RURAL LIGHTING SERVICES: A COMPARISON OF LAMPS FOR DOMESTIC LIGHTING IN DEVELOPING COUNTRIES

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Abstract: Outcomes are presented of a World Bank funded research project with the objective to provide up-to-date technical information on low-end lighting options. Emphasis is on 12 volt DC lights suitable for solar home systems in developing countries. For comparison a number of traditional light sources such as candles and kerosene lanterns have also been included. Based on the measurements a proposal is formulated for a luminous efficacy standard.

Keywords: Vienna conference - 1: lighting systems 2: lamps - 3 solar photovoltaics

1. INTRODUCTION

Lighting is a basic necessity with a very high priority among households all over the world. Many different means are available to fulfil these lighting needs. When electricity first arrives in a village, lighting is by far the most common application. Electric lamps have some major advantages over their non-electric counterparts. These advantages are: increased lighting levels, higher quality of the lighting, greater ease of use, and lower costs per unit of light output.

In conventional rural electrification with grid extension, few incentives exist to apply energy efficient lighting. Consumers lack the knowledge of alternatives and the usually low electricity tariffs do not provide a strong incentive to consider an optimal choice of lighting source.
However, when solar photovoltaics provide the electricity for rural lighting, the situation is completely different. The high electricity cost per unit stimulates careful consideration in choosing the right type of lamp.

Very little is known about lamps for household applications apart from World Bank Energy Series No. 6 report [1], and a recent publication from IT Power and Stockholm Environment Institute [2].

2. OBJECTIVES

Since the outcome of the 1988 World Bank Energy Series report, new types of low-wattage electric lamps have entered the market. Given the increasing focus of rural development planners on photovoltaics as a source of electricity, an update of the Energy Series Report No. 6 is in due time. Furthermore, the study needs to provide a firmer base for the comparison of electric with non-electric lights.

3. METHODOLOGY

Laboratory measurements of light output of a number of different electric and non-electric lamps have been made by ECN to complement the manufacturers data sheets. The common measurement methodology provides a firm framework for comparing different lamp types. Electric lamps were selected in the low-power range. They are already being applied in solar photovoltaic systems, or have a potential for solar PV lighting.

Usually, the luminous flux of electric lamps is measured in an integrating sphere (Ulbright sphere). However, special provisions would have to be made to allow measurements of non-electric lamps (kerosene- and gas lamps). Therefore another approach has been selected. The luminous intensity has been measured in different directions and integrated to obtain the luminous flux of the lamp.

The measuring device used for the illuminance measurements is a small spectroradiometer, which can accurately measure spectra from 350 nm up to 1000 nm. The light enters through a small integrating sphere which is coupled to the spectroradiometer by means of an optical fibre. A CCD-array consisting of 256 elements converts the optical signal into an electrical signal. The output from the spectroradiometer is in the form of number of counts for each of the 256 wavelength intervals, which are stored in a personal computer.

4. LUMINOUS FLUX

Total amount of light emitted by a source, the so-called luminous flux, is one of the most important characteristics of a lamp. Luminous flux of the lights in the test sample ranged from about 1 to 1000 lumen for the electric lights and from about 10 to 2000 lumen for the non-electric lamps. Figure 1 presents an overview of the

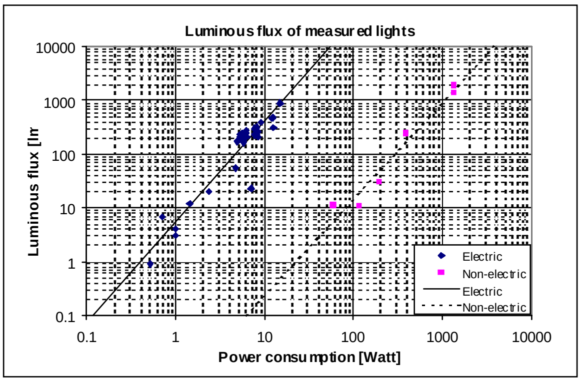

Figure 1 Luminous flux [lumen] and energy consumption [watt] for all lights included in the test sample.

luminous flux measurements of all the lights included in our test sample. As expected, the higher the power of the lamp, the higher the light output.

Electric lights are far more efficient than non-electric lights. For the household lights in the test sample it can be concluded that at the same level of luminous flux, the energy consumption of a non-electric light is about 65 times higher than for an electric light. There is no overlap in power between electric and non-electric lights in our sample: the highest power electric light is a 15 watt compact fluorescent lamp, while the lowest power non-electric light is small candle with an energy consumption of 60 watt! (This is a comparison on the basis of energy input into the light source. When comparing primary energy inputs, the equivalent energy consumption of the 15 W 230V PLET lamp amounts to about 50 watt.) If there would have been an overlap in the power range, an electric lamp would have a lumen output of about 2000 times higher than the non-electric lamps at the same wattage level.

Lights with a lumen output less than about 20 lumen are not meant for general lighting, but usually function as orientation lights only. Most users prefer to have one or more orientation lights in their homes.

5. LUMINOUS EFFICACY

Conversion of fuels or electricity in visible light takes place in a number of different processes and under different conditions, resulting in a wide range of luminous efficacy. Figure 2 shows the luminous efficacy in lumen per watt of input power for all lights in the test sample.

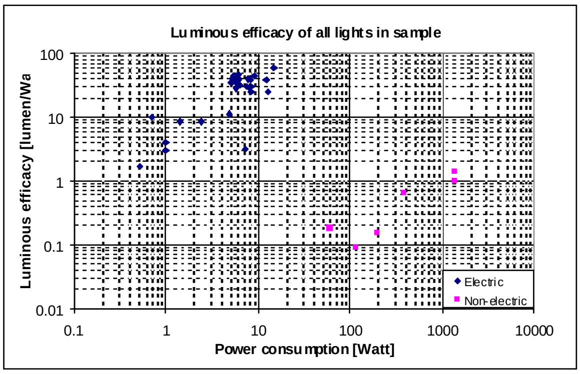

Figure 2 Luminous efficacy [lumen/watt] of all lights included in the test sample.

As could already be concluded from figure 1, electric lights are much more efficient than non-electric lights. Another interesting conclusion is that for both types of lights, the range in luminous efficacy levels is very wide. Electric lamps have luminous efficacy levels which range over a factor of 35, from 1.7 to 60 lumen per watt. The non-electric lights in our sample range from about 0.1 to 1.4 lumen per watt. These wide ranges are caused by the different technologies used and by the wide range in power of the selected lamps. Based on this figure 2, it is not possible to draw conclusions regarding the range in luminuous efficacy of the lights. This is only allowed if the lights are of the same type (technology) and operate under the same conditions (e.g. do not have a reflector). An example of lights for which it is allowed to draw conclusions from the comparison of their luminous efficacies is shown in figure 4.

The results presented in figure 2 fall well within the range as presented in the Rural Lighting publication [2] for non-electric lamps: 0.02 to 2.4 lumen/watt. However, for electric lamps the range given in the Rural Lighting publication is substantially higher than our measurements show: 8 to 80 lumen per watt. There are a number of reasons for these differences:

- We have usually selected lamps in the lower end of the power range. Generally, the higher the power the higher is the luminous efficacy;
- The light we measured with the lowest luminous efficacy (1.7 lm/W) is an experimental prototype of a 10 watt fluorescent tube operated at 1 watt;
- The range in power of available incandescent lamps is high: from 0.75 to 1000 watt. Probably, the figure presented in the Rural Lighting publication for their luminous efficacy (8-18 lumen/watt) is too high for the low end of the power range.

Some of the lights have been tested in conditions which deviate somewhat from the CIE requirements. Those lights which meet the CIE requirements with respect to ageing (at least 100 hours for fluorescent lamps) and ambient temperature (within the range of 24 to 26 °C) are labelled STC (Standard Test Conditions) in figures 3 and 4.

Most of the electric lights in the sample are fluorescent lights, because these are generally applied in solar PV systems due to their high efficiency. Luminous efficacy levels of all fluorescent lights which have been analysed are shown in figure 3.

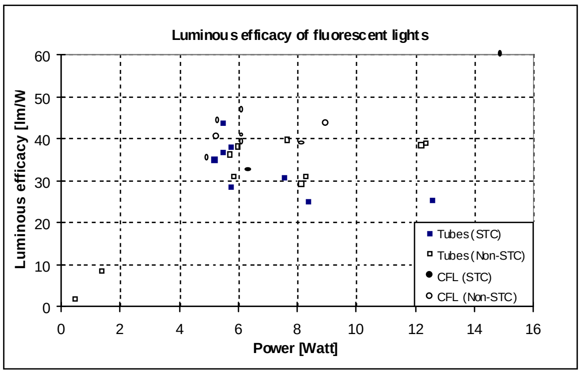

Figure 3 Luminous efficacy [lumen/watt] for all fluorescent lights in the sample.

Apart from the two orientation lights (with power consumption below 2 watt), the range in luminous efficacy of fluorescent lights is relatively small, compared to the overall sample. In the power range of 5 to 15 watt, no clear trend in luminous efficacy levels can be discerned. However, with decreasing power levels, somewhere below 5 watt, luminous efficacy levels have to drop because of the increasing weight of power losses in the electronic ballast. This is clearly illustrated by the much lower luminous efficacy of the two orientation lights. Lack of measurements (and lights!) in the power range of 2 to 5 watt prevent drawing conclusions about this drop in luminous efficacy.

In figure 3, fluorescent lights both with and without reflector have been included. A reflector results in a more concentrated beam of light, at the expense of reflection losses. A good luminaire has a luminaire efficiency (also called: Light Output Ratio, defined as the ratio of luminous flux of the luminaire to the luminous flux of the lamp operated outside the luminaire with the same ballast) of about 80%. To be able to compare the lights directly, only fluorescent lights without reflector have been selected in figure 4.

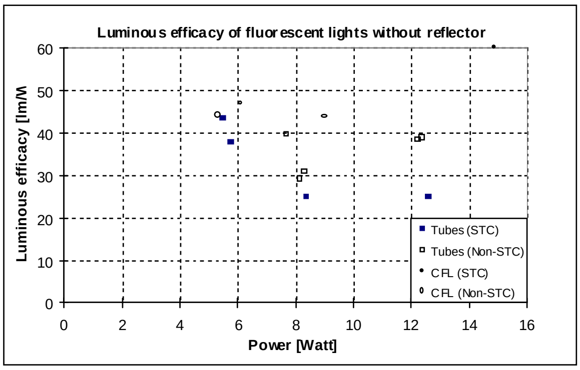

Figure 4 Comparison of luminous efficacy [lumen/watt] of fluorescent tubes and compact fluorescent lights, both without reflector.

Luminous efficacy levels of the lights in figure 4 only depend on the quality of the lamp and the electronic ballast. A comparison of the 12 volt compact fluorescent lamps (all CFLs in figure 4 except for the 15 watt CFL) with the fluorescent tubes shows that on average, the CFLs have a higher luminous efficacy. On the other hand, the best fluorescent tubes have a luminous efficacy which is close to the average of the CFL lamps.

6. CONCLUSIONS AND IMPLICATIONS FOR SOLAR PV PROGRAMMES

6.1 Suitability of lights for different tasks

With information about the spatial distribution of luminous intensity it is possible to make qualitative statements about the suitability of different light types for different tasks. For orientation lighting, very low illumination levels of 5 lux (lumens per square meter) or below are acceptable. General lighting requires 10 to 50 lux, and task lighting at least 50 lux. Lights with a lumen output of less than about 20 are usually suitable only for orientation lighting. Although most users want one or more orientation lights inside or outside their homes, the typical solar home kits do not include them because of their low efficiency. Table 1 summarises the findings.

All non-electric lights have in common with the solar lanterns that they are portable and can be used outdoors. Furthermore, the power of the gas and kerosene lamps can be adjusted somewhat to the taste of the user.

Table 1 Suitability of lights for different tasks

	General lighting	Localised and task lighting	Orientation lighting
Fluorescent tubes with reflector	+++	+++	-
Fluorescent tubes without reflector	++	+	-
Small incandescent lights	-	-	++
Halogen	--	+++	-
Cluster-LED *)	--	+	-
Solar lanterns	++	++	+
Pressure kerosene	+++	+++	--
Hurricane lamp	++	+	+
Kerosene wick lamp	-	--	+
Gas lamp	++	++	-
Candle	-	--	+

+++ = very suitable; ++ = suitable; + = possible;
- = less suitable; -- = unsuitable.
*) These conclusions are valid only for the specific type of cluster-LED which was tested, which produces a narrowly focused beam of light.

6.2 New developments

Technological developments in search of low-cost, high-efficiency lamps are concentrating, among others, on LED lamps. These lamps have only very recently been introduced to the general public for lighting purposes. Until late 1997, broad spectrum white-light LEDs were not even available. The cluster LED that was tested had a fairly poor colour rendering (it used a cluster of blue and red LEDs to produce an apparent white light). It also had a luminous distribution that was focused in a beam with a small angle that produced high levels of illumination in one direction and much lower or no levels in the other directions. This cluster LED was not considered suitable for an orientation light in a solar home system, although it might be appropriate for solar-powered torches. More recent cluster LEDs can, however, be very suitable for orientation lights. For example, white light LEDs with very good colour rendering (CRI>85) have become available since the tests took place. New tests most likely would show more positive results for LEDs than was the case in this test.

6.3 Standards for light fixtures

There are neither international standards for solar photovoltaic systems nor for their individual components. In formulating lighting standards, it is important to focus not just on the lumen output, but also on colour, ease of use, availability, lifetime, tube blackening, and, in particular, cost, as these aspects are important to consumers.

Lighting standards that are adopted should:

- Set a minimum luminous efficacy, taking into account the effects of colour;
- Apply only to the luminous efficacy of general lighting (power consumption of about 4 watts or more), not to orientation lighting;
- Include a maximum power level for orientation lights;
- Have different luminous efficacy standards for lamps or luminaires with and without a reflector.

The laboratory measurements of 36 lamps yielded a range of luminous efficacy of 25 to 47 lumens per watt. Fluorescent lights without a reflector averaged 37 lumens per watt. It is proposed to use the empirical number of 37 lumens per watt as the standard for compact fluorescent (CFL) lamps without a reflector and for fluorescent tubes without any fixture. This standard could be reviewed and fine-tuned regularly, say every two years, to stay abreast of developments in the fluorescent lighting business. The tests showed that a fluorescent tube mounted on a fixture but without a reflector has a luminous flux about 5-10 percent lower than that of a tube without any fixture. The proposed standard for fluorescent tubes without a reflector is therefore 35 lumens per watt.

Assuming a typical value of 80 percent for the efficiency of a luminaire with a reflector, the proposed efficiency standard for luminaires with fluorescent tubes and a reflector is 30 lumens per watt.

6.4 Implications for user choice

For household applications in developing countries there are numerous lighting options covering a wide range of lumen output levels, energy consumption and costs. But many technically feasible alternatives for household lighting are not commercially available in developing countries. Consumers in rural areas, in particular, have very few choices of lamps. One reason is that lamp manufacturers do not appreciate the potential of the rural lamp market and believe it is too small for more efficient low-wattage lights. Field surveys [3] have demonstrated, to the contrary, that a wider spectrum of lights, particularly in the low power range (1-10 watts), would better meet the cost and quality criteria of many rural customers. This applies both for photovoltaic installations and for rechargeable (car) batteries.

In addition, consumers should be better informed about the different factors that should guide the purchase of a lamp. Better standards would improve consumers' access to good information; printing the information on the lamp's packaging would be still better. Above all, a larger range of lamps should be available in rural retail shops. Designs of solar home systems need to offer one or more low-cost, low-wattage lights for orientation lighting. When only orientation lighting is required, a low-efficiency, low-power (for example, 1 or 2 watts) incandescent light is better than a high-efficiency 6-watt light to meet both energy-efficiency and consumer preferences.

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