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Research Note #3

Observed Minimum Illuminance Threshold for Night Market Vendors in Kenya who use LED Lamps

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A woman who sells vegetables uses an LED lamp for illumination

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The Lumina Project includes an Off-Grid Lighting Technology Assessment activity to provide manufacturers, resellers, program managers, and policymakers with information to help ensure the delivery of products that maximize consumer acceptance and the market success of off-grid lighting solutions for the developing world. Periodic Research Notes present new results in a timely fashion between the issuance of more formal and lengthy reports. Our results should not be construed as product endorsements. For a full archive of Research Notes and Technical Reports see: http://light.lbl.gov/library.html

Introduction

Creation of light for work, socializing, and general illumination is a fundamental application of technology around the world. For those who lack access to electricity, an emerging and diverse range of LED based lighting products hold promise for replacing and/or augmenting their current fuel-based lighting sources that are costly and dirty. Along with analysis of environmental factors, economic models for total cost-of-ownership of LED lighting products are an important tool for studying the impacts of these products as they emerge in markets of developing countries. One important metric in those models is the minimum illuminance demanded by end-users for a given task before recharging the lamp or replacing batteries. It impacts the lighting service cost per unit time if charging is done with purchased electricity, batteries, or charging services. The concept is illustrated in figure 1: LED lighting products are generally brightest immediately after the battery is charged or replaced and the illuminance degrades as the battery is discharged. When a minimum threshold level of illuminance is reached, the operational time for the battery charge cycle is over. The cost to recharge depends on the method utilized; these include charging at a shop at a fixed price per charge, charging on personal grid connections, using solar chargers, and purchasing dry cell batteries. This Research Note reports on the observed "charge-triggering" illuminance level threshold for night market vendors who use LED lighting products to provide general and task oriented illumination. All the study participants charged with AC power, either at a fixed-price charge shop or with electricity at their home.

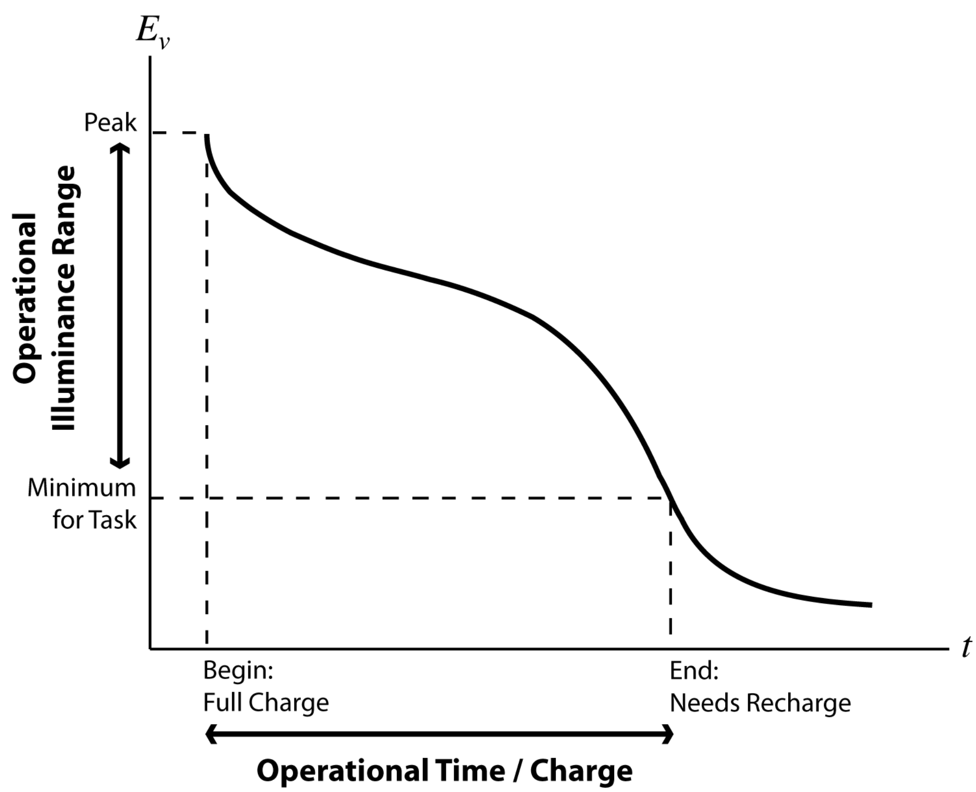

Figure 1: Typical illuminance degradation during an LED lamp discharge cycle. The curve can be steeper or flatter depending on the quality of design and components.

Background

The information and data for this work were gathered during the Lumina Project's 2008 market testing field work in Kenya's Rift Valley Province. The research was conducted in the towns of Maai Mahiu and Karagita by Arne Jacobson, Kristen Radecsky, Peter Johnstone, Maina Mumbi, and others. Maai Mahiu is a crossroads town; provision of services to travelers and freight carriers is a primary income source for the residents. In contrast, the primary income for Karagita's residents is from work in the large, factory style flower farms on the eastern shores of Lake Naivasha that specialize in producing cut flowers for export to the European market. According to residents, both towns had populations of 6,000 to 8,000 people in June 2008.

We focused on quantifying the economics of fuel-based and LED lighting technology for business use by night market vendors and shopkeepers. Our research activities with the business owners and operators included baseline measurement of their fuel-based lighting use, an initial survey, offering for sale data logger equipped rechargeable LED lamps, monitoring the adoption of the LED lamps, and a follow-up survey.[1]

Figure 2: A research participant's kiosk illuminated by an LED lamp

[1] Radecsky, K., P. Johnstone, A. Jacobson, and E. Mills. 2008. "Solid-State Lighting on a Shoestring Budget: The Economics of Off-Grid Lighting for Small Businesses in Kenya." Lumina Project Technical Report #3. http://light.lbl.gov/pubs/tr/Lumina-TR3.pdf, also see Johnstone, P., A. Jacobson, E.. Mills, and M. Mumbi. 2009. "Self-reported Impacts of LED Lighting Technology Compared to Fuel-based Lighting on Night Market Business Prosperity in Kenya." Lumina Project Research Note #2. http://light.lbl.gov/pubs/rn/Lumina-RN2.pdf

Illumination Requirements

Minimum illuminance requirements depend on the task at hand. Standards for occupational lighting levels in industrialized countries range from 100-1000+ Lux, and vary widely by task, locality, and over time.[2] The participants in our study generally utilize their lights for one or more of the following tasks at their night market businesses: Illumination of goods for sale, task lighting for cutting and processing of vegetables, social ambient lighting, illumination for making transactions. For each activity, the proximity of the lamp to the objects or space being illuminated is variable.

Methods

For this study, the illuminance of a lamp is defined in units of Lux at a 1-meter distance from the LED source (in the peak of the luminous distribution). Two methods were used to estimate the charge-triggering illuminance threshold—defined by the point in discharge at which the user elects to recharge the light—for vendors in our study:

First, long-term lamp use data were analyzed for 13 night market vendors over a 6-month period (June 2008-January 2009). For each of the 93 charging events that were observed, we identified the current draw (mA) for the lamps during the period of use prior to lamp charging. Those observations were combined with lab measurements of current-illuminance characteristics for a lamp that is of the same construction as those deployed in the field to estimate the illuminance level that triggered a charge. Figure 3 is a representative example of correlated illuminance-discharge data that were estimated for a particular charge cycle based on a long-term dataset containing time, battery voltage, and battery current.

In January 2009, our research team also used a portable power supply to conduct illuminance demand surveys for 11 of the vendors who participated in our study. We connected the power supply directly to users' lamps in the context of their actual use (at night, when the user was using the lamp at their business, see figure 3). Beginning with a bright setting (about 17 Lux at one meter), we reduced the lamp's illuminance in a stepwise fashion, dimming by approximately 1 Lux every 30 seconds. The vendors were asked to alert us when the lamp reached a lighting level step that would typically trigger them to charge their lamp. The current draw (mA) at that point was recorded and used to estimate illuminance at 1 meter with the same correlation as was used for the long term data-based estimates.

[2] Mills, E. and N. Borg. 1999. "Trends in Recommended Lighting Levels: An International Comparison." *Journal of the Illuminating Engineering Society of North America* 28(1):155-163. http://eetd.lbl.gov/emills/PUBS/PDF/JIES%201999%20155-163.pdf

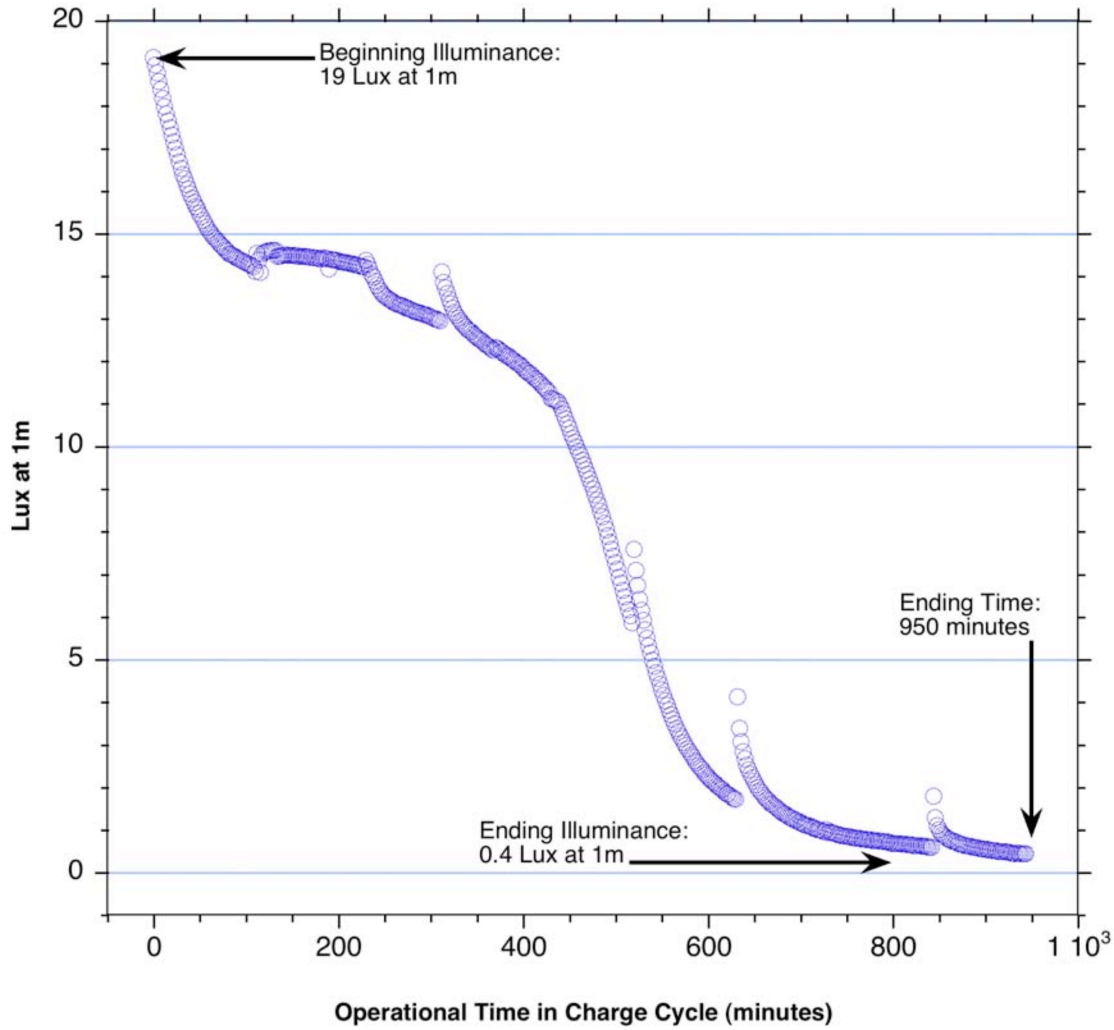

Figure 3: An example of a lamp discharge-illuminance curve representing a full "charge cycle" from freshly charged to the charge-triggering illuminance. It was estimated based on a long-term dataset. Note the discontinuities that are due to charge migration in the batteries during periods when the lamp is off.

Figure 4: A vendor chops potatoes and provides general illumination for customers with an LED lamp during an illuminance demand survey. Note the red and black wires that connect her lamp to the power supply, indicated by the arrow.

Results

We found that the minimum illuminance threshold for vendors in our study was low compared to standards for occupational lighting in industrialized countries. The median illuminance at 1 meter that triggered charging in the long-term data was 1.4 Lux, and for survey-based results the median was 2.6 Lux. Both are orders of magnitude lower than the values of 100 Lux or more that characterize typical illuminance levels for occupational settings in industrialized nations. For comparison, the illuminance at one meter for the kerosene wick and hurricane lamps used in Kenya that are targeted for replacement by LED products range from 2 to 4 Lux, and a candle typical of those used in Kenya provides about 1.5 Lux at one meter.[3]

[3] Radecsky et al. 2008

Table 1: Summary of findings: charge triggering illuminance levels (Lux at 1m)

Estimate Type	Number of Observations	Median	Mean	Variance	Minimum	Maximum
From data loggers, long term data sets	**93**	**1.4**	**3.3**	**19.4**	**0.1**	**16.7**
Illuminance demand survey responses	**11**	**2.6**	**2.1**	**1.2**	**0.4**	**3.4**

The distribution of survey-based illuminance threshold responses is narrow, as is illustrated by figure 4, ranging from 0.4 and 3.4 Lux at one meter. The distribution of illuminance threshold estimates from the long-term dataset (figure 5) is wider, weighted heavily around the median, 1.4 Lux, and includes a number of observations in the 10-17 Lux range (15 out of 93). Most of those high value observations (10 out of 15) are from around September 2008 for a particular research participant. She subsequently moved away from the study area so it remains unclear what the reason was for the repeated charge events that occurred in spite of her lamp performing relatively close to its peak, 17 Lux, beforehand. The presence of the 15 high values skewed the long term data mean upward to 3.4 Lux and led to increased variance. Inspection of the probability plot for long-term data, figure 6, indicates that about 80% of charges were triggered by illuminance at 1 meter values that were lower than 5 Lux.

A one-way analysis of variance in charge triggering illuminance due to charging cost for the long-term data indicated that the charging cost factor (paying a fee vs. not paying a fee) did not significantly impact the illuminance threshold for lamp users. ($p = 0.62$) Of the 13 vendors in the analysis 11 pay a fee at charging shops to recharge their lamp; the other two have access to a home grid connection and solar home system respectively. Based on survey results related to charging strategies, of the 93 charge events in the data record 74 were likely associated with paying at a charge shop and 19 with electricity at homes.

Sources of Bias in Results

It is likely that the survey-based method for estimating charge-triggering illuminance was biased upward due to short time intervals spent between dimming of the light levels (~30 seconds). Our hypothesis is that the survey-based result would indicate a lower charge-triggering illuminance, closer to the data logger based result, if vendors were given longer to adapt to a particular lighting level or if the LED lamp were slowly dimmed in an analog rather than stepwise manner. Future studies should account for physiological response time while maintaining a reasonable time commitment to each survey by the researchers and study participants.

The data loggers used in the study were beta versions, and technical issues related to their hardware and firmware led to long periods of lost data. As a result, only ~10% of the potential lamp use data were successfully gathered (93 of an expected 900 charging events over the collection period). As a mitigating measure, data loggers that consistently performed well were rotated between the study participants to ensure we collected representative data from each. It is unknown if or how the pattern of data that were collected biased the data logger-based results. Future data logger versions that do not have this data loss issue should resolve the potential source of bias.

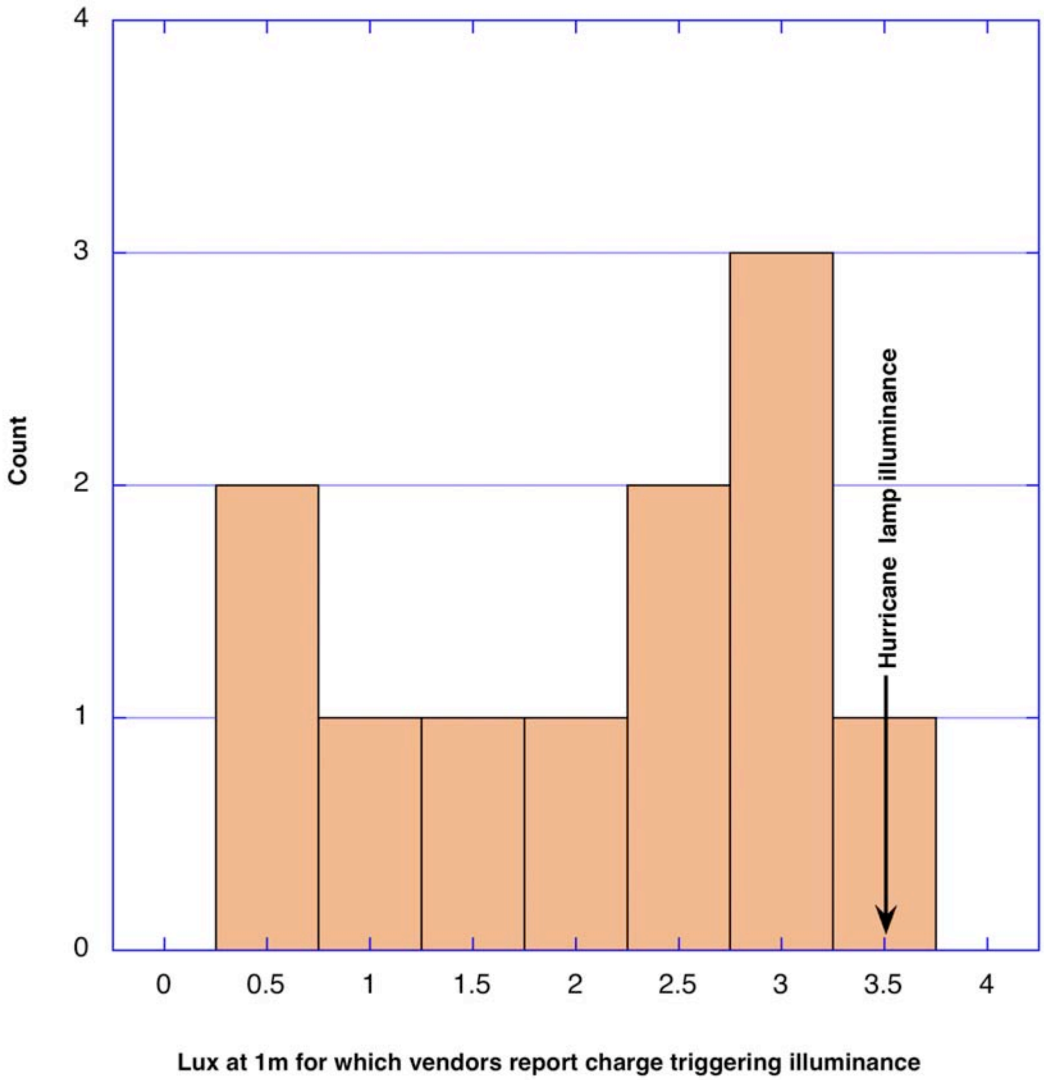

Figure 5: Histogram of the minimum illuminance at 1 meter as reported by night market vendors in an illuminance demand survey conducted in the context of their use of LED lights at their businesses (n=11). Note the line indicating approximate measured illuminance for hurricane lamps typical of those that are used in Kenya.

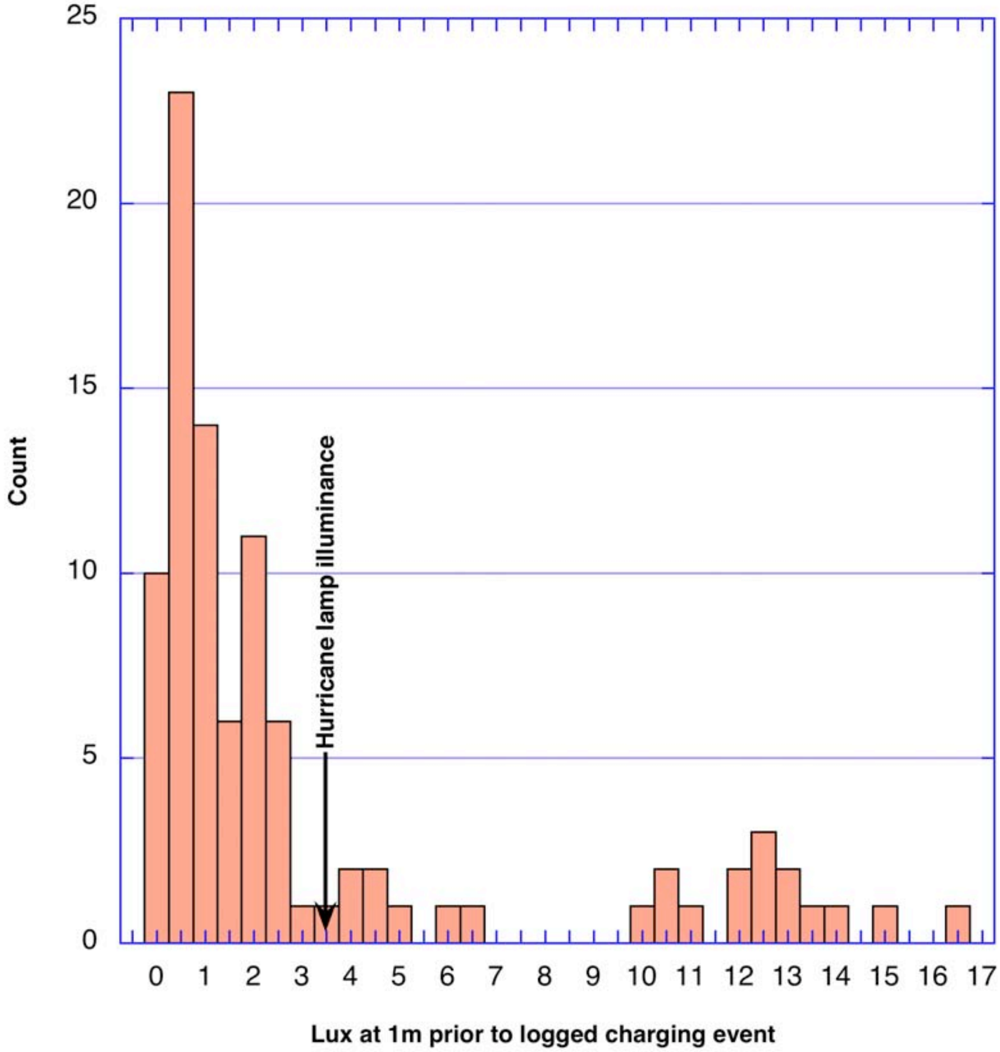

Figure 6: Histogram of illuminance at 1 meter that triggered charge events, estimated from long term data logger measurements of lamp use by night market vendors (n=93). Note the line indicating approximate measured illuminance for hurricane lamps typical of those that are used in Kenya.

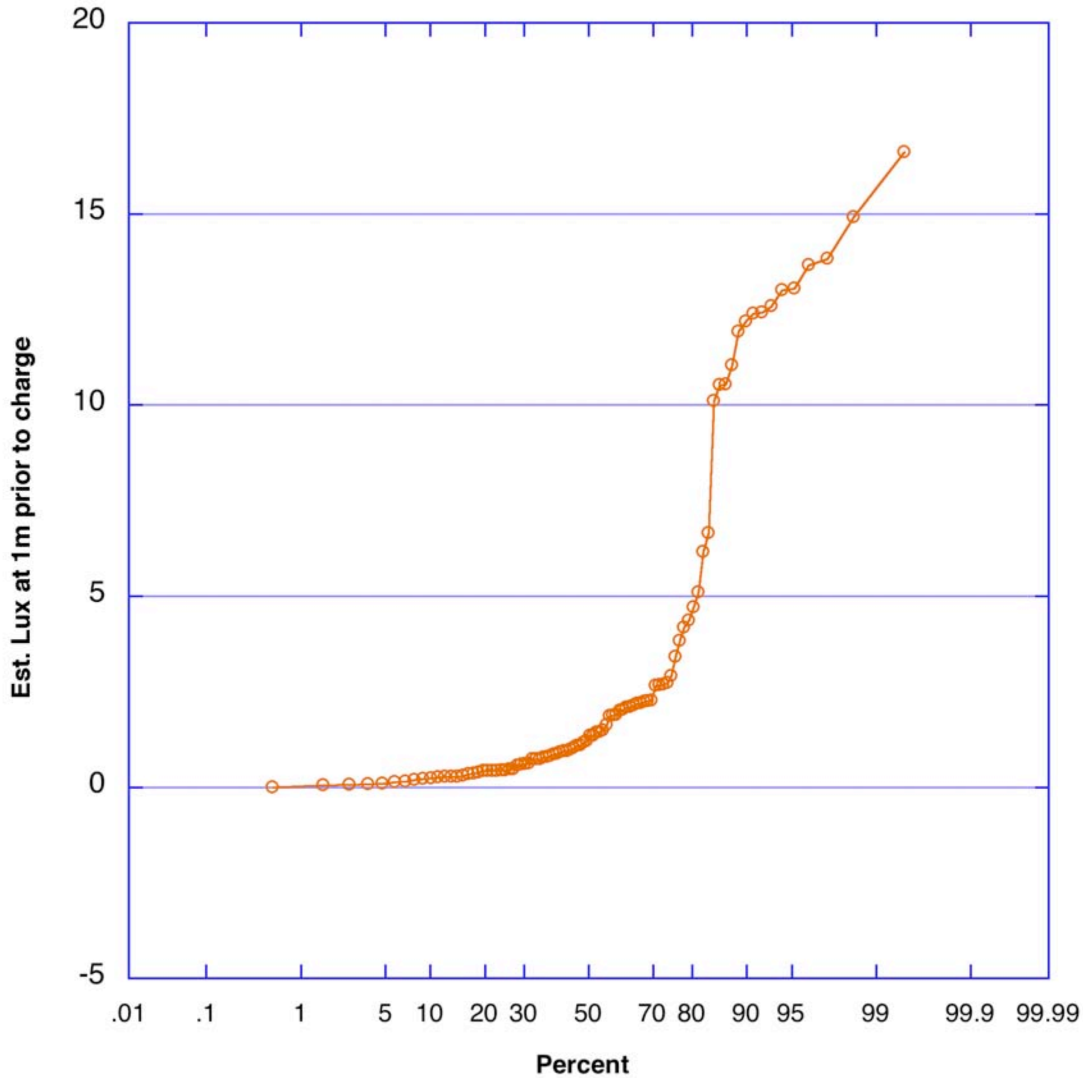

Figure 7: Cumulative probability distribution of Illuminance at 1 meter that triggered subsequent charge events, estimated from long term data on lamp use by night market vendors (n=93)

Conclusion

Using both long-term data on LED lighting use and interactive survey methods, we estimated the illuminance at 1 meter that triggers charging events. Our study participants were night market vendors using the lamps primarily in the context of their business; most pay to charge their lamps at a charging shop (11 of the 13). Based on our results, it is safe to estimate that the median illuminance demand threshold at 1 meter for the participants in our study is on the order of 2 Lux. This estimate can be used as an input to economic models that seek to quantify total cost of ownership for LED lighting products being used by people in a similar context as for those who participated in our study.