Appendix Document 7

Appendix Document 7.1-1

1 Basis of Cost Comparison of the PV and Grid-based Electricity Supply Systems

The present study has performed cost comparison between the PV system and the grid-based electricity supply system (involving grid extension and installation of distribution lines). Note that the costs considered do not include costs for lighting apparatuses and other electrical equipment as well as wiring within the customer's premise. Also, while the grid system has much larger supply capacity (from transmission lines) than the PV system does, electricity consumption assumed for estimation of the power cost per kWh is the same as power supply available from the PV system because large extension of distribution lines cannot be expected for each locality due to small power consumption.

(1) Cost estimation for the conventional electricity supply system

1) Power generation cost

In Botswana, a coal-fired thermal power plant is operated in Morupule to supply 50% of electricity demand, while the remaining 50% are imported from SAPP (Southern African Power Pool). To estimate the rural electrification cost, therefore, imported electricity is assumed to be used for the purpose.
Electricity is imported from SAPP at the unit price of RSA¢ 6~7/kWh, and if the transmission cost is added, the total cost is around RSA¢ 11 /kWh (according to BPC). Thus, the power generation cost is assumed to be Th7.5 /kWh.

2) Extension of transmission and distribution lines

If rural electrification is to be accomplished by grid extension, transmission lines need to be extended with installation of transformers and distribution lines to households.

a) Extension of transmission lines
Based on the project budget for extension of transmission lines to 72 villages (to be completed in 2001), the average construction cost per

distance from the grid was estimated. Then, it was multiplied by the escalation factor of 26% (BPC data) to obtain the present cost, as follows:

$$\text{P81,600/km} \times 1.26 \fallingdotseq \text{P103,000/km}$$

72 Village Electrification Cost (Budget)

No.	Items	Voltage	Cumulative Distance	Region	No. of villages	Total population	Cost	Cost/ km	Cost/ men	Cost/ household	25% connection	60% connection
		kV	km				kP	kP/km	P/men	P/ household	P/ household	P/ household
1	Villages with 11kV supply within 15km (total)		222.9		29	36,319	23,789	107	655	3,275	13,100	5,458
1)	Villages to be done as small works (sub-total)		13.3		6	6,313	2,276	171	361	1,803	7,211	3,005
		11	9.3	south	4	2,793	1,496	161	536	2,678	10,712	4,464
		11	4.0	north	2	3,520	780	195	222	1,108	4,434	1,847
2)	Packaged contracts based on proximity (sub-total)		209.6		23	30,006	21,513	103	717	3,585	14,339	5,975
		11	116.6	south	12	15,376	11,639	100	757	3,785	15,140	6,308
		11	93.0	north	11	14,630	9,873	106	675	3,374	13,497	5,624
2	Proposed 66kV supply lines (total)	66	349.0	south	3	4,227	26,086	75	6,171	30,856	123,425	51,427
3	Proposed 33kV lines (total)		1,132.0		17	29,609	78,695	70	2,658	13,289	53,156	22,148
		33	614.0	south	9	13,771	40,721	66	2,957	14,785	59,141	24,642
		33	518.0	north	8	15,838	37,973	73	2,398	11,988	47,952	19,980
4	Proposed 11kV lines longer than 15km (total)		526.4		21	39,422	37,509	71	951	4,757	19,029	7,929
		11	173.0	south	6	8,490	10,793	62	1,271	6,356	25,425	10,594
		11	353.4	north	15	30,932	26,716	76	864	4,318	17,274	7,197
5	Grand Total		2,230.3		70	109,577	166,078	74	1,516	7,578	30,313	12,630
1)	11kV lines total	11	749.3		50	75,741	61,298	82	809	4,047	16,186	6,744
2)	33kV lines total	33	1,132.0		17	29,609	78,695	70	2,658	13,289	53,156	22,148
3)	66kV supply lines total	66	349.0		3	4,227	26,086	75	6,171	30,856	123,425	51,427

Summary of costs on the implementation of the 72 Villages Electrification Project (Actual)

Item	Amount (P)	Activities accounted for		
Construction	172,035,000	Construction and consultancy costs	94.5%	100.0%
Operations	8,961,000	Salaries, travel, cost of mapping, rentals, e.t.c	4.9%	5.2%
Capital	1,049,000	Purchase of vehicles, network printer/copier, e.t.c	0.6%	0.6%
TOTAL	**182,045,000**		100.0%	105.8%
Total km	2,230			
Cost on Phase 9				
Unit construction cost (P/km)	77,146			
Unit extension cost (P/km)	81,635			
Cost on Phase 14				
Unit construction cost (P/km)	97,204	26% cost up		
Unit extension cost (P/km)	102,860	26% cost up		

b) Transformers and distribution lines

Household density in a target village will become more and more dispersed. Therefore, it is estimate that average total distribution line cost is P4500/Household.

3) Operation and maintenance cost

Operation and maintenance cost is assumed as 2% of total investment cost of grid extension.

(2) Cost estimation for the PV system

The cost for the PV system was estimated from data obtained in the demonstration project.

1) PV system equipment installation cost (investment)

In the demonstration project, 215 sets of the 50Wp system were installed and the total construction cost was P1,570,000. The equipment installation cost, excluding lighting and internal wiring, was P1,400,000 and the unit cost per Wp was P130. If installation work is carried out nationwide, significant cost reduction can be expected due to a much larger installation base. For the purpose of cost estimation, the installation cost is assumed to be 70% of the previous cost, namely P91/Wp.
Grid extension cost include owner side costs. Owner costs is added, then,
91 X 1.058 = P96.3/Wp

The battery cost for replacement was P714 for 105Ah in the demonstration project, and if the 80% reduction is assumed, it will be P411/50Wp-system/3 years.

2) Operation and maintenance costs

i) Field operation and maintenance costs
Assuming that a user charge collection agent and a maintenance person are assigned to each village, the monthly operation cost is estimated at P1,500/locality.

ii) Costs related to BPC headquarters and regional offices
Assuming that a project manager will be appointed at the headquarters (covering 2,000 households), and an engineer, a bookkeeper and an assistant will be assigned per 1,000 households, and a technician and an assistant per 1,000 households, who will station at each regional office. The labor cost is calculated as follows.

Project manager	10,000	P/月	×	12月	=	120,000	–	1 per 3,000 households
Engineer	7,000	〃	×	12〃	=	84,000		1 per 1,500 households
Accountant	4,000	〃	×	12〃	=	48,000		
Assistant	1,000	〃	×	12〃	=	12,000		
Local technician	5,000	〃	×	12〃	=	60,000		
Assistant	1,000	〃	×	12〃	=	12,000		
						P216,000	/Year	

Assuming that a 100Wp system is installed on average at each household, the operation cost per household is estimated by assuming that the administration cost is 50% of total salaries.

$$\frac{(120{,}000 \times 0.5 + 216{,}00) \times 1.5}{1{,}500} \fallingdotseq \text{P276/house・Year}$$

2 Basis of Cost Comparison of the PV Mini-grid and SHS Systems

(1) Estimation of mini-grid construction and operation costs

In the case of a mini-grid system, PV panel arrays will be configured by 300Wp panels instead of 50Wp panels for the SHS system (280Wp in Motshegaletau).

SHS construction cost breakdown (demonstration project)

	Amount (P)	Percentage (%)	
Equipment	1,073,391	68.4	100
Construction	496,035	31.6	46.2
Total	1,569,426	100	146.2

Then, the SHD construction cost less BCS and spare parts is estimated as follows.

	Amount (P)	Percentage (%)
SHS related equipment	610,000	68.4
SHS panels	263,846	(29.6)
BOS	346,154	(38.8)
Total SHS construction cost	610,000×1,462≒892,600	100

Thus, the panel cost is assumed to account for 30% of the total construction cost.

From the above data, the construction cost for the 300Wp panel system is estimated as follows.

1) PV panel cost

The total construction cost for 50Wp panels, denoted "S," is estimated as follows:

Panel cost (50Wp basis) = S x 0.3

If the panel module size is 300Wp, the price per Wp is assumed to remain mostly unchanged due to volume production (multiplied by 0.95).

$$\text{Panel cost (300Wp)} = S \times 0.3 \times \frac{\left(\frac{300}{50}\right)^{0.95}}{\left(\frac{300}{50}\right)}$$

$$= 0.274S$$

2) BOS (auxiliary equipment)

BOS cost (50Wp basis) = S x 0.388

The BOS cost for the 300Wp module size is assumed to be reduced by 0.7 due to volume production.

Thus,

$$\text{BOS cost (300Wp)} = S \times 0.388 \times \frac{\left(\frac{300}{50}\right)^{0.7}}{\left(\frac{300}{50}\right)}$$

$$= 0.227S$$

3) Total construction cost

Total construction cost = (0.274 + 0.227) S x 1,462

= 0.732S

Thus, the construction cost for the 300Wp module is assumed to be 75% of that for 50Wp.

4) Local distribution network construction cost

The construction cost for a low-voltage AC distribution network within a locality is assumed to be the same as that estimated for grid electrification, namely P4,500 per household.

5) Operation and maintenance costs

The mini-grid system is more complex than the SHS system and requires sophisticated operation and maintenance techniques. As localities are generally far apart from each other, a field maintenance person should be trained for each locality and a security guard is required to ensure safety. As a result, the system cost is much higher than that for the SHS system.
The total cost is therefore assumed to be twice the SHS cost for field operation and maintenance.

(2) Estimation of SHS construction and operation costs

The same assumptions for grid electrification

(3) Under the above assumptions, the total cost estimated for each system over 20 years was discounted at 15% to obtain the present value, as shown in Figures 5.3-1 – 6. (See calculation details in Appendix Table 5.3-2.)

Fig.5.3-2 compares cost advantages of the two systems on the basis of the number of households and electricity consumption when the total cost for both systems becomes identical. The calculation results indicate that, for a locality of 100 households, the SHS system has cost advantage over the mini-grid system if electricity consumption per household is 195Wp or less. The PV mini-grid system is advantageous only when a locality is densely populated or has a large number of households and consumes a relatively large amount of electricity.

Figures 5.3 – 6 compare unit electricity costs for the two systems (P/kWh) by using electricity consumption per household and the number of households as parameters.

Appendix 8 PV System Design and Environmental Measure

Appendix 8 PV System Design and Environmental Measures

8.1 PV Systems Technology

Technical evaluation was conducted in each stage of the implementation process, i.e., examination of purchase specifications and basic system configuration for equipment used in the Dissemination Project, equipment procurement, and confirmation of work quality.

8.1.1 Consideration of Botswana Standard BOS 2-1:1999 "Code of Practice for PV Energy Systems Design and Installation—Part1: Buildings"

In preparing general purchase specifications for the Dissemination Project, covering both equipment and installation work, basic requirements were established in consideration of Botswana Standard BOS 2-1:1999 "Code of practice for PV energy systems design and installation—Part1: Buildings" enacted by the Botswana Bureau of Standards, while reflecting opinions of engineers of BPC/EAD. Also, equipment specifications were determined with reference to equipment catalogs obtained from local suppliers in order to facilitate procurement from local sources. Note that Botswana Standard BOS 2-1:1999 was adopted in 1999 by revising "Code of practice for PV energy installation in Botswana" that was originally established by BoTeC and MMEWA.

The following requirements were established in consideration of the Botswana standard.

(1) Standard test condition

Solar irradiation of 1kW per m^2 at cell temperature of 55℃

IEC specifies cell temperature of 25℃, based on which manufacturers specify PV module output as rated output. This specification is based on weather conditions in Botswana and PV module output specifications need to reflect the specification. Specifically, when cell temperature of 55℃ is assumed, output from a crystalline PV module drops around 15% compared to the PV module output. This means, to achieve actual output of 50Wp, a PV module with rated output of around 60Wp should be selected. The Dissemination Project includes this item in technical evaluation on bidders for the purpose of confirming technical capabilities.

(2) Minimum design life for battery

Minimum design life for battery: 3 years

As the PV module is charged and discharged once per day, design battery life is set at 1,200 cycles after consultation with BPC/EAD engineers. The depth of discharge per day is set at 15% from PV system capacity design. As these values are relatively high specs, selection of appropriate equipment requires good knowledge on battery and this item is included in technical evaluation on bidders for the purpose of confirming their technical capabilities.

(3) PV panel installation tilt

Panel installation tilt: the angle of latitude of the site ±5 degrees

The villages where the Dissemination Project is implemented are located at 23 – 25 degrees, south latitude. While the basic angle is assumed to be 25 degrees, an installation angle is set at 30 degrees (25 + 5) in order to minimize the difference in electric energy generated between the summer and the winter due to a seasonal variation of irradiation. Note that the angle was selected by estimating electricity energies generated at each of three angles (25, 30 and 35 degrees) on the basis of average irradiation data in Gaborone in June and December, and comparing them to identify an angle that showed the least difference. The estimation results are summarized below.

Appendix Table 8.1-1

	Installation angle					
	25degress		30 degrees		35 degrees	
	Irradiation (kWh/m² /d)	Electric energy generated (kWh/d)	Irradiation (kWh/m² /d)	Electric energy generated (kWh/d)	Irradiation (kWh/m² /d)	Electric energy generated (kWh/d)
a) June (winter solstice)	5.580	0.215	5.810	0.220	5.940	0.225
	91%	91%	94%	93%	96%	95%
b)December (summer solstice)	6.160	0.237	5.940	0.227	5.670	0.217
	100%	100%	96%	96%	92%	92%
Difference between June and December 《 b - a 》	0.580	0.022	0.130	0.007	-0.270	-0.008
	9%	9%	2%	3%	-4%	-3%

Lower column (%): Ratio of each value to that obtained at 25 degrees in December.

The estimation results indicate that, at the angle identical to the latitude (25 degrees), electric energy generated in the winter decreases 9% compared to that in the summer. On the other hand, at 35 degrees, total electric energy is 3% - 4% less than that generated at 25 degrees throughout the year. On the other hand, electric energy generated at 30 degrees shows the least difference between the summer and the winter, ranging between 93% and 96% of the maximum energy generated at the optimum angle of 25 degrees.

While Botswana is located in the low latitude, there is a relatively large difference in sunset time between the summer and the winter, i.e., around 2 hours. As a result, electricity consumption is expected to increase during the winter, so that an installation angle should be established by taking into account electric energy generation during the winter.

Based on the above consideration, it is recommended to install the PV module at an angle in the range between the latitude and the latitude plus five degrees, representing a slight deviation from the latitude ± five degrees required in Botswana Standard BOS 2-1:1999.

Other relevant items in the standard are well organized to cover general aspects of PV technology, including a selection guideline for load equipment and important points in construction work. Thus, the PV module can be properly installed so long as the contractor understands and complies with the requirements in the standard.

8.1.2 Technical Evaluation of Local Suppliers (Equipment)

Local suppliers were evaluated on the basis of their proposals in the bidding process for the Dissemination Project so as to determine their ability to understand technical specifications.

10 suppliers purchased bidding documents and 3 submitted proposals. The study team examined key items of the proposals in terms of compliance with JICA specifications and analyzed their technical capabilities.

(1) PV module specifications

As pointed out earlier, the PV module with rated output of 60Wp (as specified by the manufacturer) must be selected to ensure that the output capacity meets the specifications.

Appendix Table 8.1-2

Contractor	Major specifications for Si-based PV module	Evaluation results
A	NAPS K44/62.7Wp at 25℃	To warrant 50Wp at 55℃
B	Shell Solar RMS60/58Wp at 25℃	To warrant 50Wp at 55℃
C	SIEMENS SM55/55Wp at 25℃	Less than 50Wp at 55℃/technical capability questionable

Contractor A and B have selected the module specifications that meet the installation conditions, indicating that they understand basic requirements for the PC module specifications. Thus they have the technical capability in this aspect. On the other hand, contractor C has selected the module specifications that do not meet the 55℃ requirement and its technical capability is questionable.

JICA specifications encouraged the supplier to search and propose partial use of an amorphous silicon-based PV module, which output does not decline substantially at a high surface temperature and which is even expected to show an increase in total output due to thermal recovery (annealing effect), on the condition that 90% output warranty is provided. It is designed to check the ability of local suppliers to obtain latest technical information.

Appendix Table 8.1-3

Contractor	Major specifications for amorphous Si-based PV module	Evaluation results
A	Responded that no product meets the specifications.	————
B	KANEKA PLE50/50Wp at 25℃	With 10-year output warranty
C	No proposal/information	————

Only supplier B proposed the amorphous Si-based PV module. While it is difficult to evaluate technical capabilities of all suppliers in the country from the small sample (3 suppliers who submitted proposals), the result suggests that further efforts should be made in the area of information gathering and technology implementation.

Performance of amorphous Si-based PV modules, which were installed in BCS together with Si-based PV modules, was checked during the initial inspection. The former showed a higher output (308W against the total rated output of 500Wp) than the latter (266W vs. 600Wp). Thus the amorphous Si-based PV module showed the higher output despite the lower rated output. It should be noted, however, that the amorphous Si PV module may experience an output drop of around 10% during the first few months, and continuous monitoring will be required to verify the advantage of the amorphous Si PV module in the country.

(2) Battery's charge/discharge life and other specifications

Technical specifications related to battery, as proposed by the three suppliers, are summarized as follows.

Appendix Table 8.1-4

	JICA specifications	Supplier A	Suppler B	Supplier C
1	Charge/discharge cycle 1200cycle or more at depth of discharge (DOO) 15%	1500cyc at 15% DOD	1200cyc at 15% DOD	No response
2	Maximum allowable depth of discharge 50% or higher	Best suited for DOD≦50%	≧50% applicable	No response
3	Self-discharge/month (25℃) 4% or less	About 3%	≦ 4% applicable	No response

Contractor A and B proposed appropriate specifications to indicate that they understand JICA specifications. On the other hand, supplier C did not state a detailed specification and does not seem to have enough knowledge on battery technology.

(3) Prepaid system specifications

JICA specifications set forth basic requirements for the prepaid system, as follows:

- A 30-day prepaid card system (card reader type)
- Issuance and use of prepaid cards according to the SHS size
- Indication of operating status, the number of days remained, and failure

Suppliers were asked to propose detailed specifications.
Equipment proposed by the suppliers is as follows.

Appendix Table 8.1-5

Contractor	Major specifications for the prepaid system	Evaluation
A	Shell Solar Power House	The system is field proven as it is widely used in the country. However, the basic system configuration is up to 100Wp, and modification is required for 150Wp or larger systems.
B		
C	SIEMENS MCS-PPM	No information on actual use is mentioned in the proposal and field performance needs to be checked. However, reliability seems to be warranted as the product itself is supplied by a world-class manufacturer and manuals and other documentation are attached.

The fact that contractor A and B proposed the same product indicates that the prepaid system (card reader type) available in the country is limited in variety. In fact, the scratch card system (password type) is more reliable than the card reader type because it has no risk of failure (card reader) or data loss. However, it requires data communication to which the villages do not have access, and the card reader system has been selected as the alternative solution. It is therefore important to improve reliability of the card reader system by monitoring and analyzing technical problems that occur during the Dissemination Project, including the type and frequency.

Note that BPC has adopted the scratch card system for customers in rural villages and it is desirable to use it for the Dissemination Project if data communication access can be secured.

8.1.3 Consideration of System Installation Work for Quality Assurance

In the previous PV electrification project, the following problems occurred in regards to system installation and related work:

- Incorrect orientation and installation angle
- Poor cable connection
- Roof damage due to system installation work

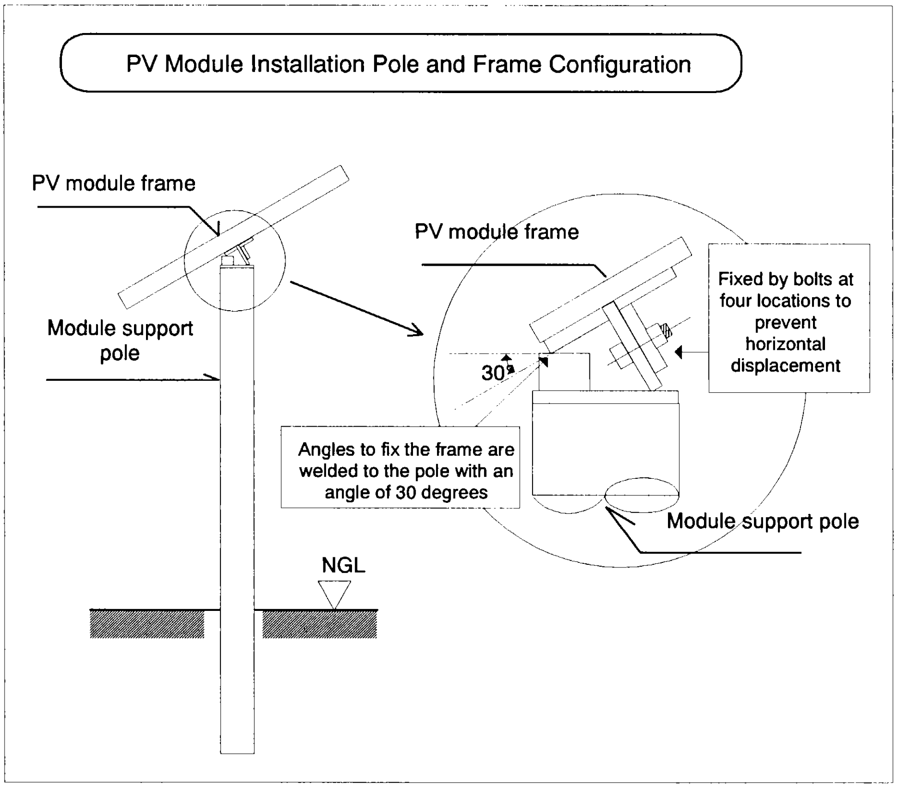
To address these issues and maintain good workmanship, it is recommended to adopt the following construction methods.

(1) Erection of a PV module installation pole

Generally, the SHS is installed on the rooftop in order to minimize the installation cost. However, as houses in the villages have roofs with varying orientations and slopes, proper installation of the system is dependent upon skills of field workers and is difficult to control. To minimize quality variation, the Dissemination Project will erect a pole to install a PV module, as described below.

The installation structure consists of a PV module frame and a pole to support the frame. It is prefabricated to allow the frame to be fixed to the end of the pole at 30 degrees. This way, the installation angle can be assured and field workers can concentrate on orientation of the frame, thus ensuring uniform quality of installation.

At the same time, there is no risk of damaging the roof during the installation work. It is therefore recommended to the pole installation method in consideration of quality assurance, which should more than compensate for cost advantage.

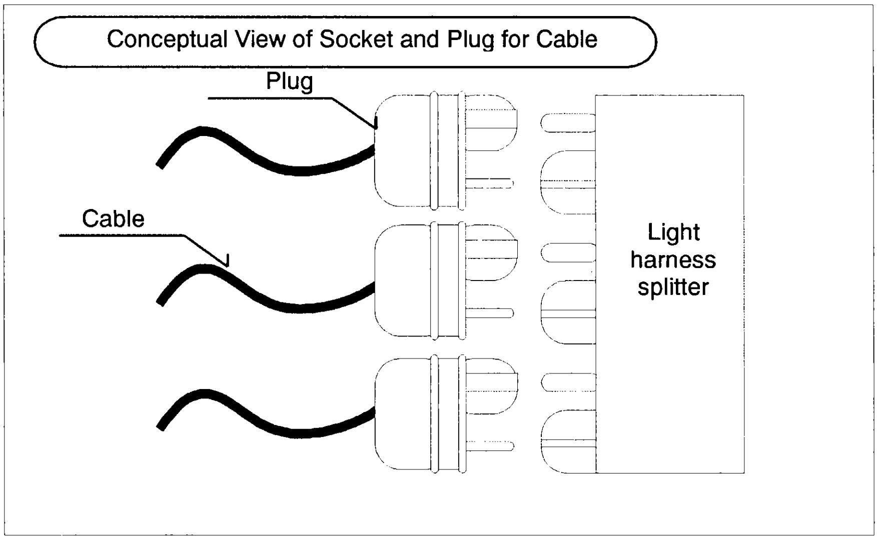


PV Module Installation Pole and Frame Configuration

(2) Secured cable connection

The problem of poor cable connection is addressed by minimizing field cabling work. Cables are connected to sockets and plugs at factory, and field workers are required to plug them in for system installation.

To improve quality of field work, the improvement of work environment is essential but is difficult to do in rural villages. It is therefore recommended to the prefabrication system as an effective means to ensure better and uniform cabling quality. The socket and plug used in the system are shown below.



8.2 Environment and Health Protection

8.2.1 Environmental Benefits of Solar Home Systems

In addition to the role for SHSs in climate change mitigation in CO_2 displacement, decentralized photovoltaic systems offer many environmental advantages relative to the energy sources they commonly replace in rural homes (such as kerosene lamps, dry cell batteries, and car batteries charged from a grid or generator).

Replacing kerosene lamps with solar-powered lights mitigates the risks and health problems associated with storing and using kerosene. In surveys conducted by India's Tata Energy Research Institute, people reported eye irritation, coughing, and nasal problems associated with the use of kerosene lamps. In addition to emitting pollutants with known respiratory impacts (such as carbon monoxide, nitrogen oxide, and hydrocarbons), kerosene lamps are a fire hazard. Furthermore, a substantial number of children reportedly die of accidental kerosene poisoning every year.

Solar electric systems often displace dry cell batteries that are used to power radios, cassette players, and flashlights. Since rural areas generally lack programs for solid waste management, the incineration or disposal of used dry cells in open dumps or as litter can contaminate soil and water sources with toxins, including mercury.

Not only are PVs environmentally superior to kerosene and dry cells, they also have advantages over other electricity supply options. PV modules generate electricity without emitting local air pollution or acid rain precursor gases, water pollution, or noise. The modules are typically roof-mounted or require very little ground space, so

PV-based rural electrification also avoids the disruptive land use impacts associated with power lines and some methods of electricity generation (such as large-scale hydropower).

Since stand-alone PV systems provide electricity without power lines, their use in protected forest areas and buffer zones can be particularly valuable for ecosystem preservation. Power-line corridors can open access for the development of forested areas, change the diversity of species within ecosystems, and cause ecosystem fragmentation. Furthermore, power-line construction and maintenance activities themselves can be quite disruptive.

In many developing countries, migration from rural to urban areas is creating tremendous social and ecological problems. People move to the city for jobs and to gain access to electricity and other modern amenities. But urban infrastructure often has not kept pace with population growth. While it is unlikely that electricity alone will stem the tide of rural to urban migration, it is possible that solar electrification in rural areas can help by improving the quality of life there.

8.2.2 Negative Environmental Impact

A negative environmental impact from SHS dissemination can result from the improper disposal of lead-acid batteries. While careful recycling of lead-acid batteries is the best way to prevent this, current recycling practices vary substantially by country. As SHSs become widespread, it will be important to encourage well-managed battery recycling programs.

Lead is a naturally occurring metal which finds its way into the environment in a variety of ways. It can enter the environment as a result of natural processes such as weathering of the earth's surface, or volcanic activity. It also enters the environment as a result of human activities such as the deterioration of lead based paint, burning of leaded gas in vehicles, industrial emissions, and the disposal of various wastes.

Lead enters our bodies in the form of fine particles which are swallowed or inhaled. Young children are the most vulnerable as they tend to suck their fingers or objects which may be contaminated with dust containing lead particles. Young children absorb up to 50% of the lead that they ingest, as opposed to adult absorption of 10-15% of ingested lead. Lead exposure in pregnant women can cause premature birth, low birth weight or even abortion. Lead exposure in young children has been shown to result in decreased IQ's, slower growth rates, reading disorders, psychological disturbances, and hearing problems. Exposure to high levels of lead results in severe brain and kidney damage in both adults and children.

The average lead acid battery is comprised of 17% metallic lead, 50% lead sulfate/oxide, 24% acid, 5% plastic and 4% residual. The components in lead-acid batteries can be used to make new lead-acid batteries, cable coverings and other products. Even the plastic casing can be recycled. About 60 percent of lead used in manufacturing lead-acid batteries is derived from recycled lead.

The majority of used lead acid batteries are recycled. However, many batteries are still discarded improperly resulting in potential problems such as vaporization of lead particles from the burning of batteries, and the leaching of lead and sulfuric acid from solid waste landfills.

8.2.3 Recycling Required by Environmental Law

(1) Recycling

Most countries in the industrialized world are becoming more environmentally conscious. This is reflected in tough environmental protection legislation which has been introduced in many jurisdictions. Generally these laws are concerned with protecting the environment from harm through the use or transportation of hazardous substances. Lead usually tops the list of substances classified as hazardous in environmental legislation. It is undisputed that handling and disposal of used lead acid batteries pose risks to the environment.

Failure to comply with environmental laws can result in onerous financial penalties, and even imprisonment. Some jurisdictions give corporate tax incentives for environmental responsibility.

Requirements by such law are exampled as follows:

a) Certain disposal prohibited: No person may place a used lead acid battery in mixed municipal solid waste, discard or otherwise dispose of a lead acid battery except by delivery to an automotive battery retailer or wholesaler, to a secondary lead smelter permitted by the Environmental Protection Agency, or a collection or recycling facility authorized under the laws.

b) Disposal by dealers: No automotive battery retailer shall dispose of a used lead acid battery except by delivery to a secondary lead smelter permitted by the Environmental Protection Agency, or to a collection or recycling facility authorized under the laws, or to the agent of a battery manufacturer or wholesaler for delivery to a secondary lead smelter permitted by the Environmental Protection Agency, or a collection or recycling facility authorized under the laws.

c) Collection for recycling: Any person selling or offering for sale at retail lead acid batteries shall:
   1. Accept, at the point of transfer, in a quantity at least equal to the number purchased, used lead acid batteries from customers in exchange for new batteries purchased.
   2. Post written notice which must be properly sized and must contain the universal recycling symbol and the following language:
      i. "It is illegal to discard a motor vehicle or other lead acid battery."
      ii. "Recycle your used batteries."
      iii. "Law requires us to accept used motor vehicle or other lead acid batteries for recycling, in exchange for new batteries purchased."

d) Lead acid battery wholesalers: Any person selling new lead acid batteries at wholesale shall accept, at the point of transfer, used lead acid batteries from customers in a quantity at least equal to the number purchased. A person accepting batteries in transfer from a battery retailer shall be allowed a period not to exceed 90 days to remove batteries from the retail point of collection.

e) Inspection of battery retailers: The Department shall produce, print and distribute the notices required by subsection (c) to all places where lead acid batteries are offered for sale at retail. The Department may inspect any place, building or premises governed by this act. Authorized employees of the Department may issue warnings and citations to persons who fail to comply with the requirements of this section. Failure to post the required notice following warning shall subject a civil penalty of $25 per day, collectible by the Department.

(2) Storage

Used lead acid batteries must be stored properly to prevent contamination or injury from acid spillage or leakage. Indoor storage is recommended because it reduces risks from temperature extremes which cause batteries to crack and leak. An indoor storage facility has at least three walls and a roof permanently attached to a masonry or other floor. An acid-resistant coating, such as epoxy, may be applied to an asphalt or concrete floor to prevent corrosion from spillage. Acid-resistant curbing should be constructed around the storage area to contain any spills that escape the building. Curbs for small storage areas could be constructed of either asphalt or a simple wooden frame completely covered with a 20-40 mil sheet of acid-resistant polyethylene, polypropylene, or polyvinyl chloride.

Batteries should be placed upright on pallets, stacked no more than five high, and inspected regularly. Cracked or leaking batteries may be placed singly in sealable 5 gallon polypropylene pails or other containers that are sturdy, acid-resistant, leak-proof and sealable, and kept closed within the storage area.

Any spilled acid must be handled as a hazardous waste because it is corrosive and may contain toxic levels of lead. Report any spills that escape the storage area to your regional office.

8.3 Results of Technical Monitoring of Dissemination Project

In order to monitor the operation of PV systems installed in Dissemination Project, the data-loggers were installed in the following 3 locations:

1) Battery Charging Station (Lorolwana)
   * Multi-crystal Module (Shell)
   * Amorphous Module (Kaneka)
2) 50Wp SHS System (Lorolwana)
3) 200Wp SHS System (Kudumatse)

Measurement items are Irradiance, Output of Array (Voltage, Current), Output of Battery (Voltage, Current), Load Voltage and Temperature of Array.

Concerning BCS, in addition to the above data acquisition system, Output of Array (Vo Hage, Current), the number of batteries on charge in the morning time (8:00), the noontime (13:00) and the evening time (17:00) has been monitored by the BCS operator, The BCS operator also has recorded when the BCS user brought the battery for recharging..

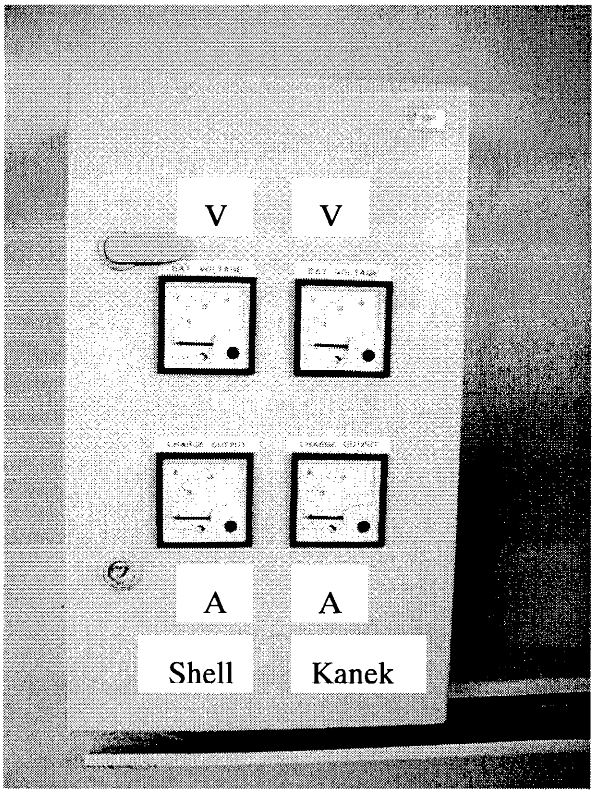
Monitoring results are shown as follows:

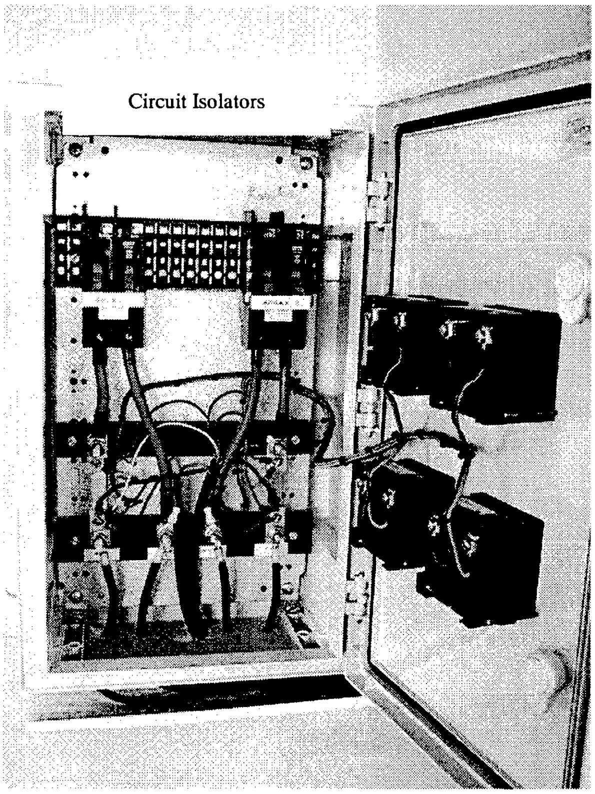
8.3.1 Battery Charging Station (BCS)

(1) Electrical Layout

1) Solar Array

The Solar Battery Charging Station consists of ten 60Wp Shell Solar panels and ten 50Wp Kaneka panels. The Shell and Kaneka panels are wired in two independent arrays (all panels wired in parallel) and charge the Solar Battery Boxes through a terminating, isolating and metering box (see schematic diagram in Attachment 4). As the name suggests, in this box the connecting terminals, circuit isolators and meters are located. Per array there is a voltmeter and ammeter to be able to monitor the arrays individually. V1 and A1 measure Shell panels voltage and current respectively, whereas V2 and A2 measure Kaneka panels voltage and current.





2) Charging Station

The Charging Station consists of 42 individual boxes that incorporate a circuit isolator, a 5A electronic current limiting circuit, a voltage regulator and a red

LED indicator. The current limiting circuit limits the charging current of individual batteries to 5A in case few batteries are on charge. The LED indicates if power is available from the solar arrays (LED on: power is available). The boxes are alternately wired to the Shell Solar panels and Kaneka panels. This result in approximately equal loading of the individual arrays when the Solar Battery boxes are connected one after the other.

3) Autonomous AC system

To provide lighting for the Solar Battery Charging Station and power for socket outlets, one Kaneka panel is electrically separated from the rest of the Kaneka array. This panel charges two Deltec 102Ah batteries through a controller. A 300W TES inverter is connected to a distribution board to power two AC lights and two double sockets.

(2) Performance Monitoring and Analysis

1) Performance monitoring

The performance of the battery charging station is monitored in two different ways:

1. Filling in an operator logbook
2. Using a data acquisition system (Data logger)

This report shows the results of the analysis using the data from the above both ways.

2) Performance analysis through the data in the operator logbook

During three different times over a day (8:00 AM, 13:00 PM and 17:00 PM) the number of batteries that are on charge, voltages and currents are noted in the operator logbook by the operator.

The data from the operator logbook has been entered in an Excel spreadsheet for further analysis (see Attachment 1 and 2). Some entries are missing but this has only minor effect on the analysis. Records of the functioning of the Battery Charging Station (BCS) have been taken since 15 February 2002. However, it appears that the BCS went into operation after 4 March 2002 since before this date few batteries have been charged. Analysis has been carried out in the following two period.

* From 5 March to 17 April 2002
* From 18 April to 2 July 2002

The following analyses have been made:

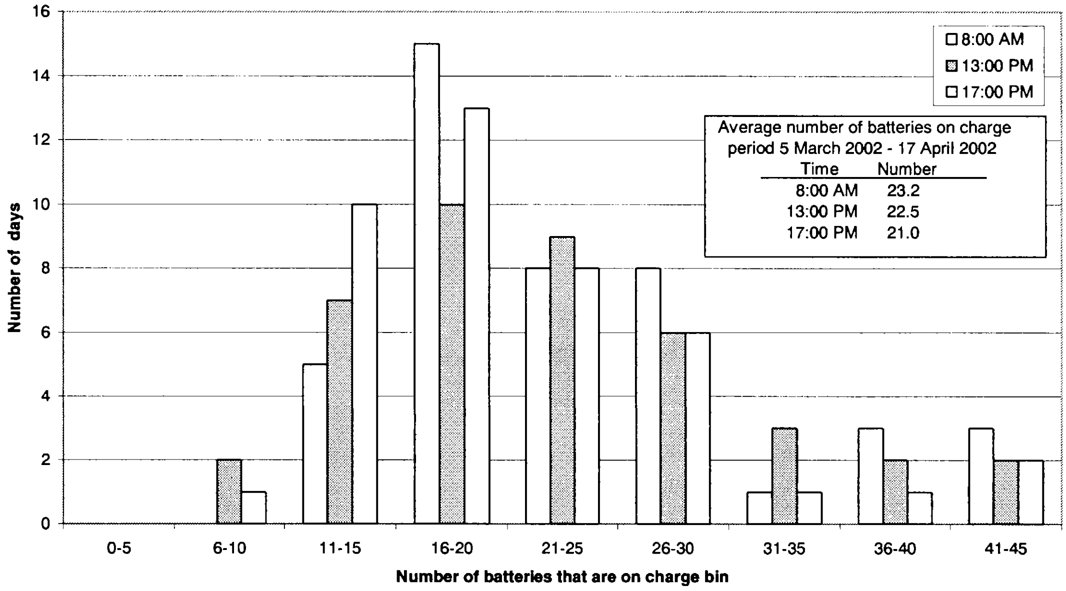
1. Number of batteries on charge,
2. The voltage output of the panels,
3. The current output of the panels.

The findings of the analyses are discussed below.

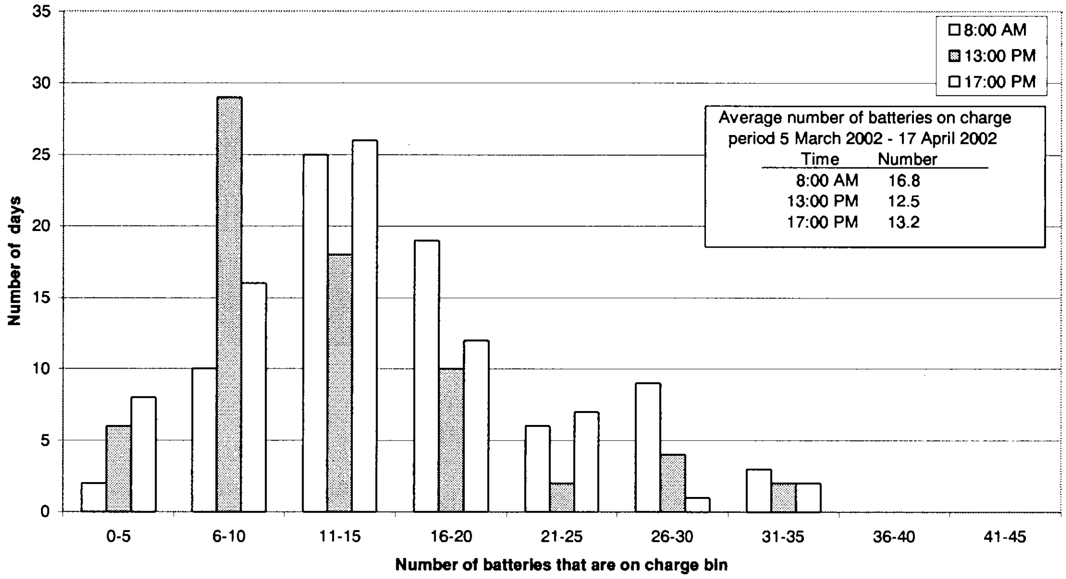
Number of batteries on charge

A histogram has been made indicating how many days during two periods a certain number of batteries have been on charge, at three different times of the day. The results are given in Appendix Figure 8.3-1 below.

Frequency Distribution of Number of Batteries on Charge
5 March 2002 - 17 April 2002



Frequency Distribution of Number of Batteries on Charge
18 April - 2 July 2002



Appendix Figure 8.3-1 Frequency Distribution of Number of Batteries on Charge

The maximum number of batteries that can be on charge at any given time is 42. From Appendix Figure 8.3-1 it can be concluded that there have been only 2 days during the time period between 5 March and 17 April that the BCS operated at full capacity. Most of the days the BCS operates at half or less of its maximum capacity. This indicates that most users use their batteries at least a number of days before they bring the batteries for recharge and also that the batteries are recharged quickly.

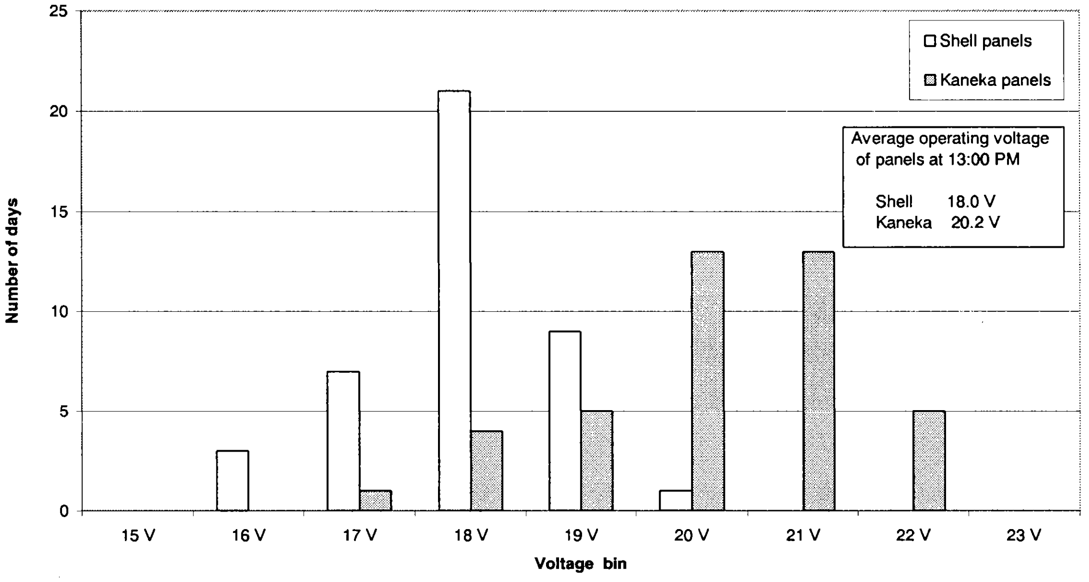
Voltage output of the solar panels

The voltage at which an array of solar panels is operating depends on a number of factors, which include:

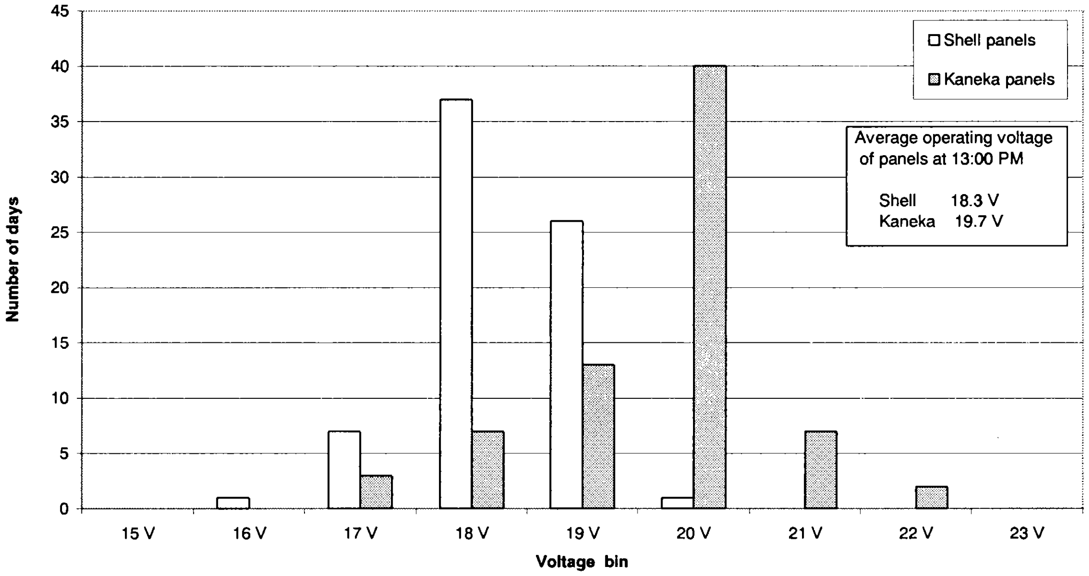
- materials used and design of the solar panel
- load connected to the solar panel
- level of irradiation to which the solar panel is exposed
- cell temperature of the solar panel

Appendix Figure 8.3-2 below gives an indication of the operating voltages of the Shell and Kaneka solar panel arrays at 13:00 PM.

Frequency Distribution of the Voltage of Panels at 13:00 PM
5 March 2002 - 17 April 2002



Frequency Distribution of the Voltage of Panels at 13:00 PM
18 April - 2 July 2002



Appendix Figure 8.3-2 Frequency distribution of the voltage output of the Shell and Kaneka panel arrays at 13:00 PM

From Appendix Figure 8.3-2 it can be concluded that most of the days the voltage output of the Shell array is about 18 V –19 V whereas the Kaneka array operates most of the days at 20 V – 21 V, which is approximately 12% higher. The average operating voltage of the Shell and Kaneka arrays under these conditions is 18.0 V and 20.2 V during the period between 5 March and 17 April 2002 and 18.3 V and 19.7 V during the period between 18 April and 2 July 2002 respectively. This confirms the results of the measurements that were carried out on individual panels, which gave an open voltage value of the Kaneka panels, which was substantially higher than the open voltage of the Shell panels under similar conditions.

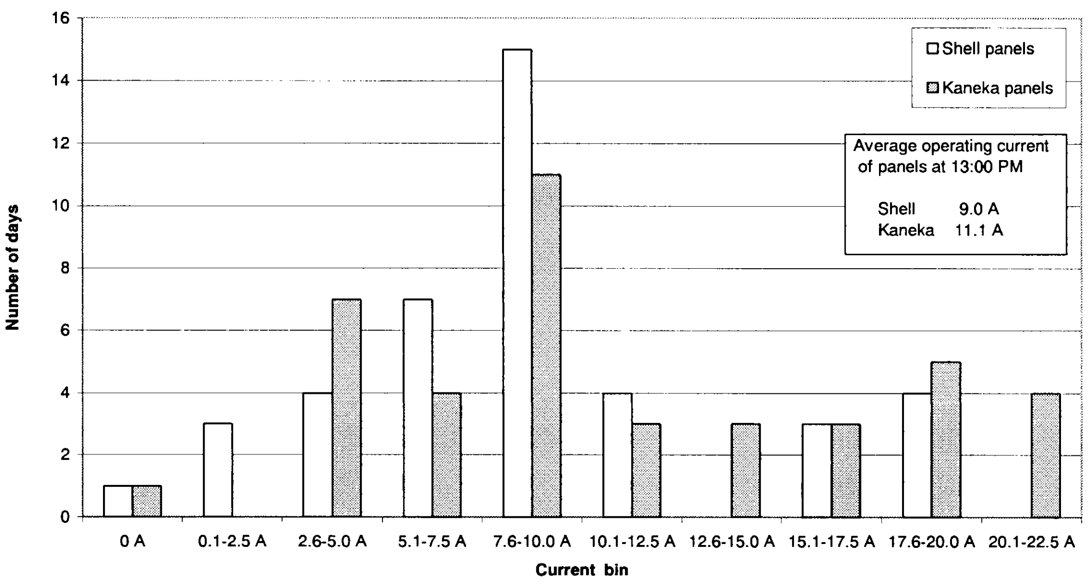
Current output of the solar panels

Like the voltage at which an array of panels operates, the current that is generated by an array of solar panels depends on a number of factors, which include:

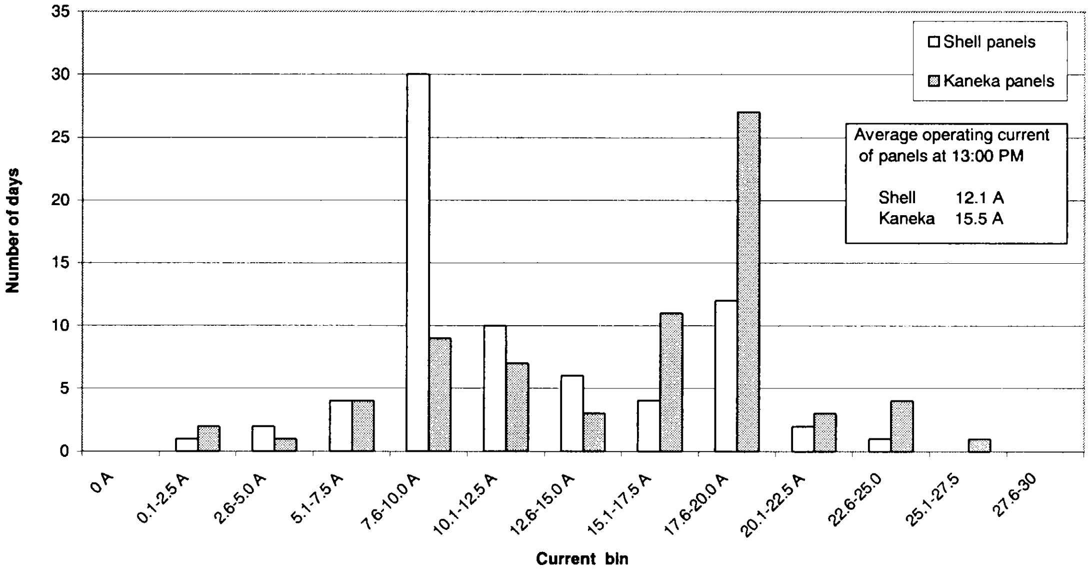
- materials used and design of the solar panel
- load connected to the solar panel
- level of irradiation to which the solar panel is exposed
- cell temperature of the solar panel

More than anything else, the current output depends on the power rating (Wp) of the solar panel.

Appendix Figure 8.3-3 below gives an indication of the current output of the Shell and Kaneka solar panel arrays at 13:00 PM.



Frequency Distribution of the Current of Panels at 13:00 PM
5 March 2002 - 17 April 2002



Frequency Distribution of the Current of Panels at 13:00 PM
18 April - 2 July 2002

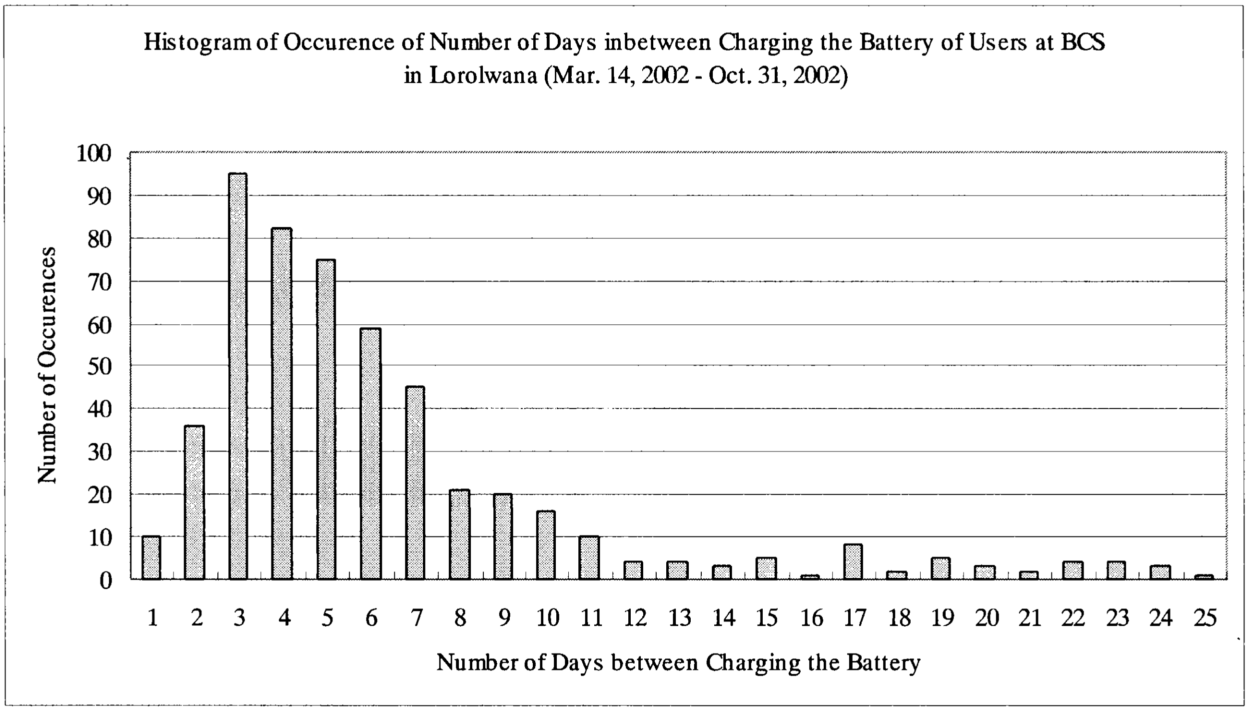
Appendix Figure 8.3-3 Frequency distribution of the current output of the Shell and Kaneka panel arrays at 13:00 PM

The average current outputs of the Shell and Kaneka arrays under these conditions are 9.0 A and 11.1 A during the period between 5 March and 17 April 2002 and 12.1 A and 15.5 A during the period between 18 April and 2 July 2002 respectively. This confirms the results of the measurements that were carried out on individual panels, which gave a short circuit current value of the Kaneka panels, which was substantially higher than that of the Shell panels, under similar conditions.

It should be noted that the Kaneka array consists of 9 solar panels with a nominal output of 50Wp (= 450Wp total array output), whereas the Shell array consists of 10 solar panels with a nominal output of 60Wp (= 600Wp total array output). In total 20 panels are installed but one of the Kaneka panels is used for powering the AC system of the BCS (see Appendix 4).

Number of Days in between Charging the Batteries

Appendix Figure 8.3-4 gives an indication of the number of days between charging the batteries at the BCS in Lorolwana, during the time period 14 March 2002 and 31 October 2002 (original data is shown in Attachment 3). Most users bring their batteries for charge within less than 10 days with a majority of users recharging there batteries within 3, 4 and 5 days. It should be noted that 5 out of the total number of 41 users, never bring their batteries for charging.



Appendix Figure 8.3-4 Histogram of Occurrences of Number of Days in Between Charging the Battery of Users at BCS in Lorolwana

3) Performance Analysis through the data acquisition system

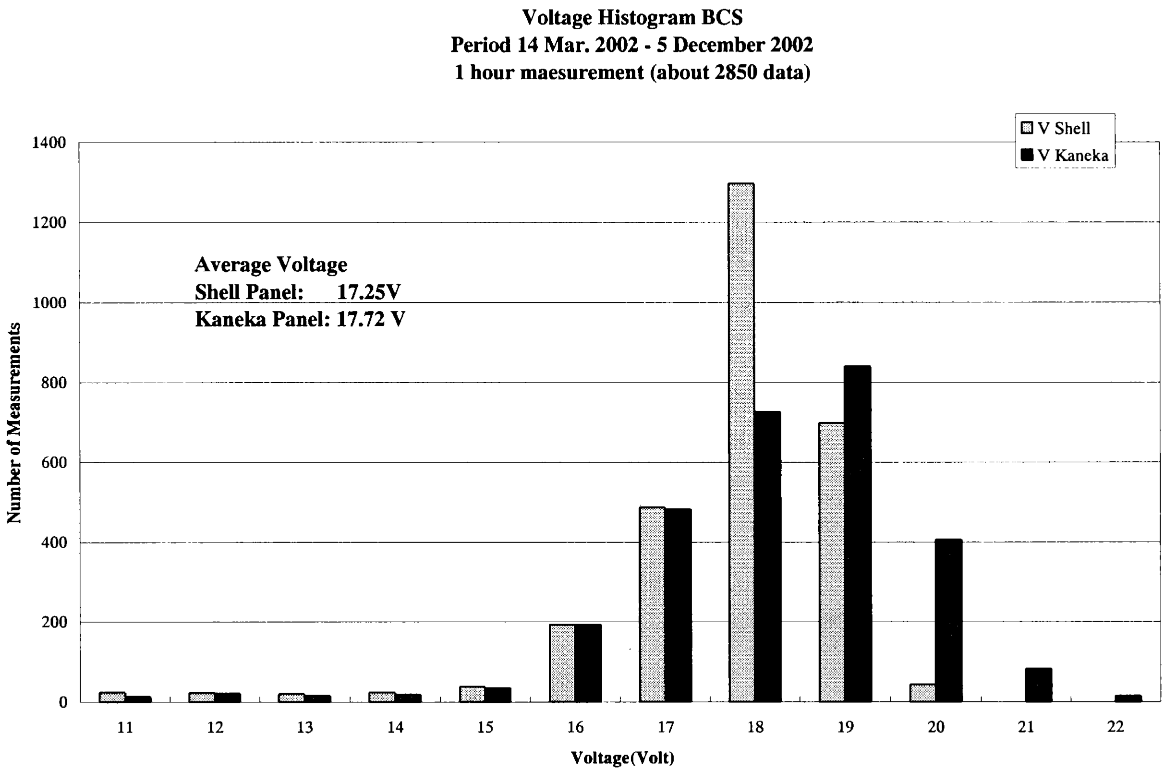
Data sampling using the data acquisition system has been done in the following period and manner.

Total 5,908 sampling data have been obtained in every one hour starting on 14 March and ending on 5 December, from which startical analyses for the voltage, current and power of the panel have been made.

Appendix Table 8.3-1 BCS Sampling Data

Data/Time		Duration (Days)	Sampling Interval (min)	No. of Sampling Data every one hour
From	To			
14/Mar 15:37	2/May 3:07	49	30	1,164
10/May 12:52	21/June 2:52	42	60	999
2/Jul 12:32	24/Jul 11:47	22	15	527
24/Jul 13:55	9/Oct 11:55	77	60	1,847
9/Oct 12:49	22/Oct 10:04	13	15	312
22/Oct 11:18	5/Dec 13:18	45	60	1,059
Total		248		5,908

Panel Voltage



Appendix Figure 8.3-5 Voltage Histogram BCS Period 14 March 2002 – 5 December 2002 1 hour measurement (about 2850 data)

Observations:

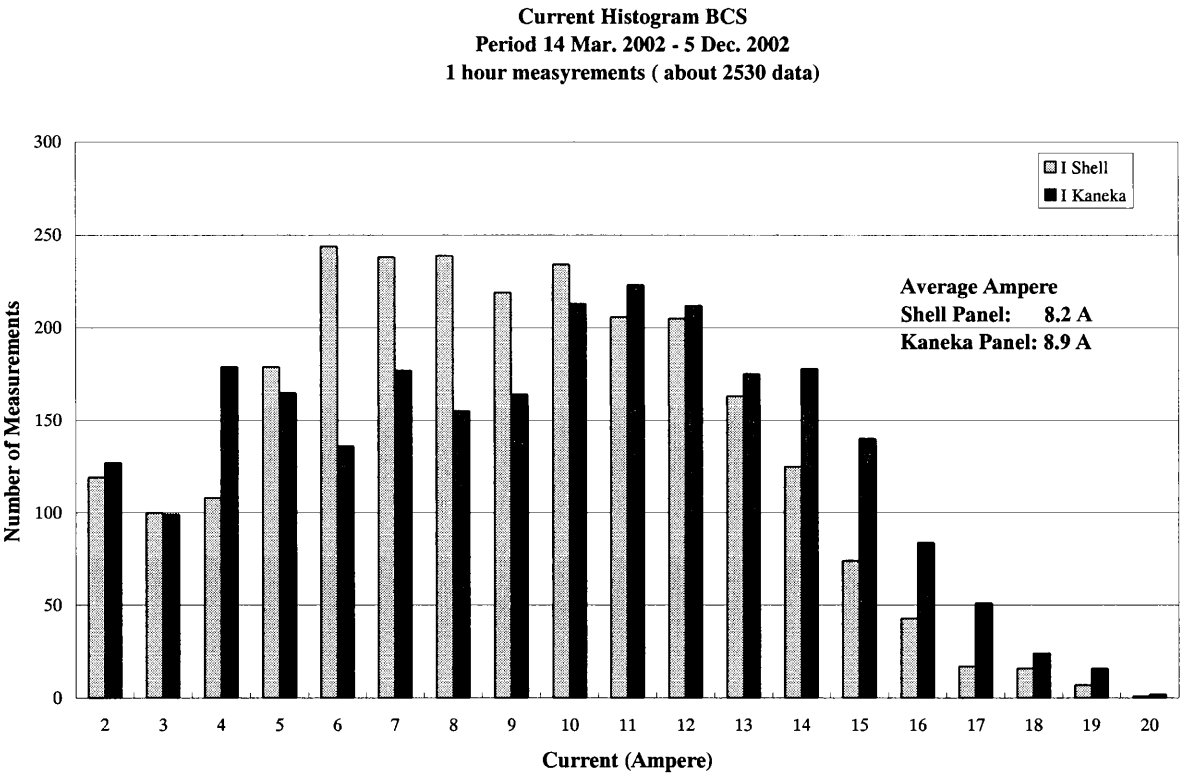
* The Kaneka array is generating higher average voltages than the Shell array.

* High voltages are measured in the load disconnect situation when batteries are fully charged or when no batteries are connected to the system.

* Most of the time high voltages are measured and therefor most of the time there is a load disconnect situation. This indicates that the system is under utilised.

* This confirms panel-testing results carried out at Solar International workshop measuring open circuit voltages.

Panel Current



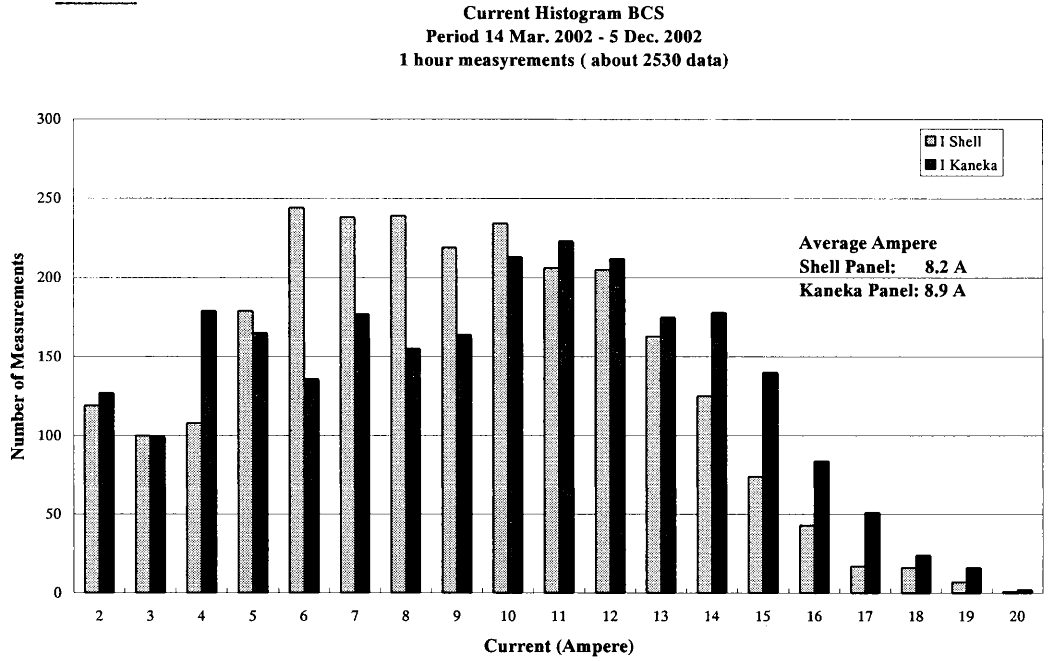
Appendix Figure 8.3-6 Current Histogram BCS
Period 14 March 2002 – 5 December 2002
1 hour measurements (about 2530 data)

Observations:

* The system is under-utilized since the Kaneka and Shell arrays are capable of generating over 30A and 40A respectively at noon when there is sufficient load.

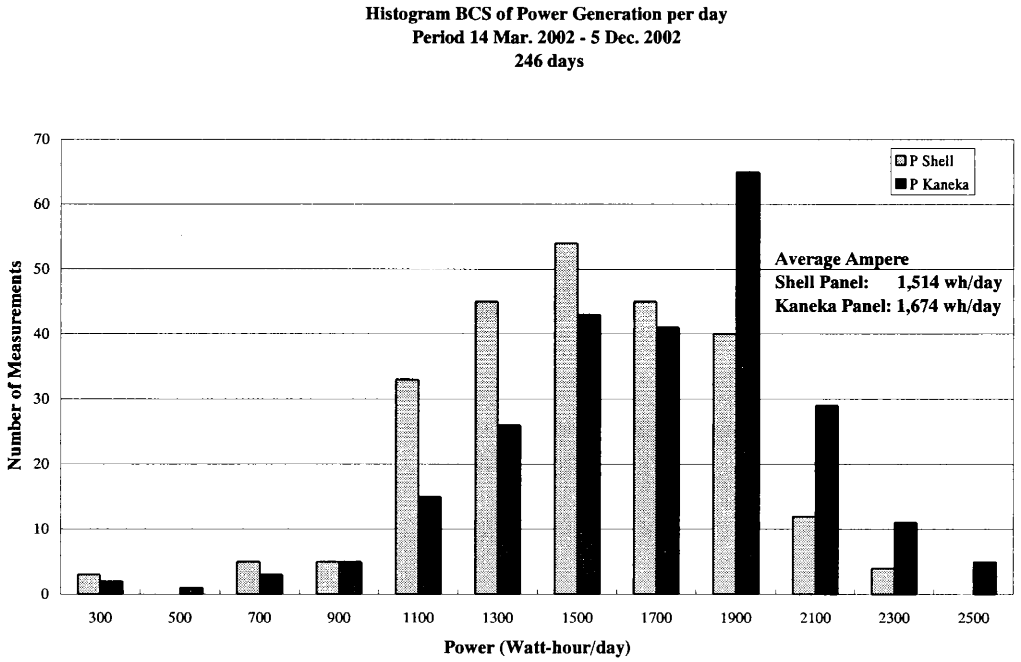
* During a larger time period higher currents are produced by the Kaneka array. This might be due to the fact that more batteries are connected to the Kaneka array at those particular times.

Power



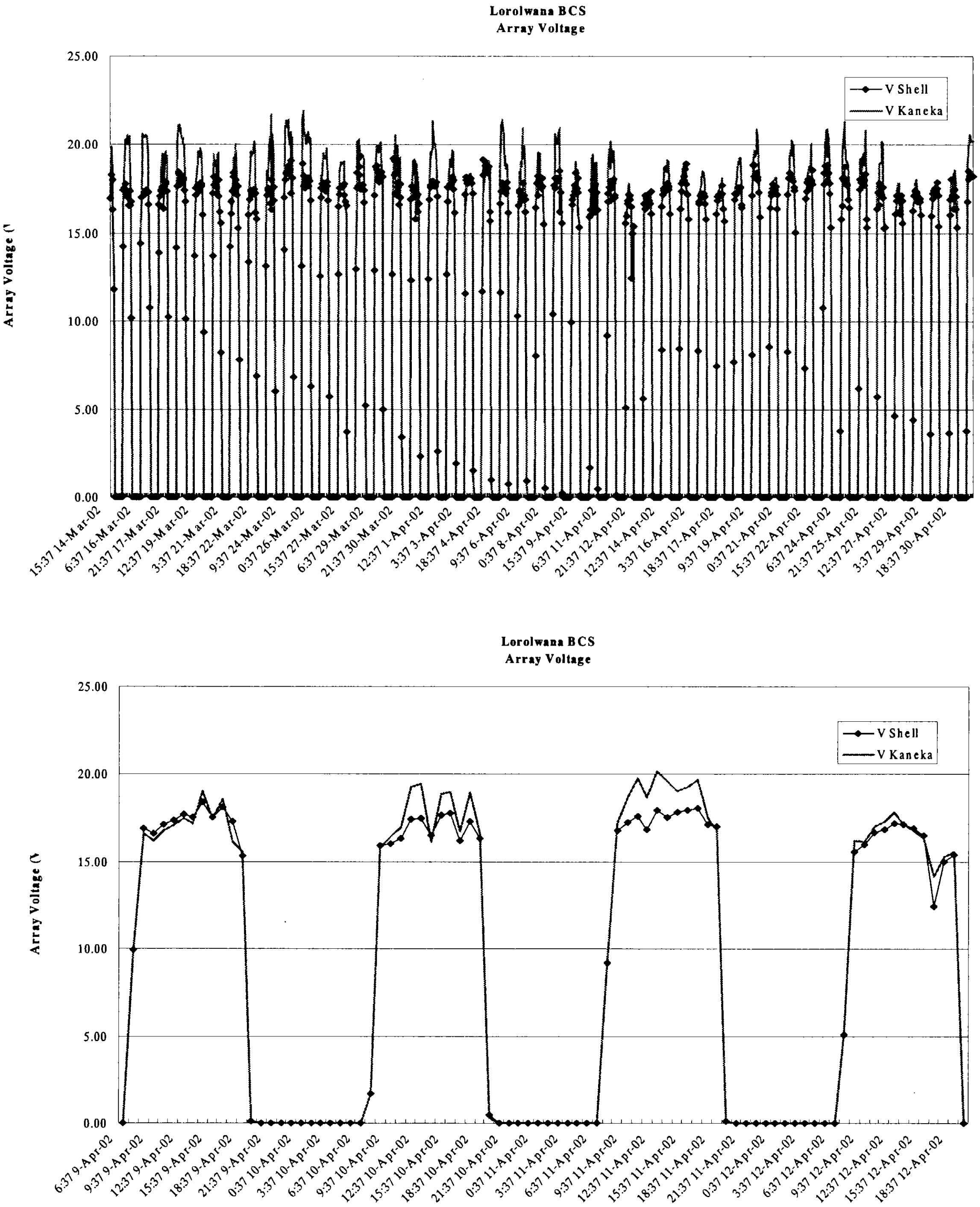
Appendix Figure 8.3-7 Current Histogram BCS
Period 14 March 2002 – 5 December 2002
1 hour measurements (about 2490 data)

Power Generation in a day



Appendix Figure 8.3-8 Histogram BCS of Power Generation per day
Period 14 March 2002 – 5 December 2002 246 days

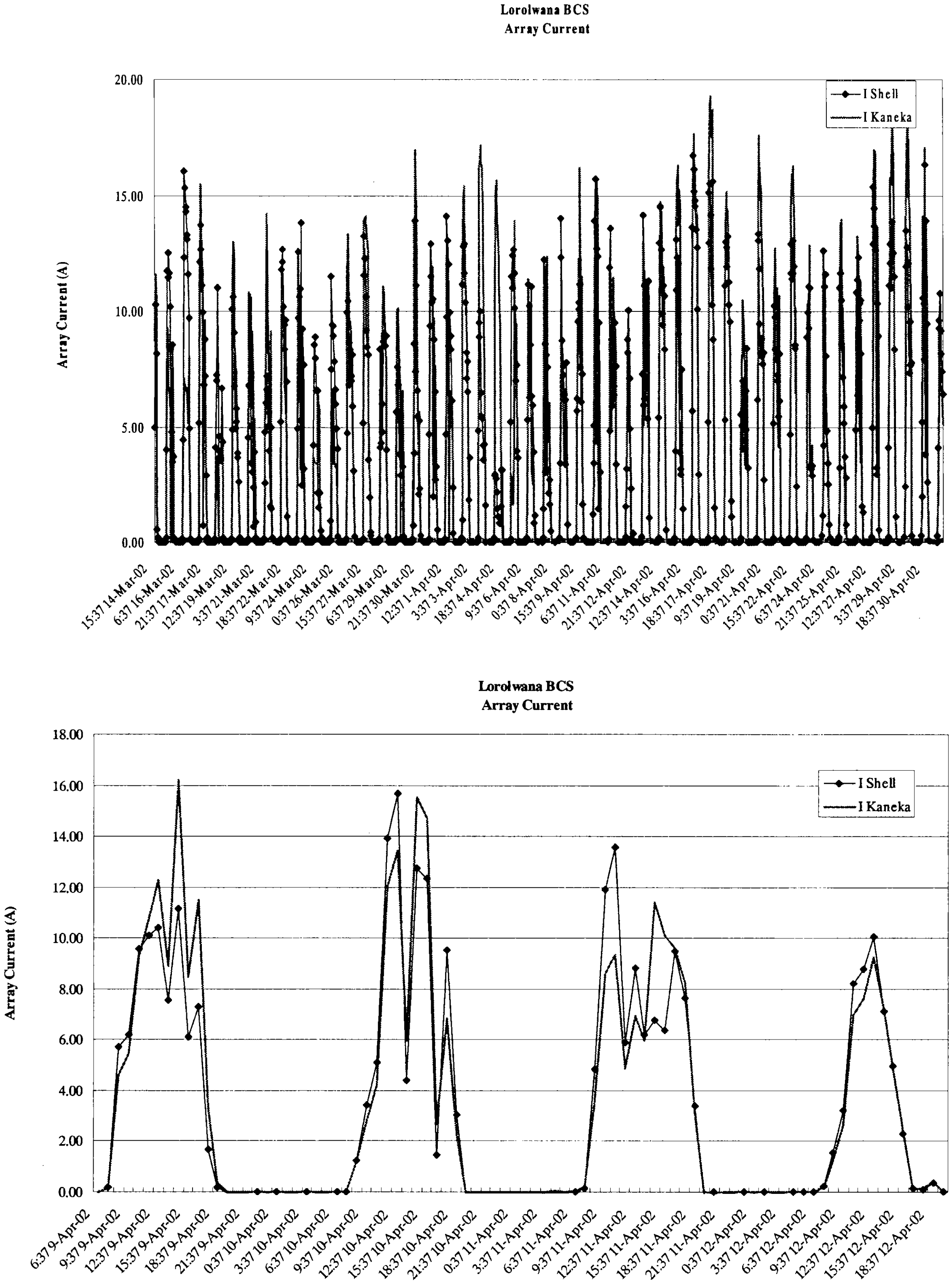
5) Typical Time Series Data



Appendix Figure 8.3-9 Lorolwana BCS Array Voltage

Observations:

- * Graph at the bottom is the middle part of the graph at the top.
- * Voltage output of Shell array is consistently lower than that of the Kaneka array.



Appendix Figure 8.3-10 Lorolwana BCS Array Current

Observation:

Two effect can be observed that take place simultaneously:

- connecting and disconnecting of batteries - change in level of irradiance.

4) Conclusions

Usage of the Battery Charging Station

- Taking into consideration the number of batteries that are on charge at any given time, it can be concluded that the power output of the solar arrays is more than sufficient for charging the batteries within a short time period.

Performance of the BCS

One should be cautious when drawing conclusions from the data and analysis presented here. The performance of a solar array depends - among other factors - on materials used and design of the solar panels, the load that is connected, the level of irradiation, dust built up on the surface of the panels and the cell temperature of the solar panels. For a correct comparison of the performance of the Shell and Kaneka arrays, all of these different factors should be equal for the two arrays and clearly, under field conditions they are not. Nevertheless, the data and analysis presented in this study suggest that the Kaneka panels outperform the Shell panels, particularly when taking into consideration that the nominal output of the Shell array is 25% higher than the nominal output of the Kaneka array (600Wp of the Shell panels compared to 450Wp of the Kaneka panels).

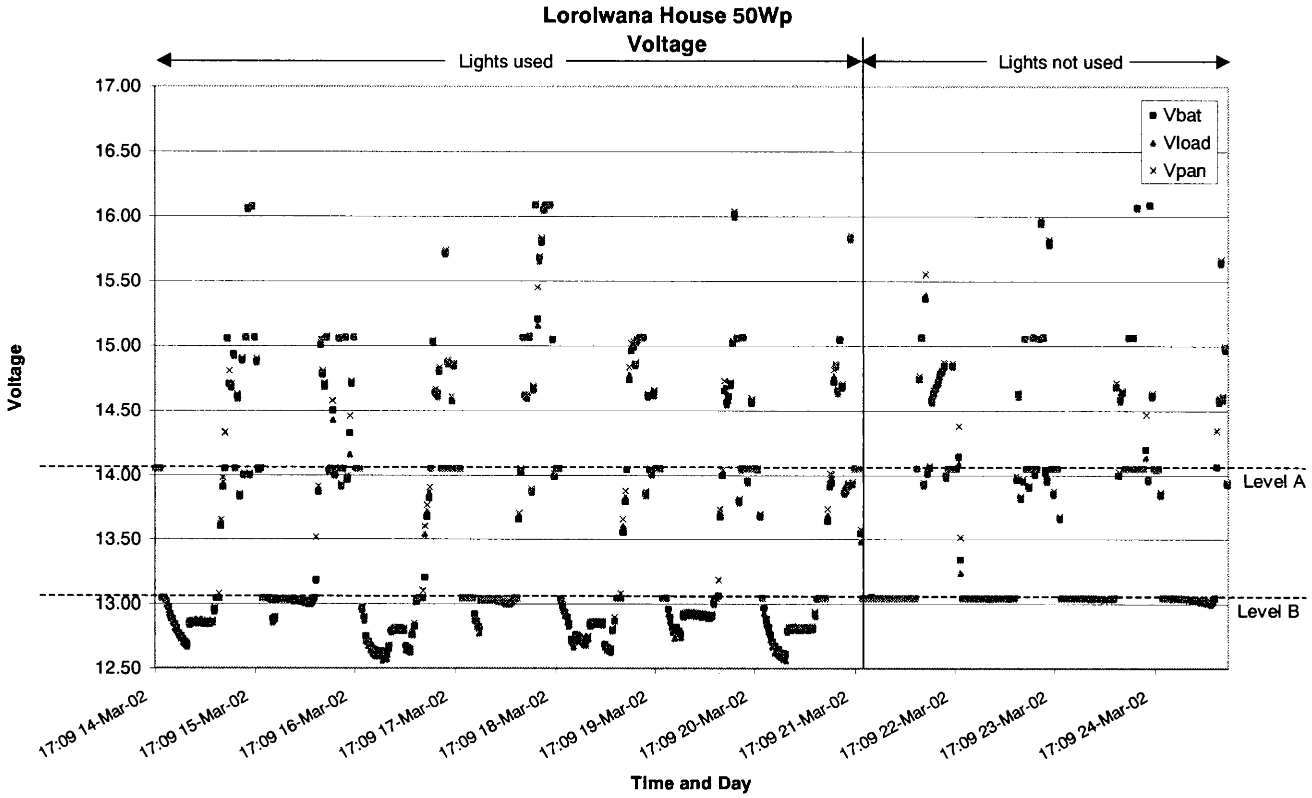
8.3.2 System 50Wp Lorolwana

Data sampling using the data acquisition system has been done in the following period and manner.

Typical time series data and comments on them are introduced in the following paragraph.

Appendix Table 8.3-2 System 50Wp Lorolwana Sampling Data

Data/Time		Duration (Days)	Sampling Interval (min)	No. of Sampling Data
From	To			
16 Feb 15:12	26 Feb 1:57	10	15	908
14 Mar 17:09	2 May 4:39	49	30	2,327
10 May 12:35	2 Jul 14:35	53	60	1,275
2 Jul 14:59	24 Jul 13:29	22	15	2,107
25 Jul 14:57	9 Oct 12:57	77	60	1,846
Total		211		8,463

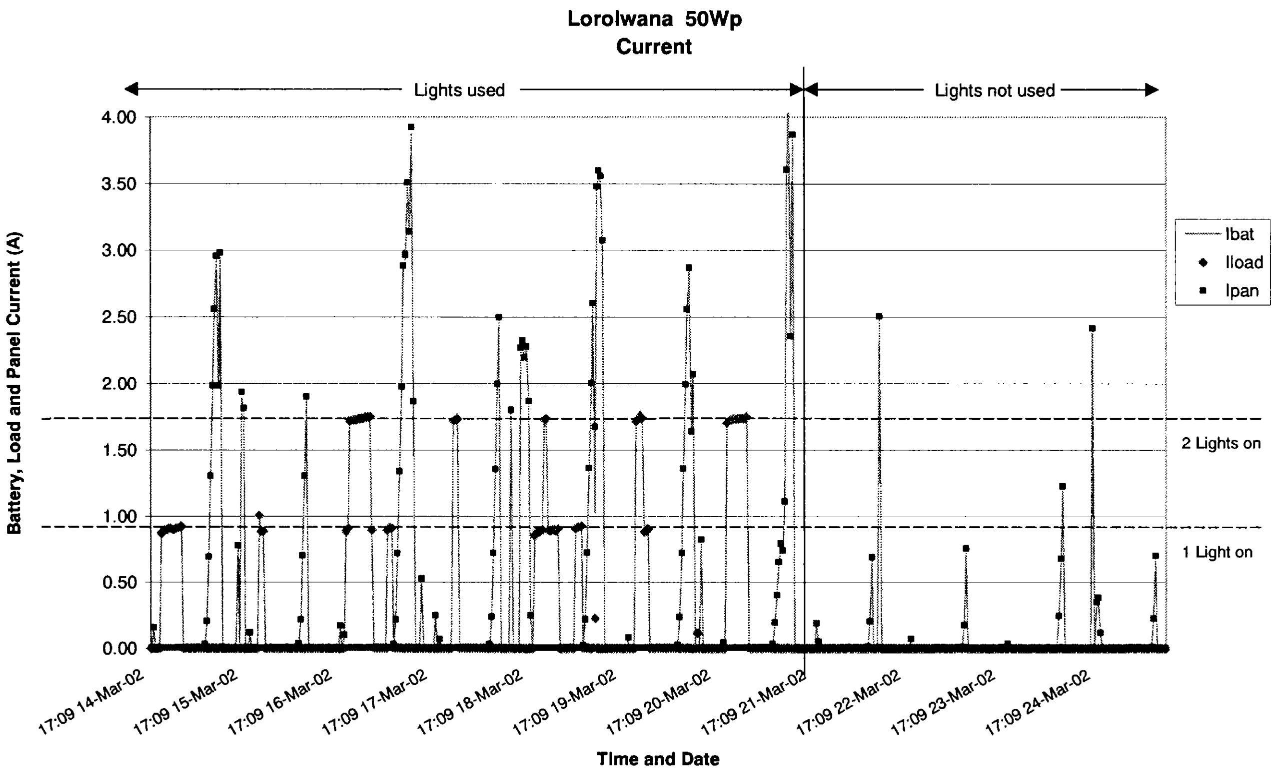


Appendix Figure 8.3-11 Lorolwana House 50Wp

The interpretation of the graph may be understood when taking into consideration the different charging modes of the Power House charge regulator (see Attachment 5).

Observations:

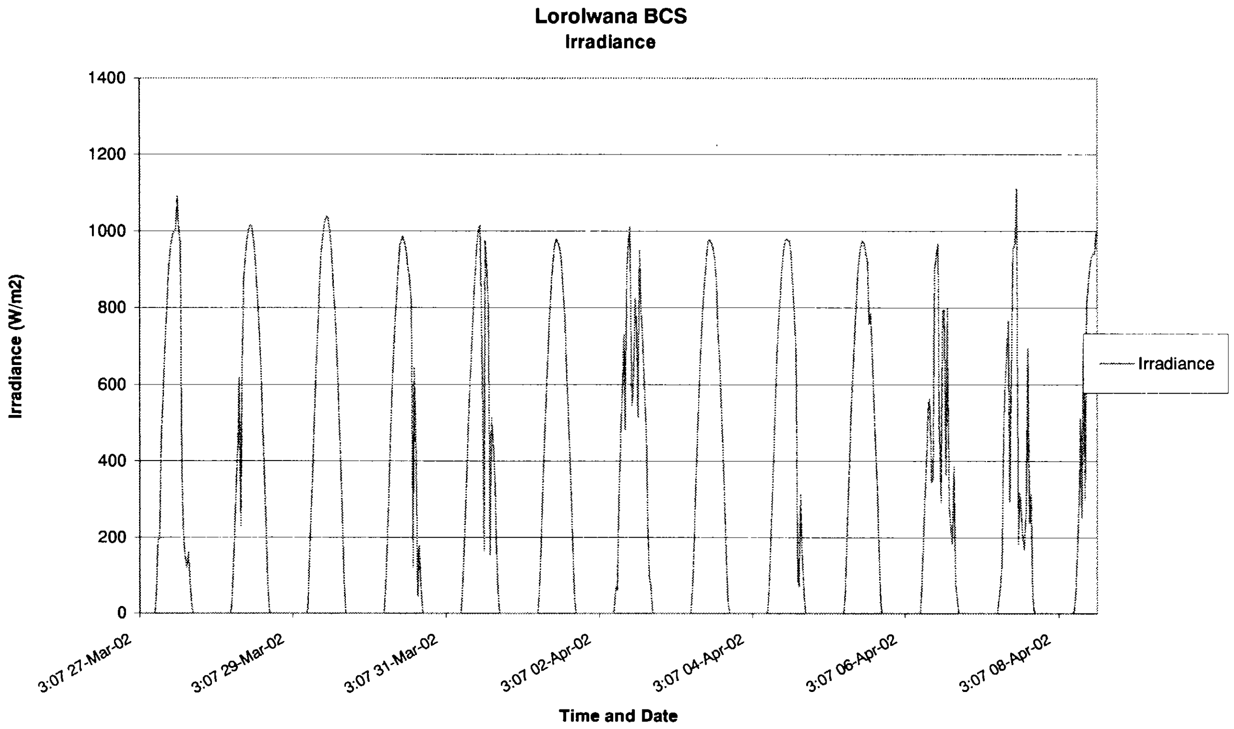
- Level A (see Appendix Figure 8.3-11) corresponds with the start of the absorb charge.
- Level B corresponds with the rest state of the battery when fully charged.
- Battery voltage drops to 12.5V when loads are connected during the evening.
- After 21 March 2002 the system was not used.



Appendix Figure 8.3-12 Lorolwana 50Wp

Observations:

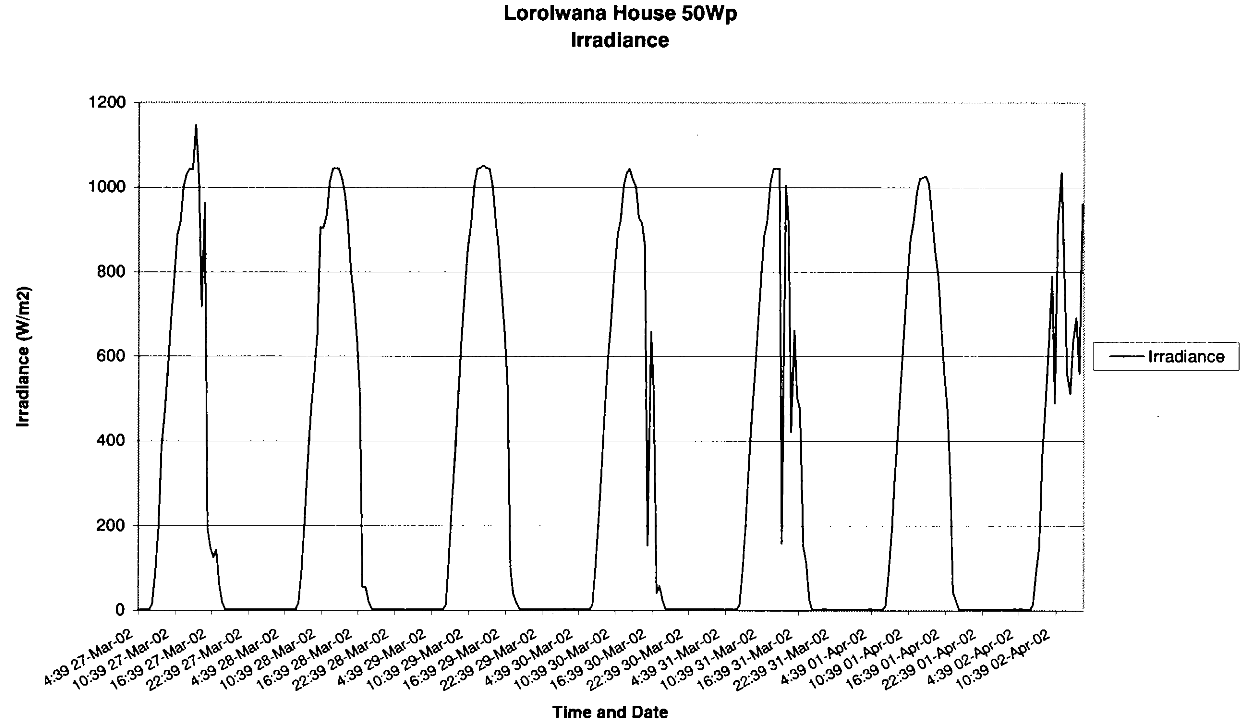
- * During daytime, battery current is equal to panel current.
- * During night-time, battery current is equal to load current.
- * It is very clear when 1 light or 2 lights are switched on.
- * Not continues charging due to pulse width modulation of the charger.
- * System is also charging due to programmed float charging of the regulator.



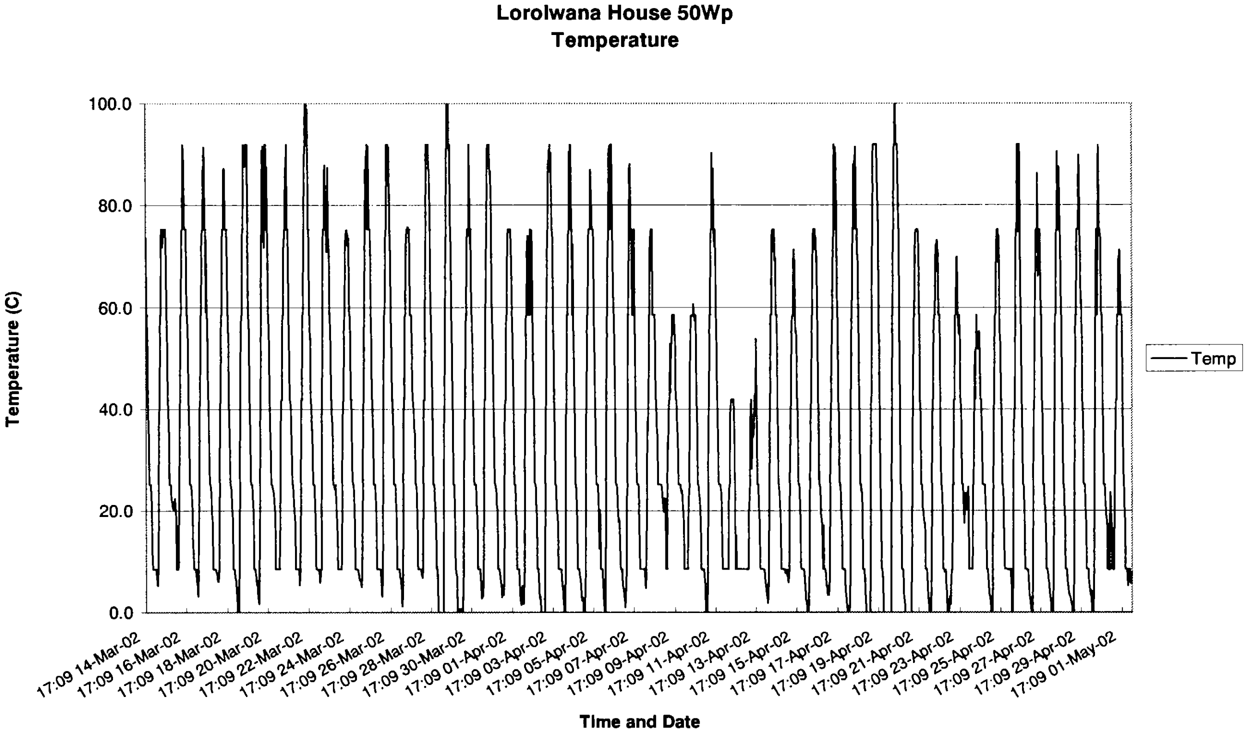
Appendix Figure 8.3-13 Lorolwana BCS

Observations:

- * Irradiance levels reach a maximum at noon
- * Variation between clear skies (e.g. 29 March 2002) and cloudy skies (e.g. 6 April 2002).



Appendix Figure 8.3-14 Lorolwana House 50Wp Irradiance



Appendix Figure 8.3-15 Lorolwana House 50Wp Temperature

Observations:

- Large fluctuations between day and night temperatures