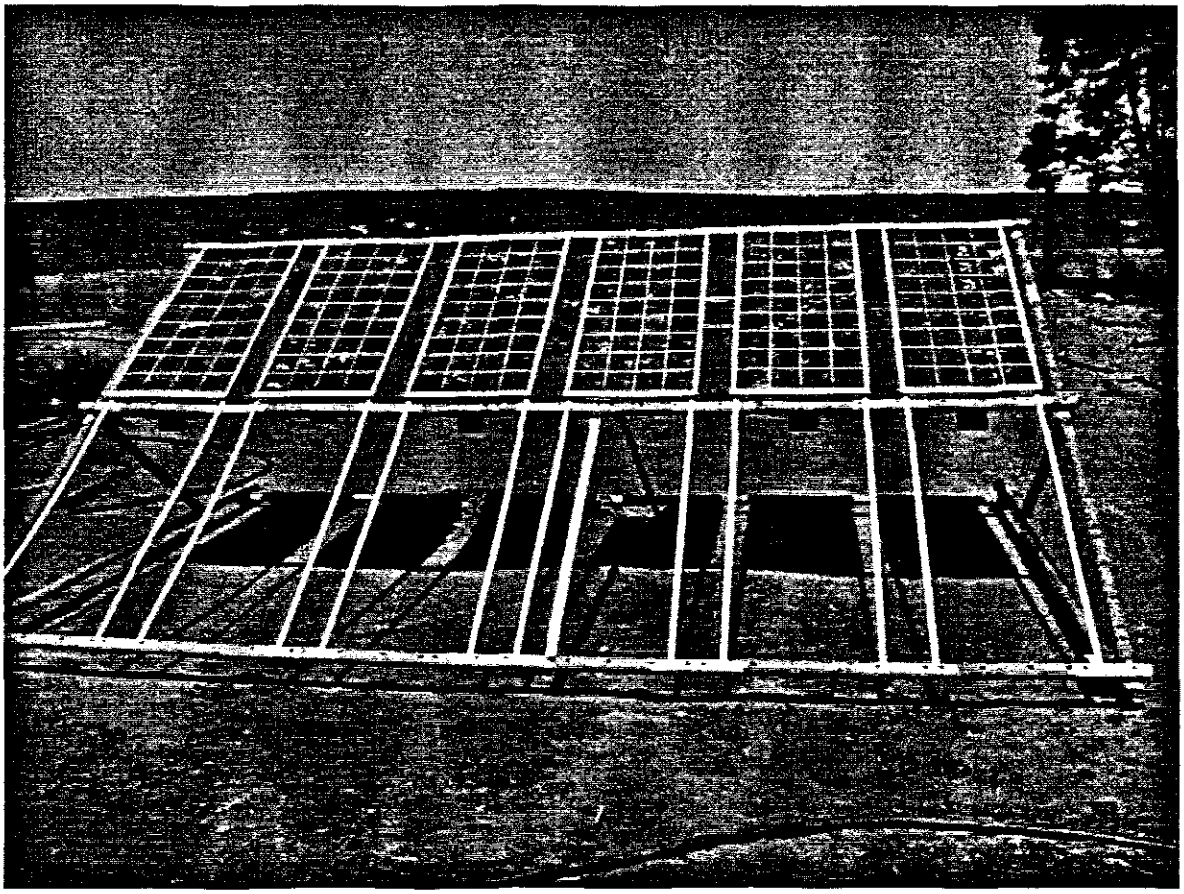


Figure 5.2.1.1: Solar panels mounted on movable frame

The TE500 solar panel specification is listed in Table 5.2.1.

Table 5.2.1: Solar panel specification

TE 500 Photovoltaic Module Specification		
Power (Wp)		80
Current at rated operating voltage (A)		3.5
Open circuit voltage (V)		22.7

Figure 5.2.1.2: The farmer at the Solar panel frame mounted on wheels

5.2.2 The Inverter

The inverter is manufactured by MTL Drives and is rated at 4kVA on the secondary side (220V AC) with a 36V dc input supply. The inverter switched off automatically if the dc supply (from the batteries) drops below 11.6V. Then the farmer is to manually start up the generator. The inverter is depicted in Figure 5.2.2.

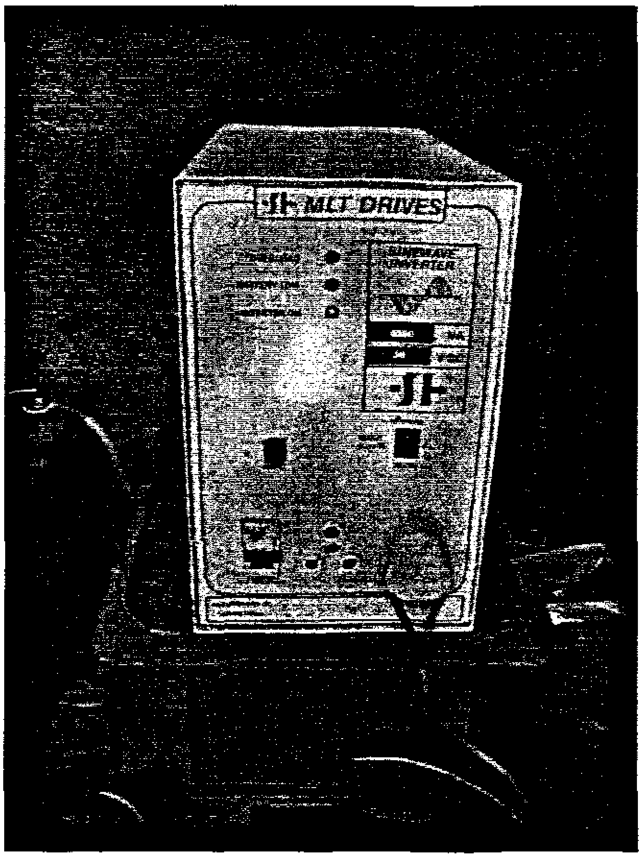


Figure 5.2.2: The Inverter

5.2.3 The Batteries

The supply to the inverter is four parallel battery banks. Each bank consists of three 12V batteries in series. The batteries are installed in an out building about 30m from the main dwelling. See Figure 5.2.3.1.

Figure 5.2.3.1: Inside the battery room

Figure 5.2.3.2 shows the measurement of the terminal battery bank voltage.

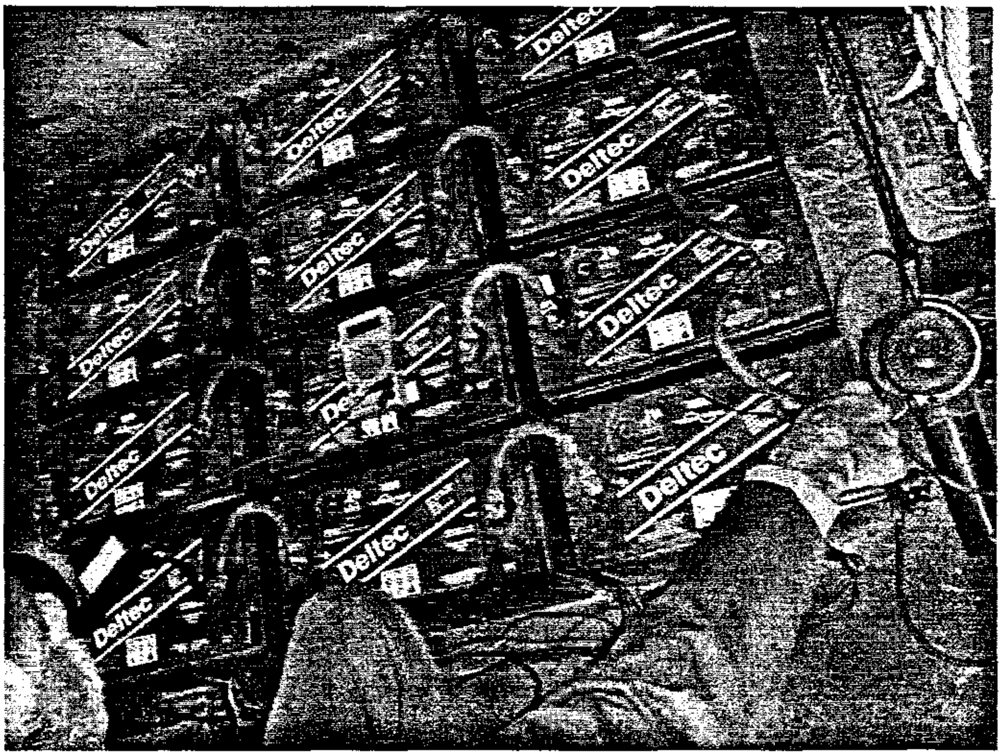


Figure 5.2.3.2: Measuring terminal battery bank voltage

5.2.4 The Generator

The disadvantage of the system was the fact that the farmer had to manually start up the generator when the battery voltage went below 11.6V. The generator on site is shown in Figure 5.2.4.

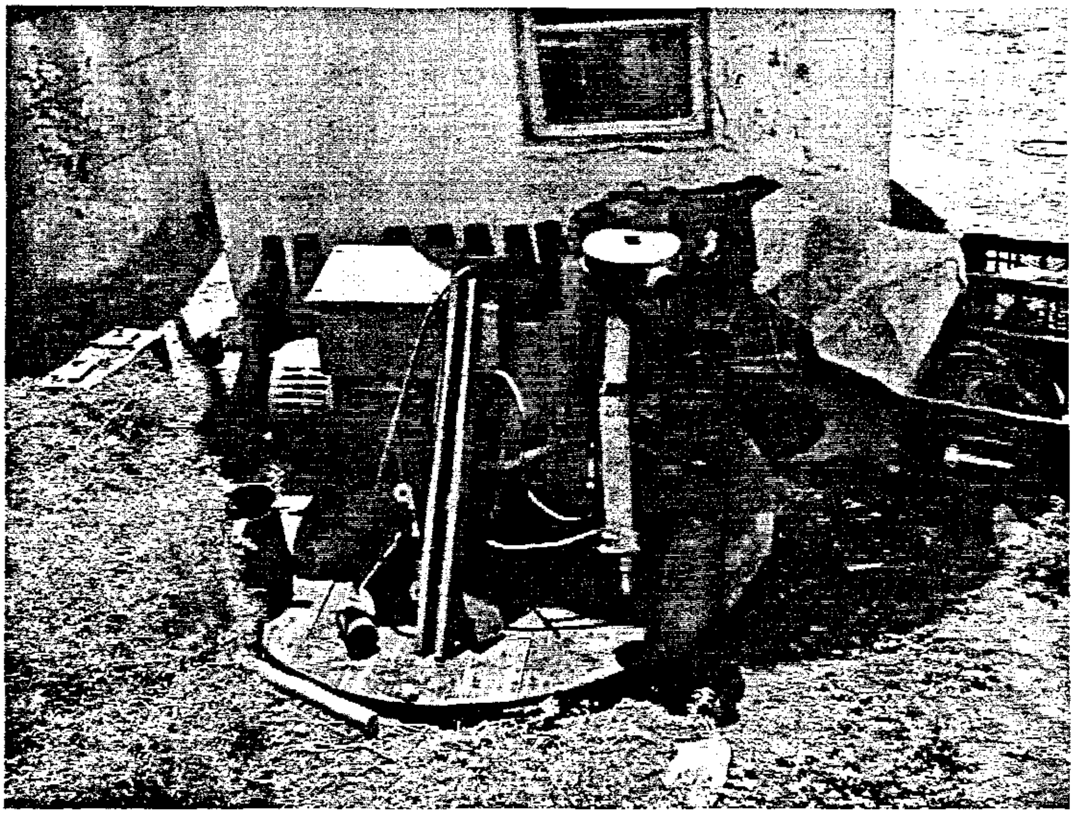


Figure 5.2.4: The generator

5.3 Optimization of System

5.3.1 Battery Theory

Batteries were invented in the early 1800's, by Alessandro Volta when he generated electric current from chemical reactions between different metals disks (zinc and silver) saturated with seawater. When Volta stacked the metal disks in a certain pattern a voltage could be measured between each zinc and silver disk. Today the basic principle stays the same with lead acid cells that that are subdued to chemical reactions while being charged and discharged. See Table 5.3.1.1 for a comparison between the different types of batteries. [Ekelectrix, 2004]. Lead acid batteries have lead plates submerged in a sulphuric acid solution (35% sulphuric acid and 65% water). The positive electrode plates are made of lead dioxide (PbO_2) while the negative electrodes are made of sponge metallic lead (Pb). The electrolyte solution provides the sulphate ions, supplying the electrons needed for current flow. During this process a by-product, namely lead sulphate ($PbSO_4$) is created and is deposited onto the electrode plates. This raises the internal resistance of the battery and lowers the battery terminal voltage. The ambient temperature and age of the battery (amount of lead sulphate deposits) determines the State Of Charge (SOC) of a lead acid battery. As more energy is drained from the battery, the ratio of sulphuric acid to water decreases, resulting in a low hydrometer reading, resulting in the generation of less free electrons. The specific gravity of a substance is a comparison of its density to that of water (1.000). The breakdown of the electrolyte reduces its overall 'weight' as the sulphur is removed from the solution. This reduces the specific gravity measurement. Table 5.3.2 shows that even if a voltmeter reading of 11.64 is given by the normal voltmeter, the SOC of the battery is zero. Deep cycle lead acid batteries are used. This is due to the fact that that it must sustain the source for a stipulated period at a specific discharge rate.

Table 5.3.1.1: Comparison between batteries

PLATE TYPE	LEAD CALCIUM	LEAD-CALCIUM ANTIMONY (6%)	LEAD-CALCIUM ANTIMONY (2%)	NICKEL CADMIUM
ELECTROLYTE	Liquid	Liquid	Liquid	Liquid
TYPICAL DOD	50%	80%	80%	100%
DESIGN USE	Automotive	Traction	Emergency Power supplies and PV	PV
SELF-DISCHARGE RATE	Low	Medium	Low	Low
CYCLE LIFE	Low	Medium - Long	Long	Long
SEAL	Vented	Vented	Vented	Vented
MAINTENANCE	Infrequent	Frequent	Infrequent	Minimal
CAPITAL COST	Low	Mid-range	Mid-range	Very High
SUITABILITY FOR PV USE	Not Recommended	Recommended	Highly Recommended	Highly Recommended

Table 5.3.1.2: State Of Charge (SOC) of Lead acid batteries

STATE OF CHARGE RELATED TO SPECIFIC GRAVITY AND OPEN-CIRCUIT VOLTAGE		
State of Charge (%)	**Specific Gravity**	**Open-Circuit Voltage (V)**
100	1.265	12.63
75	1.21	13.3
50	1.16	12
25	1.12	11.76
0	1.1	11.64

5.3.2 Battery Charge Controller with Test Results

Another essential component of the system is the battery charge controller. The charge controller is used to regulate the charging of the battery and allows the battery to be charged to a preset voltage without overheating the electrolyte. The charge controller extends the life expectancy of the battery tremendously by setting the operating voltage within specific limits. A battery charging circuit (controller) is constructed and inserted in-between the solar panel and batteries, to prevent the batteries from overcharging or being run down completely. A schematic diagram of a charge controller circuit is shown in Appendix F. This diagram was sourced in an articles in Home Power Magazine. The author however designed a voltage regulator to perform the function of a Battery Charge Controller. The schematic diagram is shown in Figure 5.3.2.

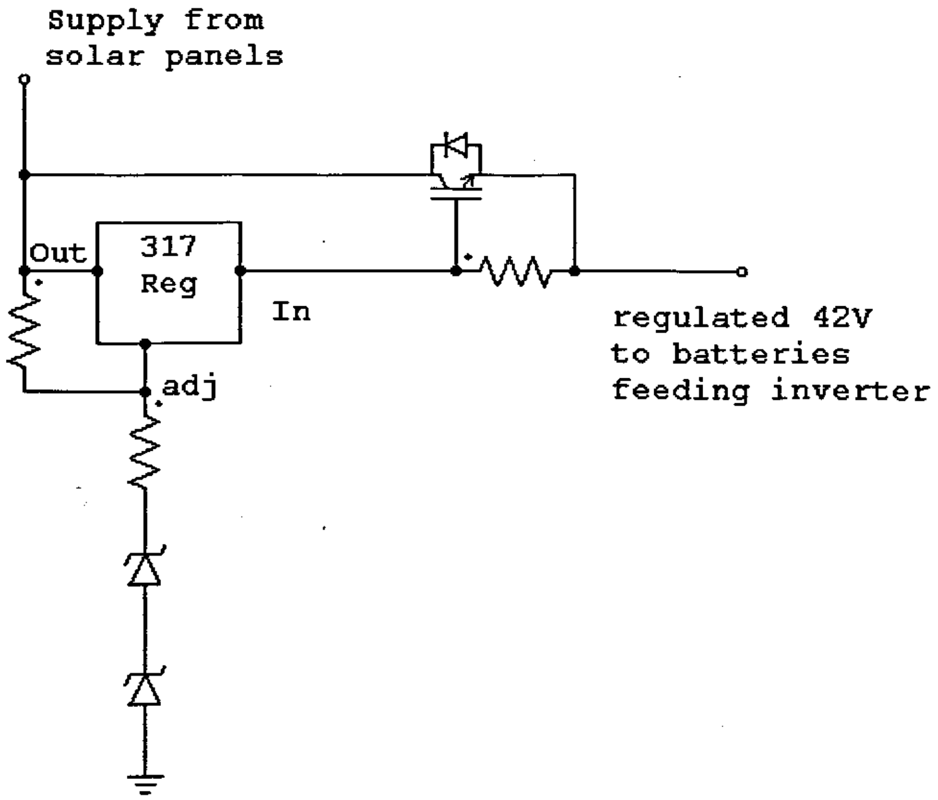


Figure 5.3.2: Schematic diagram of designed voltage regulator.

The test results of the prototype voltage regulator in Figure 5.3.2 is listed in Table 5.3.2.

Table 5.3.2: Test Results of the voltage regulator

Output of Voltage Regulator	
Supply Voltage with load (batteries)	**Supply Voltage without load (batteries**
43.6V	**43.9V**

5.4 Recommendations

To optimize the system on the farm in Calvinia the following recommendations were made:

- A new high voltage regulator was designed and is to be installed, to prevent the batteries from being overcharged.
- An energy management plan is to be implemented.
- Certain household appliances are to be connected to a timer to perform load shedding.
- Remote on-site monitoring of system parameters is to be done
- A stepper motor can be used for automatic rotation of the solar panels to constantly face the sun's direct sunbeams.
- The solar panels and batteries are installed too far from the main dwelling. The distance should be made as short as possible.
- A self-start generator that is automatically switched on when the battery voltage level goes below a certain voltage.
- Replacement of all incandescent lamps with CFLs.
- Replacement of lamps with cost effective HB-LED lamps if they become available.

5.5 Conclusion

The voltage regulator should significantly increase the lifetime of the twelve batteries. The shortened distance from the equipment to the load will decrease the voltage drop across the cables. It was recommended that appliances should be connected to a timer to perform load shedding. On-site monitoring and an energy management plan needs to be implemented. The installation of a self-start generator will prevent blackouts.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Concluding remarks of the thesis are as follows:

This thesis is based on theoretical and practical work regarding the research objectives. The research objectives of this thesis have been met by writing a program with the JAVA software to display isolux diagrams of lighting designs. It verifies lighting design results of a general lighting system. After an energy audit at the school in Worcester was done, the lighting system was retrofitted with more energy efficient lamps. A low cost energy efficient, renewable solid state lighting system was designed and a prototype was built. Recommendations were given to optimise an existing inefficient off-grid hybrid solar–diesel system in Calvinia.

6.1 Illumination Software Development

The developed software in Chapter 2 displayed the desired graphics properly. Students can now verify whether their calculations were done correctly. The current software is user friendly and warns the user when the chosen data will result in a faulty design. This can be seen on the display in Figure 2.3.2.3. The software could also confirm a design done with HB-LEDs. For future study, the software can be upgraded and grown into an expanded educational package, where lighting systems can be designed immediately on site. The importance of the implementation of the software development is that it will improve lighting efficiency. By improving lighting efficiency, electrical engineers and architects can contribute significantly to energy consumption reduction. Most northern continents have already moved far in this direction or are in the process of doing so. We need to promote the active research and development in this field in African countries.

6.2 Energy Audit at the school in Worcester

The biggest problems encountered while conducting the energy audit project at the school in Worcester were the unavailability of lighting plans, floor plans or updated floor plans, unmarked room numbers, the inaccessibility of certain areas, fused lamps, missing lamps, new installations in progress and manpower shortage. After the energy audit was conducted, it revealed that the replacement of approximately 1000 T8 and T12 fluorescent tubes with triphosphor lamps and the replacement of 800 incandescent lamps with energy efficient CFLs would reduce the energy consumption of the interior lighting of the complex with 24.5MWh. This results in a saving of R 12 782 per annum. These recommendations were implemented by Innovative Energy Projects and community members and it resulted in a payback period of just over 4 years.

This project highlights the importance of energy efficient, cost effective electrical lighting installations. The standard of living of the community has been improved as follows:

- Most of the incandescent lamps were darkened as the tungsten was deposited on the lamp walls. With the retrofit the learner's productivity is increased, due to the proper lighting levels.
- The learners can benefit from the electricity bill the savings if the now available funds are utilized elsewhere at school.
- The unemployed assisted with the lamp retrofits and cleaning of lamp covers. For their contribution they earned a wages

6.3 Development of a solid state distributed lighting system

Although the supply voltage to the stand alone-lamp, discussed in Chapter 4, was rectangular the lamp operated as if it was driven by a sine wave. The lux-levels increased drastically when a reflector was installed. The AC LED lamp has the following advantages:

- It uses less power and
- is protected against surges and spikes from the AC supply.
- It has a longer lifespan and
- runs at a lower temperature than incandescent lamps (this results in less air conditioning)
- It is more efficient,
- still operates even if some of the LEDs blow and
- directly replaces 230V conventional lamps without modifying lamp socket or fitting.
- It is environment friendly (no glass and mercury).

For future study:

- Another protection device can be investigated. Although transorbs and thermistor were installed in the supply line, sometimes high currents with switch-on still blew the HB-LEDs
- Due to lack of sufficient infrastructure, remote monitoring of the lighting system could not be implemented. A recommendation is made that remote monitoring of the lighting system be done as future studies
- The HB-LED driver for DC systems can be developed
- More renewable energy sources can be synchronized with the solar panels to create a proper distributed system

- The synchronising of the designed renewable energy systems to the existing ESKOM grid or any distributed energy generation or hybrid system.
- Another area of research would be the driving the HB-LEDs with both DC and AC sources and
- Setting LV and HV lighting and reticulation standards.
- Installation of the prototypes in rural areas.
- Standards for low voltage building reticulation networks of a HB-LED can be established
- Operating conditions of the system are to be remotely monitored by using data loggers and programmable transceivers

6.4 Optimization of an inefficient hybrid solar-diesel system on a farm in Calvinia

To optimize the hybrid solar-diesel system on the farm in Calvinia the following recommendations were made:

- A new high voltage regulator was designed and is to be installed, to prevent the batteries from being overcharged. The voltage regulator should significantly increase the lifetime of the twelve batteries.
- An energy management plan is to be implemented. Certain household appliances are to be connected to a timer to perform load shedding.
- Remote on-site monitoring of system parameters is to be done.
- A stepper motor can be used for automatic rotation of the solar panels to constantly face the sun's direct sunbeams.
- The solar panels and batteries are installed too far from the main dwelling. The distance should be made as short as possible. The shortened distance from the equipment to the load will decrease the voltage drop across the cables.
- The installation of a self-start generator will prevent blackouts.

The whole farming community can benefit from these recommendations, since it will maximise the battery life of their supply and minimise power cuts.

For future studies the following can be researched:

A self-start generator that is automatically switched on when the battery voltage level goes below a certain voltage should be investigated and established. The automatic rotation mechanism of the solar panels on the farm should be designed and implemented.

In conclusion, the execution of these four research projects was inspired by in what Mahatma Gandhi believed:

"When the last tree has been felled, and the last river has been seized, only then we will finally realize that we cannot eat money."

[Swanevelder, van Huyssteen & Hanekom, 2002:67]

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APPENDICES

APPENDIX A: JAVA Code for Illumination Software

Code of LightControl.java

```
/**
 * Write a description of class LightControl here.
 *
 * @author (your name)
 * @version (a version number or a date)
 */
public class LightControl
{
          private GuiDisplay lightDisplay;

          public LightControl()
          {
                    lightDisplay = new GuiDisplay();
                    lightDisplay.getKnownValues();
                    lightDisplay.displayResults();
          }


          public static void main (String[] Args)
          {
                    LightControl app = new LightControl();
          }
}
```

Code of GuiDisplay.java

```
/**
 * Write a description of class GuiDisplay here.
 *
 * @author (your name)
 * @version (a version number or a date)
 */
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

public class GuiDisplay extends JFrame
{
          private Container content;
          private JTextField roomLength;
          private JTextField roomWidth;
          private JTextField roomHeight;
          private JSpinner utilizationFactor;
          private JTextField maintenanceFactor;
          private JTextField efficiency;
          private JTextField heightSpaceRatio;



          /**
           * Constructor for objects of class GuiDisplay
           */
          public GuiDisplay()
          {
             super(" ILLUMINATION APPLICATION ");
                    content = getContentPane();
```

```
content.setLayout(null);

JLabel label1 = new JLabel("Length");
label1.setSize(100, 25);
label1.setLocation(30, 50);
content.add(label1);

JLabel label2 = new JLabel("Width");
label2.setSize(100, 25);
label2.setLocation(30, 100);
content.add(label2);

JLabel label3 = new JLabel("Height");
label3.setSize(100, 25);
label3.setLocation(30, 150);
content.add(label3);

JLabel label4 = new JLabel("Utilization Factor");
label4.setSize(120, 25);
label4.setLocation(230, 50);
content.add(label4);

JLabel label5 = new JLabel("Maintenance Factor");
label5.setSize(120, 25);
label5.setLocation(230, 100);
content.add(label5);

JLabel label6 = new JLabel("Efficiency");
label6.setSize(120, 25);
label6.setLocation(230, 150);
content.add(label6);
```

```
JLabel label7 = new JLabel("Hieght Space Ratio");
label7.setSize(120, 25);
label7.setLocation(230, 200);
content.add(label7);

roomLength = new JTextField("10");
roomLength.setSize(60, 25);
roomLength.setLocation(100, 50);
content.add(roomLength);

roomWidth = new JTextField("10");
roomWidth.setSize(60, 25);
roomWidth.setLocation(100, 100);
content.add(roomWidth);

roomHeight = new JTextField("10");
roomHeight.setSize(60, 25);
roomHeight.setLocation(100, 150);
content.add(roomHeight);

utilizationFactor = new JSpinner();
utilizationFactor.setSize(60, 25);
utilizationFactor.setLocation(350, 50);
content.add(utilizationFactor);

maintenanceFactor = new JTextField("100");
maintenanceFactor.setSize(60, 25);
maintenanceFactor.setLocation(350, 100);
content.add(maintenanceFactor);
```

```
            efficiency = new JTextField("100");
            efficiency.setSize(60, 25);
            efficiency.setLocation(350, 150);
            content.add(efficiency);

            heightSpaceRatio = new JTextField("50");
            heightSpaceRatio.setSize(60, 25);
            heightSpaceRatio.setLocation(350, 200);
            content.add(heightSpaceRatio);



            setSize(600, 400);
            setVisible(true);
      }

      /**
       * An example of a method - replace this comment with your own
       *
       * @param  y   a sample parameter for a method
       * @return     the sum of x and y
       */
      public void displayResults()
      {

      }
      public void getKnownValues()
      {

      }
}
```

APPENDIX B

Fluorescent Tube data

T8 (26mm)- avaliable in:

450mm =15watt (18") =0.45m
600mm =18watt (2ft) =0.6m
900mm =30watt (3ft) =0.9m
1200mm =36watt (4ft) =1.2m
1500mm =58watt (5ft) =1.5m

The diameter for all T8 lamps are: 26mm

T12 (38 mm) available in :

600mm = 20watt(2ft)= 0.6m
900mm = 30watt(3ft)= 0.9m
1200mm = 40watt(4ft)= 1.2m
1500mm = 65watt(5ft)= 1.5m
1800mm = 55watt(6ft)= 1.8m
2400mm = 75watt(8ft)= 2.4m

The diameter for all T12lamps are: 38 mm

APPENDIX C

Example of Energy Audit Form

NUWE HOOP ENERGY AUDIT

BUILDING / COMPLEX: DATE:

GROUP: ROOM NO:

Is the room number clearly indicated on the main floor plan? Yes/No

TOTAL NUMBER OF LAMPS IN ROOM: LIGHT METER MODEL NO:

LIGHT METER READINGS (lux): lights off lights on

CEILING HEIGHT: DRAWING OF FLOORPLAN

WINDOW SIZES (m): Width Height

OTHER ELECTRICAL APPLIANCES:

Notes: W Fritz

APPENDIX D

Nuwe Hoop School for the deaf Energy Audit Tables

Lighting Summary: Complete Nuwe Hoop Complex

Interior Luminaires

Location	Installed Luminaires												Installed Wattage
	T8				T12				CFL	Incandescent			
	1.5		1.2		1.5		1.2			60W	75W	100W	
	D	S	D	S	D	S	D	S					
Nuwe Hoop Junior School	14	7	0	0	447	56	24	2	7	101	0	159	98519
Nuwe Hoop Senior School	27	16	0	0	131	30	0	0	0	21	0	144	38700
Nuwe Hoop Pre-primary Hostel	0	0	0	0	1	6	0	0	0	66	0	0	5980
Nuwe Hoop Senior School Hostel	0	151	0	0	59	33	0	0	3	30	0	165	37462
Total	41	174	0	0	638	125	24	2	10	218	0	468	180661

Exterior Luminaires

Location	Installed Luminaires					
	2D (16W)	PL9 (9W)	Mercury Vapour		Halogen	
			250 W	400 W	500 W	1500 W
Junior School Exterior	4	56	7	4	9	1
Pre-Primary Exterior	0	0	0	1	1	0
Total	4	56	7	5	11	1

Total wattage reflected in Nuwe Hoop Junior School

Figure 3.7.3 Pre-Primary School Outdoor Lamps

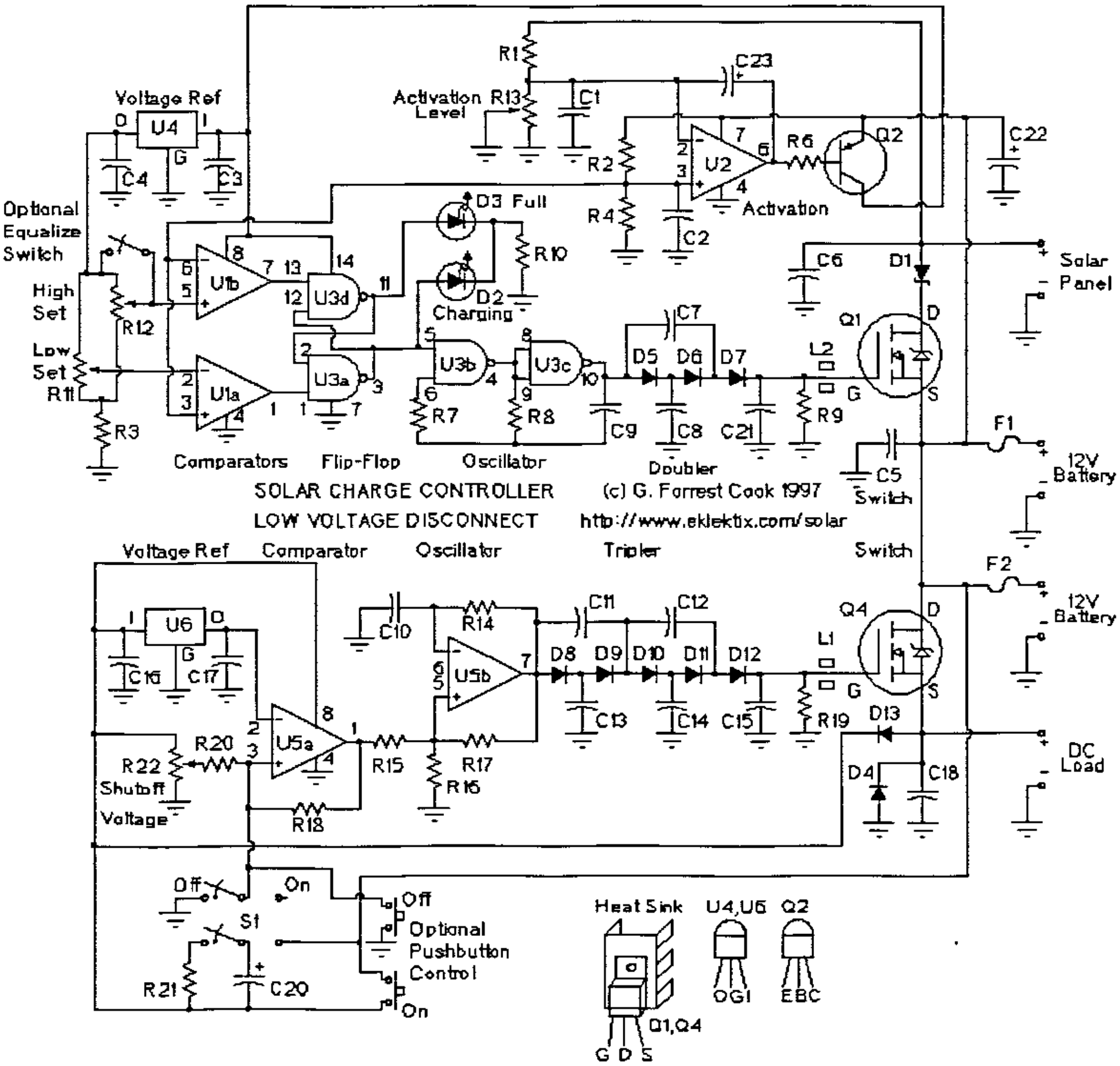
Location	Lamp Type														
	2D (16W)		PL9 (9W)		Mercury Vapour			Halogen			IL			Wattage	Total Wattage
	No.	Wattage	No.	Wattage	250W	400W	Wattage	500W	1500 W	Wattage	60W	75W	100W		
Front Entrance		0		0			0			0	1			60	60
Driveway		0		0			0	1		500				0	500
Left Front		0		0		1	400			0				0	400
TOTALS	0	0	0	0	0	1	400	1	0	500	1	0	0	60	960

APPENDIX E

Schematic diagram of Solar Panel Charge Controller

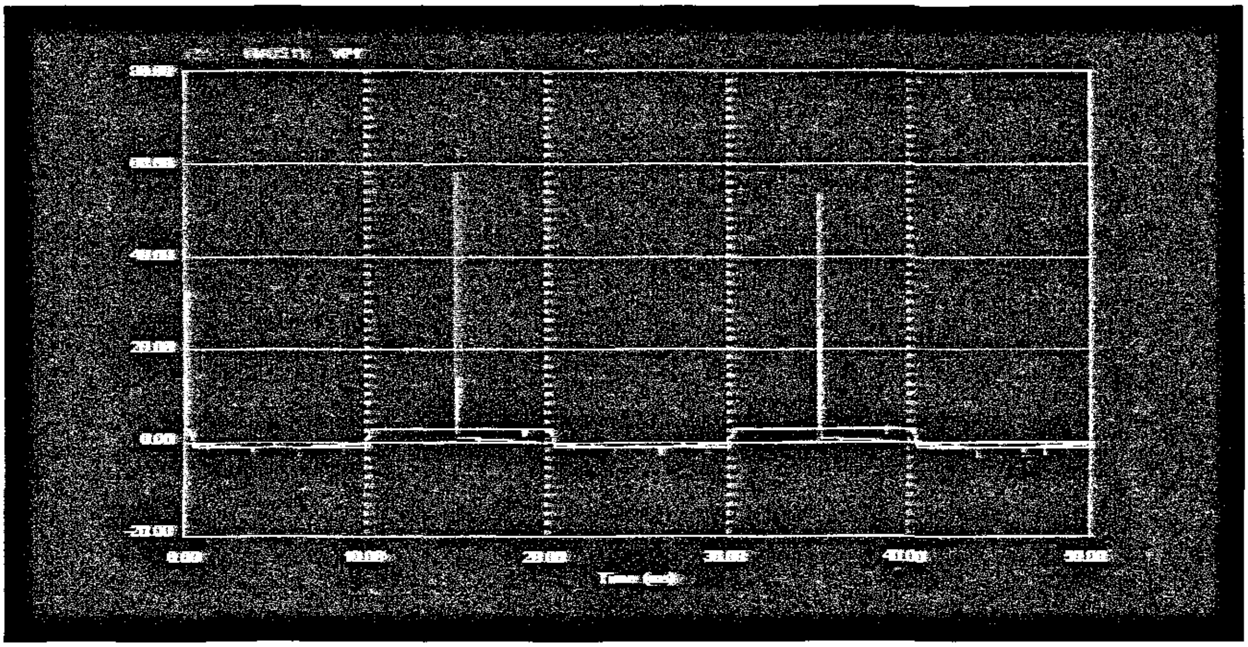
This design appeared as a pair of articles in Home Power Magazine.

The charge controller is used to connect a solar panel to a 12 volt lead acid battery, it regulates the charging of the battery and allows the battery to be charged up to a preset voltage. This prevents the battery from over-charging and boiling off electrolyte. The low voltage disconnect is used to connect a load to the same 12 volt lead acid battery, the LVD acts as a smart switch, it auto disconnects the load if the battery voltage falls below a set point. When used together, these circuits keep the battery operating within normal voltage limits which greatly extends the life of the battery.



APPENDIX F

Simulation shows surges on the supply lines produced large currents of up to 60A to flow through LED lamp



APPENDIX G

Energy Audit Report of Langa High School

APPENDIX G

Lighting Assessment for Langa High School

A project undertaken by staff and students of Peninsula Technikon in collaboration with BONESA and FEDSET.

November 2002

By:		
	H Fawkes	W Fritz
	I Omar	M Gugwana
	M Mjanyelwa	M Ngcizela
	S Mabandla	X Mpendukane
	C Nkambule	N Rachoene
	L Skosana	K Mntshontshi

PREFACE

The work described in this report was performed under the direction of the Energy Research Unit (ERU) of the departments of Mechanical and Electrical Engineering at Peninsula Technikon.

Students who collected the data and contributed to this report, attended a two-day course that introduced them to lighting, energy efficiency and electrical safety. Staff at Peninsula Technikon as well as safety training consultants presented the course.

One of the focus areas of the ERU is to identify, evaluate, and recommend, opportunities to conserve energy and minimize waste, thereby reducing costs. Our recommendations are based on observations, measurements and analyses of buildings, people, machines and operations.

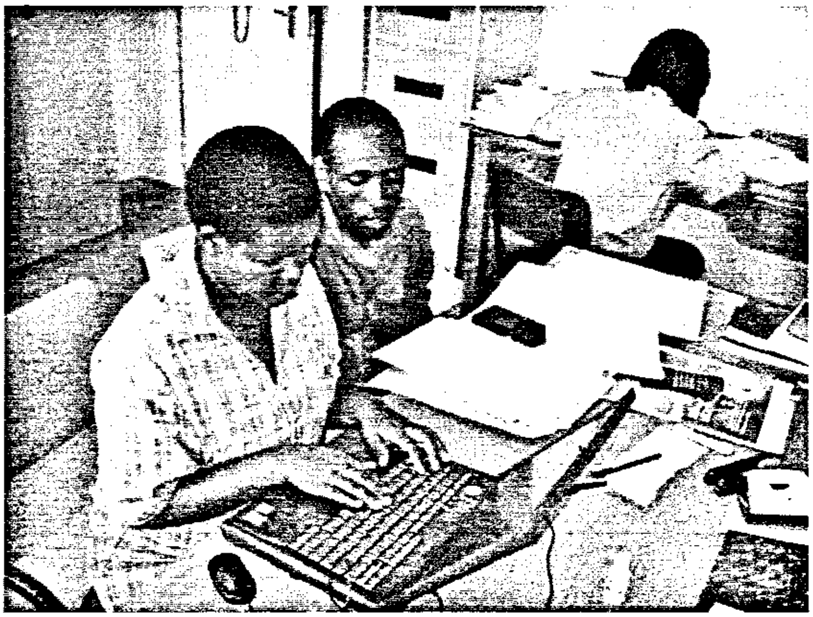
The assumptions and equations used to calculate savings for each recommendation are given in this report. The assumptions represent conservative engineering practice. If the client does not agree with the assumptions, the assumptions may be adjusted. New values for the savings for each opportunity may then be determined.

Please contact the ERU if you would like to discuss the content of this report or any questions you may have about energy use and energy efficiency.

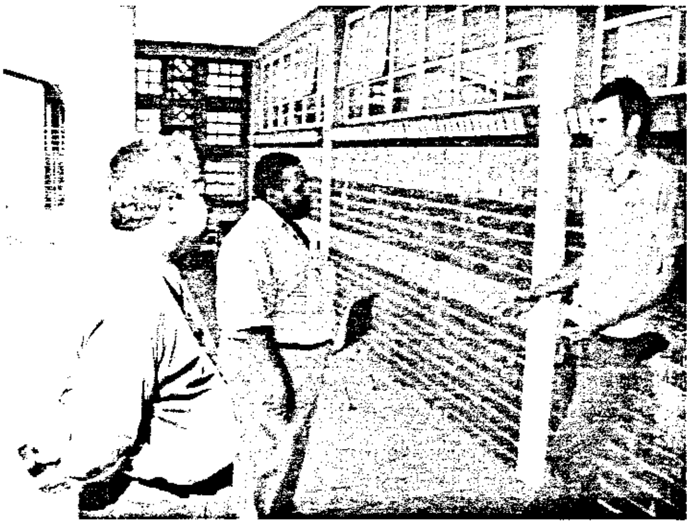
Students measuring window areas.

Acknowledgements

The Energy Research Unit of Peninsula Technikon wishes to express its thanks to Charles Marthinus of BONESA, Mr P Maragan, Ms Nmbeko Ndlovu and Mr B Biyamu, of Langa High School, for their valuable assistance during this assessment.
Thanks also to Walter Kohlhoffer for working on the images in this report.



Milicent Gugwana, OJ Godisamang and 'Sox' April working on the data



Charles Marthinus and associate discussing the project with Howard Fawkes

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8. ADDITIONAL CONSIDERATIONS

1. EXECUTIVE SUMMARY

Assessment date:	November 2002
Location:	Langa High School, Langa, Cape Town
Number of students:	1650
Number of staff	47

The average energy consumption and associated costs at Langa High School are summarized in Table 1 below.

Table 1 – Average energy consumption and associated costs

Energy type	Annual Consumption	Annual Cost
Electricity (kWh)	182 900kWh	R 55 819

If assumptions of <u>light use</u> used in this report are correct, then by far the largest use of electricity is in the light fittings in the classrooms and offices (See Table #, p#).

A summary of the energy conservation opportunities and their associated savings, implementation costs and payback periods, is shown in Table 2 below.

Table 2 – Energy conservation opportunities

	Recommendation	Annual energy saving (kWh)	Annual energy cost saving	Installation costs	Simple payback period
ECO 1	Switch off all inside lights during the night	153 249	R42 573	R25 000 +R250/ month	0,63 years

ECO 2	Replace T12 florescent tubes and all magnetic ballast with T8 florescent tubes and electronic ballast	24 276	R6 744	between R58 949 and R70 899	between 8,7 and 10,5 years

Overall recommendations

Install an alarm system that covers all classrooms and includes security response (ECO 1) so that all inside lights can be switched off during the night. The simple payback period for this action is approximately seven months.

The price of electronic ballast and it's installation costs make the second energy conservation opportunity (ECO 2) difficult to justify financially.

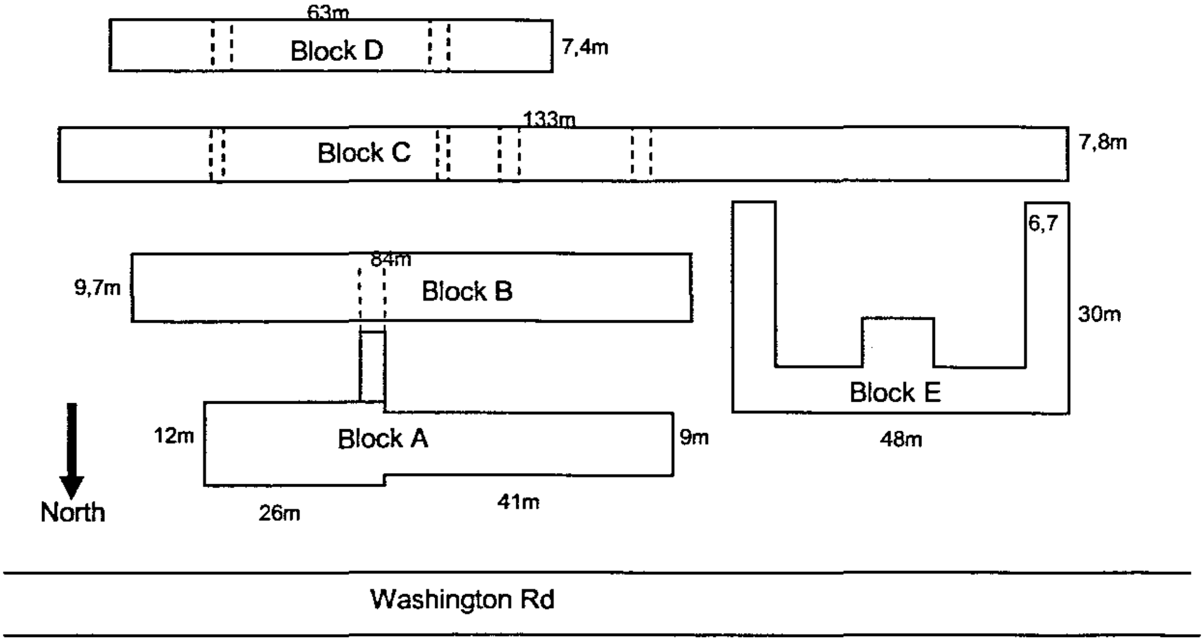
Although the calculations contained in this report represent our best estimates of your potential savings and costs, you may want to consult other sources and verify these estimates before you decide to implement the recommendations with which they are associated. We welcome inquiries and further discussions of any information contained in this report.

‘Sox’ April, working on the report details

2. GENERAL BACKGROUND

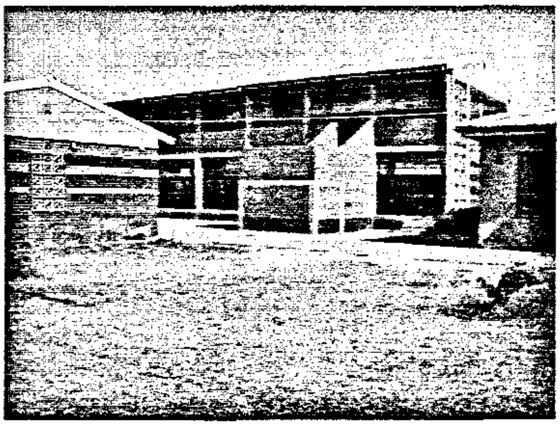
2.1 Facility Description

Langa High School comprises five separate buildings (See site layout below.)



Block A is the administration building which comprises a staff room, staff offices, reception and secretaries offices, a small kitchen and toilets. This block also includes an area that was previously used as a library but is now being used as a classroom. Block A has a ground and a first floor.

The remaining blocks B, C, D and E contain mainly classrooms/laboratories. Block B has ground and first floors. Blocks B and C contain toilets for students. Block D is a pre-fabricated building.



Blocks A, B and E from the northwest side

Block E - from the North side.

Facility Use

School class time is between 8am and 2pm. After 2pm, students use the classrooms and staff use their offices for working in. School terms are as follows:

	Period	Weekdays (excluding holidays)
First quarter:	22 January to 28 March	47
Second quarter	8 April to 27 June	58
Third quarter	22 July to 26 September	48
Fourth quarter	7 October to 5 December	44
		197

2.3 Energy forms and equipment used in the facility

Electricity is used for lighting throughout the school. In the administration block kitchen, electricity is used for an electric urn, a fridge and a stove/oven. Staff apparently use the urn every day and the stove/oven more during the winter months. Several computers and two photocopiers/printing machines are used by staff. There is no heating, ventilation or cooling (HVAC) equipment installed and staff make use of portable (domestic type) heaters and fans to adjust their office environments. There is no water heating device other than the urn and all piped (tap) water is cold.

2.4 Current energy conservation practices

Some use is being made of natural light through windows in classrooms and offices. In some blocks this use is limited by the building architecture (This is discussed in Section 8.

External security lighting is automatically switched on (at 6pm) and off (at 6am). The use of automatic timer control for the outside security lights is good energy conservation practice.

3. ENERGY USE AND ACCOUNTING

3.1 Energy management

An energy management system involves:

1. *recording* energy use regularly over a consistent time period (once a month for example)
2. *comparing* the consumption to previous months and
3. taking *corrective action* if the energy consumption is found to be unnecessarily high

Currently, electrical energy consumption is not recorded over a fixed period - sometimes meter readings are recorded over a one month period and sometimes over a five month period. Neither the users (staff and students) nor the owners (Department of Education and Training) have control over the recording procedure - records are generated by City of Cape Town - Electricity.

Energy management currently relies on the integrity and gut-feel of the staff and students. The energy consumption information is handled by the school treasurer but the information is difficult to use because the recording interval is so *variable* and is *sometimes a very long period.*

3.2 Electricity bill sample calculation

Electrical bills from 16 November 2000 to 16 September 2002 were kindly made available by the treasure and principal.

Electrical accounts show charges for kilowatt-hours (kWh) and 'Amount' (in Rands). Copies of the electricity accounts are included in Appendix A.

The following example shows electricity use, cost and price for a metered period:

For the period from 16/11/200 to 15/02/2001, the school used 20880 kWh at a cost of R6082,34 (excluding VAT). If the amount (R6082,34) is divided by the consumption (20880kWh) then the price of electricity for this period is R0,2913/kWh.

3.3 The avoided cost of electricity

The price of electricity as at November 2001 was **R0,2778/kWh**. (Calculated from electrical bill.)

3.4 Energy use and costs

Table 3 below shows the recorded consumption, charged amount (excluding VAT) and price of electricity for that period. (It is a summary of the electricity accounts.)

Table 3 – Summary of electricity accounts

Period	Consumption kWh	Amount R	Days in period	Average kWh/day
16 Nov 2000 - 15 Feb 2001	20 880	6 082	91	229.5
15 Feb 2001 - 15 Mar 2001	8 700	2 534	28	310.7
15 Mar 2001 - 17 May 2001	28 860	8 407	63	458.1
17 May 2001 - 18 Jun 2001	22 440	6 537	32	701.3
18 Jun 2001 - 18 Sep 2001	61 140	19 169	92	664.6
18 Sep 2001 - 14 Feb 2002	76 740	24 333	149	515.0
14 Feb 2002 - 17 Apr 2002	24 480	7 770	62	394.8
17 Apr 2002 - 16 Sep 2002	87 180	25 905	152	573.6

Because of the varied recording periods, the 'consumption' and 'amount' data is not particularly useful. However, if the consumption for the period is divided by the number of days in the period then average kWh/day can be plotted for each metered period. This gives a rough indication of the *rate of consumption* for that period (See Fig 1 below).

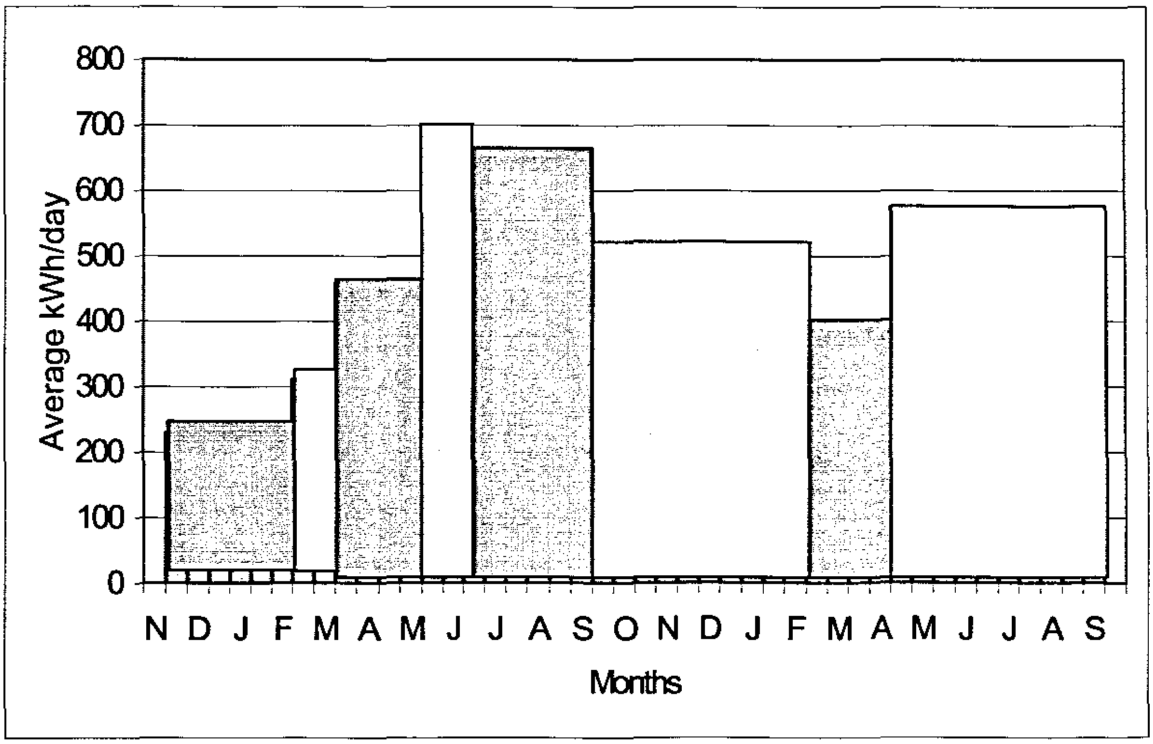


Figure 1 – Average kWh/day per metered period

A rough approximation to monthly electricity consumption is shown in Figure 2 below.

In this case, the daily electrical consumption has been multiplied by the number of days in each month or part-month (where the recording date falls towards the middle of the month).

When the quantities shown in Figure 2 were calculated, it was assumed that consumption was uninterrupted (by holidays) for all the months shown.

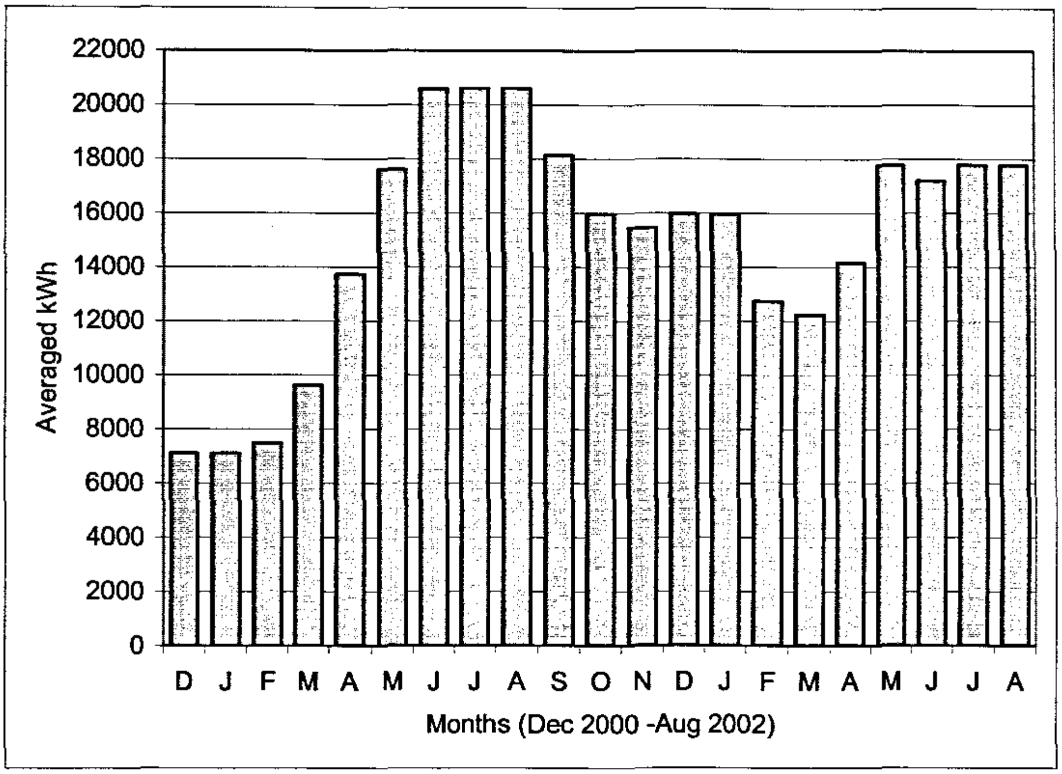


Figure 2 – Approximate monthly consumption (kWh)

The winter months show higher use, probably due to:

1. more lights switched on during cloudy days and darker early mornings.
2. the use of portable heaters in offices
3. increased use of the kitchen stove.

A significant increase in consumption can be seen between February 2001 (7481kWh) and February 2002 (12 738kWh). (Remember that the quantities above are approximate so the increase may not be quite as large as shown.)

For the year January to December 2001, electrical energy consumption was approximately 182 900 kWh.

If the approximate kWh are multiplied by the price of electricity for each month then the approximate electricity costs per month can be calculated. These quantities are shown in Figure 3 below.

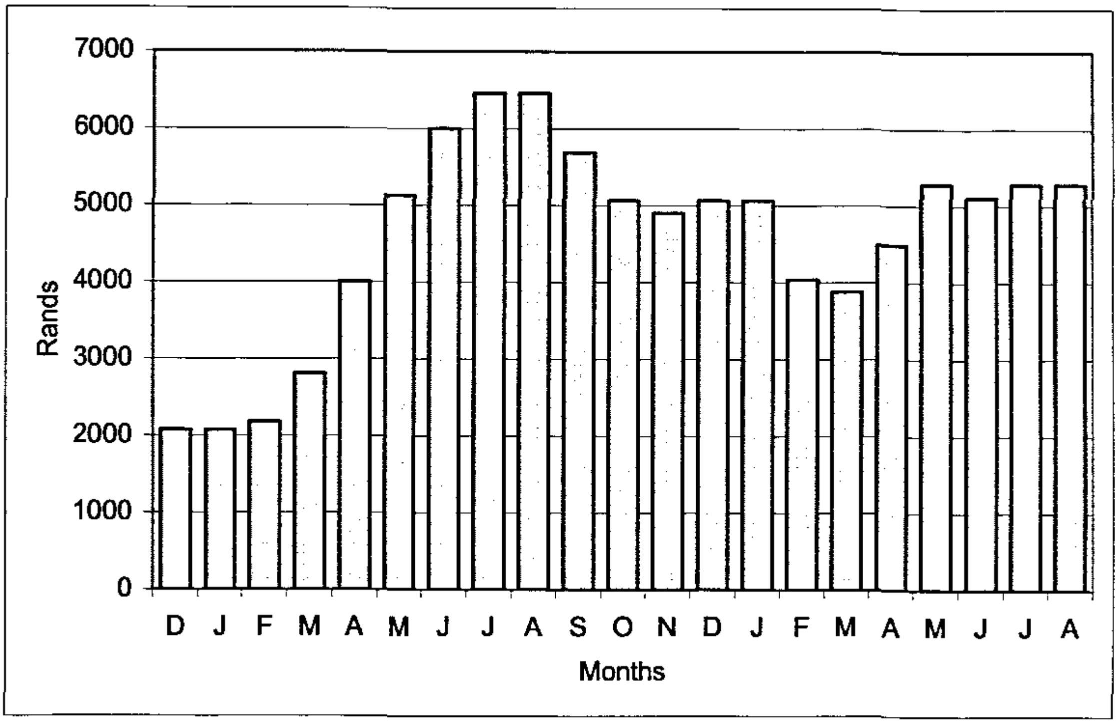


Figure 3 – Approximate monthly electricity costs

The total cost of electricity for the year January to December 2001 came to R55 819.

4. LIGHT LEVELS

Light levels (lux levels) of most of the rooms were measured between 2pm and 5pm on a sunny day in October. Each quadrant of each room was measured. At each position, the lux level was measured with the lights on and then again with the lights turned off. The difference between the lights on and lights off measurements shows the amount of effective illumination that the electrical lights provide.

4.1 Light level requirements

The OHS Act requires a minimum of 200 lux in a classroom. SABS prescribes a 'productivity value' of 300 lux (minimum average).

4.2 Findings

The recorded readings are shown in Appendix B and the findings are summarised below.

With lights turned ON

Of the 38 rooms measured:

- 7 rooms had quadrants where lux levels fell below the OHS ACT requirement (200 lux).
- 4 rooms had an average lux level that fell below the SABS requirement (300 lux minimum average). However, these four rooms, C02, B0/4, B/05 and C08 are the toilets and tuck-shop respectively and do not need to meet requirements for classrooms.

With lights turned OFF

Light readings with lights turned off show which rooms make effective use of natural light and which dont.

Of the 38 rooms measured:

- 21 rooms had quadrants where lux levels fell below the OHS ACT requirement (200 lux).
- 11 rooms had an average lux level that fell below the SABS requirement (300 lux minimum average).
- The following rooms made insufficient use of natural light: B0/3, B0/4, B0/5, C02, C08(toilets and tuckshop again), E02 (classroom) and most of block D (prefabricated classrooms).

If the difference is calculated between lights ON and lights OFF

Of the 38 rooms measured:

- 36 rooms had quadrants where lux levels fell below the OHS ACT requirement (200 lux).
- 32 rooms had an average lux level that fell below the SABS requirement (300 lux minimum average).
- This indicates that current light levels are not sufficient for night-time use of most of the classrooms.
- Inspection of data for specific rooms shows that missing and broken lamps are the reason for electric light levels not being sufficient.
    - ➢ eg room E02 has all florescent tubes working - (passes OHS and SABS requirements at night)
    - ➢ eg room E03 has three of the 8 florescent tubes working - (fails OHS and SABS requirements at night)

Wilfred Fritz and two of the assessment team checking the data

5. ELECTRIC LIGHTS AND INSTALLED POWER

Appendix C shows the record of lights that were counted in the accessible rooms at Langa High School. The following types and quantities of lights are installed:

Table 4 – Types and quantities of lights

Location	**Type**	**Number of lamps**	**Power/lamp (W)**	**Installed power (kW)**
Security lights (outside)	2D	74	21.2	**1.569**
Other 2D lights (inside)	2D	23	21.2	0.488
florescents (T8) (inside)	T8 (1,5m)	428	60	25.680
florescents (T12) (inside)	T12 (1,5m)	49	78	3.822
Inside total				**29.990**

All tubular florescents are 1500mm long. T8 florescents are the thin (ϕ26mm or 8/8ths of an inch) tubes. T12 refers to the 38mm tubes (12/8ths of an inch). A typical outside security light is shown in Figure 4 below.

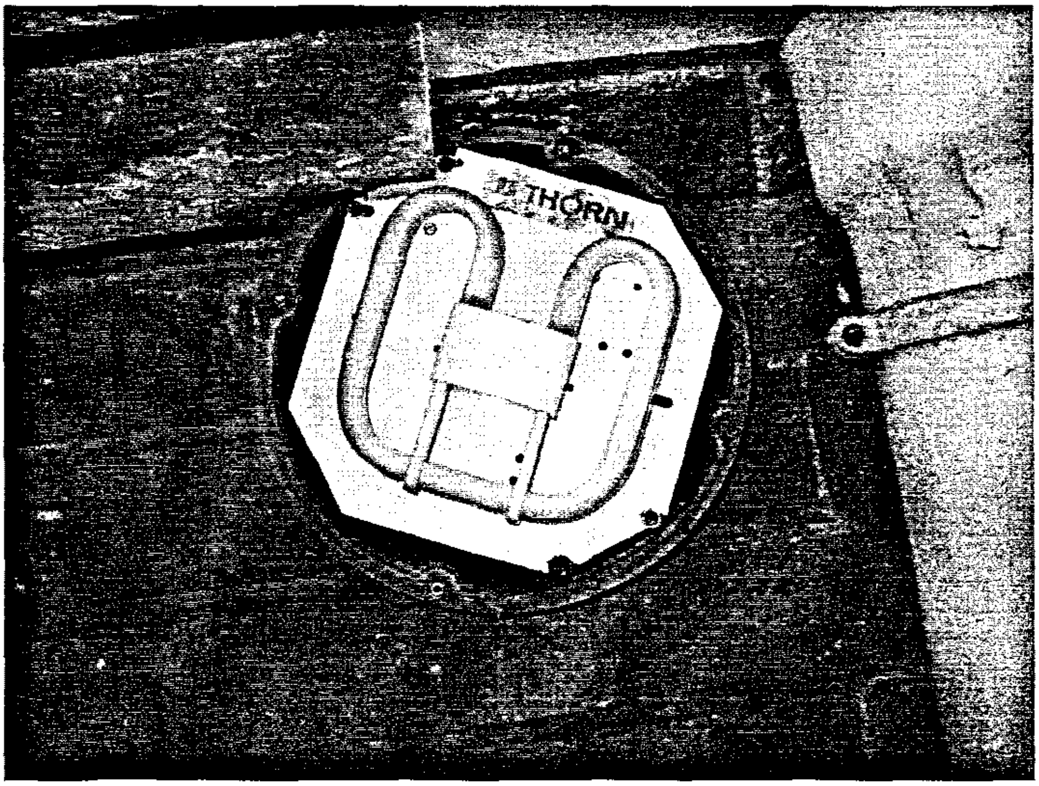


Figure 4 – Outside security lights (2D lamp– cover removed)

6. USE OF ELECTRIC LIGHTS

6.1 Use of outside security lights

The outside security lights are timer-controlled to turn on at 18h00 and turn off at 6h00 each day of the year.

Use of security lights (365 days/year)	Period	hrs/day
All outside security lights on	18h00 - 06h00	12hrs

6.2 Use of inside lights during 197 term weekdays

All inside lights are also switched on at night for security purposes and are presumably switched off at some stage during the day when they are no longer necessary. Classes start at 08h00 and end at 13h00 each weekday, but students were observed to be using some of the classrooms up until 17h00. Recalling that, with lights turned off :

- 21 rooms had quadrants where lux levels fell below the OHS ACT requirement (200 lux) and
- 11 rooms had an average lux level that fell below the SABS requirement (300 lux minimum average)...

it is likely that, during term weekdays, a fairly large proportion of the classes would have their lights turned on up until 13h00 (about half in summer and probably all in winter - giving three-quarters of the classes on average).

After 13h00, a small proportion (about a quarter) of the rooms (some administration rooms and some classes where students may be working) would remain on until 18h00 (and then into the night). This use can be quantified in the following way:

Use of inside lights - term weekdays (197 days)		
	Period	**hrs/day**
All inside lights on	18h00 - 08h00	14hrs
Three-quarters of inside lights on	08h00 - 13h00	5hrs
One quarter of inside lights on	13h00 - 18h00	5hrs

6.3 Use of inside lights during weekends and holidays (168 days)

During weekends and holidays, inside lights are switched on during the night for security purposes. These lights are switched on and off by the caretaker.

Use of inside lights - weekends and holidays (168 days)		
	Period	**hrs/day**
All inside lights on	18h00 - 08h00	14hrs

6.4 Electrical energy used for lighting and costs

Table 5 below shows the contribution of the different light groups and the energy costs. Note that power has been audited and calculated and time of use is based on information obtained from the users of the facility. Note that use of inside lights for 14 hrs (during the night) is the major contributor to energy costs. The energy used by the outside security lights is negligible in comparison.

Table 5 – Contribution of light groups to energy consumption and cost

Light group	**Use** (days)	**Power** (kW)	**Time of use** (hours/day)	**Time of use** (hours/year)	**Energy** (kWh/year)	**Cost** (R/year)
Outside security	365	1.569	12	4380	6872	1909
All inside lights	197	29.990	14	2758	82712	22978

3/4 of inside lights	197	22.493	5	985	22155	6155
1/4 of inside lights	197	7.498	5	985	7385	2052
All inside lights	168	29.990	14	2352	70536	19595
Total					189661	52688

This *estimated and calculated* figure of R52 688 per year that would be spent on electricity for lighting (during normal operation) corresponds quite closely to the *actual* R55000 annual expenditure obtained from *electricity bills.* The difference of R2300 would include electricity spent on the kitchen stove and kettle -particularly in winter.

The data in the above table will be used to calculate energy and cost saving opportunities in the following section.

7. ENERGY CONSERVATION OPPORTUNITIES

Two specific energy conservation opportunities were identified they are:

ECO 1 - Switch off all inside lights during the night
ECO 2 - Replace T12 florescent tubes and all magnetic ballast with T8 florescent tubes and electronic ballast

Some additional items to be considered are discussed in Section 8.

ECO 1 - Switch off all inside lights during the night but ensure security through an alarm system and security company.

Energy saving	153 249 kWh/year
Energy cost saving	R42 573/year
Installation cost	R25 000 +R250/month
Simple payback	0,63

Background

All inside lights are switched on between 18h00 and 08h00 for security purposes. If security could be achieved by some other means then switching the lights on, then these inside lights could be kept switched off.

Energy and energy cost savings

The new energy consumption and cost, without the 14 hour per day security requirement is shown in Table 6 (below). The grey areas are the periods when the indoor lights will no longer be used for the security requirement.

If the inside lights can be turned off at night, the total energy consumption for lights will be reduced from 189 661 kWh to 36 412 kWh per year. This is an energy saving of 153 249 kWh per year.

The total energy cost is reduced from R52 688 down to R10 115 per year (See Table 6). This is an energy cost saving of R42 573/year.

Table 6 – Consumption of light groups with inside lights turned off at night

Light group	Use (days)	Power (kW)	Time of use (hours/day)	Time of use (hours/year)	Energy (kWh/year)	Cost (R/year)
Outside security	365	1.569	12	4380	6872	1909

All inside lights	197	29.990	0	0	0	0
3/4 of inside lights	197	22.493	5	985	22155	6155
1/4 of inside lights	197	7.498	5	985	7385	2052
All inside lights	168	29.990	0	0	0	0
Total					36412	10115

Installation costs

Security improvement will cost in the region of R25 000 for the installation of alarm equipment and R250/month for emergency response. (See Appendix E).

Simple payback

The simple payback period can be calculated by dividing the installation costs by the annual energy cost savings.

$$\text{simple payback} = \frac{25000}{42573-(12\times 250)} = 0{,}63\,\text{years}$$

ECO 2 - Replace T12 florescent tubes and all magnetic ballast with T8 florescent tubes and electronic ballast

Energy saving	24 276 kWh/year
Energy cost saving	R6 744/year
Installation cost	between R58 949 and R70 899
Simple payback	between 8,7 and 10,5 years

Background

Tubular florescent T8 (26mm) × 1500mm with magnetic ballast (EC65 A90) are fitted throughout most of the classrooms and offices at Langa High School (428 tubes were counted). This combination uses 120W (measured total circuit power per double tube fitting).

Electronic ballast units use less energy and operate the lamps more efficiently (at a much higher frequency). If the two magnetic ballast units, in each double tube fitting, are replaced by a single electronic ballast (that can drive both tubes) then the total circuit power per fitting would be reduced to 107W (Tridonic catalogue - ballast type PC 2/58 T8 PRO - Appendix #)

Energy and energy cost savings

If the changes detailed above are made, then the table of installed power (from Table 4, p11) will change as shown below (compare grey shaded cells of Table 7 with those in Table 4, p11). Notice that the installed power for inside lights is reduced from 29,990kW to 26,007kW.

Table 7 – Installed power of light groups with T8's and electronic ballast installed

Location	Type	Number of lamps	Power/lamp (W)	Installed power (kW)
Security lights (outside)	2D	74	21.2	**1.569**
Other 2D lights (inside)	2D	23	21.2	0.488
florescents (T8) (inside)	T8 (1,5m)	477	**53.5**	**25.520**
Inside total				**26.007**

The new energy consumption and cost, with this reduced installed power, is calculated in Table 8 (on the following page).

With T8 lamps and electronic ballast installed, the total energy consumption for lights will be reduced from 189 661 kWh to 165 385 kWh per year. This is an energy saving of 24 276 kWh/year.

The total energy cost is reduced from R52 688 down to R45 944 per year. This is an energy cost saving of R6 744/year.

Table 8 – Consumption of light groups with T8's and electronic ballast installed

Light group	Use (days)	Power (kW)	Time of use (hours/day)	Time of use (hours/year)	Energy (kWh/year)	Cost (R/year)
Outside security	365	1.569	12	4380	6872	1909
All inside lights	197	26.007	14	2758	71727	19926
3/4 of inside lights	197	19.505	5	985	19213	5337
1/4 of inside lights	197	6.502	5	985	6404	1779
All inside lights	168	26.007	14	2352	61168	16993
Total					165385	45944

Installation costs

T8 × 1500 58W florescent tubes are cheaper than T12 × 1500 58W florescent tubes so there will actually be a saving of approximately R400 when the existing T12's are replaced by T8's.

At a price of R196,65 (including VAT) for an electronic ballast that can drive two T8 × 1500mm florescent tubes, the equipment cost for ballast will be R46 999 for 239 ballast units.

The two magnetic ballasts in each light fitting must be replaced with a single electronic ballast that will drive both T8 tubes. A labour cost of between R50 and R100 per fitting has been estimated (Richard's Electrical) therefore the total installation cost would be between R11 950 and R23 900. A site inspection by the electrician would eliminate this uncertainty.

Because of the uncertainty of the labour cost, the total installation cost will fall somewhere between R58 949 and R70 899.

Simple payback

The simple payback period can be calculated by dividing the installation costs by the annual energy cost savings.

$$\text{simple payback (@ R50/fitting)} = \frac{58949}{6744} = 8{,}7\,\text{years}$$

$$\text{simple payback (@ R100/fitting)} = \frac{70899}{6744} = 10{,}5\,\text{years}$$

8. ADDITIONAL CONSIDERATIONS

Some aspects of energy use are not as easily quantified (as in ECO 1 and ECO 2). The use of natural light in buildings, the use of heat from the sun for office and classroom warming in winter and the avoidance of the suns heat in offices and classrooms during summer are examples of energy conservation opportunities that are difficult to quantify. For this reason, the use of sunlight for lighting, heating and cooling is discussed briefly as an additional item to be considered (AIC).

AIC 1 Install internal or external shading where necessary for better heat and light control

Some use is being made of natural light through windows in classrooms and offices. In some blocks this use is limited by the building architecture. Where sunlight cannot be used effectively, electricity gets used instead. For example, if too much sunlight shines into an office and the office has opaque internal blinds then the blinds are drawn to keep the intense sun out and the lights are switched on in order to see.

Figure 6 below shows the optimum angles for external window shading for the purposes of gaining optimum benefit from solar heat.

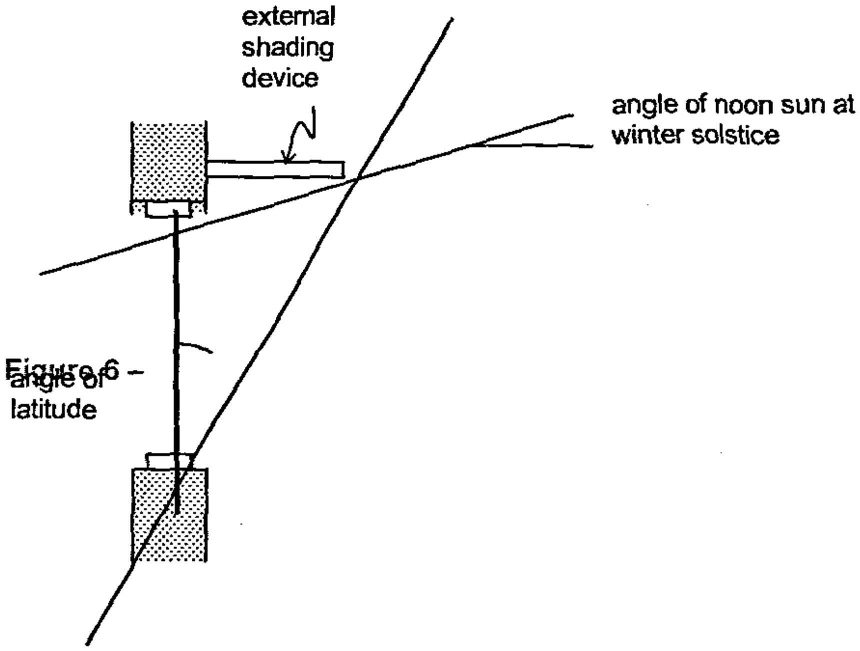


Figure 6 - External shading for optimum benefit from solar heat

Further shading may be required to reduce glare even when the optimal external shading is installed. A "light shelf" can be used (Figure 7 on the following page) to reduce intense light close to a window and project the excess light into darker areas further away from the window.

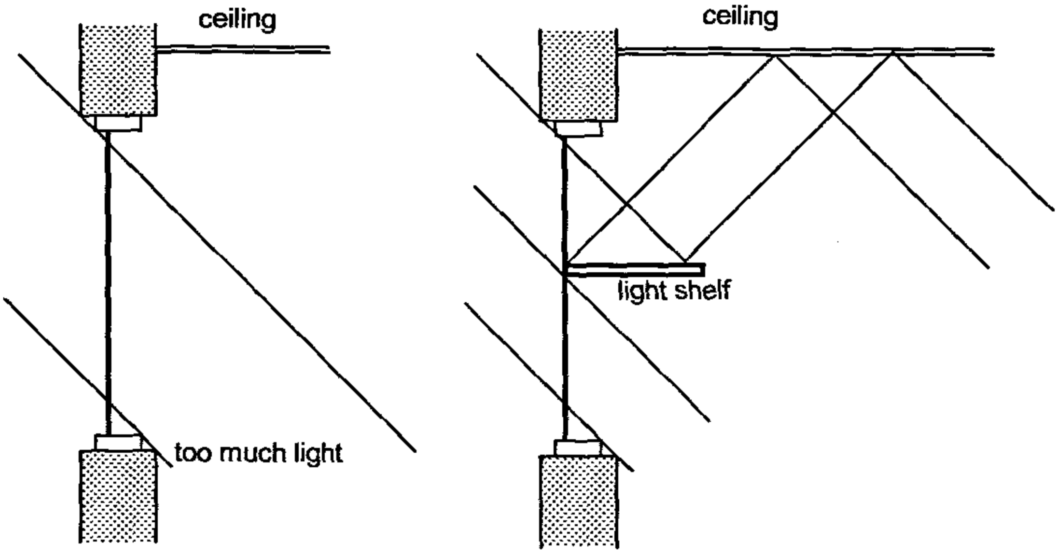


Figure 7 – Use of a "light shelf" to disperse and move light deeper into a room

On west and east facing windows, vertical blinds are better for shielding against glare from low sun angles.

The lightness (colour) of internal walls determines how well light is reflected and distributed in a room.

Although difficult to predict and quantify, more effective use of natural light would reduce electrical lighting requirements and reduce heating and cooling requirements.

9. OVERALL RECOMMENDATIONS

- Install an alarm system that covers all classrooms and includes security response (ECO 1) so that all inside lights can be switched off during the night. The simple payback period for this action is approximately seven months.

- The price of electronic ballast and it's installation costs make the second energy conservation opportunity (ECO 2) difficult to justify financially. Unless better prices are attainable we do not recommend this energy conservation opportunity.

- Identify rooms where natural light is a problem and take steps to make improvements.

- Although the calculations contained in this report represent our best estimates of your potential savings and costs, you may want to consult other sources and verify these estimates before you decide to implement the recommendations with which they are associated. We welcome inquiries and further discussions of any information contained in this report