LED Flashlights in the Kenyan Market:
Quality Problems Confirmed by Laboratory Testing

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Flashlights for sale in Kericho, Rift Valley Province, Kenya

About Lighting Africa

Lighting Africa, a joint World Bank and IFC program, seeks to accelerate the development of markets for modern off-grid lighting products in Sub-Saharan Africa where an estimated 10 to 30 percent of household incomes are spent on hazardous and low quality fuel-based lighting products**.** The goal is to mobilize and provide support to the private sector to supply quality, affordable, clean and safe lighting to 2.5 million people by facilitating the sale of 500,000 off-grid lighting units by 2012 while, at the same time, creating a sustainable commercial platform that will realize the vision of providing 250 million people with modern off-grid lighting products by 2030. This platform will provide an avenue for social, health and economic development, especially for households and small businesses that will realize significant cost savings and increases in productivity.

Lighting Africa is implemented in partnership with: the Global Environment Facility (GEF), the Energy Sector Management Assistance Program (ESMAP), Good Energies Inc., The UK, Luxemburg, The Netherlands, Norway, The Public-Private Infrastructure Advisory Facility (PPIAF), The Renewable Energy & Energy Efficiency Partnership (REEEP), and the Asia Sustainable and Alternative Energy Program (ASTAE). For more information: www.lightingafrica.org

Executive Summary

The Issue is that over a billion people do not have access to electricity in their homes and will not have it any time soon; many turn to candles, kerosene-fueled lamps, and dry-cell battery powered lamps for illumination (IEA, 2002). Compared to grid based lighting systems, these are expensive, inefficient, and provide poor quality light. Users of off-grid lighting can pay 150 times more per unit of useful lighting service than grid-connected people (Mills & Jacobson, 2008). Economic hardships aside, burning fuels indoors for light is a major source of indoor particulate matter that causes numerous acute and chronic respiratory diseases (Apple, et al., 2010).

A Solution might be Light Emitting Diode (LED) lighting systems, which are quickly emerging as an efficient, clean and affordable alternative that may alleviate many of the economic, environmental and health issues that are associated with fuel based lighting. The best LED lights for home illumination are still priced too high for many people who would benefit from their service; but LED flashlights (or torches), both dry cell and rechargeable, have become inexpensive and ubiquitous enough to be within reach across much of Africa. In only a few years time they have moved from the fringe to being a clear market leader over the venerable incandescent flashlight. Wider African trends can be inferred from early research that has been carried out in early adoption counties such as Kenya, where we found that LED flashlights are many people's first experience with LED lighting (Johnstone, Tracy, & Jacobson, 2009). The quality of the experience will impact their impressions and willingness to pay for other LED lamps as they become more widely accessible in the market.

A Roadblock to widespread adoption of efficienct lighting is being formed by quality problems with LED flashlights; quality issues in the flashlight segment are spoiling the market in general. In field research with LED flashlight users in Kenya, almost 90% reported problems and dissatisfaction (Tracy, Jacobson, & Mills, 2009). In this report we document our laboratory performance testing of eight LED flashlights and one incandescant flashlight that were purchased through retail outlets in Kenya. The outcomes lend creedence to the complaints of everyday consumers and reveal that:

1. LED flashlights **perform poorly in several key areas** including run time, battery capacity, durability, lumen maintenance, and battery charge control.

2. Under normal use scenarios, most of the products we tested are **limited to two months of useful life** before they have severe performance degradation or a total failure.

3. The marketing and packaging materials for LED flashlights are **misleading consumers with false claims** of product performance. For a typical user, we estimate the one-year cost of ownership is five times greater than the cost implied on the packaging.

4. There is an **immediate need for national and regional quality assurance and consumer education programs** for modern off-grid lighting products, including LED flashlights, to prevent badly performing, misleading products from spoiling the market.[1]

Lighting Africa is working to develop a quality assurance framework for off-grid lighting products in general, including the flashlight segment. Informing consumers about the relative quality differences between products and about the potential benefits from good quality lighting products are keys to the healthy development of a modern off-grid lighting market.

Among other activities, Lighting Africa is holding an Outstanding Product Awards competition in order to publically recognize good quality, affordable off-grid lighting products. The good quality and performance of the winning products, which will be announced on May 18, 2010 at the Lighting Africa 2nd International Business Conference and Trade Fair in Nairobi, Kenya, stands in stark contrast to the poor performance of the LED flashlights tested in this study. Information about the winning products will be available on the Lighting Africa website (http://www.lightingafrica.org) following the May 18 awards ceremony.

[1] This report is a component of the ongoing effort on the part of Lighting Africa to provide intelligence about the off-grid lighting market in sub-Saharan Africa, as well as to support the development of standard quality assurance testing methods for off-grid lighting in the developing world in general. These testing methods are designed to provide feedback to manufacturers, protect customers from false advertising, and support the ongoing development and dissemination of small-sized LED lighting technologies. Ultimately, these methods need to be transferred to quality assurance testing centers in regions where these products are needed most, particularly in the Global South.

Background

LED Flashlights

LED rechargeable flashlights have become ubiquitous throughout the Kenyan market (Johnstone, Tracy, & Jacobson, 2009). Anecdotally, this is true across Africa. However, many consumers are dissatisfied with the product quality. Estimates suggest the market penetration of flashlights is significant, with over 50% of Kenyan households reporting ownership(Kamfor, 2002). In more recent studies it appears that LEDs have emerged as the preferred flashlight technology type; Tracy et al (2009) found that 92% of the owners surveyed in Kenya reported owning LED flashlights while only 8% reported owning incandescent flashlights. The same survey found that end-user dissatisfaction levels were extremely high, with 87% of users experiencing problems with their flashlights within the first six months of ownership. Four product failure modes were particularly common: durability (21% of flashlights in the study had this problem), LED failure (20%), water leakage (18%), and battery capacity (14%).

Test Methods

Our goal was to test flashlights that are representative of what is currently available in the Kenyan market using standardized methods. In June of 2009 members of our team at the Schatz Energy Research Center (SERC) at Humboldt State University travelled to Kenya under the auspices of Lighting Africa, a project of the World Bank and International Finance Corporation. In addition to collecting relevant market data, we purchased 58 samples of low-price flashlights (see Figure 1) from a variety of retail outlets, including street vendors, shops, and outdoor markets. The products that we purchased represent a cross section of low cost flashlights that were available in Kenya in June and July of 2009. The mean retail price per sample was 2.94 USD, with sample prices ranging from 0.64 to 5.14 USD.[2] We purchased and later tested five to seven samples each for nine distinct flashlight models. Eight manufacturers are represented, and the group includes three dry-cell and six sealed lead-acid (SLA) rechargeable products.

[2] The flashlights were purchased in Kenyan Shillings (KSH). The exchange rate at the time was approximately 78 KSH per USD.

Figure 1: *The nine flashlight models tested in this study.*

During December 2009 and January 2010, we tested the flashlights using standard test methods developed by the Fraunhofer Institute for Solar Energy (FISE) specifically for off-grid lighting in the developing world; the work by FISE was carried out under the auspices of Lighting Africa (FISE, 2009). These methods are designed to assess the relative performance of LED based lighting systems with respect to quality and usability. In some cases, we made modifications to the method to accommodate the unique attributes of the products under test (see Appendix A for detailed descriptions of individual testing methods). The key tests of performance for flashlights measure:

- The number of hours of light on each full charge or fresh set of batteries ("run time"), which strongly impacts the ongoing cost of ownership of a flashlight.

- The storage capacity of the battery, for those that were rechargeable, which is a key "truth in advertising" parameter.

- The brightness of the flashlight at various distances, which is a measure of the lighting service they provide.

- The rate at which the brightness of the flashlight declines over time with use; this is also called the lumen maintenance or lumen depreciation. This is a key factor that influences the useful lifetime of the flashlight.

Laboratory Test Results for LED Flashlights

The flashlights we tested performed poorly in general. The measurements we made indicated poorer performance than the specifications in every case. The claims of manufacturers were inflated by up to 10 times compared to the measured performance. Table 1 summarizes the key findings of our tests for each of the flashlights and lists their retail prices. The test results fall into one of two categories: performance ratings and "end of useful life" factors. The hours of light per full charge (run time), brightness, and battery capacity are complementary performance ratings. The other end-of-life contributors we measured are durability in a drop test and battery voltage protection, which are not included in the summary table.

Table 1 *Summary of key results. Missing data are indicated with "-."*

Product code	Battery type*	# tested	Price (USD[3])	Date of purchase	Lumen maint. (L_{70},hours)	Light hours per charge (run time)		Battery capacity	
						Mean (hours)	% of rated	Mean (mAh)	% of rated
GYA	R	6	$3.21	Jun 2009	53	4.8	27%	683	42%
AAB	R	5	$5.14	Jun 2009	84	1.2	7%	370	42%
AAC	R	6	$2.12	Jun 2009	46	2.6	14%	287	39%
AAD	R	2	$2.63	Jan 2010	41	4.7	26%	273	41%
EJB	R	6	$2.76	Jun 2009	87	5.5	31%	219	27%
OCB	R	5	$3.21	Jun 2009	84	4.3	22%	367	37%
CTA	R	5	$4.50	Jun 2009	14	1.8	18%	265	32%
AKA#	D	6	$0.64	Jun 2009	N/A	7.2	N/A	N/A	N/A
DDA	D	6	$1.93	Jun 2009	52	30.5	N/A	N/A	N/A
DTA	D	6	-	Jun 2009	22	19.7	16%	N/A	N/A

*For battery type, "R" denotes rechargeable, "D" denotes dry cell.

Flashlight "AKA" is the only incandescent product, and is included as a measure of the "traditional" flashlight market.

[3] Exchange rates from Central Bank of Kenya (http://www.centralbank.go.ke/forex/). The average rate for June 2009 was 77.9 KSH per USD.

Performance Ratings and Truth in Advertising

Battery Capacity

For the seven SLA rechargeable battery powered flashlights, there is a substantial difference between the manufacturers' rated battery capacity specifications and our laboratory's measured values. The rated specifications for these products range from 600 to 1300 milliamp hours (mAh), but Figure 2 shows that the lab-measured capacities range from 27 to 42% of these rated values. For the end-user, this translates into two to four times shorter run time per charge. The implication is that users must recharge the flashlight two to four times more frequently, all other factors being equal.

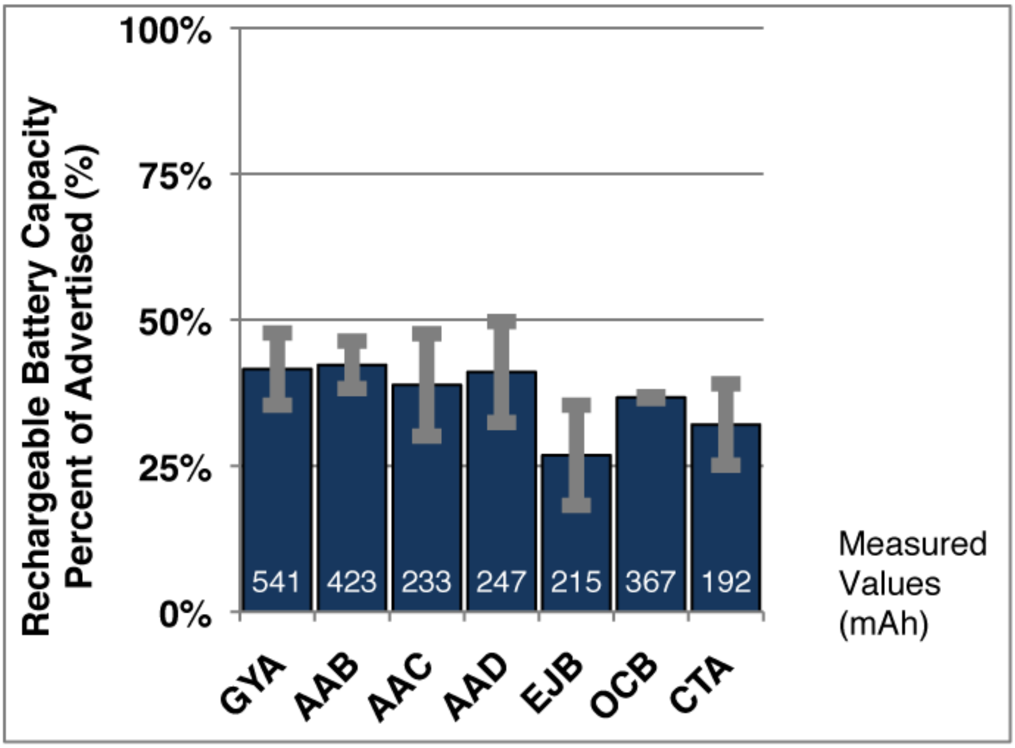


Figure 2 *Blue bars indicate average measured battery capacity for each SLA product, presented as a percentage of rated capacity. Grey bars indicate 95% confidence interval.*

Brightness

Field observations indicate that many people who buy flashlights strongly consider brightness when selecting a model for purchase. In this area, LED flashlights do quite well, which is a bright spot on their otherwise poor test record. The initial brightness of each product is shown in Figure 3 in terms of the distance away that the fully charged flashlight can provide illumination to at least 5 lux, which might be considered a minimum level for general way finding illumination. Compared to flashlight "AKA," the product containing an incandescent light bulb, all of the LED-based flashlights are brighter. Some are even able to provide sufficient illumination at a 10-meter distance. However, as reported below, the initial brightness of the LED flashlights does not last.

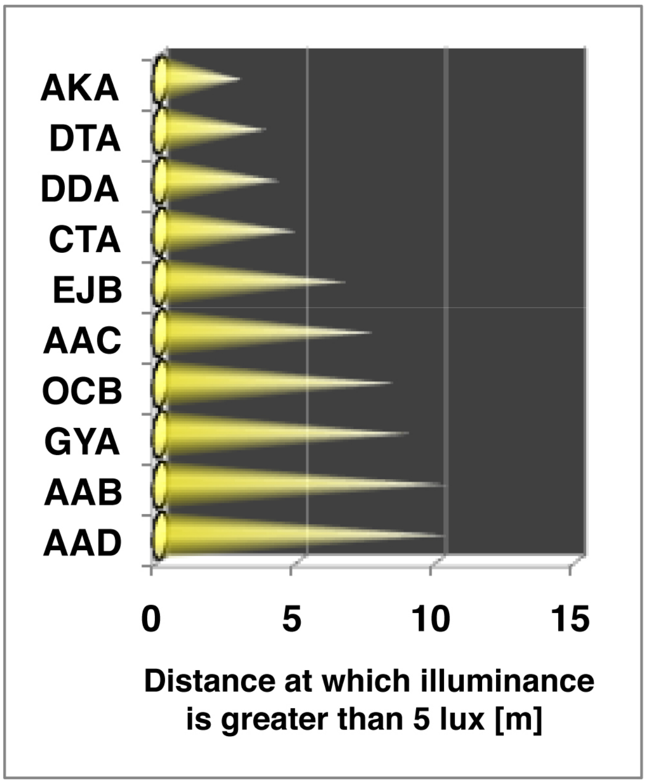


Figure 3 *Initial brightness of each product in terms of the distance away that the fully charged flashlight can provide illumination at a level of at least 5 lux.*

Run Time

In addition to brightness, the run time (number of hours of light on a full charge) is an important performance measurement for consumers. For those who pay to recharge batteries or buy replacement dry cells, run time can make a big difference in operating costs. A comparison between manufacturers' rated specifications of run time and measured values from lab testing reveals that almost all of the flashlights perform well below the advertised levels. The poorest-performing rechargeable product yielded an average measured run time of 1.2 hours, merely 8% of the advertised 18 hours. The highest-performing rechargeable product yielded an average measured run time of 5.5 hours, which is only 37% of the advertised run time of 18 hours (Figure 4). For the typical end-user this translates into the need to recharge the flashlight three to ten times more frequently than would be true if the flashlight performed to the level indicated by the manufacturer's specifications. For dry cell flashlights the run times were longer, but it was nonetheless more expensive to operate the dry cell flashlights than the rechargeable ones.

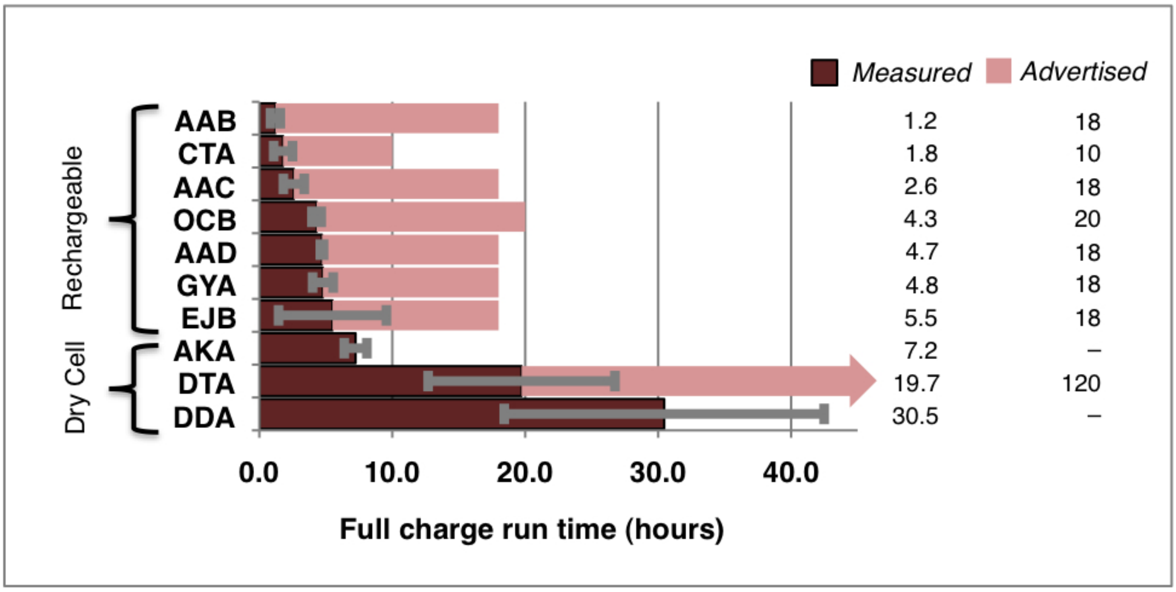


Figure 4 *Run time, in hours of lighting service per charge. Grey bars represent 95% confidence intervals.*

Causes of Early Flashlight Failure

Above, we established that the LED flashlights tested did not perform according to rated specifications with respect to the battery storage capacity or run time. Not only was the performance of newly purchased flashlights poor, their useful lifetime was often very short due to a number of failure modes intrinsic to their design. Users of LED flashlights have reported that they tend to last about two months (Tracy, Jacobson, and Mills, 2009); this is far shorter than the "long life" that is advertised on many of their packages. The measurement based results from this study are consistent with the experiences reported by flashlight users. Early flashlight failure can be caused by mechanical problems, exposure to the elements, early battery failure, or LED failure that is either catastrophic or from steadily declining brightness (lumen depreciation).

Mechanical Durability

Mechanical durability issues are the most frequently cited failure mode (24%) for LED flashlights from field surveys (Tracy, Jacobson, & Mills, 2009). These complaints can be broken into two categories: switch wire failure, and dropping and breaking. To evaluate switches and wires, we tested all products in accordance with a method developed by PVGAP that involves cycling one sample on and off 1000 times. To assess mechanical durability, we drop-tested all products using a method based on IEC 60598-1 with minimal modifications. For the drop test, each sample was dropped once on each of its six sides from a height of 1 meter onto a concrete surface. The sample passes if it retains basic structural integrity and functionality after the drops. Figure 6 shows the result of a particularly catastrophic drop test failure. While four of nine flashlights failed the drop test, only one of the nine, a dry cell product, failed the switch cycling test. This failure was due to corrosion caused by leaking battery electrolyte.

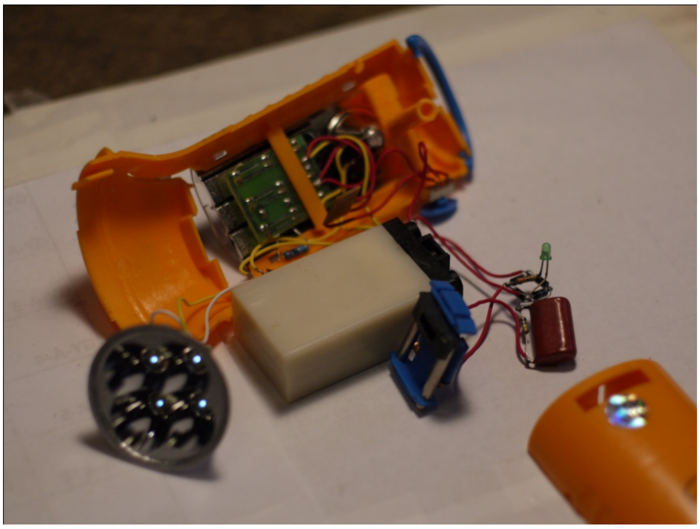


Figure 5 *Catastrophic failure of an LED flashlight during a drop test.*

Protection against exposure to the elements

Water penetration accounts for 21% of the reported complaints from field surveys (Tracy, Jacobson, & Mills, 2009). Members of our team inspected each product following the guidelines established by National Electrical Manufacturers Association's Degrees of Protection Provided by Enclosures (IP Code) (NEMA, 2004)(see Appendix B). This standard is a system for classifying the degrees of protection provided by the enclosures of electrical equipment for two conditions: 1) the protection of persons from hazardous parts and the protection of the equipment from the ingress of foreign objects, and 2) the ingress of water. IP Codes are given for each condition: 0-6 and 0-8 respectively.

With respect to the first category, we categorized all products with an IP Code of four. This translates into a basic protection from penetration of objects less than or equal to one millimeter (mm). With respect to the second category, we categorized all of the SLA products with an IP Code of one and the three dry cell products as two. An IP Code of one translates into a protection against falling water of less than 5mm per minute for a period of 10 minutes or less, while an IP Code of two provides slightly more protection against water falling at an angle of up to 15 degrees without ingress.

Charge control, deep discharge protection, and their connection to battery life

Sealed lead acid batteries can provide useful service for hundreds of cycles[4] if they are properly charged and discharged[5] (Linden and Reddy, 2001). Unfortunately, the 4 volt SLA batteries are not properly maintained in the LED flashlights we tested, leading to short cycle lives. There are three factors that can lead to shortened cycle lives for the SLA batteries in LED flashlights:

1) **Long storage at low state of charge damages the battery:** LED flashlights are often stored for months between the factory and point of sale; they can self-discharge or be switched on during the storage, leading to damage that can be permanent.

2) **Lack of undervoltage protection leads to deep discharge:** If a rechargeable flashlight is used until it is very dim, the battery can quickly be discharged below the minimum safe discharge voltage, about 3 volts for the LED flashlights we tested. Even if an SLA is properly recharged, the cycle life can be severely diminished by deep discharge beyond the working capacity (Linden and Reddy, 2001).

3) **Lack of an overvoltage cutoff leads to over-charging:** Sealed lead acid batteries are very sensitive to overcharging; repeated and sustained overcharging can severely impact the cycle life. For small, 4 volt SLA batteries of this type, battery life is adversely affected if the charging voltage regularly exceeds 5 volts. When charging voltages regularly reach 5.2 volts, battery life can be reduced from hundreds of cycles to dozens of cycles (Linden & Reddy, 2001)(Buchmann, 2003).

Of the rechargeable flashlights we tested, seven of eight had mean maximum charging voltages above 5.2 volts when charged for eight-hours, as recommended by the manufacturers. As mentioned above, seven out of seven products we tested had measured battery capacities of less than half of the advertised values. Overcharging these already underperforming batteries will likely lead to a further reduction in battery life, resulting in product failure within dozens of battery cycles. For the average end-user, this could mean failure within a few months of purchase.

[4] Cycle life is defined as the number of charge-discharge cycles until the battery reaches 80% of its original capacity.

[5] The inclusion of a charge control system is highly recommended for rechargeable lead-acid lighting products in order to maintain long life. Both overcharging and over discharging can have a deleterious effect on battery life (FISE, 2009). None of the rechargeable flashlights tested in this study have charge control systems.

LED Failure Mechanisms

LEDs can be damaged through processes that lead to either catastrophic failure or a decline in light output over time. Two key mechanisms that lead to LED failure in the types of flashlights tested in this study are outlined below.

Catastrophic Failure During Recharging

One common catastrophic failure mechanism for LEDs occurs during flashlight recharging. If the switch is turned "on" during charging or when the flashlight is plugged into the wall***, the LED array can be instantly burned out by a brief surge of high voltage***. While there is a warning for this on the package of each product, avoiding this failure mode is dependent on the end-user being vigilant while grid-charging their flashlight. Since accidentally bumping or brushing against them can turn on switches, this failure mode is a real concern even for users that attempt to follow the manufacturers' instructions.

Steady Brightness Degradation (Lumen Maintenance/Depreciation)

A second failure mechanism is related to a decline in the light output of the LEDs over time. As a result of this failure, the initial brightness of LED flashlights that is so appealing to consumers frequently does not last long. Lumen maintenance,[6] often also referred to as lumen depreciation, is a measure of a lamp's "useful life." It is typically defined as the time required for the brightness of the flashlight to depreciate to 70% of the initial brightness (L70), the industry standard cutoff point. The conventional wisdom is that L70 is the threshold at which the human eye can detect the brightness difference, at which point the consumer may begin to consider a replacement. In this test, all thirty samples that we tested experienced catastrophic failure. A common LED industry minimum L70 standard is 10,000 hours, and manufacturers often target and achieve 50,000 to 100,000 hours depending on the application (US Department of Energy, 2010). Of the samples that we tested, 79% reached L70 in less than 100 hours and none surpassed 230 hours (see Figure 5). In other words, 79% of these samples would fail in less than 2 months of being used just 2 hours per day. Based on our results, we can establish with 95% confidence that 88% of flashlights like the ones we purchased in Kenya will reach L70 within 230 hours of operating time. Nevertheless 100% of our samples failed before 230 hours. This is backed up by previous Lighting Africa findings that found LED lighting products in Africa are vulnerable to extremely rapid lumen

[6] Lumen maintenance depends not only on LED quality, but also on thermal management and the quality of the electronic ballast. Poor thermal management (overheating of LED) is associated with rapid reduction in light output and dramatically reduced "useful life." (FISE, 2009) (Lighting Africa, 2010) With respect to Lumen Maintenance, L70, or 70 % of initial illuminance, can be considered the industry standard "cutoff" for "useful life." (ASSIST, 2007) See Appendices A and C for further information on lumen maintenance.

depreciation (Lighting Africa, 2010). Lighting Africa encourages all manufacturers to test their products for at least 2000 hours prior to releasing them into the market.[7]

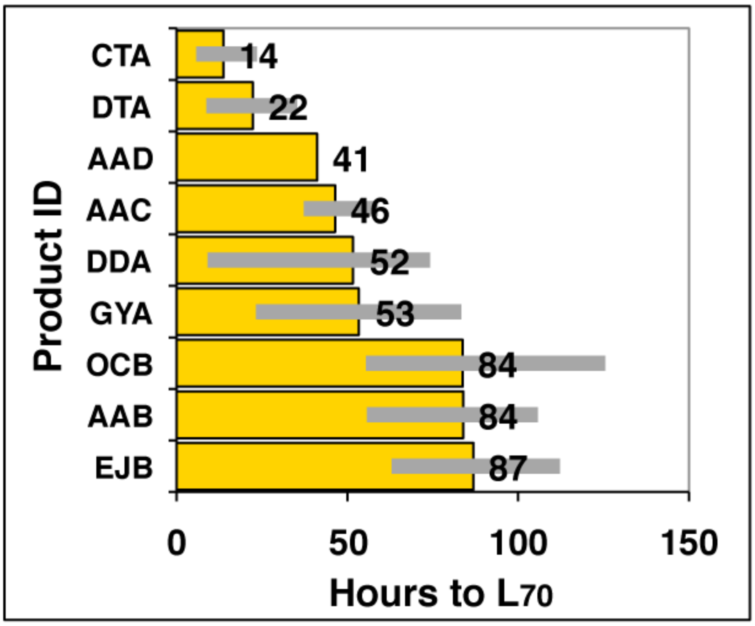


Figure 6 *Lumen Maintenance for nine LED flashlight models. Yellow bars indicate number of hours until light output reaches 70% of initial. Grey bars indicate the high and low values for a given model.*

Evaluating truth in advertising in the absence of industry standards

Manufacturers of flashlights and other LED off-grid lighting products need to provide consumers with accurate information in their marketing and packaging materials. With respect to the performance metrics that we measured in this study, there is a wide gap between manufacturer's specifications and the actual product performance. However, this gap is only part of the story. For some performance metrics such as "run-time" there is no clear industry standard definition for manufacturers to base their claims on. This makes verifying the relative veracity of advertising claims very difficult. A clear set of standards, labeling, and quality enforcement could guide manufacturers as they work to improve their product quality, help regulatory agencies keep the worst products out of the market, and supply customers with truthful marketing and packaging materials to make purchasing decisions. Lighting Africa has developed a set of standardized definitions and test procedures that can be used for this purpose.

[7] See Appendix C for graphical representations of acceptable and unacceptable lumen maintenance performance for products if the goal is to achieve at least 2000 hours of operation above the L70 performance level.

Conclusion

This study complements recently published survey results (Tracy, Jacobson, & Mills, 2009) that indicated high levels of end-user dissatisfaction with low-cost LED flashlights in Kenya. Laboratory testing confirmed end-users' reports that low-cost LED flashlights perform poorly for several key performance indicators: battery capacity, durability, lumen maintenance, and run time. Furthermore, marketing and packaging materials mislead consumers with false claims of product performance. This leads to greater than 500% discrepancy between the average actual one-year cost of ownership and the estimated cost based on manufacturers' specifications. This scenario has the potential to cause widespread market spoilage at this critical moment in the dissemination of LED technologies. With possible implications beyond the flashlight market, this market failure may contribute to the stalling of the uptake of LED illumination technologies in general and inhibit the dispersion of the benefits they promise to deliver. These results support the need for national and regional quality assurance and consumer education programs for LED flashlights and other small off-grid lighting products. In the end, the real losers are the consumers who purchase "efficient" and "modern" lighting products that are not truthfully advertised or well designed. The story of Samuel, below, illustrates the economic impact of poor product quality on consumers and underscores how their bad experiences with LED technology may lead to market spoilage.

The Story of Samuel: a typical flashlight user

Samuel is a night watchmen living in rural Kenya; his job requires that he use a flashlight each night for about one hour.[8] When he bought his first rechargeable LED flashlight to use on the job he was pleased to read on the packaging that the product would last for 18 hours[9] on a fully charged battery and that the flashlight had a "long-life," which he assumed must be at least one year. With an initial cost of 150 Kenyan shillings (Ksh)[10] and a recharging fee of 20 Ksh,[11] Samuel estimated that over one year he would have to pay about 550 Ksh to own and operate the flashlight (Figure 7). Samuel, like 86% of Kenyans, does not have electricity in his home and must take his flashlight to a shop in town to be recharged. A typical monthly income for Samuel is 3,750 Ksh,[12] so this amounted to about 1% of his annual income; he figured this was a fair cost to help him do his job.

One year later, Samuel reflected on the actual amount he paid to own and operate his flashlight. It had cost him over five times more to own and operate his flashlight than his estimate based on the flashlight packaging. In actuality, his flashlight lasted about two months before it no longer functioned,[13] after which he had to purchase a new one, over and over again. Throughout the year Samuel had to buy 5 new replacement flashlights. Furthermore, the flashlight only stayed lit for 3.5 hours after a full charge,[14] so Samuel had to recharge it five times more frequently than suggested on the packaging – twice a week instead of every two and a half weeks. In the end, owning and operating his flashlights required about 7% of Samuel's annual income. Samuel's case is not unique; millions of low-income people who use flashlights are subject to the same misleading information that can significantly affect their financial livelihoods.

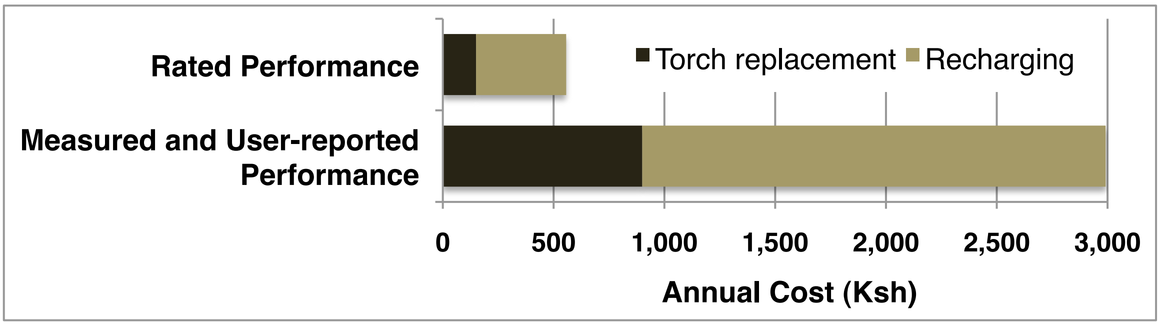


Figure 7 *An estimate of the annual cost to own and operate a flashlight as indicated on flashlight packaging (Rated Performance) compared to the cost estimate based on measured performance results from this study combined with user reported values from previous studies (Measured and User-reported Performance).*

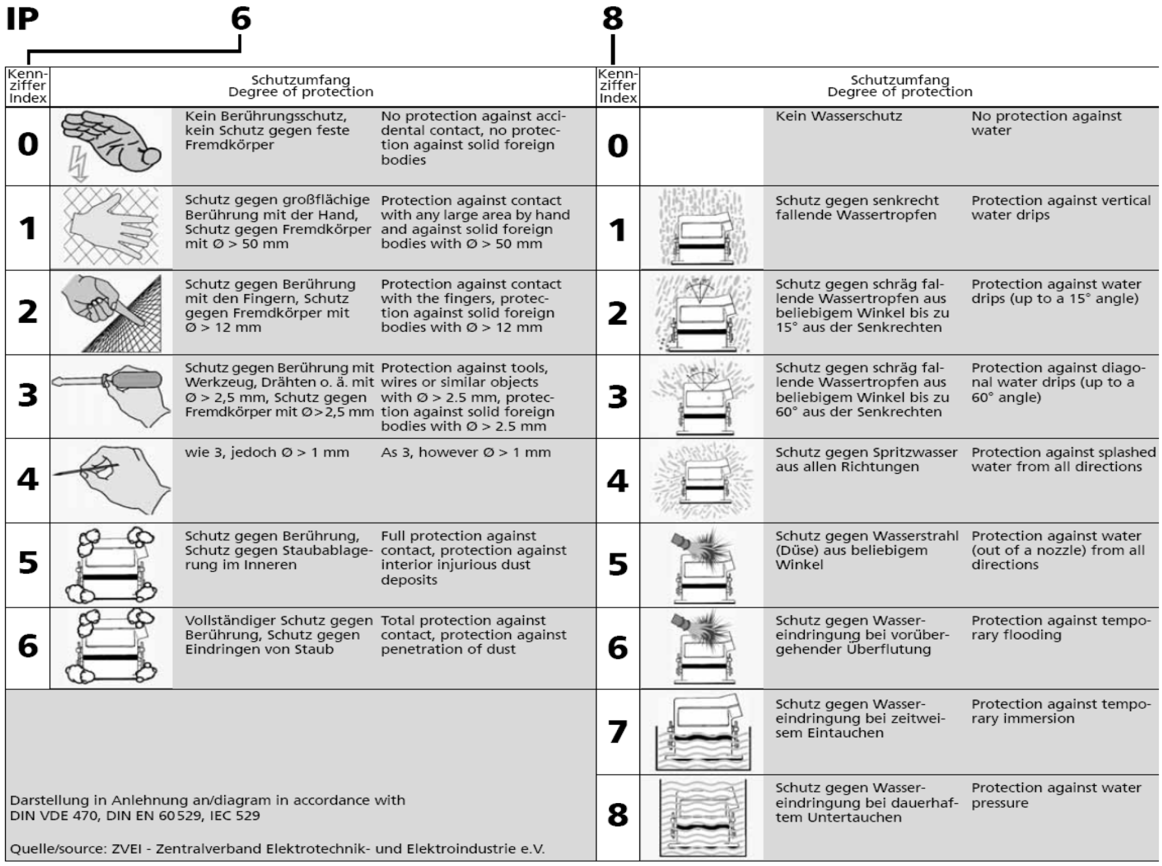
[8] In a study by Tracy (2010) Kenyan night watchmen used their flashlights for a total of about one hour per night during a 12-hour work shift that lasts from 7:00 pm to 7:00 am.
[9] Most common claim of run time among the flashlights we tested.
[10] In a study by Johnstone et al. (2009) the average cost of a flashlight sold within the Kenyan towns identified was 150 Ksh; $1US = 77 Ksh.
[11] In a study by Tracy et al. (2010) the typical fee to charge a rechargeable flashlight was 20 Ksh.
[12] In a study by Tracy et al. (2010) the average reported monthly income for a night watchman was between 3,500 Ksh and 4,000 Ksh.
[13] In a study by Tracy et al. (2010) flashlights generally lasted 2 months before failing.
[14] Measured hours of service per charge as reported by this study.

Appendix A

Table 2 *Summary of test procedures.*

Test Name	Description
Battery Capacity	Battery capacities were estimated using two 7000 series Cadex battery analyzers, along with the BatteryShop software. The results are reported in milliampere hours (mAh). To measure the battery capacity, the battery is first isolated from the rest of the flashlight's electrical circuit and charged fully. Battery capacity is measured as the battery is discharged at a constant rate that corresponds to a 20 hour discharge time as estimated from the manufacturer's rated capacity.
Maximum charging voltage	Voltage across the battery is recorded every minute during an 8-hour grid charge using a 230 volt, 50 Hz AC source. The maximum charging voltage is defined as the highest voltage recorded across the battery during the 8-hour grid charge.
Lumen Maintenance	Lumen maintenance is a measure of the number of hours that it takes for the light output from an LED light to reach 70% of its initial light output (L70). In our tests, dry cell flashlights are operated at constant voltage equal to the average measured voltage after 20 minutes of use on new batteries. SLA flashlights are operated at nominal voltage (4V). Light output is measured in a cardboard "integrating tube" of 1 meter in length with an Extech datalogging light meter (model 401036) affixed to one end. The flashlight is positioned so that its light shines in from the other end until a maximum reading is recorded. Measurements are made 3-4 times daily for the first week and then less often as time progresses until levels depreciate to 30% of the initial level. The data are then analyzed to determine the number of hours it takes for the flashlight to reach 70% of its initial light output.
Run Time	Run-time, sometimes referred to as total autonomous run-time, is a light discharge test that is used for estimating the duration of useful light output from a fully charged battery. In this test the flashlights are mounted in a dark box exactly one meter from an Extech digital light meter. Current, voltage and lux are recorded every minute throughout the test. Run time is defined as the time (in hours) until light output levels reach 25% of the 20 minute burn in level from a fully charged battery. To date no strict industry standard exists for defining this metric.
Drop Test	The light is dropped from a height of one meter onto a concrete surface. After impact it is tested to confirm if basic functionality is maintained. This process is repeated six times, once for each "side," or until it loses basic functionality. The result is reported as "pass" or "fail."
Switch Cycling Test	The durability of switches is tested by switching them on and off one thousand times. The result is reported as "pass" or "fail".

Appendix B



IP 6 8

Kennziffer Index	Schutzumfang	Degree of protection
0	Kein Berührungsschutz, kein Schutz gegen feste Fremdkörper	No protection against accidental contact, no protection against solid foreign bodies
1	Schutz gegen großflächige Berührung mit der Hand, Schutz gegen Fremdkörper mit Ø > 50 mm	Protection against contact with any large area by hand and against solid foreign bodies with Ø > 50 mm
2	Schutz gegen Berührung mit den Fingern, Schutz gegen Fremdkörper mit Ø > 12 mm	Protection against contact with the fingers, protection against solid foreign bodies with Ø > 12 mm
3	Schutz gegen Berührung mit Werkzeug, Drähten o. ä. mit Ø > 2,5 mm, Schutz gegen Fremdkörper mit Ø>2,5 mm	Protection against tools, wires or similar objects with Ø > 2.5 mm, protection against solid foreign bodies with Ø > 2.5 mm
4	wie 3, jedoch Ø > 1 mm	As 3, however Ø > 1 mm
5	Schutz gegen Berührung, Schutz gegen Staubablagerung im Inneren	Full protection against contact, protection against interior injurious dust deposits
6	Vollständiger Schutz gegen Berührung, Schutz gegen Eindringen von Staub	Total protection against contact, protection against penetration of dust

Kennziffer Index	Schutzumfang	Degree of protection
0	Kein Wasserschutz	No protection against water
1	Schutz gegen senkrecht fallende Wassertropfen	Protection against vertical water drips
2	Schutz gegen schräg fallende Wassertropfen aus beliebigem Winkel bis zu 15° aus der Senkrechten	Protection against water drips (up to a 15° angle)
3	Schutz gegen schräg fallende Wassertropfen aus beliebigem Winkel bis zu 60° aus der Senkrechten	Protection against diagonal water drips (up to a 60° angle)
4	Schutz gegen Spritzwasser aus allen Richtungen	Protection against splashed water from all directions
5	Schutz gegen Wasserstrahl (Düse) aus beliebigem Winkel	Protection against water (out of a nozzle) from all directions
6	Schutz gegen Wassereindringung bei vorübergehender Überflutung	Protection against temporary flooding
7	Schutz gegen Wassereindringung bei zeitweisem Eintauchen	Protection against temporary immersion
8	Schutz gegen Wassereindringung bei dauerhaftem Untertauchen	Protection against water pressure

Darstellung in Anlehnung an/diagram in accordance with DIN VDE 470, DIN EN 60529, IEC 529

Quelle/source: ZVEI - Zentralverband Elektrotechnik- und Elektroindustrie e.V.

Figure 8 *IP protection class system in accordance with DIN EN 60529 / IEC 60529* (NEMA, *2004).*

Appendix C

Lumen Maintenance

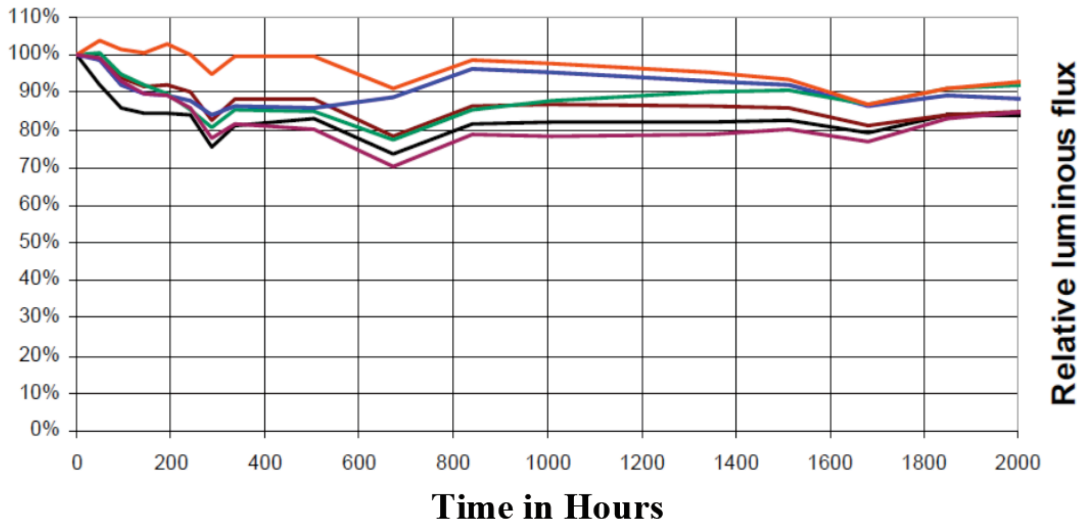


Figure 9 *Example of acceptable lumen maintenance test results for a light that is expected to achieve an L70 performance level after 2000 hours of operation* (Lighting Africa, 2010).

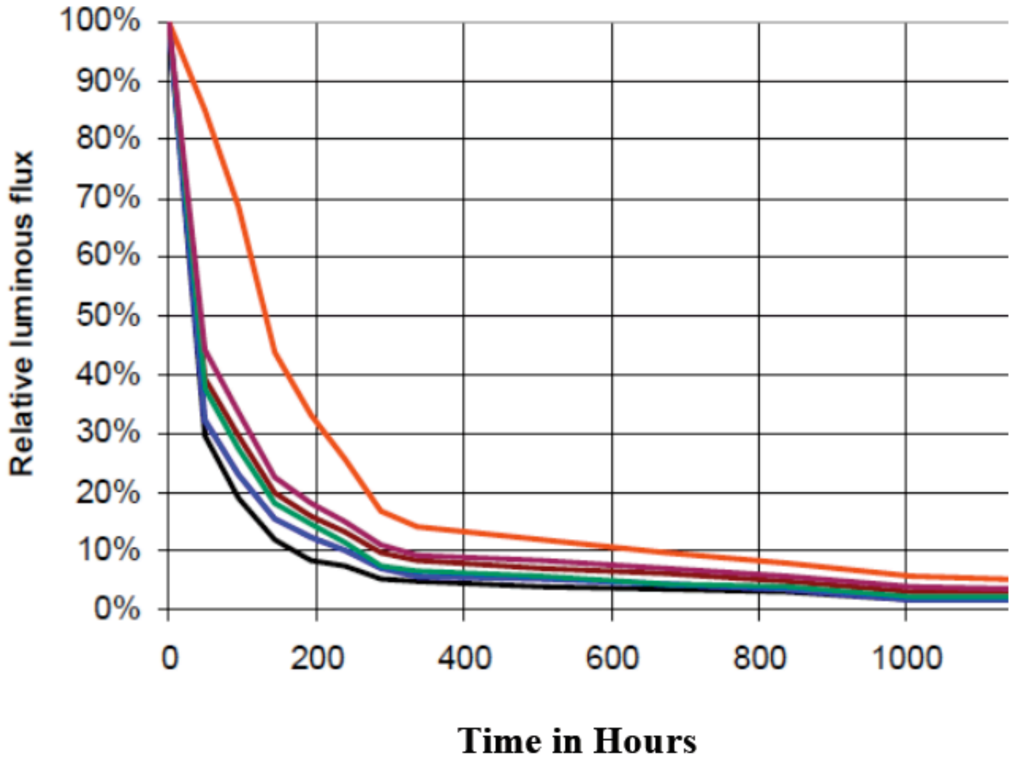


Figure 10. *Example of test results that show rapid lumen depreciation* (Lighting Africa, 2010).

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