Solar Lighting for Off-grid Dwellings

Of all the material things that we take for granted perhaps nothing is more overlooked or important than electricity. We use it to earn our livings, to reduce our chores, to learn, for entertainment, and to enable the communications and connectivity that keep us in touch with each other. Despite the importance of electricity, between 1.2 and 1.4 billion people or 20% of the world's population live in houses which do not have access to grid electricity, and because of this they cannot make the most fundamental use of electricity – to provide light. The alternative to electric light is fire from candles, wood, or most commonly kerosene, and the consequences of using fire to provide light are terrible:

- The poorest people in the world spend as much as 25% of their earnings or $36-40 billion dollars each year buying fuel for lighting.
- The World Health Organisation (WHO) estimates that close to 2 million people a year die prematurely due to the effects of inhaling smoke in their houses, mostly from kerosene lighting, and many millions more are burned in accidents involving kerosene lanterns.
- Kerosene lighting is the dirtiest way to use fossil fuel; burning a litre of kerosene in a lamp produces 100 times more black carbon soot than the equivalent in a diesel engine. As a result kerosene lamps add the warming equivalent of 240 million tonnes of carbon emissions each year.

In the 1850s kerosene replaced whale oil and candles as the main source of indoor light, and for the last 160 years it has continued to provide light for people who do not have access to electricity. Over the last 10 years, advances in solar, battery, electronics and Light Emitting Diode (LED) technology have finally brought us to the point where it is technically and commercially feasible to replace kerosene lighting with solar electric lighting. Before looking at the elements of solar lighting it is worth reviewing some basics of light and lighting.

Light and Lighting

What we perceive as the brightness of light is called illuminance, which is most commonly measured in units called lux (lx). The amount of light we need depends very much on the situation and tasks we are doing, as well as personal preferences, some examples of would be;

Situation	Illuminance
A bright sunny day	10,000 to 100,000 lux
An overcast day	100 to 5,000 lux
A brightly lit office	300-600 lux
A well lit room at home at night	100-200 lux
A moderately lit room at home at night	10-50 lux
Poorly lit area where reading is barely possible	1-5 lux
Full moon outdoors	0.1 lux
Darkened room, barely possible to see anything	0.01 lux

Our eyes have an amazing ability to adjust to different light levels, so we do not fully register huge changes in light levels. For example walking outside on a sunny day could expose us to a thousand times more light than inside, but we quickly adjust to this difference. At the low end of the scale the minimum light for anything other than sleeping or watching TV would be around 5-10 lux, which is much higher than the 1-3 lux that would exist in most rooms illuminated by kerosene lamps, candles or wood fires.

When considering sources of light, a different unit is used to measure total light output. This is called the luminous flux, and it is most commonly measured in lumens (lm). The typical light outputs of some common light sources are below;

Device	Total Light Output
Candle	10 lumens
Kerosene lantern	30 lumens
Typical LED flashlight (torch)	25-50 lumens
LP gas lantern	250 lumens
25 watt light bulb or 3 watt LED	250 lumens
75 watt light bulb or 10 watt LED	1000 lumens
Pressurised kerosene mantle lamp	1200 lumens
18W fluorescent tube	1300 lumens

The lumen rating does not tell the whole story as it measures all light coming from the source rather than just the useable light which we see. Most sources apart from LEDs send light in all directions where most is lost, so in reality their useable lumen value is a half to a third of their maximum value. Most solar lanterns emit between 25 and 50 lumens, although some go as high as 100 lumens. If the light from such a system is efficiently focussed and directed it could be 10 times greater than that of a typical kerosene lantern.

Solar Lighting Goals and Technologies

There are many ways to harness the sun to light homes, and numerous small solar electric grids are being deployed in villages and towns around the world, but if there is no grid the easiest and most practical way to get electric lighting for a house will be from an individual solar lighting system. This is a small system or device which can illuminate a small room or a few rooms using the energy it collects from the sun. The best way to understand such systems is to consider their key properties and what they ideally should be:

High light output for a long time: Small inexpensive solar lights cannot match the output of grid connected lights, but they can easily better fire-based lighting. A good goal would be to provide at least 3-5 times the light output of a kerosene lantern for 6 hours from a day of solar charging. This would mean a light output of 50-100 lumens giving 15-40 lux illumination at 1 metre from the lamp.

Robust with a long lifetime: The living conditions of those without grid power are generally much harsher in terms of humidity, temperature, and dust than the conditions that most electronic appliances have been designed for, so an effective system needs to be able to withstand these conditions. Given the costs and distribution difficulties the system should work in harsh conditions without maintenance for 3 to 5 years. This life could be further extended if the system had field replaceable parts such as batteries or solar panels.

Easy to use: There are many ways in which solar lighting can be implemented; there are self-contained portable systems, portable units which are charged from a common central battery and solar panels, or fixed systems where the solar panel is permanently positioned. Ideally the system should be easy to install and as convenient to operate as the light in a grid-enabled house. An added bonus would be for the system to provide an output to charge small battery devices like mobile phones, radios, and flashlights.

Small and lightweight: Transportation is part of the cost and difficulty in distributing systems, particularly in remote areas without road access, so the smaller and lighter a system is the easier and less expensive it will be to distribute. Ideally the whole system should weigh less than 500 grams and be smaller than a hardcover novel.

Inexpensive - People who use fire for light are poor so any alternative needs to be cheap enough for them to afford to buy it or be given it. Solar lights can be bought for as little as $10, but their performance is poor and most would not last for a year, on the other hand, multi-light fixed solar systems can be bought for $100-$200, but these are large and too expensive for most people. A good compromise would be something that cost around $20 to build whilst meeting the other goals outlined above.

There are over a hundred small solar lighting systems available today, but few if any of them effectively balance all the above goals and many are based on what might be called first generation technology. In particular most systems fall short when it comes to robustness and lifetime, light output and duration, or convenience of use. The features of solar lights are largely determined by their main elements so it is worth looking at these elements, which are the solar panel, battery, LED and the drive electronics.

Battery: The battery is the biggest influence on cost, weight, light duration, and lifetime of a system. In the past sealed lead acid (SLA), nickel metal hydride (NiMh), and nickel cadmium (NiCd or NiCad) batteries were used, but these are all heavier, shorter lived and hold less energy than the newer alternatives. Lithium batteries are superior in most regards, there are several different types, the most appropriate for solar use being Lithium Polymer (LiPo or Li Ion), and Lithium Ferrophosphate (LiFePO or LFP). LiPo is commonly used in mobile phones, laptops, and hybrid cars and is widely available. LiFePO batteries have been recently developed for electric cars, they have most (but not all) of the advantages of LiPo, but their main advantage is a potentially much longer useable life. The next few years should see further advances in Lithium batteries which will flow on to solar lighting.

LED: Coloured LEDs have been available for 40 years, but white LEDs are relatively new and improving all the time. LEDs are more efficient at producing light than almost any other light source, plus they are low cost, have almost unlimited life, and are easy to use. There is considerable variation in the efficiency and light output of LEDs, so not all types are suited for lighting. Single high power 1 Watt or 3 Watt LEDs give better results than multiple low power LEDs. A key aspect of LED lighting is to focus and direct the light effectively, this is best done using specifically designed lenses rather than reflectors or diffusers which are less efficient.

Solar panel: Solar cell technology is rapidly evolving and there is a vast array of technologies used to make solar panels for large scale domestic and industrial use. Individual lighting systems only require a few Watts of power which is easily achieved, so solar panel technology selection is not so difficult provided the panel has the necessary power and voltage to charge the system. Typical voltages would range from 5-12 Volts, supplying 1-4 Watts of power. Solar panels generally have a long lifetime as long as they are housed in waterproof enclosures with a transparent top that lets as much light through as possible.

Drive electronics: Electronics is more mature than the other technologies involved in solar lighting, but over the last 15 years the increasing numbers of mobile phones and portable computers which are reliant on LED displays and rechargeable batteries has led to a proliferation of low cost highly efficient control electronics which can be used to advance solar lighting systems.

Conclusion

Off-grid lighting in the third world is on the cusp of a solar powered revolution driven by various advancing technologies, but today despite this potential only about 1 percent of off-grid dwellings have solar lighting systems. Tremendous work is already being done by many organisations to distribute solar lights, and as designs improve and awareness of the benefits grows this will accelerate the solar spread and reduce the terrible impact of fire-based lighting.