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ILLUMINATING THE PECKING ORDER IN OFF-GRID LIGHTING

A Demonstration of LED Lighting for Saving Energy in the Poultry Sector

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ABSTRACT

The Lumina Project and Lighting Africa conducted a full-scale field test involving a switch from kerosene to solar-LED lighting for commercial broiler chicken production at an off-grid farm in Kenya. The test achieved lower operating costs, produced substantially more light, improved the working environment, and had no adverse effect on yields. A strategy using conventional solar-fluorescent lighting also achieved comparable yields, but entailed a six-fold higher capital cost and significantly higher recurring battery replacement costs. Thanks to higher energy and optical efficiencies, the LED system provided approximately twice the illumination to the chicken-production area and yet drew less than half the power.

At the study farm, 3000 chickens were grown in each of three identical houses under kerosene, fluorescent, and LED lighting configurations. Under baseline conditions, a yearly expenditure of 1,200 USD is required to illuminate the three houses with kerosene. The LED system eliminates this fuel use and expense with a corresponding simple payback time of 1.5 years, while the solar-fluorescent system has a payback time of 9.3 years. The corresponding reduction in fuel expenditure in both cases represents a 15% increase in after-tax net income (revenues minus expenses) across the entire business operation. The differential cost-effectiveness between the LED and fluorescent systems would be substantially greater if the fluorescent system were upsized to provide the same light as the LED system.

Providing light with the fluorescent or LED systems is also far more economical than connecting to the grid in this case. The estimated grid-connection cost at this facility is 1.7 million Kenya Schillings (approximately 21,250 USD), which is nearly six-times the cost of the fluorescent system and 35-times the cost of the LED system.

The LED system also confers various non-energy benefits. The relative uniformity of LED lighting, compared to the fluorescent or kerosene lighting, reduced crowding which in turn created a less stressful environment for the chickens. The far higher levels of illumination also created a better environment for the workers, while eliminating the time required for obtaining fuel and maintaining kerosene lanterns. An additional advantage of the LED system relative to the solar fluorescent system was that the former does not require a skilled technician to carry out the installation. The portable LED system lighting layout is also more easily adjusted than that of the hard-wired fluorescent systems. Furthermore, switching to the LED system avoids over one metric ton of carbon dioxide emissions per house on an annual basis compared to kerosene.

There is high potential for replication of this particular LED lighting strategy in the developing world. In order to estimate the scale of kerosene use and the potential for savings, more information is needed on the numbers of chickens produced off-grid, as well as lighting uses for other categories

of poultry production (egg layers, indigenous broilers[1]). Our discovery that weight gain did not slow in the solar-fluorescent house after it experienced extended lighting out ages beginning on day 14 of the 35-ay study suggests that conventional farming practices in Kenyan broiler operations may call for more hours of lighting than is needed to achieve least-cost production.

Keywords: off-grid lighting, poultry sector, kerosene lanterns, LED luminaires

1. INTRODUCTION

The energy-savings potential for LED lighting in the developing world is enormous [1], but prior studies have not examined applications in the food-production sector. Kenya's poultry industry directly contributes to the income of 3 million Kenyans and indirectly supports the livelihoods of many more (Poultry News 2010). It contributes to 6.1% of livestock GDP, which equates to 0.7% of Kenya's total GDP.[2] Broiler chickens are produced for food in a large number of relatively small farms. Omiti [2] states that, as of 2006, there were nearly 27,000 broiler farms in Kenya, an unknown number of which are un-connected to the electricity grid.

Although there is great potential for growth in poultry production given increasing protein consumption in Kenya, there has been little gain over the last several years. Slow growth has in part been attributed to the increased cost of inputs. Between 2006 and 2010, the cost of production rose by more than 200%, from 1.9 billion Kenya shillings (Ksh) to 4.3 billion Ksh while farmers' net profits have not enjoyed the same growth rate [3].

Farmers must pay to provide sufficient illumination for certain types of poultry products, primarily in broiler production. In order to achieve standard growth rates under a broiler-production model, chickens are raised in houses that are lit for between 20 and 24 hours per day throughout the growth cycle, which typically lasts 35 days. This requires the use of artificial lighting during the evening hours. The conventional wisdom behind this practice is that light stimulates the chickens to eat and in turn gain weight quickly. The production of broilers beyond the reaches of grid electricity therefore requires farmers to use alternatives, typically a fuel-based source of lighting, most commonly kerosene or diesel generators, or solar or wind powered systems.[3]

The current study is an effort to identify more cost-effective approaches to providing the illumination necessary for raising broiler chickens. Through an experimental study we assessed the cost of raising broilers using three types of off-grid lighting alternatives: kerosene lanterns, solar-wind powered fluorescent lighting, and small portable solar LED lighting. Under each lighting option we examined the costs, lighting service levels, and production outcomes in a full-scale broiler-production setting.

2. EXPERIMENTAL DESIGN

The study took place on a chicken farm in the town of Maai Mahiu, in Kenya's Rift Valley Province (**Fig. 1**) between August 6 and September 10, 2010. The owner of the farm has been in the business of raising broiler chickens for five years. At the time of the study the farmer had a contract with Kenchic Ltd, Kenya's dominant chicken distributor, under which he purchased the chicks and later sold back the grown chickens.

The experiment took advantage of the existing commercial facilities and production practices, making minimal alterations. The facilities included three side-by-side chicken houses of equal size and proportions, approximately 280 m^2 each, constructed of stone block walls with wire mesh window/ventilation, corrugated metal roofing, and dirt floors (**Fig. 2**).

The houses were very similar in design and setting, and received essentially identical amounts

1 Raising indigenous chickens for meat can be described as backyard or "free-range" production. It is a small-scale, low-cost production method with minimal inputs. The chickens are generally free range, scavenge for food or get food scraps. Their growth and maturation for meat sale takes considerably longer than that for broiler operations.

2 Of Kenya's 31.4 million poultry population in 2008, about 84% were indigenous (free-range, subsistence-oriented) chickens, 8% were layers, 6% were broilers, and the remaining 2% included ducks, geese, turkeys, guinea fowl, etc. [2]. The Rift Valley province dominates production at 22%, followed by Nyanza at 20%, Central at 17% and Eastern at 14%. The Coast and Nairobi provinces contribute more modestly at 9% and 8%, respectively, and less than 1% of production takes place in North Eastern province [4].

3 Government publications also endorse the use of kerosene lanterns for the informally produced "indigenous[1]" chickens [5].

4 The map of Kenya was sourced from http://www.africa-within.com/tour/kenya/maps_of_kenya.htm.

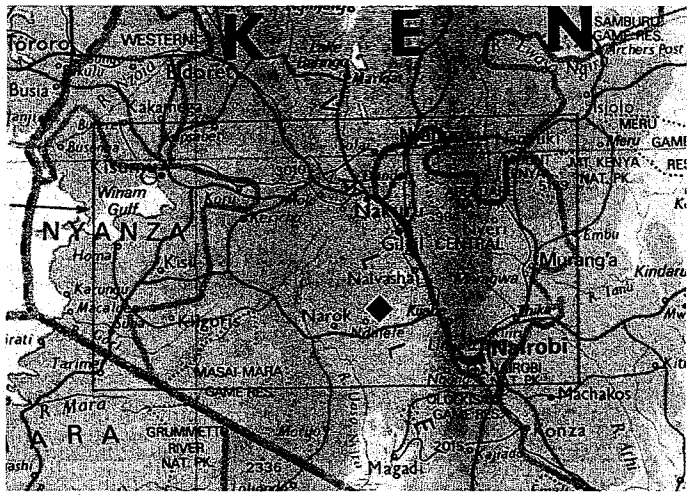

Fig 1. Map of Kenya highlighting the Rift Valley and Central Provinces, the black diamond represents the approximate location of the chicken farm[4]

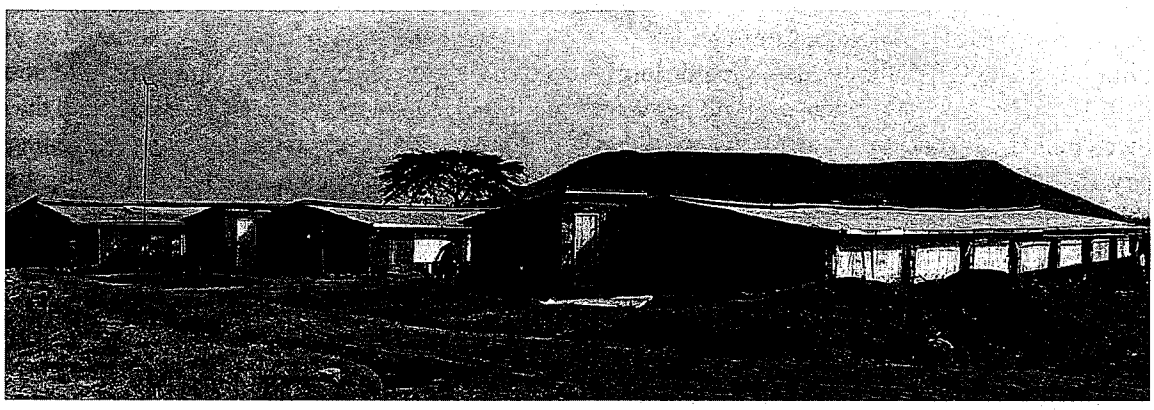

Fig. 2.The three chicken houses. (Left to Right): fluorescent house powered by a solar-wind hybrid system, the kerosene house, and the LED house

of daylight. Each house produces 3,000 chickens per cycle, and the chicks for all three were delivered on the same day. Throughout the standard 35-ay growing cycle, the area occupied by the chickens within the houses was gradually expanded (per standard practice) by moving portable screens, depending upon the size of the birds. From day-zero to day-15 one-third of the house area was used, day 15 to 18 two-thirds were used, and from day 18 through the end of the cycle the full capacity of the houses was utilized. Each house was monitored and maintained by a single caretaker throughout the production cycle. This particular farmer completes five of these cycles in an average year. More intensive production levels would yield larger differential savings between the electric and fuel-based lighting techniques.

In the initial years of operation the houses were illuminated in the evening with kerosene lanterns. One year ago, the farmer installed a 520-watt solar-wind hybrid system to power fluorescent lamps. For the purpose of this study the farmer agreed to operate one house under the solar-wind fluorescent system, revert one to kerosene lanterns, and to allow us to install a simple, commercially available solar powered LED lighting system in the third (**Figs. 3–5**).

The solar-wind system consisted of four 12-volt 100 AHflooded lead-acid batteries charged by a 120-watt PV panel and a 400-watt wind turbine, operating three 5 W compact-fluorescent lamps and two 6 W linear fluorescent lamps for a total of 27 lighting watts.The LED system consisted of six sealed-lead-acid battery-packs (2 LED lights per pack) that were each charged by a 5-watt PV panel, operating a total of twelve 1 W LED lights for a total of 12 lighting watts. Over the growth cycle, depending upon the area of the houses in use and the judgment of the caretakers, the number of lighting sources varied, with an upper limit of five fluorescent lights, eight hurricane lanterns fueled with kerosene, and twelve LED lights (**Table 1 and Fig. 6**).

Table 1. Type and number of lighting systems in use. More light sources are engaged as more floor area is brought into use

Lighting Source	Day 1–12	Day 13–14	Day 15–17	Day 18–20	Day 20–35
Kerosene Lantern	6 lanterns	6 lanterns	6 lanterns	6 lanterns	8 lanterns[5]
FluorescentLamps	2 lamps	3 lamps	4 lamps	5 lamps	5 lamps
LED Lamps	3 LEDs	3 LEDs	8 LEDs	12 LEDs	12 LEDs

Table 2. Initial cost of each of the three systems

Lighting System	Capital Cost (Ksh)	Capital Cost (USD)[6]
Kerosene	2,480	31
Solar-Wind Hybrid Fluorescent	300,000	3,750
Solar Portable LED	46,800	585

The cost of each system (inclusive of wiring, lamps, and installation costs) is shown in **Table 2**.

While the LED lights likely have greater luminous efficacy (measured as lumens of light per watt of power input) than the fluorescent system, their primary advantage is the far higher optical efficiency achieved by the delivery of more light to the floor of the houses. In contrast, the fluorescent and kerosene lighting sources emit light spherically, with much going onto the ceiling and high wall areas where it is not of use. As a result, the LED system provided approximately twice the illumination to the chicken-production area with less than half the energy input.

When the chickens reached a sufficient size and the houses were at their maximum utilization – fully opened and all available lighting points in use – we measured simple transects of the lighting layout using an Extech 401036 light meter (see **Fig. 6** for the lighting layout of each house and location of measurements).The kerosene house received by far the least amount of illumination, the fluorescent house was intermediate, while the LED house received the highest levels of illuminance. The LED house also attained the most uniform light distribution throughout the house (**Figs. 7–8**).

As part of their normal routine, the caretakers of the houses kept daily records of food consumption and mortality, as well as weekly records of weight and medicine administered. In addition, we asked the caretakers to record the number of light sources used each day in their respective houses and the time at which they turned on the lights in the evening and off in the morning. The duration of lighting for the fluorescent and the LED houses was also monitored using HOBO data-loggers to verify operator reports, and on-time (with the exception of the solar-availability episode noted below) was verified to be comparable across the three houses. The caretaker of the kerosene house also recorded the amount of kerosene used each day. We visited the farm weekly, at which time were caved the records from the caretakers, downloaded the logged data, and asked a set of questions to the caretakers about the performance of the lights, deviations from the normal routine, chicken behavior, and general observations and comments each had about the lights and the impact upon the chicken-production operation.

3. RESULTS

LED lighting was the clear favorite from the perspective of the caretakers and the farm owner. The LED lights delivered the most light, had the most consistent performance, were the easiest lighting choices to manage, and were conveniently versatile.

The farmer identified multiple non-energy benefits of the LED systems compared to the other lighting approaches:

1. Unlike the fluorescent system, the LED systems did not require a skilled electrician for installation or maintenance.

[5] On Day 18 all three houses were opened up to their full floor area. The caretaker of the kerosene house continued to use six lanterns for two days after which he decided it was not bright enough, adding the final two lanterns totaling eight lanterns on Day 20.

[6] All Kenya Schillings to US-dollar price conversions use an exchange rate of 80 Ksh/USD as per August 2010.

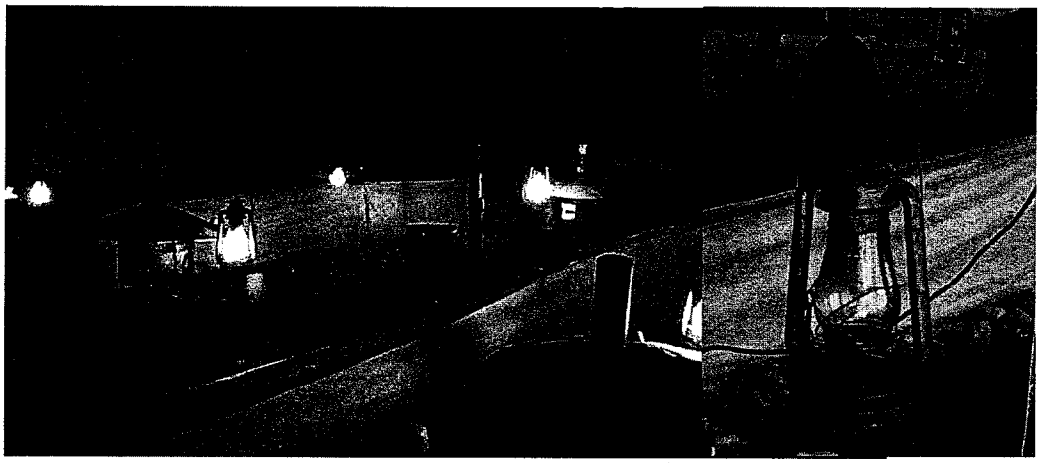

Fig. 3. Kerosene house

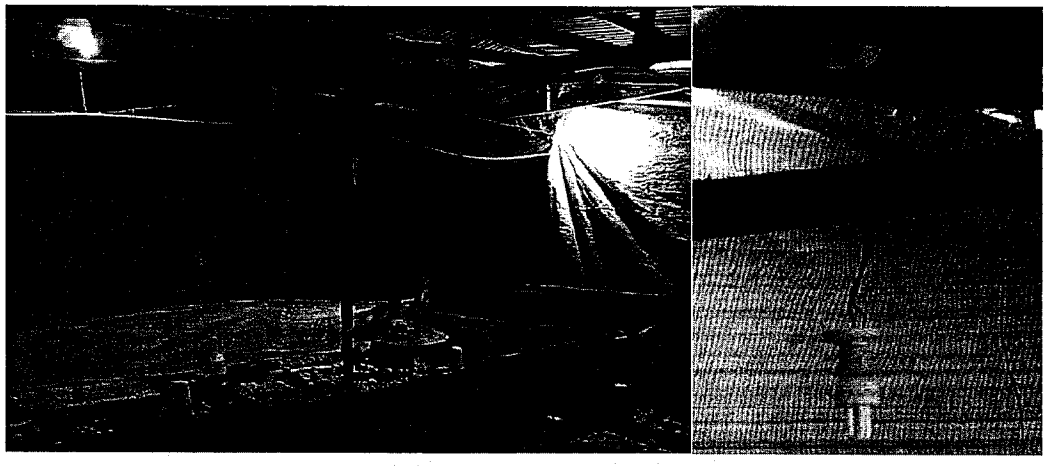

Fig. 4. Fluorescent house

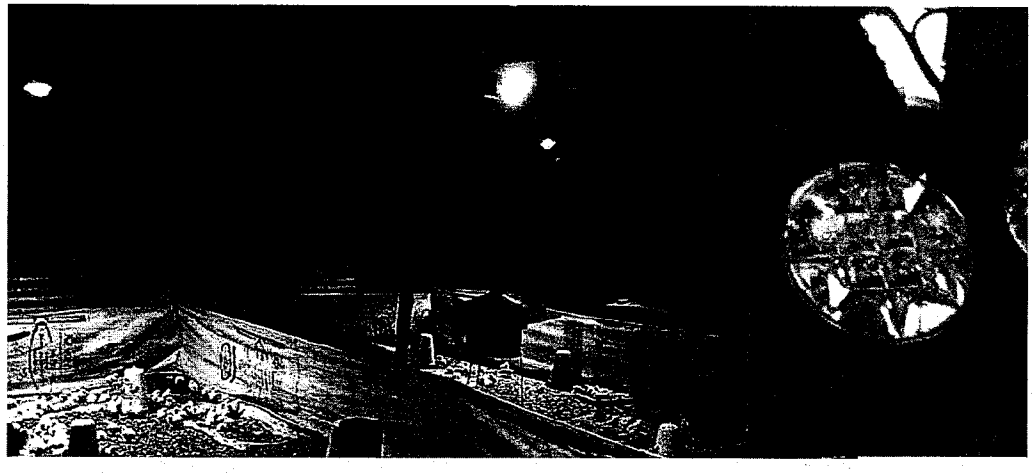

Fig. 5. LED house

2. Throughout the growing cycle the caretaker was readily able to reposition the lights based on the desirable placement, unlike the permanently fixed fluorescent lamps.

3. In comparison to the other lighting systems, the caretaker of the kerosene house had to devote more time to obtaining fuel, preparing the kerosene lanterns, and cleaning the accumulated soot from the glass chimneys daily.

4. As a result of an undersized solar-wind fluorescent system – and 15 days of minimal sun – the duration of light output in the fluorescent house was

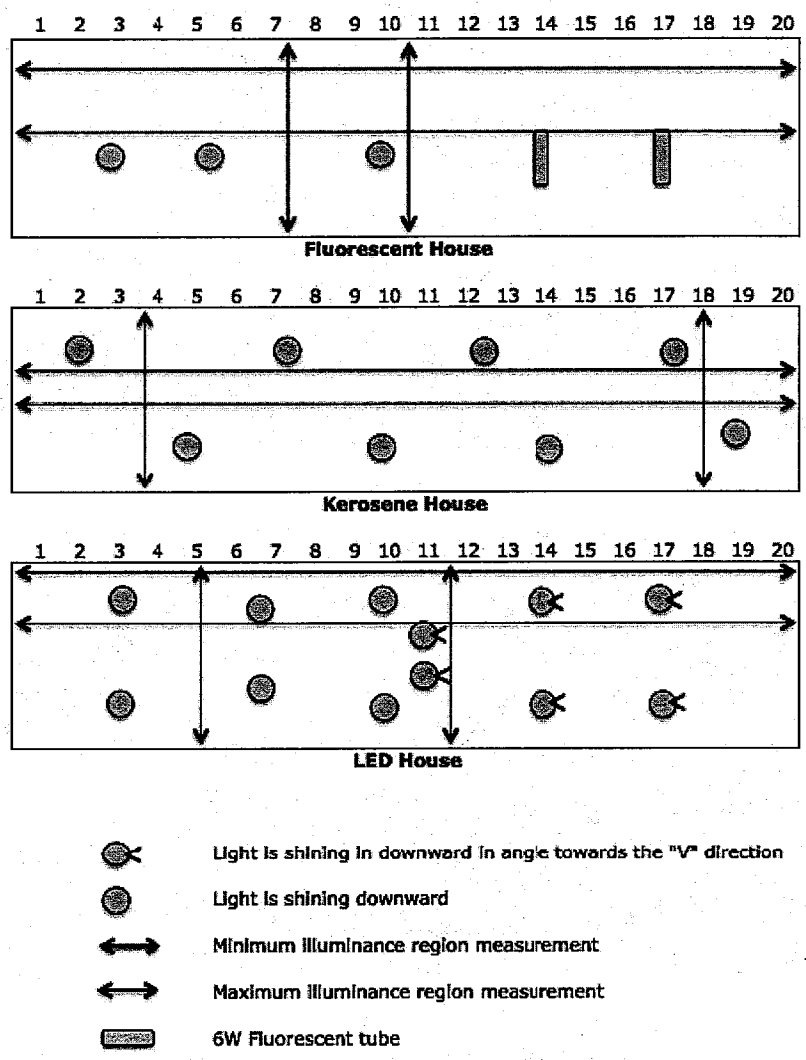

Fig. 6. Lighting layout of each of the three houses and location of illuminance measurements presented in Figs. 7–8, each horizontal/length unit equals 5 feet and each vertical/width unit equals 3.75 feet

reduced by nearly 40 % compared to the duration intended. The LED system, on the other hand, never failed prematurely and provided the intended duration of light output consistently throughout the entire cycle, as did the kerosene lanterns, which were simply refilled when necessary.

5. Because they experienced more uniform lighting distribution than the houses lit by the other light sources, the chickens in the LED house distributed themselves more evenly during feeding. This was verified because the food in the feeders located throughout the LED house was equally depleted, whereas such uniform depletion was not the case in the other two houses. According to the farmer, extreme clustering during feeding causes unnecessary stress that affects the chickens. Therefore, the LEDs were seen as advantageous as they reduced the level of clustering during feeding times.

Neither the growth rate of the chickens nor the rate of food consumption varied significantly among the houses. This was a surprising outcome given the significant reduction in lighting duration in the fluorescent house during the overcast period. According to the farmer, nighttime illumination is most important during the first 15 days of the birds' life.

The mortality rate among the three houses differed significantly, but this cannot be causally linked to the lighting sources. Instead, it is likely a result of Gumboro disease affecting the chickens in the kerosene house and not the other two houses. Gumboro is a common chicken virus in Kenya that attacks the immune system with mortality rates typically reaching 20 %. It can be prevented with a vaccination; however, once the disease hits there is nothing that can be done [6]. All of the chickens were vaccinated for Gumboro on day ten, but

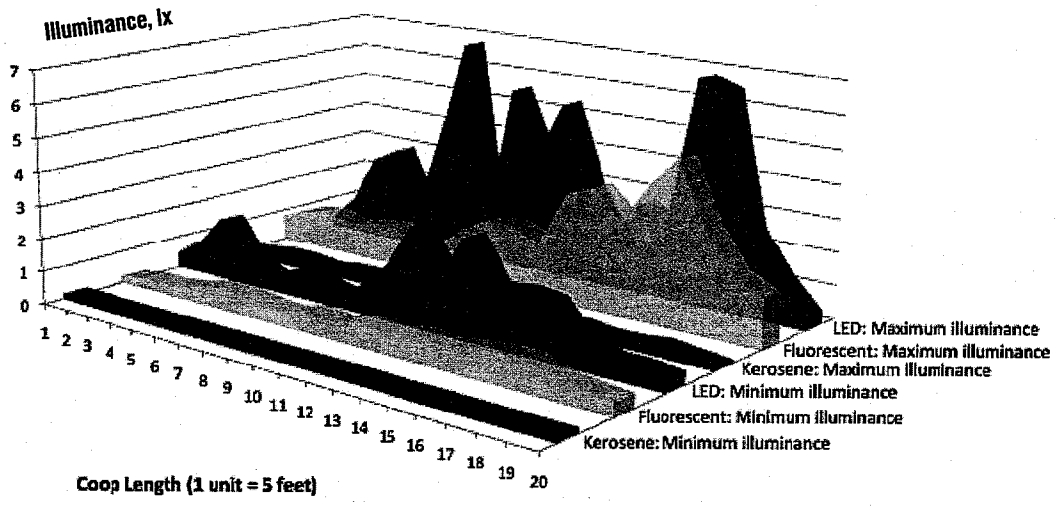

Fig. 7. Minimum and maximum illuminance measurements across the length of each house, the measurement transects are shown in Fig. 6

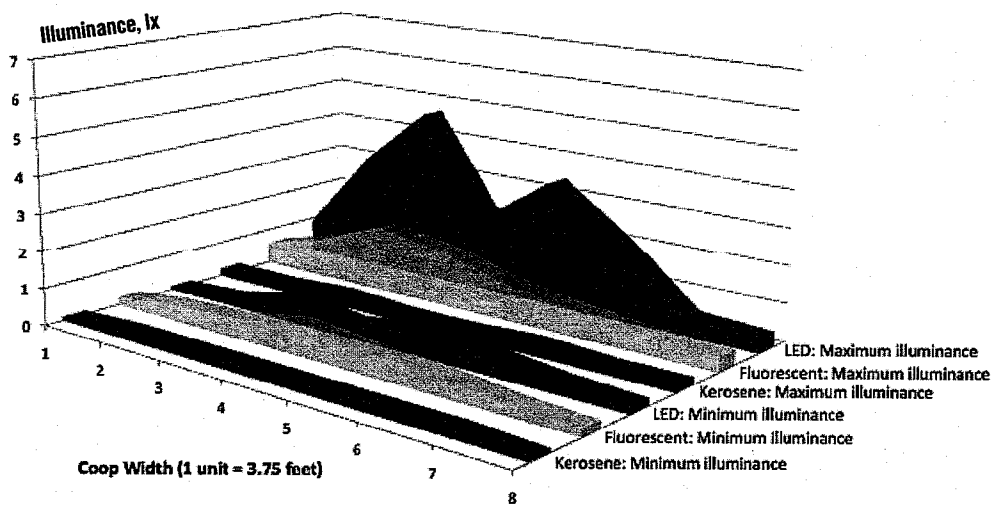

Fig. 8. Minimum and maximum illuminance measurements across the width of each house, the measurement transects are shown in Fig. 6

a second vaccination, which the farmer sometimes administers, was not given to any of the chickens. This is the likely reason for higher mortality rates in the kerosene house within the last 5 days of the cycle. It is unknown, however, why Gumboro led to higher mortality in the kerosene house than the other two houses.

LED lighting was by far the most cost-effective of the three systems tested. On a per-cycle basis, the fluorescent and the LED systems increased after-tax net income (revenues minus expenses) by15% compared to the kerosene system. **Table 3** provides a breakdown of the per-cycle costs and revenues. Considering the initial cost of each of the lighting systems and assuming five growing cycles per year,[7] the LED system will pay for itself in 1.5 years while the fluorescent system will take 9.3 years.[8] A higher number of cycles would decrease the payback times proportionately.

Providing light with fluorescent or LED systems is far more economical than connecting to the elec-

[7] The number of cycles per year carried out by the farmer in our study.

[8] This payback period does not account for any maintenance costs that may be required over the years, such as battery replacement. Battery-replacement costs are included in our cash flow and profitability analysis, however.

Table 3. Cash flow and profitability for each house over the 35-ay growing cycle

	Kerosene House		Fluorescent House		LED House	
	Ksh	USD	Ksh	USD	Ksh	USD
Expenses						
Purchase of Chicks	172,500	2,156	172,500	2,156	172,500	2,156
Caretaker Salary	16,000	200	16,000	200	16,000	200
Chicken removal	1,000	13	1,000	13	1,000	13
Feed	347,917	4,349	347,917	4,349	347,917	4,349
Food feeders	600	8	600	8	600	8
Medicine	17,500	219	17,500	219	17,500	219
Water	200	3	200	3	200	3
Water feeders (for bigger chickens)	1,500	19	1,500	19	1,500	19
Water feeders (for chicks)	170	2	170	2	170	2
Charcoal room heaters/Jiko	560	7	560	7	560	7
Charcoal	10,200	128	10,200	128	10,200	128
Sawdust	10,000	125	10,000	125	10,000	125
Materials for wind protection	1,440	18	1,440	18	1,440	18
Sanitizer	140	2	140	2	140	2
Manure removal	1,400	18	1,400	18	1,400	18
Petrol	1,800	23	1,800	23	1,800	23
Rent	4,000	50	4,000	50	4,000	50
Miscellaneous (tests, supplies, repairs)	2,500	31	2,500	31	2,500	31
Energy						
Kerosene wicks	80	1				
Kerosene fuel	6,305	79				
Kerosene Lamp Chimney Replacement	59	1				
Battery Replacement			3,067	38		
Battery Replacement: LED System					1,350	17
Total expenses	**595,870**	**7,448**	**592,493**	**7,406**	**590,777**	**7,385**
Revenues	**660,178**	**8,252**	**660,178**	**8,252**	**660,178**	**8,252**
Results						
Net pre-tax income	64,307	804	67,684	846	69,401	868
Income taxes (30% of net income)	19,292	241	20,305	254	20,820	260
Socal security taxes (5% of wages)	850	11	850	11	850	11
After-tax net income	44,165	552	46,529	582	47,731	597
Kerosene: % of after-tax net income	**15%**					
Lighting System Cost	2,480	31	300,000	3,750	46,800	585
Simple Payback Time (vs. kerosene) - years			**9.3**		**1.5**	

(Note: average actual values across the three houses are used here to suppress inter-house noise and clarify the relative impact of lighting choices.[9] Expenses for assets lasting longer than one production cycle (feeders, heaters, batteries) are prorated to per-cycle values)

tricity grid. The estimated grid-connection cost at this facility (which is located close to a nearby distribution line) is 1.7 million Kenya Schillings (approx 21,250 USD), which is nearly six-times the cost of the fluorescent system and 35-times the cost of the LED system.

In addition to cost savings, switching to the LED system avoids over one metric ton of carbon dioxide

[9] There were differences in mortality rates among the houses, which influenced the food inputs. It cannot be concluded that the differences were related to the lights, and in fact one house was determined to have a minor outbreak of the disease Gumboro. Therefore, in order to standardize the cost-benefit analysis for the different lighting systems, we used average feed cost and sale revenues across all houses. The LED systems would appear significantly more profitable using the raw data.

emissions per house on an annual basis compared to kerosene. Given the virtually complete elimination of kerosene light in farms opting for LED lighting, these projects would be particularly conducive to carbon-trading arrangements because of the relatively low uncertainties regarding the degree of expected displacement [7]. In many other contexts, verification is far more difficult and only partial substitution can be realistically assumed.

4. CONCLUSIONS

Significant quantities of kerosene are used to provide illumination for chicken production in off-grid settings. Through a controlled test in a full-scale chicken-production setting, we found that net revenues could be materially improved with the conversion to grid-independent electric lighting systems. The choice of kerosene, fluorescent, or LED lighting sources did not make a perceptible difference in chicken growth rates. However, the LED system produced the most illumination, paid for itself in saved kerosene in one-sixth the time of the fluorescent system, and offered many co-benefits for the workers in comparison to the other lighting systems. There is significant potential for replication of this LED lighting strategy in the developing world.

About The Lumina Project

The Lumina Project – an initiative of the U.S. Department of Energy's Lawrence Berkeley National Laboratory – provides industry, consumers, and policymakers with timely analysis and information on off-grid lighting solutions for the developing world. Lumina Project activities combine laboratory and field-based investigations to ensure the formation of policies and uptake of products that maximize consumer acceptance and market impact. Lumina Technical Report No.8, for more information, please visit http://light.lbl.gov

About Lighting Africa

Lighting Africa, a joint IFC and World Bank program, seeks to accelerate the development of commercial off-grid lighting markets in Sub-Saharan Africa as part of the World Bank Group's wider efforts to improve access to energy. *Lighting Africa* is helping mobilize the private sector to build sustainable markets to provide 2.5 million people with safe, affordable, and modern off-grid lighting by 2012. The longer-term goal is to eliminate market barriers for the private sector to reach 250 million people in Africa without electricity, and using fuel based lighting, by 2030. Improved lighting provides significant socio-economic, health and environmental benefits such as new income generation opportunities for small businesses. Lighting Africa contributes to the goals of the Clean Energy Ministerial. For more information, please visit http://www.lightingafrica.org.

Lighting Africa is implemented in partnership with the Asia Sustainable and Alternative Energy Program (ASTAE), the Energy Sector Management Assistance Program (ESMAP), the Global Environment Facility (GEF), Good Energies Inc., Italy, Luxembourg, the Netherlands, Norway, the Public-Private Infrastructure Advisory Facility (PPIAF), the Renewable Energy and Energy Efficiency Partnership (REEEP) and the United States.

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(Footnotes)

1. On Day 18 all three houses were opened up to their full floor area. The caretaker of the kerosene house continued to use six lanterns for two days after which he decided it was not bright enough, adding the final two lanterns totaling eight lanterns on Day 20.

2. All Kenya Schillings to US-dollar price conversions use an exchange rate of 80 Ksh/USD as per August 2010.

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