DEVELOPMENT OF HYBRID ACTIVE-PASSIVE SOLAR LIGHTING SYSTEM

MOHD ZULFADULI BIN MAYZAN

ELECTRICAL & ELECTRONICS ENGINEERING
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By

MOHD ZULFADHLI BIN MAYZAN

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Submitted to the Electrical & Electronics Engineering Programme
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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved:

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A.P Dr. Balbir Singh Mahinder Singh,
Supervisor.

ASSOC. PROF. DR. BALBIR SINGH
Senior Manager
Academic Central Services

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Zulfadhli Bin Mayzan

ABSTRACT

The main idea of this project is to develop Hybrid Active-Passive Solar Lighting System for domestic usage. The demand of electrical power for the lighting system keep increasing in the domestic area especially at house which cause more fossil fuel burning to produce more electricity. To reduce the power consumption from the conventional power supply, some of the lighting system can get power from the renewable energy such as Solar Energy. The project carries out the feasibility studies on solar energy characteristics to determine whether it is possible to use solar electricity for lighting system. The sustainability of solar energy has been a problem as the load demand is not proportional to solar radiation. Due to that, in photovoltaic application the storage is an important part in order to maintain the sustainability of energy supply and making the solar system reliable for domestic house usage. The solar lighting system also has electronics circuit to control the storage charging activity and turn on the lighting. Besides that, the project shows the design of domestic house roof model to utilize the Day Lighting. The output of this project is to provide effective and efficient solar lighting system.

ACKNOWLEDGEMENTS

In the name of Allah, The Most Gracious, The Most Merciful

First of all, my utmost thanks to Allah for everything. For the air that I breathe and for the five senses given, I am still alive with which I can see His greatness through His creation. Utmost thanks also given to Him for the honor of being born as a Muslim and for the honor of having faith in Him. With His Greatest power, I have successfully completed this Final Year Project 2.

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LIST OF ABBREVIATIONS

DC	Direct Current
PV	Photovoltaic
LED	Light Emitting Diode
HPLED	High Power LED
UV	Ultra Violet
LDR	Light Dependent Resistor

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Solar is one of the energy sources for human life. The demands for the solar in electrical appliances are increasing and still continue because it can reduce the effect of Global Warming which increases the global temperature. The problem become as a serious issue in the world including Malaysia because of the effect human activities such as fossil fuel burning and deforestation. In Malaysia the main method used to generate electricity is by using fossil fuel and gases. Figure 1 shows the other sources uses in Malaysia to generate electricity.

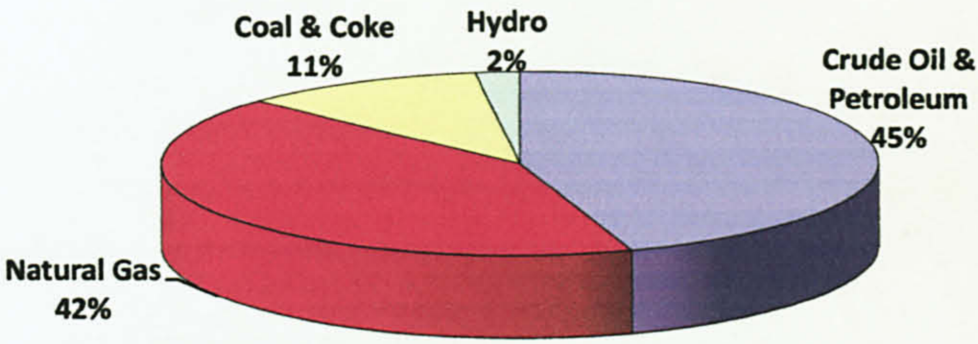


Figure 1 Resources Used for Electricity Generator in Malaysia

During the process to generate electricity, the fuel and gases burning produce much carbon dioxide increasing the concentrations of greenhouse gases. This problem can be reducing by using other alternative energy to generate electricity such as Solar Energy. The radiation from the sun can generate electricity by using photovoltaic (PV) panel which is the new technology to convert solar energy directly into electricity.

Lighting is one of the scopes that can be developed by using the solar energy as one of the electricity resources. In Ninth Malaysia Plan it is already stated that our country will invest more in developing renewable energy to reduce the burning of fuel and gases source. In domestic homes, they mainly use conventional lighting such as fluorescent lamps as light sources. This project will use the photovoltaic panel to develop the new lighting system which can consumes less power at domestic house.

The history of lighting system start with filament bulb as a first generation of lighting and then it develops into fluorescent lighting. The existing Fluorescent Lighting System at home consumes so much power to operate which is around 18-40W. The others type of fluorescent lighting commonly used by domestically are Compact Fluorescent Lighting (CFL) bulbs which consumed 15W. Although it consume less power than tube fluorescent bulbs, it is not safe to human body because it does not have prismatic diffusers to filter Ultra Violet (UV) radiation.

There is a need for efficient solar lighting system and new technology in lighting such as a good solution is LED. This LED lighting system is more efficient to produce light source and it consume less power than conventional lighting. The solar lighting system in this project is a stand alone with the solar cell and the storage. It will turn on depending with the day lighting intensity and solar cell charging the storage automatically. In this study solar LED lighting system will be combined with Day lighting to develop Hybrid Active-Passive Solar Lighting System.

1.2 Problem Statement

Malaysia is located at equator which has average six hours sunny day for daily. The radiation from the sun to the earth can achieve the maximum value until *1000* W/m^2 *[1]* and in Malaysia it can be around *800*W/m^2 because the factor of cloud diffusion. The solar energy can be develop and maximize their usage in Malaysia based on the lighting system by implementing photovoltaic panel to operate the lighting system around the domestic house.

Lighting is one of the important things in human life to illuminate the dark area. The conventional lighting system uses fluorescent lamps which consume high power to operate and not good for human health because it content mercury. The electricity which is generated based on fossil fuels can be a waste for lighting because it can be used for other more useful. The fluorescent lamps can be replaced with other alternative lighting which has low power consumption because the load with lower power can make the solar lighting system more sustainable and reliable. The sunlight (Day Lighting) also can be utilized as a light source to illuminate house area.

1.3 Objective

The objectives of this project are as follows:

1. To carry out feasibility studies on the possibility of using solar electricity for domestic lighting.
2. To design LED based lighting system to implement in a system where electricity is generated by using solar cells.
3. To design and develop Hybrid Active-Passive Solar Lighting System for domestic usage.

1.4 Scope of Study

The area of study for this project will be divided to 3 parts: the solar panel, the electronic circuit to control the solar lighting system and the house roof design to utilize day lighting. For solar panel, it is crucial to understand the concept of solar geometry and PV sizing but the actual focus should be the storage. The scope of study covers:

- Solar Geometry
- The efficiency of solar panel
- The sizing of battery storage and solar panel

For the electronics circuit, it is needed to design the automatic charge controller and LDR switching circuit to control the solar lighting system. Due to that, the design should be tested to make sure it can be operated by people with limited engineering ability. The study that needs to be covered is:

- The concept of automatic charge controller and switching circuit
- The purpose of charge controller circuit
- The suitable range of voltage for battery
- The study of LDR sensor and voltage regulator

The last part of this project is to study the house roof design for passive lighting concept. It needs to design the model by using AutoCAD software and construct the house roof model for the small scale size.

CHAPTER 2
LITERATURE REVIEW

2.1 Energy from Sun

The sun is a sphere of intensely hot gaseous matter which has a diameter of 1.39×10^9m and the average distance from earth is about 1.5×10^{11}m. The sun has an effective blackbody temperature of 5762K while the central interior regions is variously estimated at 8×10^6 to 40×10^6 K [1]. The solar energy radiated from the sun consists of beam radiation and diffuse radiation. The beam radiation is received from the sun without having been scattered by the atmosphere that means the radiation is directly from the sun while diffuse radiation received from the sun after its direction has been changed by scattering by the atmosphere.

The radiation emitted by the sun and its spatial relationship to the earth result in a nearly fixed intensity of solar radiation outside of the earth's atmosphere. The solar constant, G_{sc}, is the energy from the sun which measure in per unit time. It received on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth's mean distance from the sun and outside of the atmosphere.

Recently, the solar constant had to be estimated from ground based measurement of solar radiation after it had been transmitted through the atmosphere and thus in part absorbed and scattered by components of the atmosphere. The measurements were made with a variety of instruments in nine separate experimental programs. One of the instruments they use is 'Pyrheliometer'. They resulted in a value of the solar constant, G_{sc}, of 1353W/m^2 [1].

2.2 Photovoltaic (PV) Modules

The photovoltaic effect was discovered in 1839 by French physicist A. E. Becquerel. But the first solar cell was developed in 1883 by Charles Fritts which produce 1% efficiency [2]. This technology kept developing until there is three generation of solar panel or photovoltaic panel. The first generation using crystalline silicon and vacuum deposition which limit the efficiency up to 31%. The second generation uses a thin film that produces from cadmium telluride (CdTe), copper indium gallium selenide, amorphous silicon and micromorphous silicon, while the third generation is the improvement from the thin film that can produce efficiency between 30-60% [2]. The following are some of the photovoltaic modules.

2.2.1 Monocrystalline

This is the oldest and more expensive production technique, but it is also the most efficient sunlight conversion technology available which is 10-13%. Monocrystalline Silicon has a single and continuous crystal lattice structure with practically zero defects or impurities. These panels are easily identifiable, made up of uniformly stacked rounded cells. Because they're made from just one crystal, not multiple crystals fused together, the process of making them is very complex and costly. This means that every panel will cost more. However that increased cost is buying additional efficiency, meaning that one panel will produce more power than the lower priced options. The lifespan of a monocrystalline cell is a minimum of 25 years and can be more than 50, making them a worthwhile investment for long term use. These panels retail at between USD 10.00 and USD 11.00 per watt [17]. Figure 2 shows the monocrystalline silicon module:

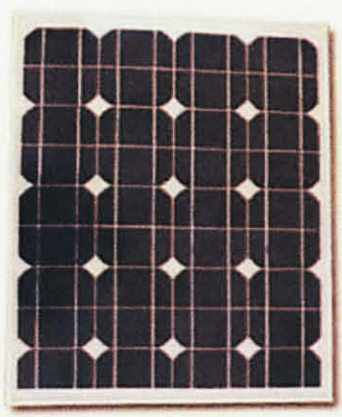


Figure 2 Monocrystalline Silicon Module

2.2.2 Polycrystalline

A polycrystalline solar panel module is made from a block of silicon that has multiple crystals. These panels are square in shape, and may have a surface that looks somewhat like a mosaic. That is because of all the different crystals that make up the module, Polycrystalline solar modules are less efficient than those made from a single crystal. However, they are much simpler to produce, and cost far less to manufacture. This makes them much less expensive for buyers. These panels retail at between USD8.50 and USD9.50 per watt and lower lifetime 10-25 years with efficiency 9-12% [17].

Polycrystalline solar panel modules could put solar power into the hands of people who could not afford the monocrystalline cells. The main advantage of Polycrystalline Silicon over other types of silicon is that the mobility can be orders of magnitude larger and the material also shows greater stability under electric field and light-induces stress. This allows far more complex, high-speed electrical circuit that can be created on the glass substrate along with the amorphous silicon devices which are still needed for their low-leakage characteristics. Figure 3 shows the polycrystalline silicon module:

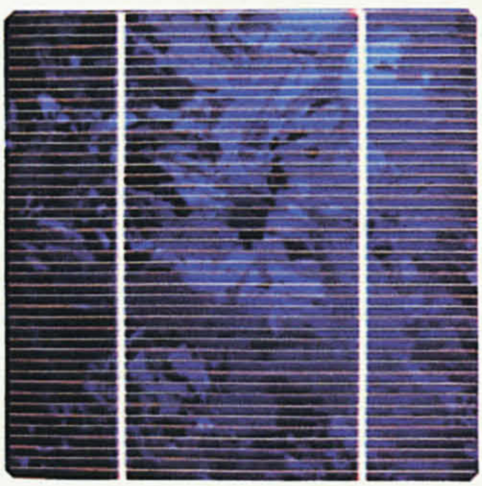


Figure 3 Polycrystalline Silicon Module

2.2.3 Amorphous Silicon

Amorphous silicon (a-Si) is the non-crystalline allotropic form of silicon. The cells have a uniform typically black appearance. This silicon material is vaporized and deposited on glass or stainless steel. An amorphous silicon module costs the lowest than the two modules discussed above, with an efficiency of 6-8% and life time of up to 10 years. Aside from being low-cost, amorphous silicon can be produced at a lower temperature and can be deposited on low-cost substrates. It has been use in portable items such as pocket calculators for many years but it has only been since about 1998 that they have become available on rooftops. This type of module retails for about USD 10.00 per watt [17]. Figure 4 shows the amorphous silicon module:

Figure 4 Amorphous Silicon Module

2.3 Conventional Lighting System

The fluorescent lamp design, which has fallen mostly by the wayside, used a special starter mechanism to light up the tube. Diagram below is shown how this system works.

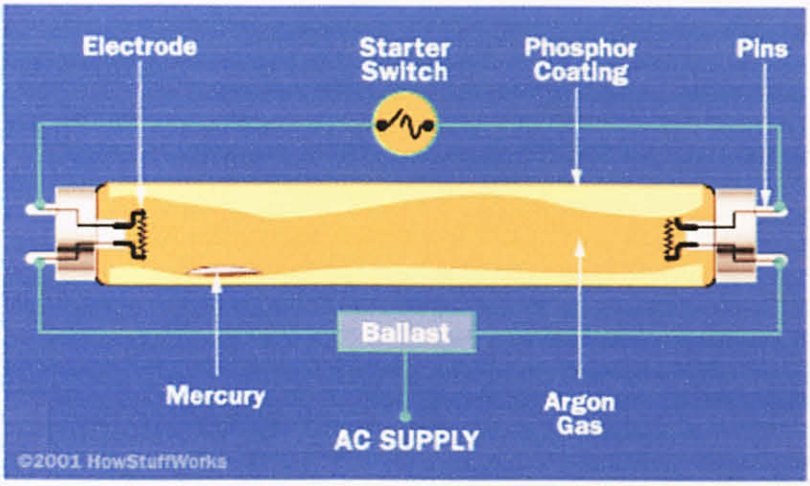
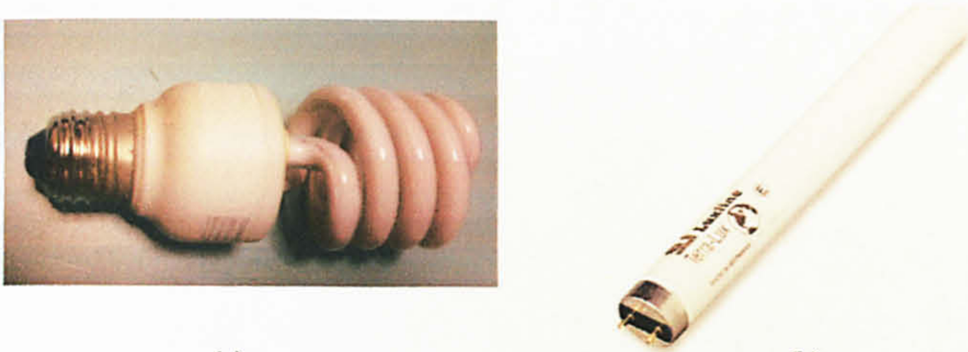


Figure 5 Fluorescent Lighting System[4]

When the power supply is turned on, the path of least resistance is through bypass circuit, and across the starter switch. In this case, the current passes through the electrodes on both ends of the tube. These electrodes are simple filaments which are the same one used in a filament light bulb. When the current passes through the bypass circuit, electricity heats up the filaments. This boils off electrons from the metal surface, sending them into the gas tube, ionizing the gas.

At the same time, the electrical current sets off an interesting sequence of events in the starter switch. The conventional starter switch is a small discharge bulb, containing neon or some other gas. The bulb has two electrodes positioned right next to each other. When electricity is initially passed through the bypass circuit, an electrical arc, which is a flow of charged particles jump between these electrodes to make a connection. This arc lights the bulb in the same way a larger arc lights a fluorescent bulb.

The power 40W use to energize the ballast before the ballast injects the high current to the fluorescent tube when the starter opens to produce arc lights. This will increase the power consumption in the house. The mercury inside the fluorescent lamp is also not good for human and environment. Figure 6 shows the conventional lighting that commonly used in domestic houses.



(a) (b)

Figure 6 (a) Compact Fluorescent Light 18W, (b) Conventional Fluorescent Light 36W

2.4 Measurement Unit for Light

The lux (lx) is the SI derived unit of illuminance or illumination. It is equal to one lumen per square meter. For example, sunlight on average day ranges from 32000 to 100000 lux [5]. Lumens measure "luminous flux". This is a measure of the total number of packets or quanta of light produced by a light source such as a globe or fluorescent tube. This is the “quantity” of light emitted by the light source. The value of lux tells us how many lumens needed to light up our house.

An illuminance of 500 lux might be possible to achieve in a home kitchen with a single fluorescent light fixture with an output of 1200 lumens. To light a factory floor with dozens of times the area of the kitchen would require dozens of such fixtures. Thus, lighting a larger area with the same number of lux requires a larger number of lumens.

The difference between the lux and the lumen is that the lux takes into account the area over which the luminous flux is spread. 1000 lumens, concentrated into an area of one square meter, lights up that square meter with an illuminance of 1000 lux. The same 1000 lumens, spread out over ten square meters, produce a dimmer illuminance of only 100 lux [5].

Next is about watts versus lumens produced. This is a difficult one because the wattage of a light source refers to the power consumed to drive the source while lumen refers to the brightness of that source as the human eye perceives it. The wattage of course would be the sum of the heat generated as well the energy of the light emitted. Basically the lumens per watt for fluorescent lamp are lower than LED lighting. That means the conventional lamp produce more heat than LED lighting. The standard lux levels for several locations are given in the appendix section.

2.5 LED (Light Emitting Diode)

A light-emitting diode (LED) is an electronic light source. The first LED was built in the 1920s by Oleg Vladimirovich Losev [6], a radio technician who noticed that diodes used in radio receivers emitted light when current was passed through them. The LED was introduced as a practical electronic component in 1962. All early devices emitted low-intensity red light, but modern LEDs are available across the visible, ultraviolet and infra red wavelengths, with very high brightness.

LEDs are based on the semiconductor diode. When the diode is forward biased, electrons are able to recombine with holes and energy is released in the form of light. This effect is called electroluminescence and the colour of the light is determined by the energy gap of the semiconductor. The LED is usually small in area which is less than 1 mm^2 with integrated optical components to shape its radiation pattern and assist in reflection. One LED consumes current around 20mA [6].

LEDs present many advantages over traditional light sources including lower energy consumption, longer lifetime, improved robustness, smaller size and faster switching. Therefore, the LED can be a good load to develop a sustainable and reliable solar lighting system. Figure 7 shows the physical part and inner workings of an LED.

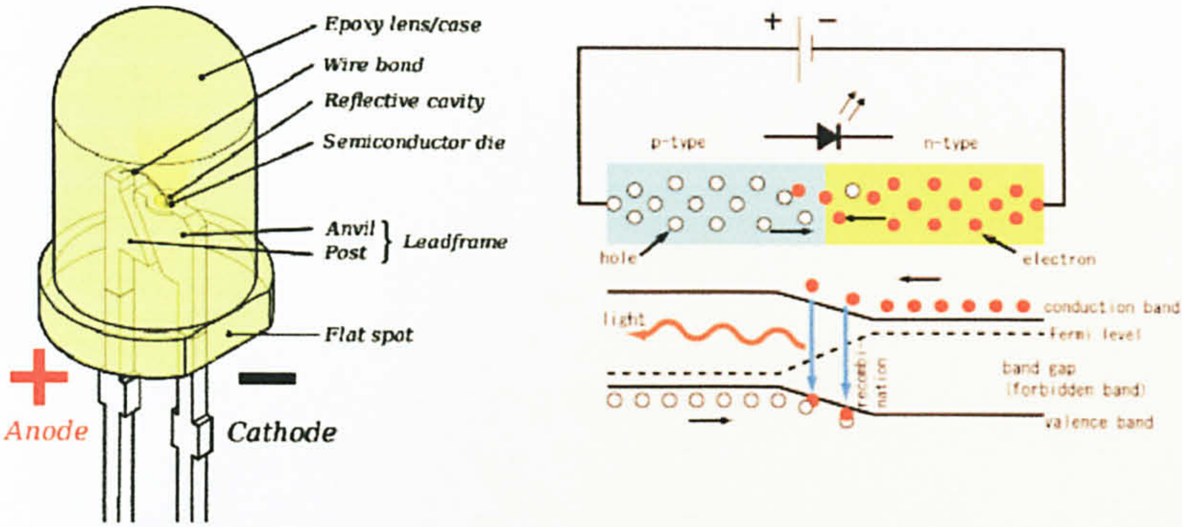


Figure 7 Parts and Inner Working of an LED[6]

Like a normal diode, the LED consists of a chip of semiconducting material impregnated, or doped with impurities to create a p-n junction. As in other diodes, current flows easily from the p-side, or anode, to the n-side, or cathode, but not in the reverse direction. Charge carriers electrons and holes flow into the junction from electrodes with different voltages. When an electron meets a hole, it falls into a lower energy level, and releases energy in the form of a photon [6].

The wavelength of the light emitted, and therefore its colour, depends on the band gap energy of the materials forming the p-n junction. In silicon or germanium diodes, the electrons and holes recombine by a non-radioactive transition which produces no optical emission, because these are indirect band gap materials. The materials used for the LED have a direct band gap with energies corresponding to near-infrared, visible or near-ultraviolet light.

2.6 Day Lighting

Day lighting refers to the level of diffuse natural light coming from the surrounding sky dome or reflected off adjacent surfaces. Day lighting can be a very effective light source, even on the most dark and overcast day. It levels can also be quite variable and depend on the amount or type of cloud in the sky and the time of day. However, there exist a range of mathematical models that allow the calculation of how bright different parts of the sky will be under different sky conditions. Light and heat normally come together, however the amount of heat produced by different lights for the same lighting intensity can vary significantly. It turns out that, in terms of the number of lighting lumens per watt of heat energy, diffuse daylight is about 5 times more efficient than a normal incandescent bulb and as much as twice as efficient as a fluorescent tube. In a typical office building, turning the lights off and substituting daylight alone can reduce overall heat loads by as much as 40%, principally by reducing over-illumination near peripheral windows [7].

Table 1 Efficiency of Various Forms of Daylight and Electric Lamps [7]

Light Source	**Efficiency (lumens/Watt)**
Direct Sun (low altitude)	90
Direct Sun (high altitude)	117
Direct Sun (mean altitude)	100
Diffuse Sky (clear)	150
Diffuse Sky (average)	125
Global (average of sky and sun)	115
Incandescent (150 W)	16-40
Fluorescent Tube (40 W)	50-80

Table 1 shows that the luminous efficiency of direct sunlight is greater than that of most commonly used electric alternatives. However, it is also considerably brighter so it will introduce significant heat gains if allowed to enter the building directly at the wrong time of year. Obviously in many climates this heat gain may be welcomed in winter. This requires the careful use of shading devices and light diffusers to properly protect against direct summer sun penetration whilst distributing natural light deep into each space. The selection of glass type is also an important factor.

There are many ways to allow natural light into the spaces within a building. Vertical windows are the most commonly used type of day lighting system. Many rooms have windows only on one side, however light levels fall off quite quickly as you move deeper into the space. But this problem can overcome by putting window in the both side like shown below.

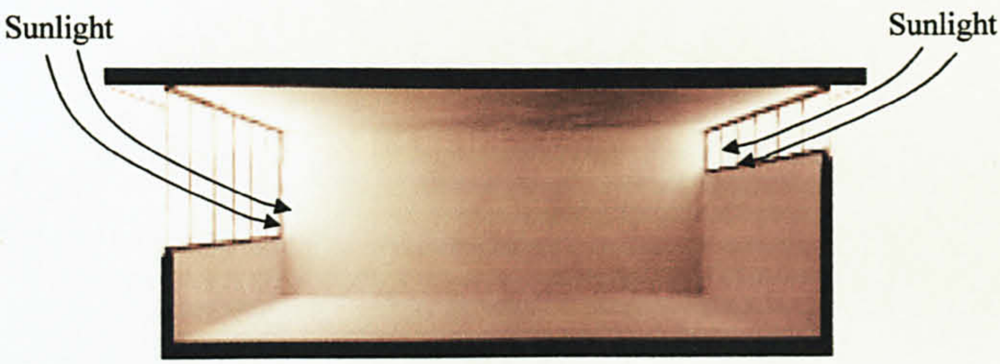


Figure 8 Window Design for Day Lighting[7]

Besides windows, other designs include the skylights concept. These designs are apertures cut through the roof of a building. Whilst skylights give excellent daylight levels, it is difficult to control the direct beam solar radiation from the Sun when it is directly overhead. Angled louvers or some other form of seasonally adjustable shading must therefore be used, especially in hot climates. Figure 9 shows the skylight design concept.

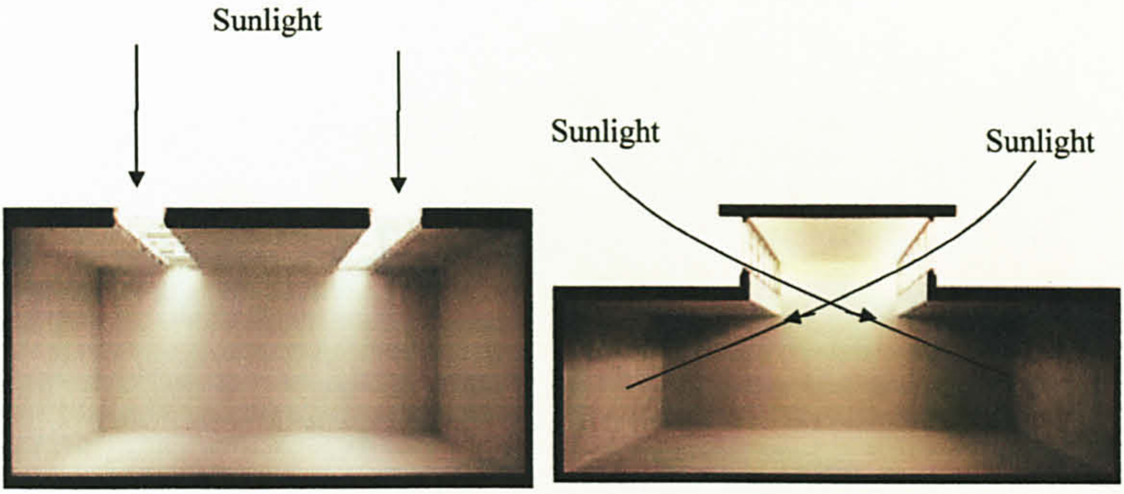


Figure 9 Skylight Design for Day Lighting[7]

2.7 Concept of Hybrid Active-Passive Solar Lighting System

The project proposes the concept of Hybrid Active-Passive Solar Lighting System to develop high energy efficient which reduces the usage of energy produce by the fossils source. Passive lighting comes from sunlight while active lighting is produced by the solar lighting system. During the day time, people can utilize sunlight as a light source by opening their window. In the future, the house design in Malaysia can be consider skylight or window concept for utilize day lighting. Nowadays, the window can use photochromic glass which absorb the sun radiation and remove the sunlight glare in any house area. This glass can also reflect the ultra violet (UV) radiation and reduce the heat from go through inside the house. The photochromic glasses become darkens automatically with the sun and lighten at dusk. So, this is one of the solutions to reduce the global warming issues that the world faces today. Figure 10 shows the difference between normal glass and photochromic glass.

(a) (b)

Figure 10 (a) Normal Glass (b) Photochromic Glass [13]

2.8 Environmental and Health Concerns

The fluorescent light bulbs contain mercury, which emits Ultra Violet (UV) radiation when it is electrically excited. This UV radiation similar to outdoor exposure levels on a sunny day. British's Health Protection Agency now recommend that people should not be closer than 30 centimeters from the fluorescent light bulb for more than one hour per day [8]. This UV radiation can cause eczema, dermatitis, headache, eyestrain, increased stress and fatigue. This mercury can be released into the environment if the bulb is accidentally broken in the home, incinerated, or disposal at a landfill. For example, it will flow to the river and cause water pollution. That is why the government needs is proper procedure to dispose it. The cost to eliminate it may be higher from the production cost.

CHAPTER 3
METHODOLOGY

3.1 Project Identification

3.1.1 Project Flow

This project, follow the methodology that shows the each detailed activities and its expected duration to be completed. The project started with choosing the title and sketching the expected outcome based on knowledge gathered from literature review. This project is divided into two parts; the research in solar geometry and research of solar lighting system. For solar geometry part, it involves in collecting solar radiation data at Tronoh and calculation of data in order to sizing the solar panel and battery storage.

Solar lighting system part was divided to two sections; Passive Lighting and Active Lighting. For passive lighting, it needed to design the house roof model to utilize day lighting as a light source. Active lighting, it involves the design of LED lighting, charge controller and LDR switching circuit. This circuitry will be tested and modify until it can functional properly. Finally, the prototype will be assembled together. The whole project flow can be seen at Figure 11.

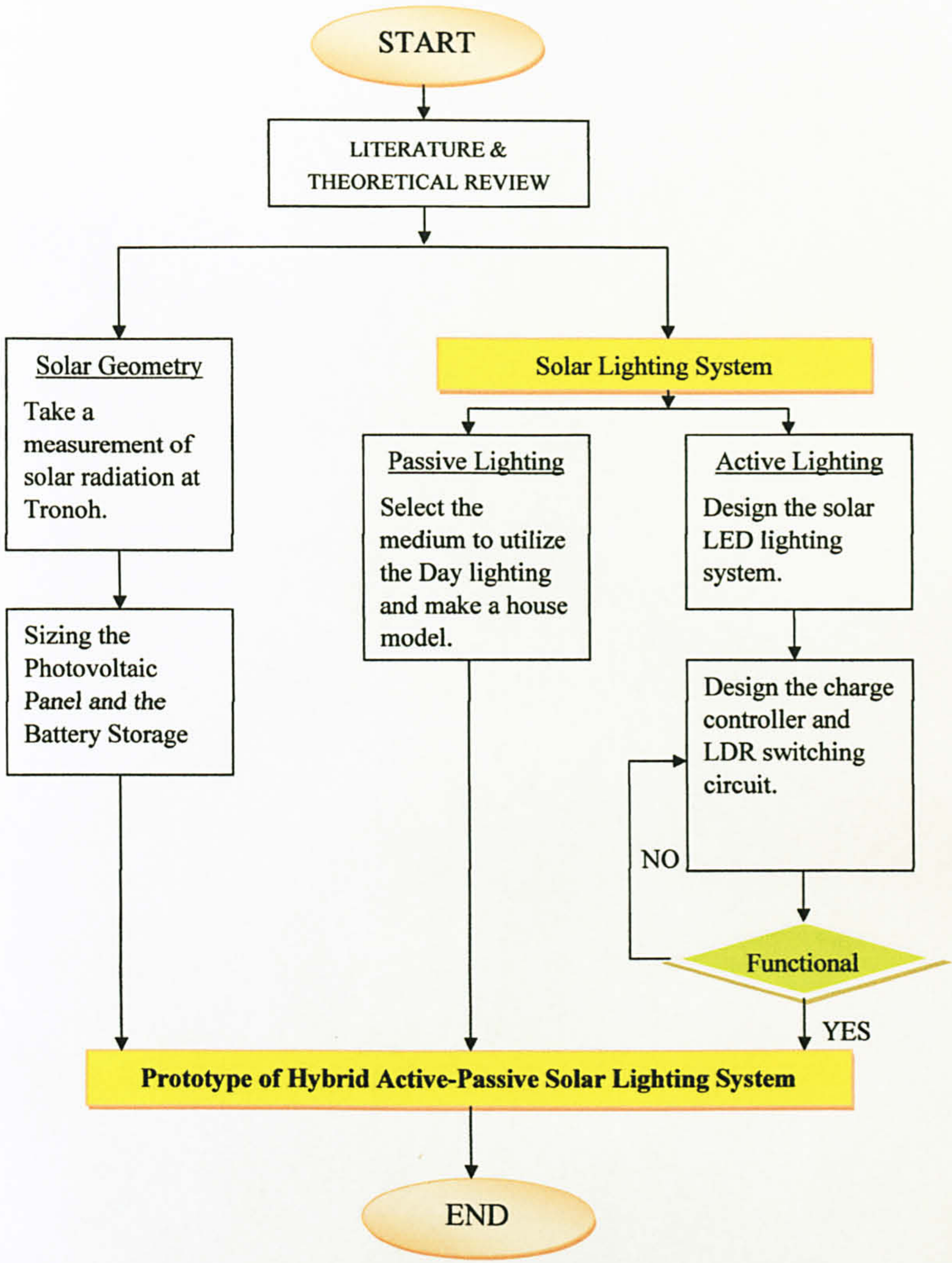


Figure 11 Process Flow for the Project

3.1.2 Gantt Chart

The project flow is according to the schedule. This project completed the calculation to size the solar panel and battery storage, the design of charge controller and switching circuit. For this project, the Gantt Chart is shown in the appendix section.

3.2 Hardware and Software Required

During the process of this project, it uses several software and hardware to build and design the prototype and wrote the report progress. At Table 2 and Table 3 as show the hardware or tools and software use respectively.

Table 2 Hardware / Tools

No	Name	Description
1	Lux Meter	To measure the lamp intensity.
2	Solder Equipment	To solder the electronic components on the veroboard. The equipment including the sucker and soldering iron.
4	Digital Multimeter	To measure the value of resistors, capacitors, voltage and current.
5	Vero board	To connect the entire electronic component. It very light if want to compare with breadboard.
6	Saw and Glue	To do the house model.
7	UTP Solar Tracker	To measure the solar radiation at Tronoh.

Table 3 Software

No	Name	Description
1	HOMER	The software use to simulate the solar system connectivity and take the reading for the solar radiation.
2	Microsoft Word	The most useful software for writing the report like proposal, progress report and final report.
3	Microsoft Power Point	The software to make a slide show for presentation.
4	PSpice Student	This software we use to design the circuit and do simulation.
5	AutoCAD	This software use to design the 3D house model.

3.3 The Circuit Components

The circuit has been divided to 2 parts; the charge controller circuit and LDR switching circuit. The charge controller circuit connected between solar panel and battery storage while LDR switching circuit connected between battery storage and the LED lighting. Table 4 and Table 5 below show the components use to construct the charge controller and LDR switching circuit respectively.

Table 4 Charge Controller Circuit Components

NO	COMPONENT	QUANTITY
1	Solar Panel 20W	1
2	Sealed Lead Acid Battery 12V 1.3Ah	1
3	Electrolyte Capacitor 1µ	2
4	Electrolyte Capacitor 100µ	2
5	Voltage Regulator 7815	1
6	Resistor 330Ω	1
7	Red LED	1
8	Zener Diode 5W	1
9	Diode 1N4001	1

Table 5 LDR Switching Circuit Components

NO	COMPONENT	QUANTITY
1	LDR Sensor	1
2	Resistor 10kΩ	2
3	Resistor 470Ω	2
4	Resistor 1.6kΩ	1
5	Resistor 1kΩ	1
6	IC LM741	1
7	Red LED	1
8	Transistor 2N3904	1
9	Electrolyte Capacitor 220µ	1
10	Relay 12V	1
11	Potentiometer 10kΩ	1
12	Diode 1N4001	1

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Measurement of Solar Radiation at UTP

In this project, the Tronoh area is taken as a research area to develop the Hybrid Active-Passive Lighting System because the Tronoh area exposes with the much more sunlight radiation. One of the factor this area highly expose to the sunlight because it located near with the sea. The solar radiation was measured by using the Universiti Teknologi PETRONAS (UTP) Solar Tracker.

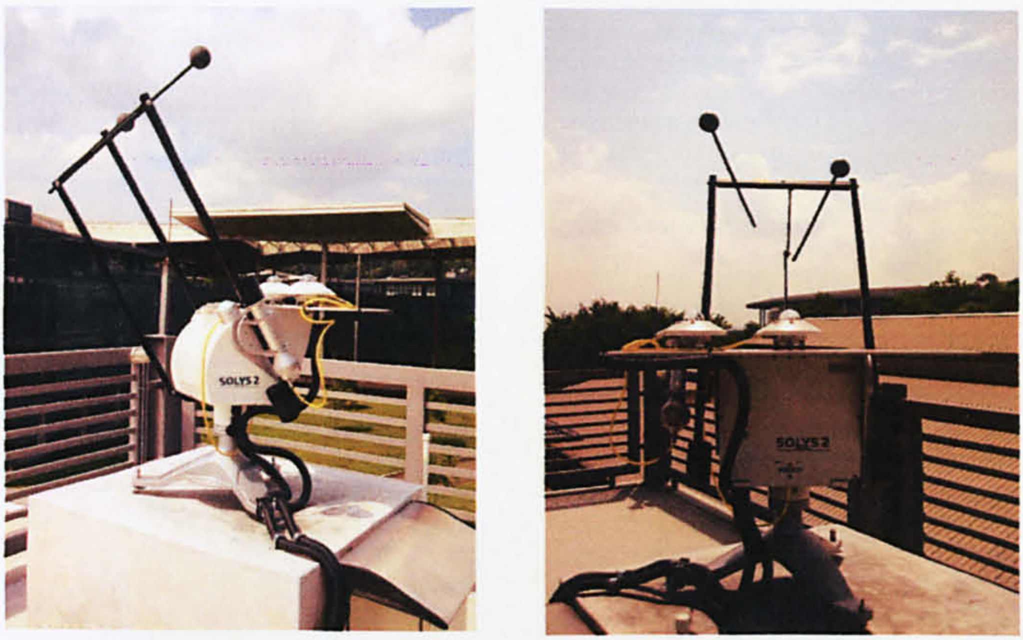


Figure 12 Solar Insulation Measuring Device

The solar radiation data taken like has shown in the Figure 13. The data collected is solar global radiations which are the total sum of radiation of beam and diffuse radiation. The data was collected on 24th January 2010.

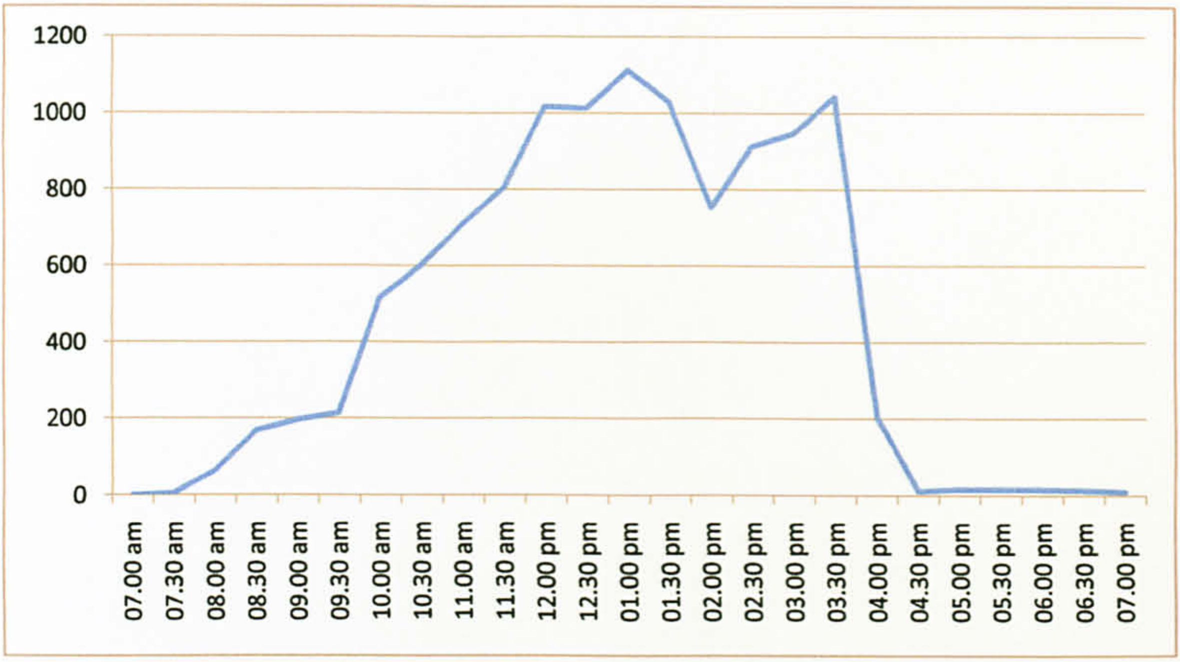


Figure 13 Graph of Solar Global Radiation (W/m^2) collected on 24th January 2010

From the data collection, the average solar radiation at Tronoh area is around 949.72$W/m^2/h$. The highest reading for solar radiation is 12.00 pm until 01.00 pm. So that's, the solar lighting system need the battery storage to store the solar energy and the solar radiation reading can be use to sizing the photovoltaic panel.

4.2 Sizing Photovoltaic (PV) Panel

To sizing the photovoltaic panel, it needs to know the power rating for the battery storage. In this project prototype was use sealed lead acid battery with rating 12V, 1.3Ah which the power rating equal to 15.6 Watts as a storage. So, the output power for the photovoltaic panel must be higher than 15.6 Watts to charging the battery. For the sizing, assume that 20 Watts output power need to produce by the photovoltaic panel because the power produce need to be bigger than the storage power. In the market the good solar cell efficiency is around 25% which is for Siemens photovoltaic panel [11]. By using that data, the area of the photovoltaic panel can be calculated. Figure 14 shows the sealed lead Acid battery.

Figure 14 Battery Sealed Lead Acid 12V 1.3A

The output power needed = 20W

Total average input power get from sunlight = 949.72 W/m^2

$$Efficiency, n = \frac{P_{out}}{P_{in}} \times 100 = \frac{20W}{949.72W \times A} \times 100 = 25\%$$

So, the area is:

$$Area, A = \frac{20W}{949.72W \times 0.25} = 0.0842m^2 \cong 0.09m^2$$

The area of photovoltaic can be reducing if the panel efficiency increases. Below is shown the effect to the photovoltaic panel area when the efficiency increase.

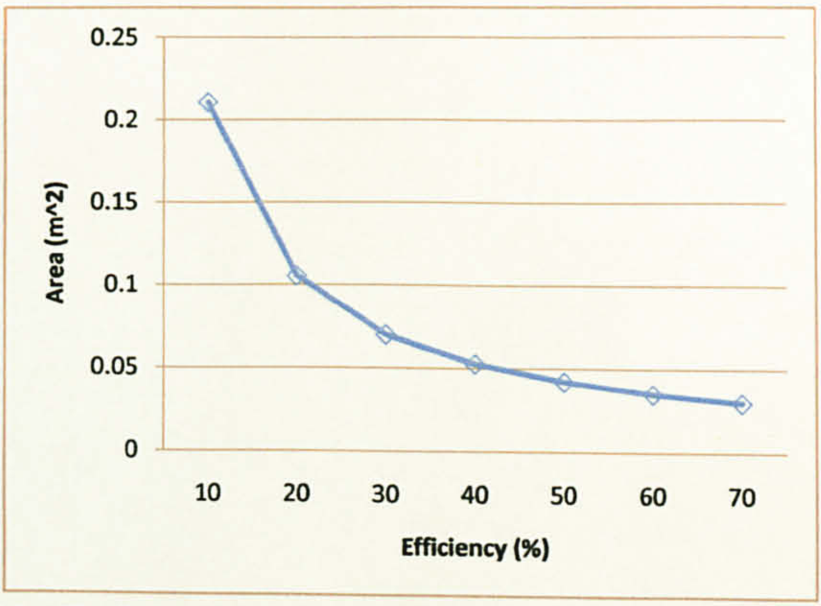


Figure 15 The Relationship Between Photovoltaic Efficiency (%) and Its Area (m^2)

4.2.1 Efficiency Calculation for Photovoltaic Panel 20W

However, in this project use a polycrystalline photovoltaic panel 20W which is manufactured by China for the prototype. Below is showing the efficiency calculation for the photovoltaic panel prototype.

Photovoltaic panel area: 0.28m x 0.55m = 0.154m^2

Maximum power output of the photovoltaic panel: 20W

Maximum Solar Radiation: 1111.54W/m^2

$$Efficiency, n = \frac{P_{out}}{P_{in}} \times 100 = \frac{20W}{1111.54W/m^2 \times 0.154m^2} \times 100 = 11.68\%$$

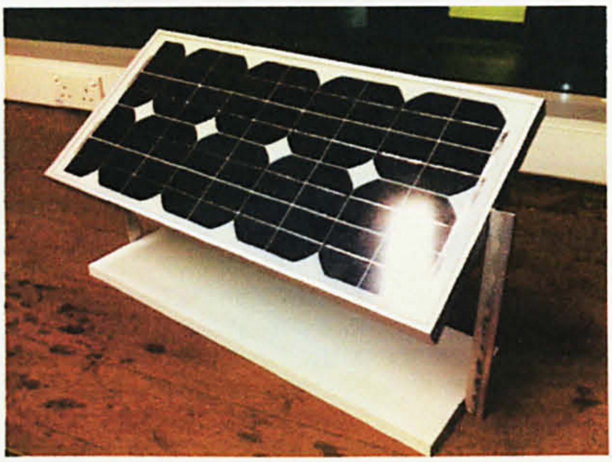


Figure 16 Solar Panel 20W

Based on the calculation, it proves that the solar panel efficiency is 11.68% which is in the range of the real efficiency for polycrystalline PV (9-12%).

4.3 Hybrid Active-Passive Solar Lighting System

Active lighting is automatically on if the day lighting intensity reduce because of cloud for example raining day. This active light source produces by solar lighting system which the type of lighting use will discuss in the next topic. The lighting operation is control by the LDR sensor circuit. It will switch on when the sunlight intensity reduce. Below is the block diagram to show how the Hybrid Active-Passive Solar Lighting System operates.

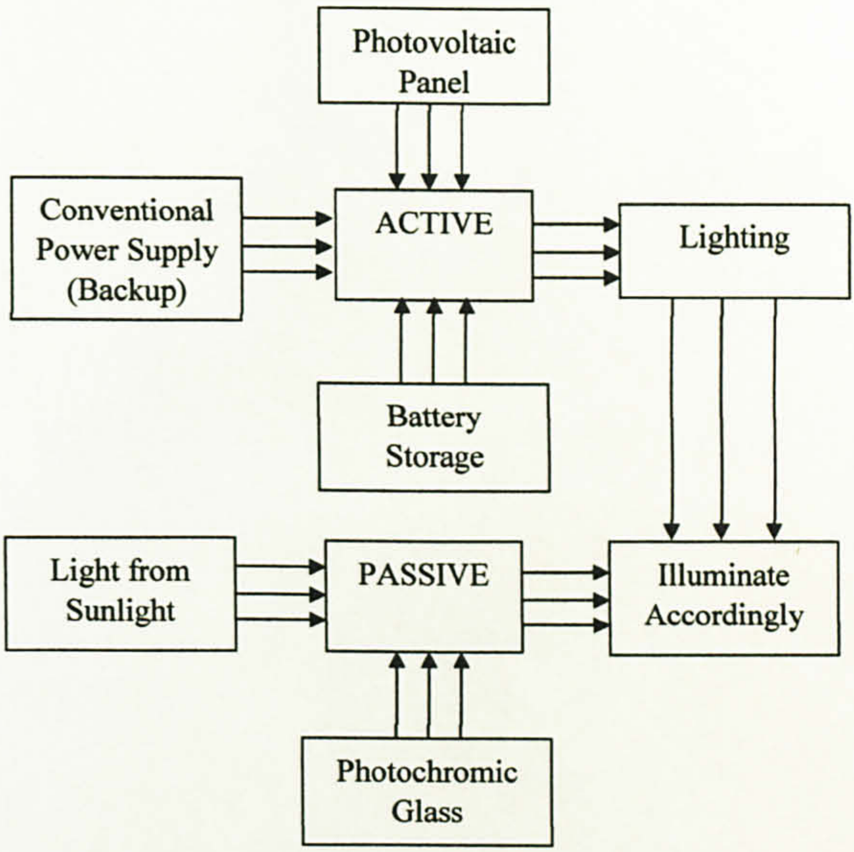


Figure 17 Block Diagram for the Hybrid Active-Passive Solar Lighting System

In the day time, the system use passive lighting more than active lighting and the solar energy will store in the battery storage. The active lighting will turn on if suddenly the sky becomes cloudy. While for the night time, the intensity of moonlight is lower than sun, so the system will use active lighting to illuminate the house by using the power store in the battery storage. This system has a higher energy efficient to produce light in the house.

4.4 Design of LED Based Lighting System

In this project, it develops an alternative lighting to use along side with the solar system. This lighting is made by using the array of brightness white LED which connected parallel with each other. The design connected parallel because if one LED breakdown, the others still operate. There are many advantages if use LED as lighting for solar system. For example the power rating consume by the lighting. Table 6 below is shown the comparison power rating between the LED and with other conventional lighting.

Table 6 *Power Rating for Lighting*

Type of Lighting	Power, Watts (W)
a) Compact Fluorescent Light	23W
b) DC Energy Saving Lamp	18W
c) Conventional Fluorescent Light	40W
d) LED Lighting	**5W**

Based on the power rating, it shows that LED consumes less power than other lightings. There are many other advantages if the solar system use LED as active lighting source. It can increase the energy efficiency of the solar lighting system and reduce the heat produce by the conventional lighting. In the actual testing this LED consume current 1.04A at voltage 5V. So the total power equal to 5W. Figure 18 is shown the LED that develops in this project and the comparison of intensity level between it with the others type of lighting.

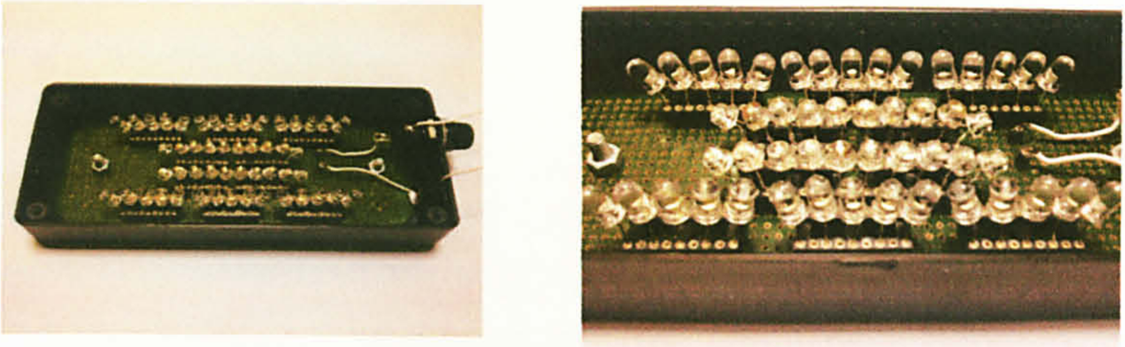


Figure 18 LED Lighting 5W

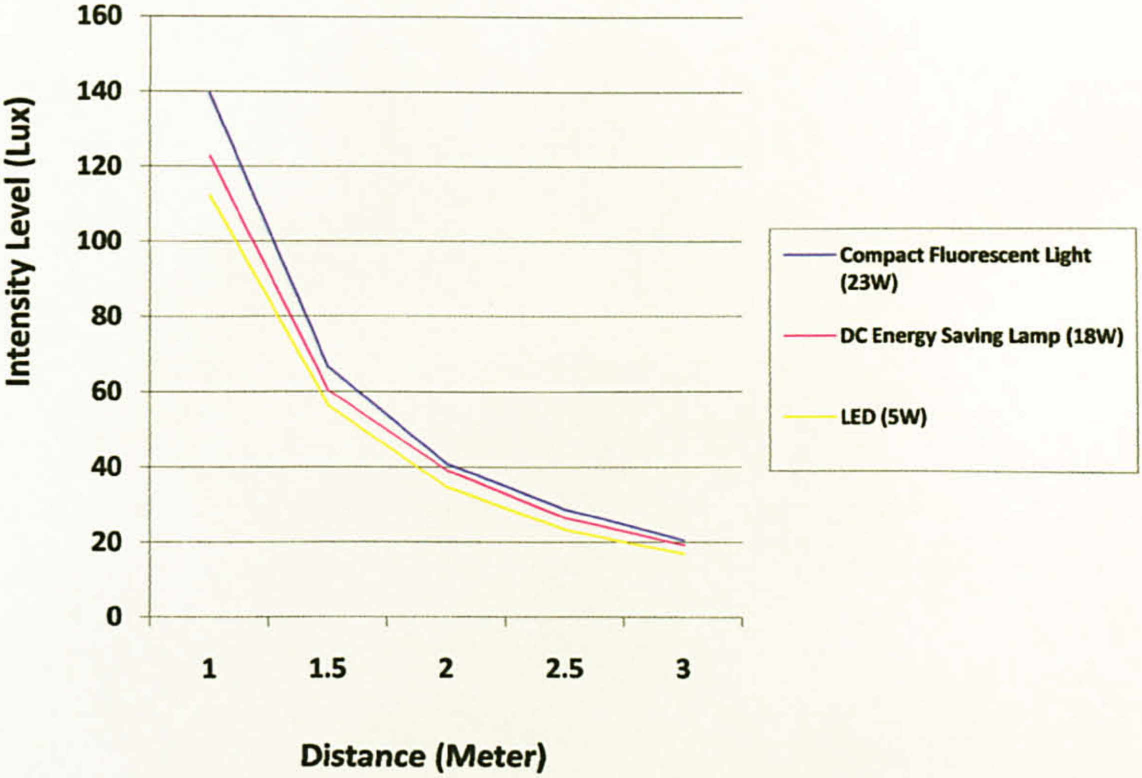
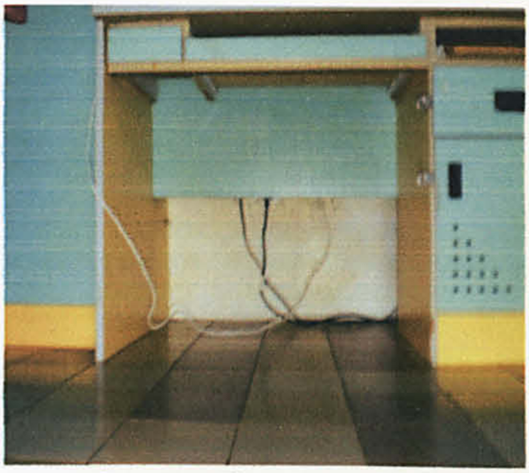
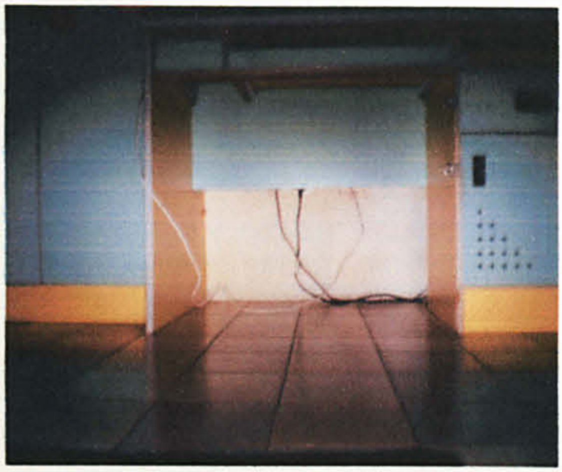


Figure 19 Intensity Level of Lighting Vs Distance from the Working Plane

Based on Figure 19, there shown that the LED intensity level is mostly equal to the conventional fluorescent lighting in illuminate dark working plane. During the measurement, the Lux Meter was put with starting distance 1 meter from the light source and then increasing the distance. In the picture below can be seen that the LED lighting cover small angle then fluorescent lamp but it consume less power which can make the solar lighting system more energy efficient. This also can be improving in the future when the brighter LED will be developing.



Compact Fluorescent Light



LED

Figure 20 Comparison on Illuminate Dark Area

4.5 Design of House Roof Concept for Passive Lighting

In this project is proposing the design of house roof to utilize the Day Lighting which uses the direct sunlight as a light source. In the design, it use the windows roof concept which using the photocromic glass. This glass can changes automatically from clear to a dark tint when the sunlight shines on it. The glass also can reflect the ultra violet radiation. Below is shown the design concept done by using the AutoCAD software and the real house roof model.

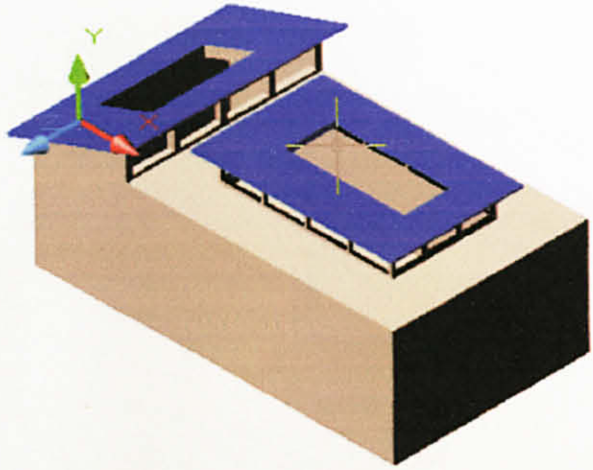


Figure 21 Design of House Roof by Using AutoCAD

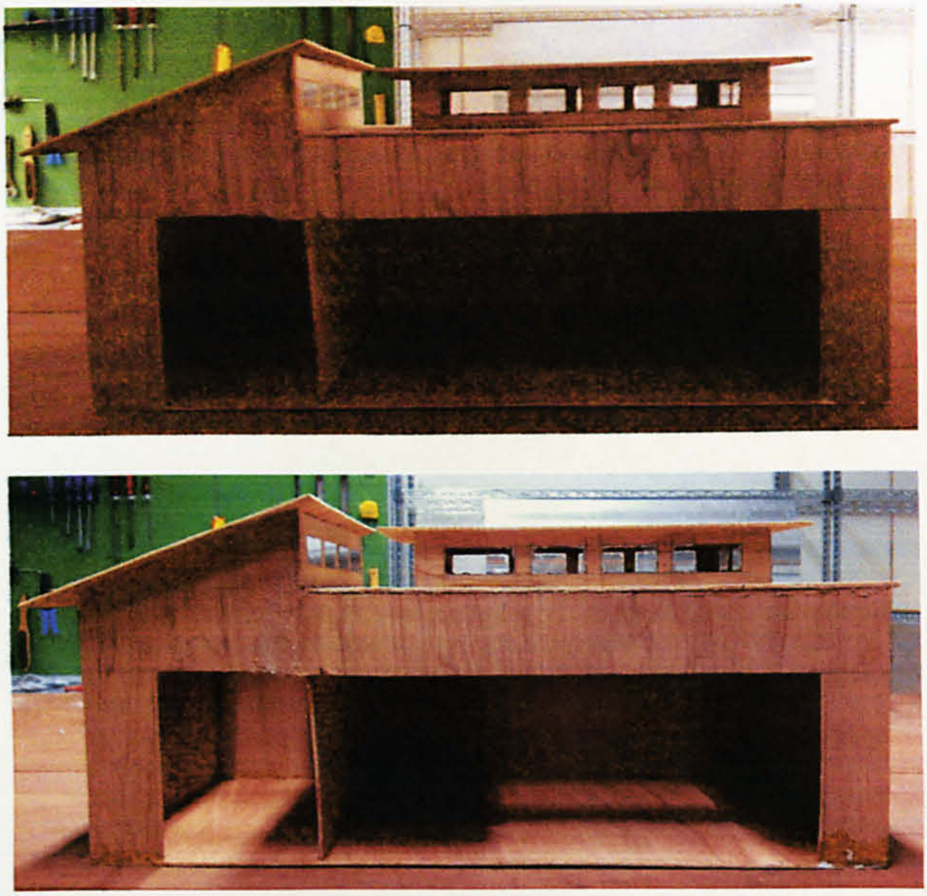


Figure 22 House Roof Model that Show Window Roof Concept to Utilize Day Lighting

4.6 Circuitry for Active Solar Lighting System

4.6.1 Solar Regulator Circuit

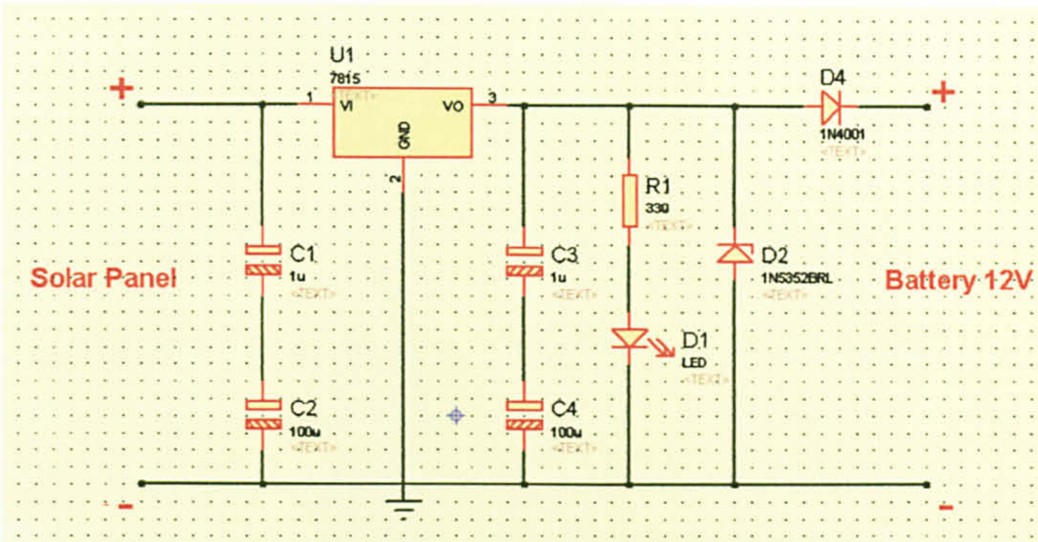


Figure 23 Solar Regulator Circuit

The electricity produced by the photovoltaic panel is always fluctuating because the level of sunlight radiation is not constant. So, before connecting the solar panel to the battery storage it will go through the voltage regulator which also acts as a charge controller. The circuit design by using voltage regulator LM7815C which can produce 15V positive output voltage. It was been selected because the input voltage to charge battery 12V need to be higher than 12V. The diode D4 function is to stops current from flowing out of the battery and back into the circuit while the LED use as a indicator that the circuit is functioning. The zener diode, D2 clamps the voltage at 14.3V. If the batteries are fully charged the solar panel will try to bring them above 14.3V. So, to make sure batteries is not over charged, the extra energy is release as heat in the 5W rated zener.

4.6.2 LDR Switching Circuit

The active solar lighting system is control automatically by using IC LM741 and light sensor which is LDR (Light Dependent Resistor). This circuit is connecting between battery and the LED. The circuit like shown below.

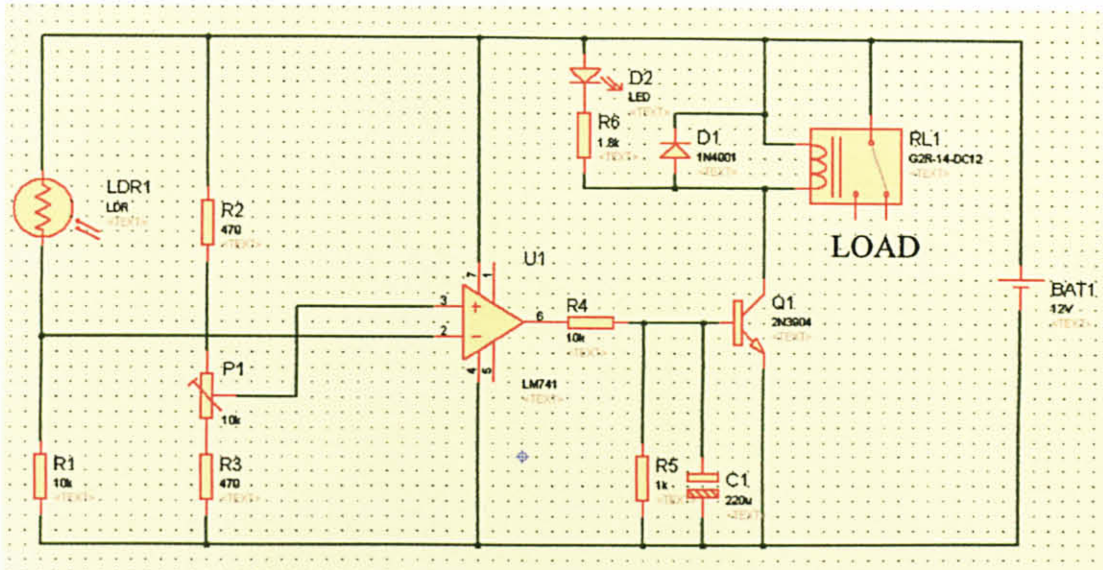


Figure 24 LDR Circuit for Switching Control

The relay 12V will be closed only when no light falls on LDR sensor. However, in testing this circuit proved to work very well with the user able to adjust the potentiometer (P1) to automatically close the relay at whatever light level they chose. This switching control can increase the energy efficiency of the system because in only on the active lighting source automatically when the house areas become dark [16].

4.7 Prototype Battery Sizing

One of the important parts in solar lighting system is the battery storage because to make sure the system more reliable to supply power to the load. For the prototype it use Sealed Lead Acid Battery 12V 1.3Ah and the power rating for the load (LED Lighting) is 5W. Below is shown how many hours the load can sustain to operate.

The current consume by LED:

$$Current, I = \frac{Load\ Power, W}{Voltage, V} = \frac{5W}{12W} = 0.42A$$

Operating Hours:

$$Hours = \frac{Battery\ Ampere\ Hour, Ah}{LED\ Current, I} = \frac{1.3Ah}{0.42A} = 3.1Hours \cong 3Hours$$

From the calculation, the battery can supply power continuously for 3 hours to operate the solar LED lighting system. Figure below show that the operating hours for the prototype is directly proportional to the battery ampere hour (Ah).

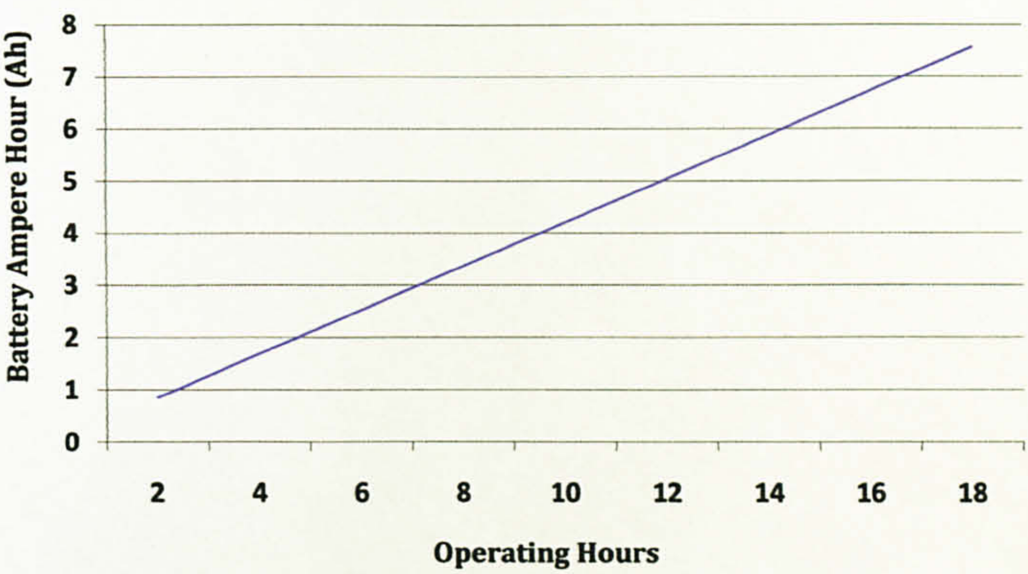


Figure 25 Relationship between Battery Ampere Hour (Ah) and Operating Hours.

4.7.1 Experimental to Measure the Battery Discharging Rate

The experiment has been conducted to prove that the battery (12V, 1.3Ah) using for the prototype can continuously operate with LED lighting for 3 hours which based on the calculation. The voltage of the battery was taken every 15 minutes and the load was setup like shown below.

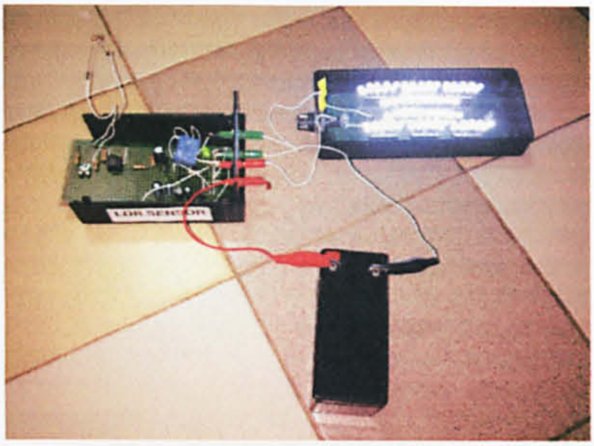


Figure 26 Discharging Circuit

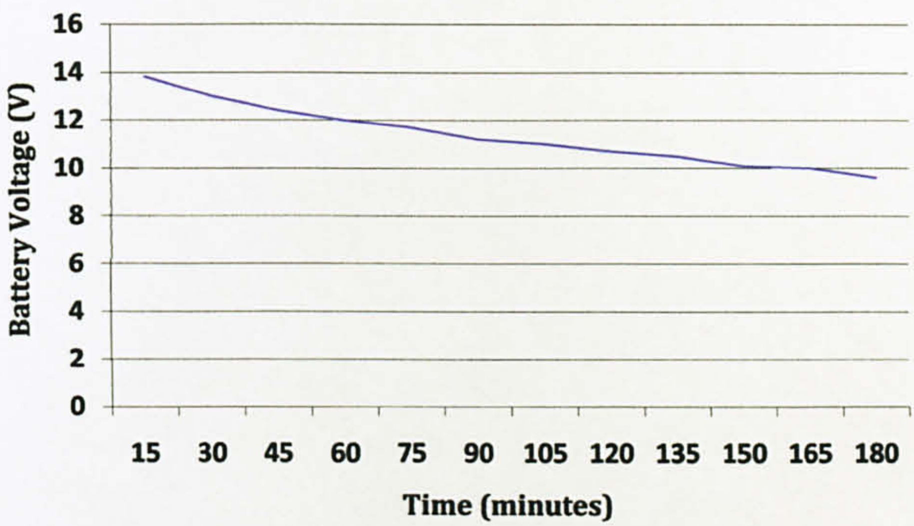


Figure 27 Discharging Graph

From the experiment prove that the battery storage can power up the LED lighting within 3 hours continuously. The voltage drop is still in the battery tolerance (+/- 20%) which is between 14.4V – 9.6V. So that, the battery must store power as much as possible from the photovoltaic panel and this battery need to be maintain to make sure it in good performance.

4.8 Energy Saving Calculation

By using the LED lighting in solar lighting system it can conserve a lot of energy. Below is a show the energy that can be save if the Hybrid Active-Passive Solar Lighting System is implementing at domestic area to replace the conventional lighting.

Power rating for Compact Fluorescent Light: 23W
Power rating for LED Lighting: 5W
Energy save, 23W – 5W = 18W.

In 1 year, assume that

1. Operating hours = 12 hours
2. Operating days = 365 days

Total **energy saving** for the LED Lighting is:

$$18W \times 12hours \times 365days = 78.84kW/year$$

So, if 100 normal Compact Fluorescent Light 23 W is replaced with LED Lighting, total **energy savings** is:

$$78.84kW/year \times 100 = 7.88MW/year$$

From the result, that proves the Hybrid Active-Passive Solar Lighting System is efficient in term to saving the energy generate from the fossil fuels. This concept can be implementing for the future domestic house development.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This project has covered various works of study. Starting for the part of solar geometry, followed by the study of day lighting house design, the types of solar panel, the concept of conventional lighting implement at domestic house, the charge controller circuit, the LDR switching circuit, solar panel and battery sizing. Solar geometry is important to get a maximum solar energy to be stored to in battery. The study of day lighting house designs is also an important part of this project to utilize the solar radiation as a light source during day time.

The concept later has been used to develop the Hybrid Active-Passive Solar Lighting System based on LED lighting for domestic usage. The house model prototype which was implemented the window and skylight concept show that it can utilize the day lighting as a light source. The charge controller circuit and LDR switching circuit work properly when assemble together with the LED lighting. The charge controller charges the battery automatically when the battery voltage drop and the LDR switching circuit automatically on the LED lighting when the surrounding area become dark. With the system installation, the battery is predicted to maintain its lifetime for at 5 years under the temperature 33^0C while the solar panel is around 20 years. This project hopefully can give a great contribution in helping to make solar as major alternative in the future. Finally, the objectives of this project were achieved.

5.2 Recommendation

This project can be modified and improved for the future to increase the system efficiency. For example, in the future it will be develop a brighter white LED and consume less power can be developed to replace the LED lighting used in this project. This system can be more energy efficient if a solar panel with higher efficiency is used because more solar radiation can be converted to electricity with the small area of solar panel.

The LDR switching circuit can be upgraded by using occupancy sensor which will turn on the active solar lighting system automatically when if senses a movement inside the house [19]. This LDR sensor can be used together with this occupancy sensor to increase the performance of Hybrid Active-Passive Solar Lighting System. The passive lighting can also be modified using fiber optic to distribute the sunlight inside the house or implement the skytube design to illuminate the dark area.

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APPENDICES

APPENDIX A

Gantt Chart

	Semester 1														Semester 2														
Details / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of project title/ supervisor	■																												
Preliminary research → Solar radiation → Solar geometry		■		■																									
Research on solar energy and photovoltaic				■	■																								
Submission of Prelim Report				■																									
Research on conventional lighting at domestic area						■	■															MID SEM BREAK							
Submission of progress report								■																					
Project work →Calculation → Project Proposal			HIN1 HOLIDAY					■	MID SEM BREAK	■	■	■	■																
Seminar											■																		
Submission of final interim report														■															
Oral Presentation														■															
Experiment at Tronoh for • Solar radiation data															■														
Feasibility study using actual data																■													
Design prototype for Hybrid Active-Passive Solar Lighting System • House Roof Model • LED Lighting • Regulator Circuit • LDR Sensor Circuit																	■	■	■	■	■								
Submission of progress report																					■								
Prototype construction and development																							■	■	■				
Poster exhibition																										■			
Draft report submission																											■		
Submission of dissertation (Soft bound)																												■	
Final presentation																													■
Submission of dissertation (Hard bound)																													■

APPENDIX B

Standard Lux Levels at Industry and Working Area

Lux Level(lx)	Area
20	1. Outdoor storage area
40	1. Corridor 2. Passageways
50	1. Parking 2. Security
80	1. Warehouse involving search & retrieval tasks 2. Stairs
100	1. Substation
160	1. Entrance halls 2. Foyers 3. Waiting Rooms 4. Canteens 5. Machine shop general work bench 6. Interior-Rough work 7. Recreation Play
240	1. Counters 2. Kitchen (food preparation area)
320	1. Offices 2. Open Hearth
400	1. Stores 2. Machine shop high tolerance work bench
500	1. Machine shop-Rough Work 2. Rolling mills
550	1. Material Handling 2. Ordinary Manufacturing
600	1. Electronic assembly work 2. Jewellery & Watch repair
750	1. Laboratory
1000	1. Machine shop-Medium work
2200	1. Highly difficult Manufacturing Tasks
5000	1. Machine shop-Fine work
7500	1. Most difficult Manufacturing Tasks
10000	1. Machine shop-Extra fine work

APPENDIX C

Datasheet LM7815

National Semiconductor

May 2000

LM78XX
Series Voltage Regulators

General Description

The LM78XX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. One of these is local on card regulation, eliminating the distribution problems associated with single point regulation. The voltages available allow these regulators to be used in logic systems, instrumentation, HiFi, and other solid state electronic equipment. Although designed primarily as fixed voltage regulators these devices can be used with external components to obtain adjustable voltages and currents.

The LM78XX series is available in an aluminum TO-3 package which will allow over 1.0A load current if adequate heat sinking is provided. Current limiting is included to limit the peak output current to a safe value. Safe area protection for the output transistor is provided to limit internal power dissipation. If internal power dissipation becomes too high for the heat sinking provided, the thermal shutdown circuit takes over preventing the IC from overheating.

Considerable effort was expanded to make the LM78XX series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

For output voltage other than 5V, 12V and 15V the LM117 series provides an output voltage range from 1.2V to 57V.

Features

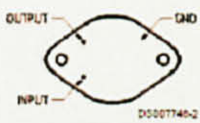
- Output current in excess of 1A
- Internal thermal overload protection
- No external components required
- Output transistor safe area protection
- Internal short circuit current limit
- Available in the aluminum TO-3 package

Voltage Range

LM7805C	5V
LM7812C	12V
LM7815C	15V

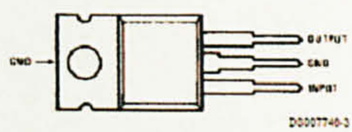
Connection Diagrams

Metal Can Package
TO-3 (K)
Aluminum



Bottom View
Order Number LM7805CK, LM7812CK or LM7815CK
See NS Package Number KC02A

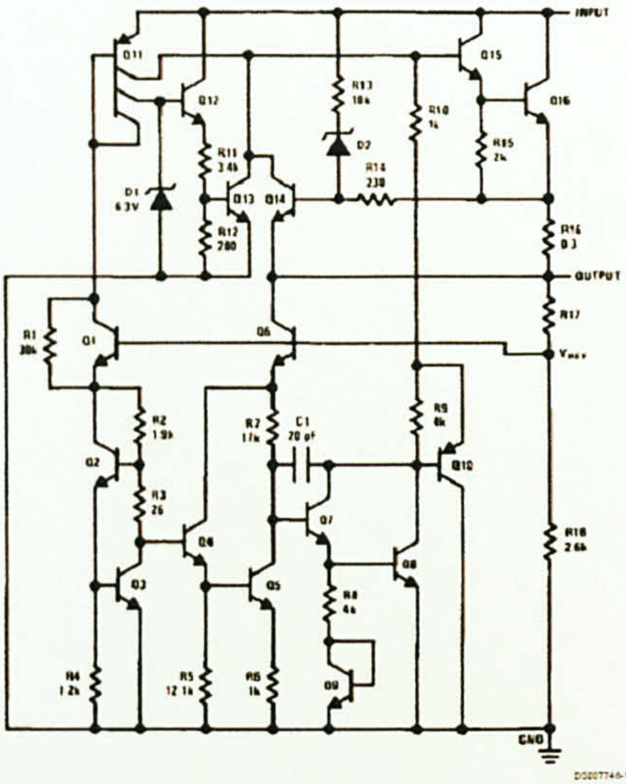
Plastic Package
TO-220 (T)



Top View
Order Number LM7805CT, LM7812CT or LM7815CT
See NS Package Number T03B

www.national.com

Schematic



Absolute Maximum Ratings (Note 3)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Input Voltage	
(V_O = 5V, 12V and 15V)	35V
Internal Power Dissipation (Note 1)	Internally Limited
Operating Temperature Range (T_A)	0°C to +70°C
Maximum Junction Temperature	
(K Package)	150°C
(T Package)	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package K	300°C
TO-220 Package T	230°C

Electrical Characteristics LM78XXC (Note 2)

0°C ≤ T_J ≤ 125°C unless otherwise noted.

Output Voltage				5V			12V			15V			Units
Input Voltage (unless otherwise noted)				10V			19V			23V			
Symbol	**Parameter**	**Conditions**		**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	
V_O	Output Voltage	Tj = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA	Tj = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	(7 ≤ V_{IN} ≤ 25)			14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			50			120			150	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 1A	Tj = 25°C			50			120			150	mV
			ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)			V
			0°C ≤ Tj ≤ +125°C			25			60			75	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	Tj = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_O ≤ 750 mA			25			60			75	mV
		5 mA ≤ I_O ≤ 1A, 0°C ≤ Tj ≤ +125°C				50			120			150	mV
I_Q	Quiescent Current	I_O ≤ 1A	Tj = 25°C			8			8			8	mA
			0°C ≤ Tj ≤ +125°C			8.5			8.5			8.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		Tj = 25°C, I_O ≤ 1A				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 500 mA, 0°C ≤ Tj ≤ +125°C				1.0			1.0			1.0	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, Tj = 25°C or	62	80		55	72		54	70		dB
			I_O ≤ 500 mA 0°C ≤ Tj ≤ +125°C	62			55			54			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	Tj = 25°C, I_{OUT} = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ

Electrical Characteristics LM78XXC (Note 2) (Continued)

$0^\circ C \le T_J \le 125^\circ C$ unless otherwise noted.

Output Voltage			5V			12V			15V			Units
Input Voltage (unless otherwise noted)			10V			19V			23V			
Symbol	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Short-Circuit Current	Tj = 25°C		2.1			1.5			1.2		A
	Peak Output Current	Tj = 25°C		2.4			2.4			2.4		A
	Average TC of V_{OUT}	$0^\circ C \le Tj \le +125^\circ C$, $I_O = 5\ mA$		0.6			1.5			1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	$Tj = 25^\circ C$, $I_O \le 1A$		7.5		14.6			17.7			V

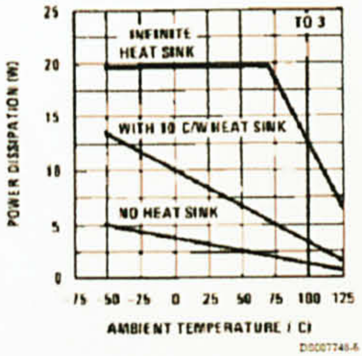
Note 1: Thermal resistance of the TO-3 package (K, KC) is typically 4°C/W junction to case and 35°C/W case to ambient. Thermal resistance of the TO-220 package (T) is typically 4°C/W junction to case and 50°C/W case to ambient.

Note 2: All characteristics are measured with capacitor across the input of 0.22 µF, and a capacitor across the output of 0.1µF. All characteristics except noise voltage and ripple rejection ratio are measured using pulse techniques ($t_w \le 10$ ms, duty cycle $\le 5\%$). Output voltage changes due to changes in internal temperature must be taken into account separately.

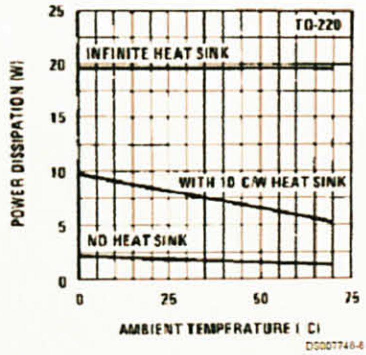
Note 3: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. For guaranteed specifications and the test conditions, see Electrical Characteristics.

Typical Performance Characteristics

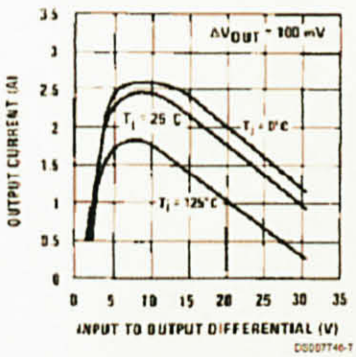
Maximum Average Power Dissipation



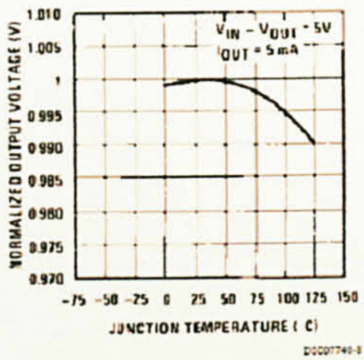
Maximum Average Power Dissipation



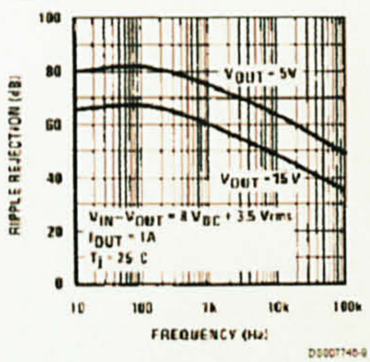
Peak Output Current



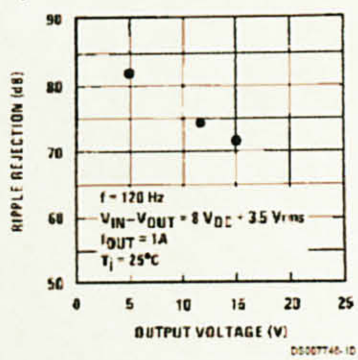
Output Voltage (Normalized to 1V at $T_J = 25°C$)



Ripple Rejection

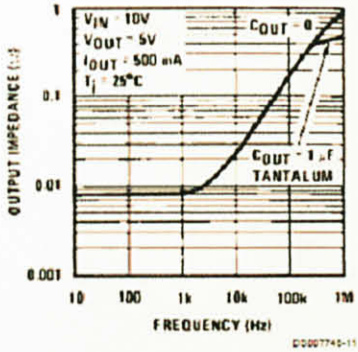


Ripple Rejection

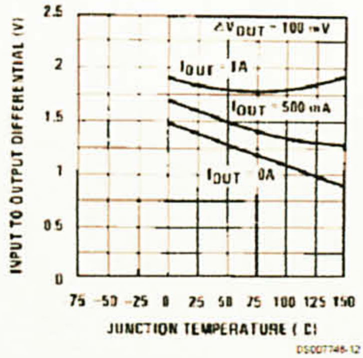


Typical Performance Characteristics (Continued)

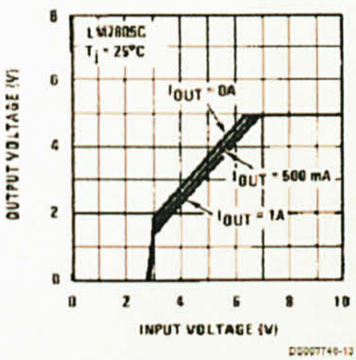
Output Impedance



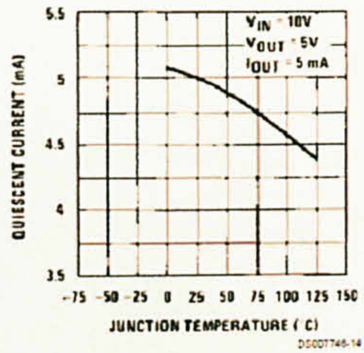
Dropout Voltage



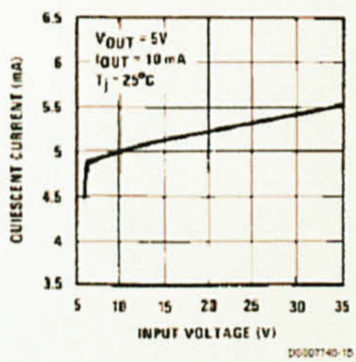
Dropout Characteristics



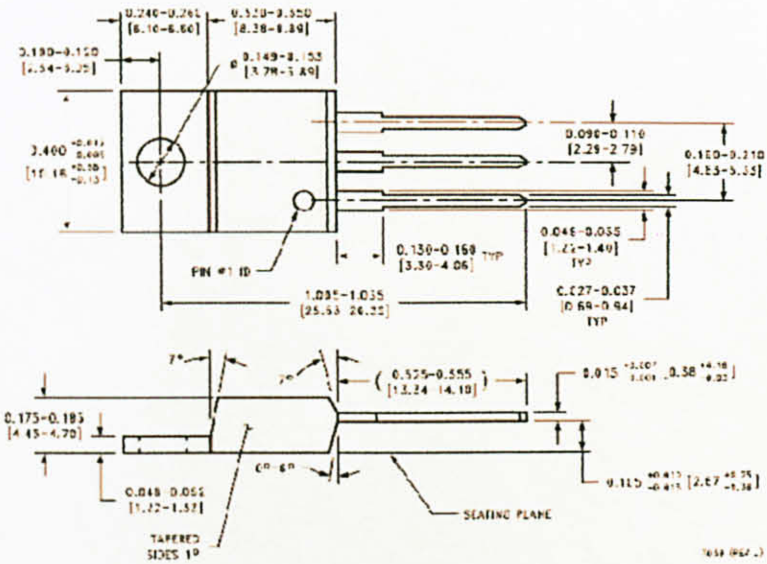
Quiescent Current



Quiescent Current



Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



TO-220 Package (T)
Order Number LM7805CT, LM7812CT or LM7815CT
NS Package Number T03B

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Fax: 1-800-737-7018
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www.national.com

National Semiconductor Europe
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Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507

APPENDIX D

Datasheet LM741

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

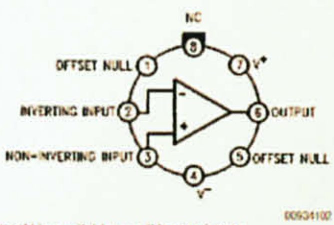
The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Features

Connection Diagrams

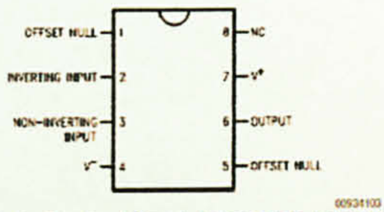
Metal Can Package



Note 1: LM741H is available per JM38510/10101

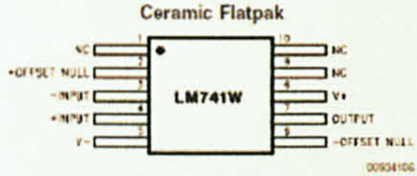
Order Number LM741H, LM741H/883 (Note 1), LM741AH/883 or LM741CH
See NS Package Number H08C

Dual-In-Line or S.O. Package



Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

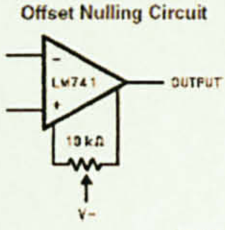
Ceramic Flatpak



Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55°C to +125°C	−55°C to +125°C	0°C to +70°C
Storage Temperature Range	−65°C to +150°C	−65°C to +150°C	−65°C to +150°C
Junction Temperature	150°C	150°C	100°C
Soldering Information			
N-Package (10 seconds)	260°C	260°C	260°C
J- or H-Package (10 seconds)	300°C	300°C	300°C
M-Package			
Vapor Phase (60 seconds)	215°C	215°C	215°C
Infrared (15 seconds)	215°C	215°C	215°C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

	LM741A	LM741	LM741C
ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25°C$										
	$R_S \le 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \le 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \le T_A \le T_{AMAX}$										
	$R_S \le 50\Omega$			4.0							mV
	$R_S \le 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							μV/°C
Input Offset Voltage Adjustment Range	$T_A = 25°C$, $V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25°C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/°C
Input Bias Current	$T_A = 25°C$		30	80		80	500		80	500	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	μA
Input Resistance	$T_A = 25°C$, $V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \le T_A \le T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25°C$							±12	±13		V
	$T_{AMIN} \le T_A \le T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	$T_A = 25°C$, $R_L \geq 2\ k\Omega$										
	$V_S = \pm 20V$, $V_O = \pm 15V$	50									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				50	200		20	200		V/mV
	$T_{AMIN} \leq T_A \leq T_{AMAX}$, $R_L \geq 2\ k\Omega$,										
	$V_S = \pm 20V$, $V_O = \pm 15V$	32									V/mV
	$V_S = \pm 15V$, $V_O = \pm 10V$				25			15			V/mV
	$V_S = \pm 5V$, $V_O = \pm 2V$	10									V/mV
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB
Supply Voltage Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$,										
	$V_S = \pm 20V$ to $V_S = \pm 5V$										
	$R_S \leq 50\Omega$	86	96								dB
	$R_S \leq 10\ k\Omega$				77	96		77	96		dB
Transient Response	$T_A = 25°C$, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	$T_A = 25°C$	0.437	1.5								MHz
Slew Rate	$T_A = 25°C$, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	$T_A = 25°C$					1.7	2.8		1.7	2.8	mA
Power Consumption	$T_A = 25°C$										
	$V_S = \pm 20V$		80	150							mW
	$V_S = \pm 15V$					50	85		50	85	mW
LM741A	$V_S = \pm 20V$										
	$T_A = T_{AMIN}$			165							mW
	$T_A = T_{AMAX}$			135							mW
LM741	$V_S = \pm 15V$										
	$T_A = T_{AMIN}$					60	100				mW
	$T_A = T_{AMAX}$					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100°C/W	100°C/W	170°C/W	195°C/W
θ_{jC} (Junction to Case)	N/A	N/A	25°C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

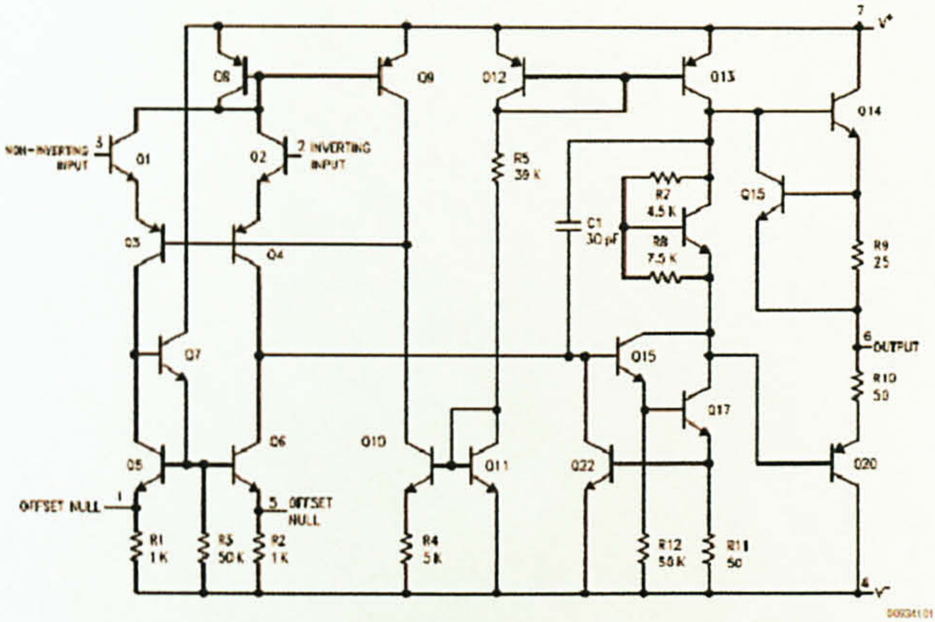
Note 5: Unless otherwise specified, these specifications apply for $V_S = \pm 15V$, $-55°C \le T_A \le +125°C$ (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to $0°C \le T_A \le +70°C$.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

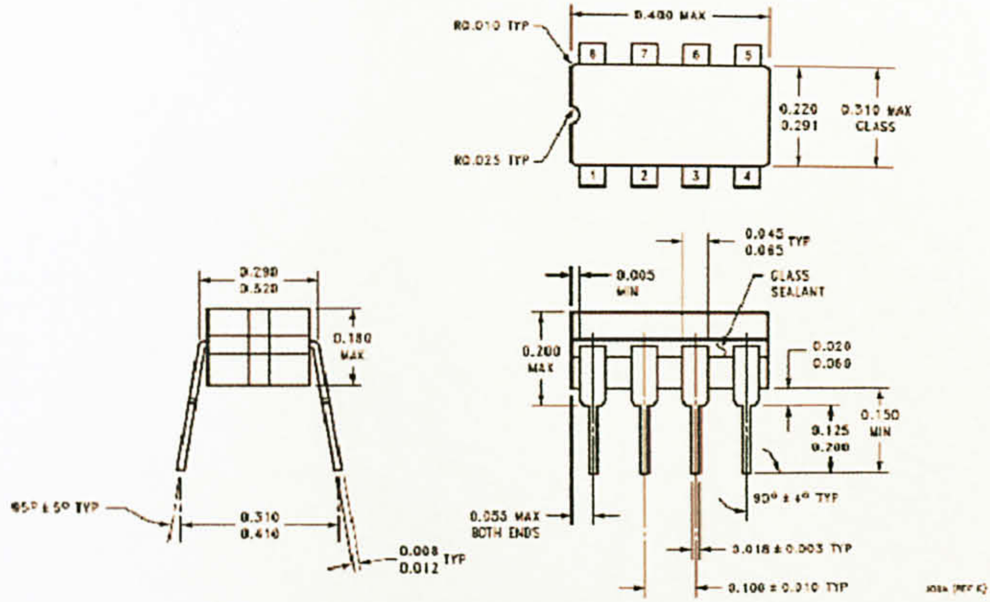
Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

Note 8: Human body model, 1.5 kΩ in series with 100 pF.

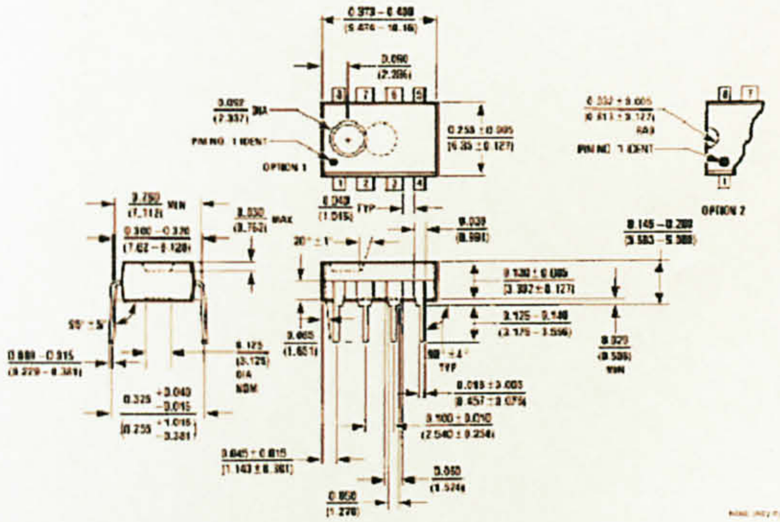
Schematic Diagram



Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

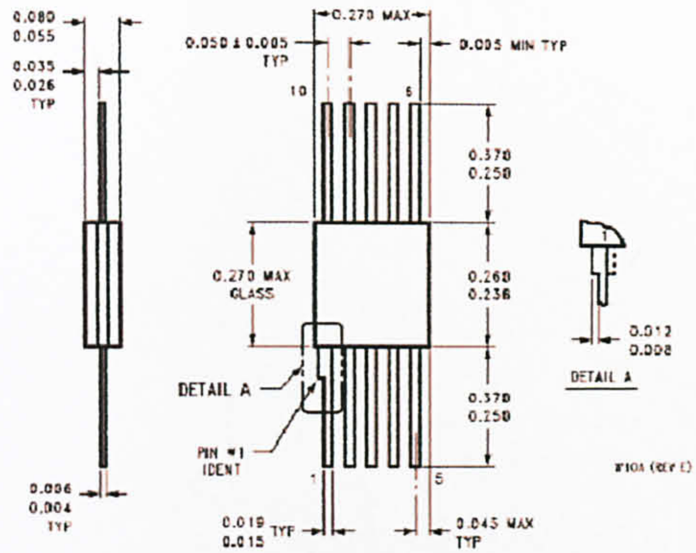


Ceramic Dual-In-Line Package (J)
Order Number LM741J/883
NS Package Number J08A



Dual-In-Line Package (N)
Order Number LM741CN
NS Package Number N08E

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883, LM741WG-MPR or LM741WG/883
NS Package Number W10A

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APPENDIX E

Prototype