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Replacing Fuel Based Lighting with Light Emitting Diodes in Developing Countries: Energy and Lighting in Rural Nepali Homes

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Abstract—More than one quarter of the world's population, who does not have access to electric light, live in the developing countries. Nepal is one of these countries, where the people in the remote rural areas have to rely on fuel based lighting to bring minimal lighting services in their homes. This paper reviews the quality of lighting, energy and health issues due to the use of fuel based lighting in rural Nepali villages. Recommendations are given on the amount of light needed as the first time electric lighting services in those remote places. The measurement results show that LED technology can bring necessary light in these rural homes with least energy use and it is the potential technology to replace fuel based lighting in a sustainable way. Replacing fuel based lighting by white LEDs can also contribute to the overall development of the underprivileged and underdeveloped communities by helping to improve the health, education and life expectancy of the people as well as income generation.

1 INTRODUCTION

Since the beginning of the human civilisation, artificial lighting has been an important commodity for human social and economic activities. In 2005, the worldwide annual use of electric light was 133 petalumen-hours (Plmh) with an average of 20 megalumen-hours (Mlmh) per person, and this consumes about 19 percent of total global electricity use (IEA 2006). On the other hand, two billion people in the world are still living without access to electricity (Mills 2002). Almost all of these people live in the developing countries, with four out of five living in rural areas (IEA 2002). About 14 percent of the urban population and 49 percent of the rural population in the developing countries were without electricity in 2000, and in the least developed parts of Africa (for example,

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Ethiopia, Uganda) only 1 percent of households had access to electricity (Mills 2005).

The lack of electricity and heavy reliance on traditional biomass are hallmarks of poverty in developing countries (IEA 2002). Nepal is one of these countries, where fuel based lighting is the only option to bring minimal lighting services into the homes in the early mornings and evenings. People in the very remote parts of Nepal use precious trees as firewood on open fire places at their homes for cooking, room heating, and lighting. This has a direct impact on their chronic health problems due to the rooms filled with smoke, resulting in low life expectancy, and high death rates of young children (IEA 2002). The extremely harsh and rugged environments of these communities in the midst of the Himalayan mountain region isolate them completely from the urban areas, and therefore most villages will not be reached by electric grid extensions within the foreseeable future. Thus the efficient use of available renewable energy resources and the adoption of appropriate contextualized technologies are essential for sustainable development of these rural communities. White LED based lighting has already shown its applicability in those circumstances. This study explores the opportunities offered by the LED technology for lighting remote communities with no access to electrical networks. The comparison of different aspects of LED lighting with traditional fuel based lighting shows that it not only improves the quality of lighting, but also the general living standard of the people, resulting in a notable improvement of the United Nation's Human Development Index (HDI) factor of the community.

2 LIGHTING IN THE DEVELOPED AND DEVELOPING COUNTRIES

In the industrialized countries electric lighting is taken as a basic necessity. On the other hand, in the developing countries, particularly in rural areas, having a basic lighting for the daily activities demonstrates already a privileged status. The estimated per-capita consumption of electric light in 2005 in different regions in the world is given in Fig. 1. Many studies have shown that there is a relationship between the household annual lighting electricity consumption and economic wealth (ACMR 2004; Mills 2002). Most parts in the developing countries are still out of reach of electrical networks. Less than 5 percent of the rural and less than 40 percent of the urban households in Africa have access to electric network (ABB 2005). Furthermore, even if the houses are electrified, many homes have only intermittent access to power as electricity blackouts are frequent, hence inducing the need for alternative energy sources. For example in the Indian state Madhya Pradesh, over 90 percent of rural electrified households use kerosene as a backup fuel for lighting (IEA 2002). Lighting is the primary consumer of the total electricity production in the developing countries, where it accounts for a significantly higher share (up to 86 percent) of residential electricity consumption compared to the industrialized countries (5–15 percent) (Mills 2002).

Due to very large differences in the household incomes and in the availability of energy sources, there are enormous differences in the quality of lighting encountered in the developed and developing countries. Furthermore, in the developing countries, there exist large differences in the quality and quantity of lighting used between the urban and rural areas. In most of the developing countries, there are no guidelines on recommended lighting levels and lighting

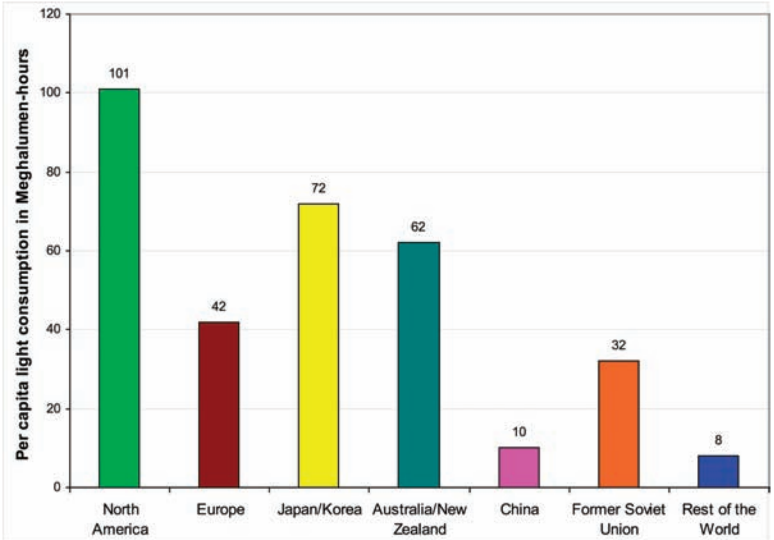


Fig. 1. Estimated per-capita consumption of electric light in 2005 (IEA 2006).

systems are usually installed without proper calculations by technicians without sufficient professional training. The lighting levels applied are usually lower than required because of the lower affordability of electric lighting. In contrast, in the industrialized countries, there exist detailed codes and recommended levels for each specific application (CIBSE 1997; CIE 2001; IEA 2006). According to the new European Union Energy Performance in Buildings Directive, EU member states are obliged to have a national standard to enable lighting energy performance to be included in the energy-performance metric of the whole building (EC 2002).

3 FUEL BASED LIGHTING IN RURAL NEPALI VILLAGES

Around 80 percent of the 28.5 million population of Nepal live in rural areas, and about half of them live in areas which are very remote and difficult to access (Zahnd 2005). Due to the geographical remoteness, harsh terrain, low population density, rural electrification in Nepal is infeasible. Therefore many villages in Nepal will not be reached by electric network extensions within the foreseeable future.

The primary energy source used to provide the necessary daily energy services in Nepal has for centuries been firewood, often supplemented by crop residues and animal manure. The high dependence on the traditional energy resources is due to the fact that there are no significant deposits of fossil fuel resources in the country. In 2003/2004, biomass provided 86 percent of the nation's total energy consumption. Respectively, petroleum amounted for 9 percent (mainly consumed by urban areas), electricity 2 percent, and renewable energy sources only 1 percent of Nepal's total energy consumption (CRT 2005). Only 40 percent of the population has access to electricity, of which 33 percent relies on national electrical network and 7 percent on alternative energy resources. The rest of the homes, mostly in rural areas, use kerosene, oil based wick lamps or resin soaked twigs to provide minimal lighting to their living conditions.

In the remote Nepali villages, the price of commercial liquid fuels (kerosene, oil) increases proportionally with proximity to roads, as all equipment and materials have to be carried by porters. This is particularly true for the remote mountain communities in Humla, which is the most northern district on the northwestern region of Nepal. This region is isolated from the mainstream development in Nepal due to its remoteness. To reach Simikot, the district center of Humla, one has to walk for 16 days from the nearest road. The families and communities in upper Humla have to use "jharro", a resin soaked high altitude pine wood stick, to get minimum, but smoky indoor lighting (Fig. 2 and 3). "Jharro" is gathered by inducing a deep "wound" on the pine tree, forcing it to produce locally a high amount of resin in order to "cure" the wound. This high resin content wood layer is cut away after a week and burned in small sticks to generate light. In this work, illuminance measurements in houses burning "jharro" sticks were carried out in several villages. Burning "jharro" sticks are typically placed on an elevated stone or mud pile or on a hanging metal plate (Fig. 3) at a height 40–50 cm from the floor. The average illuminance on the floor up to a horizontal distance of 1 m from the source was 2 lx. In the room corners (floor level), which were more than 1 m from the burning jharro sticks, the illuminances were less than 1 lx. These low lighting levels make it just possible to move around the room and to do some general work close to the light source, but the lighting is not adequate for any visually oriented tasks such as reading.

Fig. 2. "Jharro", a resin soaked pine tree stick for indoor lighting in Humla.

In these Nepali villages, precious trees are cut in order to meet the basic and most urgent energy service demands with firewood for cooking, room heating and lighting. This accelerates the already occurring devastating deforestation in these regions. Also, the indoor cooking on open fireplaces has a direct chronic impact on people's health, such as respiratory chest diseases, asthma, blind-

Fig. 3. Open fire places for cooking and heating, and light through "Jharro" create hazardous indoor air pollution conditions.

ness and heart diseases (IEA 2002). This contributes to the low life expectancy of women and the high death rate of children in these areas (Warwick 2004).

4 DEFINING BASIC LIGHTING LEVELS FOR REMOTE COMMUNITIES IN DEVELOPING COUNTRIES

There are many factors that affect the definition of appropriate light levels for the homes of remote villages in developing countries. The availability of the local energy resources, the cost of the lighting technology, and the local people's prevailing lighting practices should be considered in order to make the implemented lighting projects and programs sustainable. The defined lighting levels should be suitable and affordable for the rural people's activities and needs. The rural electrification projects are often first-time electrification projects for a community, and thus have to aim to provide just minimal lighting for defined tasks, however in an affordable and sustainable way.

The primary function of any home lighting system is to provide a safe visual environment for movement around the space, to make it possible to perform visual tasks, and to provide a comfortable and pleasant visual environment. On the other hand, the lighting system has to be cost-effective, efficient, nonpolluting, and easy to clean and maintain. The standards and guidelines for the recommended lighting levels in the developed countries often categorise the household in different areas and give recommendations on lighting levels according to the specific need of each area. However, the homes for example in rural Nepali villages are made up of flat muddy roofs with stones and wood beams, each home consisting of two rooms with low ceilings. There are no separate rooms for specified tasks. The whole family accommodates in the two rooms and these rooms serve them as kitchen, bedroom, study room, dining room and living room. In these homes, lighting is needed for cooking, orientation, security, and also for the children to do their homework in the evenings.

The illuminance measurements under fuel based lighting in the villages in Humla showed that the average illuminance levels available on the floor were around 2 lx. These lighting levels were just enough to move around the room and see the people and items in it. It was not possible to read at this lighting level, and any reading task had to be done very close to the light source. It was possible to read texts of a book when the illuminance level was around 25 lx, which level was observed by bringing the book close to the light source. This was tested by having the local school children (less than 18 years) to perform reading tasks. Cooking was easier, because the light source is usually located near the cooking place in the houses. The illuminance level on the cooking stove varied between 5 – 15 lx depending on the height of the cooking place. It is not feasible to recommend different lighting levels separately for orientation, cooking, cleaning, and reading for the rural homes that require the first-time basic electric lighting. Rather, two levels of illuminance can be recommended, one for reading purposes and another for all other activities. Based on the illuminance measurements under the traditional "jharro" lighting, it was concluded that lighting level of 2 lx is not sufficient for general purpose. An improved illuminance of about 5 to 15 lx is recommended for general purpose. As it was possible to read at a lighting level of 25 lx, for reading tasks, an illuminance level ≥25 lux is recommended as a first-time elementary lighting service for home lighting in these communities.

Fig. 4. Rural village house illuminated by LED light in Humla, Nepal.

5 LIGHTING WITH LEDS IN RURAL NEPALI VILLAGES

5.1 LEDS AND RENEWABLE ENERGY SOURCES FOR LIGHTING

The idea of using LEDs for lighting the unelectrified rural Nepali villages was initiated by Canadian professor Dave Irvine-Halliday, while he was trying to find solutions for lighting houses in villages with no access to electric networks (Rolex 2006). He saw children in Nepali mountain villages trying to read in dark classrooms. That gave birth to the Light Up the World Foundation (LUTW), which was the first humanitarian organization to utilize white LEDs in order to replace fuel based lighting in developing countries (LUTW 2006). The low energy required by the white LEDs is the key point to make them suitable for sustainable solutions, as it is possible to light an entire rural village of up to 30 homes with less energy than used by a single conventional 100 W incandescent lamp. In 2000, LUTW started its work by providing LED lighting to homes of four small Nepali villages; Thulo Pokhara, Raje Danda, Thalpi, and Norung (Shailesh 2006). Since then the organization has lit up more than 14 000 homes in 26 countries including the organization's birth place Nepal, directly influencing the lives of over 100 000 people (LUTW 2006).

Since the first home lighting projects in Nepal, LUTW is helping to light up the villages by providing LEDs to a local nongovernmental organization RIDS-Nepal (Rural Integrated Development Services- Nepal). RIDS-Nepal uses solar photovoltaic (PV) systems and pico hydro power plants with white LEDs to implement lighting in villages as part of long-term community development projects. Until January 2007, RIDS-Nepal has electrified five villages in the remote upper Humla through elementary village electrification projects. Four villages generate their energy through solar PV systems and one village through a 1 kW pico hydro power plant. In these villages, a total of 366 homes with 2196 people have now minimal indoor electrical lighting for about seven hours a day. The selection of the energy sources is driven by the fact that these rural villages are rich in renewable energy resources such as water, solar and wind power. With an annual average water runoff of 225 billion m^3 from over 6,000 rivers, the theoretical potential hydro power capacity of Nepal amounts to around 83 000 MW, with technically and economically feasible potential of around 43 000 MW (UNDP 2001). Nepal lies around the 30° northern latitude solar belt, with the solar energy presenting a sustainable energy resource, with an average insolation of 5.5 – 6 kWh/m^2 per day (Zahnd 2005).

There are three different approaches applied in the implementation of rural solar PV lighting systems: the *central*, the *cluster*, and the *solar home* system approach. If the geographical conditions of the villages are favorable and the houses are built close to each other, the solar PV system of the villages can be built as a central PV system, where the central village power house contains the battery bank and the charge and discharge controllers for the whole village. This central PV system consists of a two-axis self-tracking frame in which four 75 W (300 W total) solar PV modules are mounted. These two-axis self-tracking frames follow the sun's position, increasing the daily energy output between 30 percent–40 percent compared to the output at stationary mode depending on the season. In case the houses in the village are scattered, different clusters of houses are formed in the village and each cluster is electrified with one 75 W PV module with supporting infrastructure such as: battery, and charge and discharge controllers. In case the houses are more scattered, a single solar home system approach is implemented, making each home an individual energy generating station with a 12W – 16W solar PV module, a battery bank, and charge and discharge controllers. In all the above mentioned systems, each house is provided with three luminaries with white LEDs.

5.2 MEASUREMENT RESULTS

Illuminance measurements were carried out at the homes of Humla villages under LED lighting. The luminaries used in the villages were also measured in the Lighting Laboratory of Helsinki University of Technology to test their performance. There are two different types of LED luminaires manufactured for RIDS-Nepal village illumination programs, one consists of nine Nichia NSPW510BS white LEDs (low power white LEDs); and the other consists of a single white LED, Luxeon Star from Lumiled (high power LED), Fig. 5. All the luminaires are manufactured in Nepal by Pico Power Nepal (PPN), a local manufacturing company. The luminaire with low power LEDs is driven by using series resistors and a reverse protection diode. Three sets of LED strings, each string containing three LEDs, are connected in parallel and with one resistor. Since the current through each LED is small (20 mA), the amount of losses in the resistors are minimal. The rated current of the high power LED is 350 mA and it is thus uneconomical to drive it with resistor due to high power losses. Hence it is driven by a driving circuit based on a switching regulator.

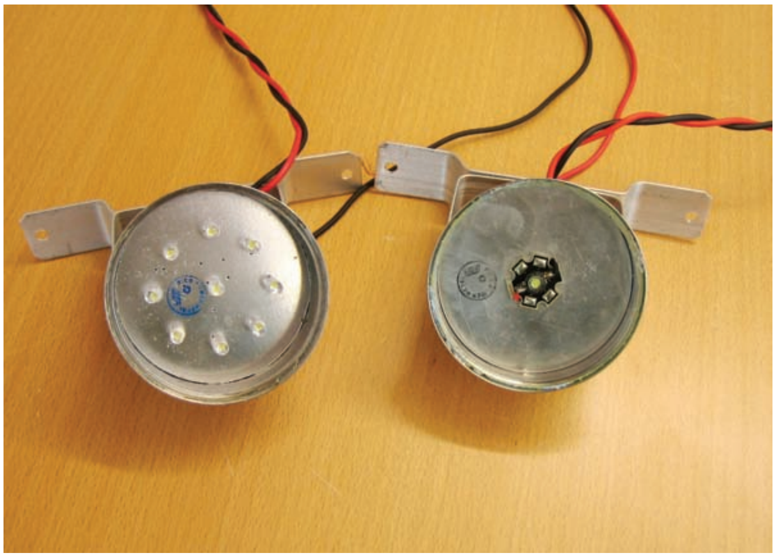


Fig. 5. White LED luminaires manufactured in Nepal for rural village lighting using Nichia NSPW510BS LED (left) and Lumiled's Luxeon Star LED (right).

The luminous fluxes of both luminaries were measured in an integrating sphere at Helsinki University of Technology. The operating current and voltage were also measured for calculating luminous efficacy. In order to make a direct comparison of LED light source with the "jharro" light source, the luminous efficacy of "jharro" was also calculated. The energy content of the resin soaked pine stick was measured using a calorimeter at University of Jyväskylä and the value was converted into equivalent electrical power. The luminous flux of the "jharro" was measured in a dark room at Helsinki University of Technology. Table 1 shows the characteristics of the two LED luminaires and the pine stick "jharro". The measurements indicated that the luminous efficacy of the pine stick lamp (0.04 lm/W) is half of the efficacy of kerosene fuel based lamp (0.08 lm/W (Mills 2005)) and more than 300 times less than that of white LED luminaire used in the villages. The differences between measured and rated values of luminous efficacy among the LED luminaires are due to the losses in the driving circuit and in the luminaire. The difference is significant in the high power white LED luminaire as it was driven with a lower than rated current, resulting also in a significant reduction in the light output. The loss in the driving circuit of the high power LED luminaire is considerably higher than that of the low power LED luminaire, indicating the need for a more efficient and better driving circuit for the high power LED luminaire.

TABLE 1.
The Measured Values of Power (W), Luminous Flux (lm), and Luminous Efficacy (lm/W) of the LED Luminaires and "Jharro", and Rated Luminous Efficacy of the LEDs as Given by the Manufacturers.

Light Source Type	Power (W)	Luminous Flux (lm)	Luminous Efficacy (lm/W)	Rated Luminous Efficacy of LED (lm/W)
Luminaire with 9 Nichia LEDs	0.73	11	15	29
Luminaire with 1 Luxeon LED	1.07	14	13.1	38
"Jharro" (pine stick)	2167	88	0.04	

Each home in the villages is provided with two luminaires with 9 LEDs, and one luminaire with a single LED. The two low power LED luminaires are installed in the bigger room used for cooking and the luminaire with a single high power LED is installed in the smaller room. The luminaires in the homes are installed on the ceiling of the room at a height of about 1.8 m from the floor. The average illuminance in the bigger room with the two luminaries at the floor level was 5 lx, while in the other room under the high power LED luminaire it was 3 lx. Based on the people's reaction on the lighting (interview), an average illuminance of about 5 lx seemed to be adequate for general purposes, while the average illuminance of 3 lx was found inadequate. The illuminances measured in laboratory in dark room under both LED luminaires at different horizontal and vertical distances are shown in Fig. 6 and 7. When the luminaire with low power LEDs was installed at 0.5 m above the illuminated plane, the illuminance on the plane directly under the luminaire was 112 lx. Thus the LED luminaires can provide sufficient light to read and to perform other visual tasks. The appropriate installation height of the luminaire depends on the type of illumination needed. While the illuminance directly under the luminaire is high with the luminaire installed at lower heights, the illuminance at the adjacent areas is decreasing sharply. In contrast, the reduction of illuminance on wider horizontal plane is not so sharp under the high power LED luminaire because of the wide viewing angle (110°) compared to the LEDs (50°) of the low power LED luminaire. A wider angle provides more evenly distributed horizontal illuminance on wider area though with lower illuminance level, while a narrower angle provides higher illuminance directly under the luminaire but on very narrow area, as indicated in Fig. 6 and 7.

5.3 TECHNICAL AND ECONOMIC ASPECTS

The performance and life time of the lighting system is dependent on all the auxiliary components associated. Routine checking of the equipments is needed to maintain the quality of the lighting. Cleaning of the PV panels, checking the battery voltage, topping up the batteries with rain water, and cleaning the glass of the luminaire should be done regularly. The solar PV modules are the most expensive equipment in a PV system and they have the longest life time. The monocrystalline PV arrays used in the Humla villages are guaranteed by the manufacturer to provide 90 percent and 80 percent of rated power output after 12 and 25 years, respectively. The climatic conditions are very important factors while designing the PV systems. Monocrystalline and polycrystalline PV modules have an average power output reduction of 0.4 percent to 0.5 percent per increased °C above the rated temperature. Similarly, the power output increases compared to manufacturer's rated power when the temperature of a PV module is less than the rated temperature. The design of a battery bank depends on the "independence of sunshine" (number of days without sunshine). The battery bank has to be large enough to provide the energy without being charged and

Fig. 6. Illuminance at floor level under the low power LED luminaire as a function of horizontal distance and at three different luminaire mounting heights.

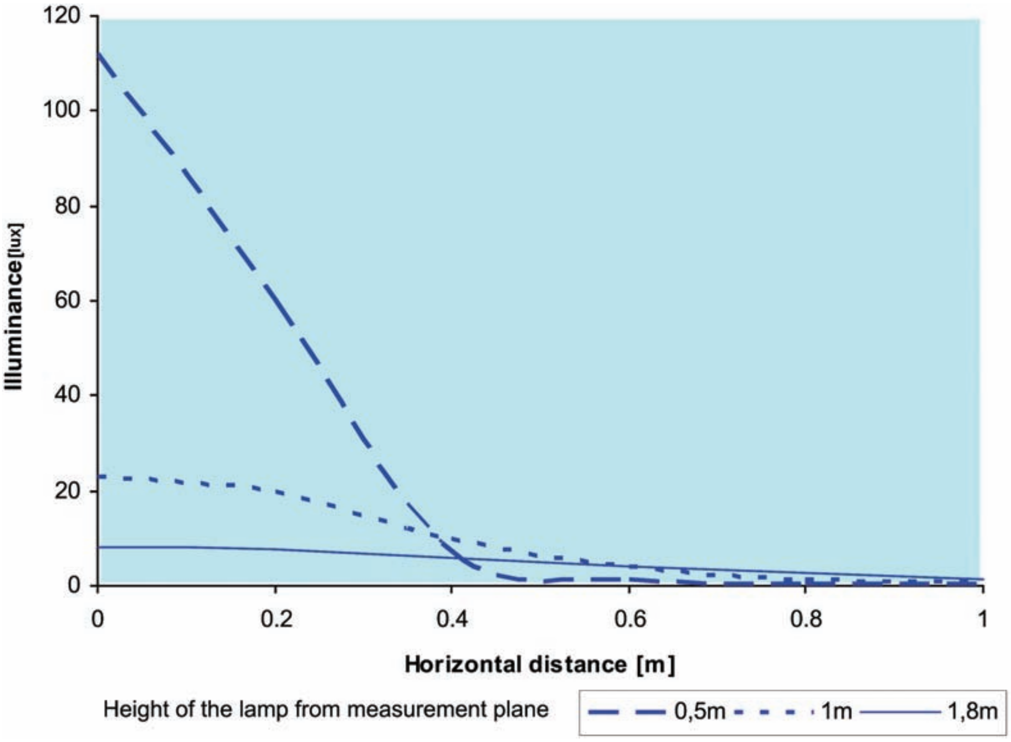
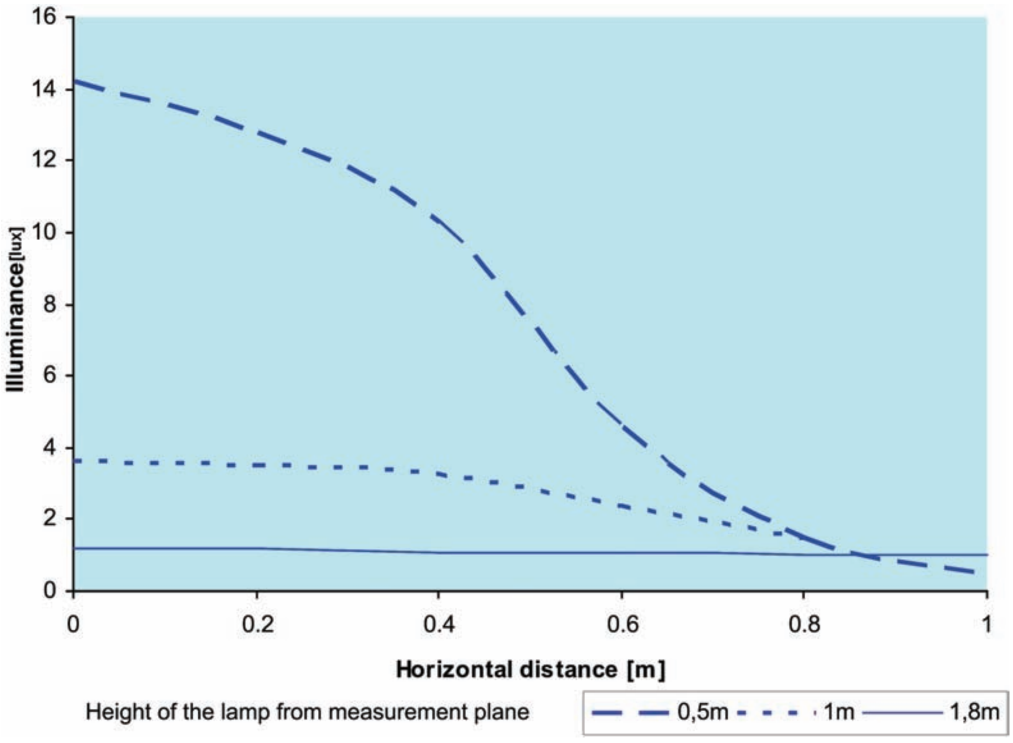


Fig. 7. Illuminance at floor level under the high power LED luminaire as a function of horizontal distance and at three different luminaire mounting heights.



without being too highly discharged during the days without sunshine. Overcharging and too low discharging of the battery leads to shorter life expectancy. The charge and discharge controllers protect the battery bank from overcharging and too low discharging, which allows the deep cycle lead acid battery used in the villages to last for 8–9 years. The charge and discharge controllers manufactured in Nepal have lifetime of about 8–10 years. The whole system is protected by automatic fuse for short-circuits and overloading.

Cost analysis of two types of LED lighting system and of jharro lighting was done to compare the costs in terms of per lumen hours of light. Initial costs and variable costs of the lighting installations were converted in to annual costs. In jharro lighting, there were no initial costs and the cost involved only the amount of jharro consumption. The amount of jhorro consumption per hour in jhorro lighting was measured at Helsinki University of Technology. It was found that the amount of jharro consumption for one jharro lamp giving 88 lumens (Table 1) is 0.27 kg/hour. Assuming lighting use of five hours a day, the annual jharro consumption can be calculated as:

$$0.27 \text{ kg/hour} \times 5 \text{ hours/day} = 1.35 \text{ kg/day}$$

$$1.35 \text{ kg/day} \times 365 \text{ days/year} = 492.75 \text{ kg/year}$$

The cost of jharro on the Humla villages can be assumed as Rs 100 / kg (Rs 100 is equivalent to 1.42 U.S. dollar). Hence the annual cost of jharro lighting providing 88 lm of light output is Rs 49275, which corresponds to Rs 307 ($4.36) per klmh (kilolumen-hour).

For the solar power LED lighting systems, the initial cost consists of the cost for solar PV array, battery, charge and discharge controllers, wires, switches, LED luminaries, and the cost of the installation. The variable costs consist of the cost for maintenance, and cost for the replacement of battery, controllers, and other auxiliaries. The cost analysis was done for 25 year life cycle, assuming the life of solar panels to be 25 years. An example of solar home system with 12 W solar panel, two deep cycle batteries, charge and discharge controller, luminaries, and switches were taken for the calculation. Cost of each component was assumed to be the cost at which they are available in the electrification project in Humla. We calculated from our analysis the cost of high power LED (Luxeon) lighting to be Rs 15.12 ($ 0.21) per klmh, while the cost of low power LED (Nichia) lighting as Rs 15.59 ($ 0.22) per klmh.

Due to the development of LED technology, the prices of LEDs are deceasing and the luminous efficiencies of LEDs are increasing. This will further increase the cost efficacy of LED lighting compared to the traditional jharro lighting in the future.

6 POSSIBLE HUMAN DEVELOPMENT INDEX (HDI) IMPROVEMENT THROUGH ELEMENTARY WHITE LED INDOOR LIGHTING

6.1 HDI FOR THE HUMLA DISTRICT IN NEPAL

The United Nations HDI (Human Development Index) is a widely accepted tool to rank the countries' development status in regard to poverty, literacy, education and life expectancy over a whole nation. The United Nations Development Programme's annual *Human Development Reports*, since the first in 1990, have published HDI as a composite measure of human development (UNDP 2001). HDI measures the average achievements in a country in three basic dimensions of human development: *long and healthy life*, as measured by the life expectancy at birth; *knowledge*, as measured by the adult literacy rate and the combined gross enrollment ratio for primary, secondary, and tertiary schools; and *a decent standard of living*, as measured by Gross Domestic Product (GDP) per capita at Purchasing Power Parity (PPP) in US dollars (UNDP 2005).

Each of the three basic dimensions counts a third towards the HDI of a particular group of people, community or nation in mind. As the HDI is identified for each country, one has to be careful in interpreting the given value, as the local context of a community or group of people can be very different, especially in certain fast growing urban areas of the developing countries. The national HDI of Nepal in 2003 – 2004 was 0.499 -0.504 (NPC/UN 2005), though the HDI for Humla was only 0.244 (KRDRC 2002). In the following, the Humla district is reviewed at its present development stage.

The first, "long and healthy life" indicator, identifies a life expectancy of 85 years as highest (factor 1), and 25 years as lowest (factor 0). The average life expectancy of Humla women and men is 54 years (KRDRC 2002), resulting in a life expectancy index of:

$$\textit{Life Expectancy Index} = \frac{54\ \textit{years} - 25\ \textit{years}}{85\ \textit{years} - 25\ \textit{years}} = 0.483$$

The second, "knowledge" indicator measures adult literacy and combined gross enrolment ratio for primary, secondary and tertiary schools. With an average adult literacy rate of 18 percent (women of 4.8 percent, men 31.2 percent) and an estimated gross enrolment of 33 percent, the combined education index is calculated as:

$$\textit{Adult Literacy Index} = \frac{18 - 0}{100 - 0} = 0.180$$

$$\textit{Gross Enrollment Index} = \frac{33 - 0}{100 - 0} = 0.330$$

$$\textit{Education Index} = 2/3\ \textit{Adult Literacy Index} + 1/3\ \textit{Gross Enrollment Index} = 2/3\ (0.18) + 1/3\ (0.33) = 0.23$$

The third indicator, the "GDP per capita", measures the annual income of the people. A logarithmic curve is assumed, as achieving a decent living standard does not need unlimited financial resources. In calculating the GDP index, US$ 40,000 represents factor 1. In Humla the average per capita income is US$ 72 (KRDRC 2002), derived mainly from selling firewood and trading goods between China, Nepal and India. As more than 95 percent of families in Humla are farmers, an additional estimated annual US$ 40 value from their annual crops can be added. Thus the GDP index factor is calculated as following:

$$\textit{GDP Index} = \frac{\log(112) - \log(100)}{\log(40000) - \log(100)} = 0.019$$

The final HDI is the average of the individual three indexes:

$$\textit{HDI} = 1/3\ (\textit{Life Expectancy Index}) + 1/3\ (\textit{Education Index}) + 1/3\ (\textit{GDP Index}) = 1/3\ (0.483) + 1/3\ (0.230) + 1/3\ (0.019) = 0.244$$

6.2 POSSIBLE HDI IMPROVEMENT THROUGH ELEMENTARY WHITE LED INDOOR LIGHTING IN HUMLA HOMES

In order to utilize the synergetic benefits that elementary indoor electric lighting can provide, each electrification project RIDS-Nepal is implementing in Humla is part of a long-term holistic community development (HCD) project. The main factors of HCD projects include the building of an efficient smokeless metal cooking and heating stove, a pit latrine for each family and a commonly owned village drinking water system. Based on the implementation of a long-term community development HCD project including white LED indoor lighting, the following HDI calculation parameters can be assumed due to the changes over a ten years time span, compared to the unchanged neighboring villages.

6.2.1 HEALTHY AND LONG LIFE

The installed white LED lighting instead of the "jharro" (pine stick) in addition with the installed smokeless metal stove for cooking and heating enable clean indoor air. PM_{10} (Particulate Matter less than 10 μm) value measurements in traditional houses in Humla in November 2006 showed that over a 24 hours time span, the average indoor air pollution was up to 20 times less with LED lighting and a smokeless metal stove compared to the use of "jharro" for lighting and cooking on an open fire place. These improvements over a ten years time will incur considerable positive health improvements, especially in regard to chronic respiratory chest diseases. It is assumed that this will enable a prolonged life expectancy of about 10 years, from present 54 to 64 years. Thus, the "healthy and long life" HDI factor increases from 0.483 to 0.650.

6.2.2 EDUCATION

Nonformal education classes for adults and out-of school children are part of the RIDS-Nepal community development projects in Humla. The installed white LED lighting is providing clean and smoke free light to enable people to read. That means that one of the synergetic benefits from the LED lighting is that the educational level is foreseen to significantly increase over the next ten years. Also the number of children enrolling in school will increase substantially, once the mothers are aware of the changes education brings to their village, life and the future of their children. It is therefore realistic to assume a doubling of the literacy rate and school enrolment over a ten years time span. Thus, the combined "education" HDI factor increases from 0.230 to 0.460.

6.2.3 GDP PER CAPITA

Adequate lighting inside the home provided by LEDs, clean indoor air due to the use of a smokeless metal stove, a pit latrine, access to clean drinking water, are all bringing synergetic benefits if implemented alongside with each other in a village. The increased social gatherings in a more comfortable environment bring forth new ideas for community and income generation activities such as knitting, bamboo basket weaving and other simple handicrafts. An elementary village electrification system using white LEDs is often the very first step of a family to start learning and experiencing electric light inside their home. Such an electrification system does not aim to generate enough power for tools or electrical equipment for the production of home based commodities. While this may be the ultimate aim in the years to come, a community has first to learn and experience the benefits of elementary electric lighting. Undoubtedly, LED based lighting allows an increase in home based income generation abilities, supported by better health and educational status. But, compared to the first two HDI indexes, it may not be the major factor. Thus it is reasonable to assume that a 40 percent increase of the annual income can be achieved in ten year period, which means that the "GDP" HDI factor can increase from 0.019 to 0.075.

Adding up the new calculated three HDI factors increases the overall HDI index from 0.244 to 0.395, an increase of 60 percent over the assumed time span of ten years. This expected increase in the HDI index shows that replacing fuel based lighting with LEDs in combination with other related community development projects can substantially improve the socio economic development of the communities.

7 CONCLUSIONS

While electric lighting is taken as granted in the industrialized world, more than one quarter of the world's population is still using fuel based lighting for their basic lighting needs. The pine stick based lighting used in rural Humla in Nepal was found to be more than 300 times less efficient than the new white LED based lighting. Still, the LEDs currently used in the villages are not the most efficient as the manufacturer has already announced the introduction of LEDs with 150 lm/W luminous efficacy compared to the 29 lm/W LEDs used in the current installations (Nichia 2006). Although the lighting levels provided by the LED based lighting are minimal, they can be considered adequate for a first time indoor elementary lighting installation. A whole village of up to 30 homes can be lit with the comparative power of one 100 W incandescent lamp. With the continuous advancement in the efficiency of LED technology, more light in the future will be available using the same amount of energy.

The replacement of fuel based lighting can be done in a sustainable way by using the existing and environmentally friendly renewable energy sources like wind, solar and hydro power. This sustainable way of lighting the villages is expected to improve the general living standard of the communities, contributing significantly to health, education, and income generation improvement of the local people.

REFERENCES

ABB. 2005. Access to Electricity. White paper on ABB's initiative for Access to Electricity. www.abb.com accessed on 4th Dec, 2006.

[ACMR] All China Marketing Research. 2004. Survey Report for Annual Follow-Up Evaluation of the Promotion Item of China Green Lighting Project. China Greenlight Project Management Office, Beijing, China

CIBSE. 1997. CIBSE Code for interior lighting 1994: Additions and corrections 1997. ISBN 0 900953 64 0.

[CIE] Commission Internationale de L'Elairage. 2001. ISO. 2002. Lighting of indoor work places. International standard ISO 8995:2002, CIE S 008/E-2001.

[CRT] Centre for Rural Technology. 2005. National Energy Situation Survey Report Nepal. Report submitted to International Network for Sustainable Energy (INFORSE), www.inforse.org. Accessed on 13th Dec, 200.

[EC] European Commission. 2002. Energy Performance of Buildings Directive, 2002/91/EC.

[IEA] International Energy Agency. 2002. World Energy Outlook. IEA Publications, France.

[IEA] International Energy Agency. 2006. Light's Labour's Lost. IEA Publications, France.

KRDRC. 2002. Governance in the Karnali, an Exploratory Study. Karnali Rural Develop. & Research Center, Jumla, Nepal

[LUTW]Light Up The World Foundation. 2006. http://www.lutw.org/about.htm. Accessed on 28th Dec, 2006.

Mills E. 2002. Why we're here: The $320-billion global lighting energy bill. *Proceedings of the 5th International Conference on Energy-Efficient Lighting*, Nice, France. p 369–385.

Mills E. 2005. The Specter of Fuel Based Lighting. Science, Vol. 308, No. 5726, p 1263–126.

Nichia, 2006. http://www.nichia.com/about _ nichia/2006/2006 _ 122001.html accessed on 28th Dec, 2006.

Rolex. 2006. The Rolex Awards: Cheap LED lighting, D. Irvine-Halliday. http://www.rolexawards.com/laureates/laureate-67-irvine _ halliday.html. Accessed on 28th Dec, 2006.

Shailesh KR. 2006. White LED Based Illumination Systems for Indian Villages. LEUKOS, The Journal of the Illuminating Engineering Society of North America, Vol 3, no. 2, p 167–17.

Warwick H *et al* 2004. Smoke - the Killer in the Kitchen. ITDG Publishing. ISBN 1 85339 5889.

NPC/UN. 2005. Nepal Millennium Development Goals, Progress Report 2005, National Planning Commission / United Nations, Published by HMG Nepal, Singh Durbar, Kathmandu, Nepal

UNDP. 2005. Human Development Report 2005.United Nations Development Programme (UNDP), New York: Oxford University Press. Technical notes 1.

UNDP. 2006. Expanding access to modern energy services: Replicating, Scaling Up and Mainstreaming at the local level. United Nations Development Programme (UNDP) Publication, USA

Zahnd A. McKay, K. 2005. Renewable Energy Resources for Improved, Sustainable Livelihood A Case Study of a Holistic Community Development Project with a Remote and Poor Mountain Village in the Nepal Himalayas. In proceedings of 6APRSCP (Asia Pacific Roundtable for Sustainable Consumption and Production) Melbourne, AUS, 10^{th} – 12^{th} October 2005.