PHOTOCELLS
for
VILLAGE WATER SYSTEMS

1987

PHYSICS DEPARTMENT

WATER RESOURCES CENTER
UNIVERSITY OF SAN CARLOS
CEBU CITY, PHILIPPINES

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ACKNOWLEDGMENT

The following study was made possible by the cooperation of several groups. Shell Philippines sponsored two installations and two years of observations. The United States Agency for International Development through the Bureau of Energy Development sponsored the third installation and its operation. The ideas originated for a substantial part from the Water Resources Center, while the Physics Department of the University of San Carlos provided the manpower to create a line in the mountain of figures.

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IMPORTANT REMARK ON ABSOLUTE VALUES

The solar data as reported may be wrong by up to 36%, because the accepted reference has been found to be 36% low 6 months after the last observations.

Thus irradiation figures as reported are low in

Table 5.1   Figure 5.1 to 5.2
5.2
5.3

The efficiency figures as reported are high in

Table 5.4
5.5
5.8
5.9

It is not known which correction factor must be applied. So all irradiation related figures are referred to the Haenni #1 sensor.

Only absolute values are affected, comparisons between figures in the study remain valid.

CALIBRATION OF THE SOLARIMETER

It is known that semiconductor sensors require a yearly recalibration in cases where accurate comparisons are made. In addition, Haenni in a formal communication of May 1986 indicates that some of the earlier Solar 118 meters "had given troubles in meeting the reference of the World Radiation Centre (Davos)". Later issues "are more accurately adjusted".

Against this background it was very fortunate that in the beginning of 1987 USC-WRC gained access to a

Kipp pyranometer CM11
which was calibrated in October 1986,
against standard CM11 800065,
with World Radiometric Reference,
to give 5.55×10^{-6} V per W/m^2,
of global radiation.

This sensor is mounted by means of 2 bolts with 1/8" diameter on a steel plate. The 3 levelling screws are the only other contacts with this base, so that the zero offset on hot days is expected to be negligible, it being appreciably below the -10 W/m^2 which may occur when the housing is in full contact with the base.

This sensor was connected to a

Modas 84 datalogger.

This logger guarantees a 0.4% resolution and has been calibrated in December 1986 at 28°C by means of an electronic voltage standard.

Its zero reads one count, equals 4.9 W m^{-2}, during 50% of the time. The amplification is correct, because the 5.55 mV corresponding with 1000 W/m^2 was essentially easier to materialize with the voltage standard than the zero.

The logger scans the sensor every two seconds and was arranged to integrate over 900 data points, 30 minutes. These 30-minutes data remain available in the permanent memory.

During the calibration run the Haenni sensor was placed on the same steel plate as the Kipp sensor. The body of the Haenni sensor is in contact with the steelplate over roughly 50.25 cm^2. This corresponds with the situation during the field observations where the sensor was placed on the flange of an aluminum angle bar of 5cm × 5 cm. No temperature measurements were made during the calibration run, but it is known that the temperature of the photocells on hot days run between 60 and 65°C. Thus it is accepted that during the calibration the sensor temperature was not more than 65°C.

The location is near ideal: the horizon is everywhere very close to 90° zenith angle. Exception is a 10° wide sector to the West where hills at more than 200 meters distance rise some 5° above the horizon.

The observations were made at 30 minutes intervals synchronously with the quarts-controlled Modas 84 clock.

The data are given in the table. At 6 occasions it was not possible for the observer to maintain the 30 minutes schedule. Longer intervals were then accepted.

A liner curve fit, $y = A + B x$, gives for 19 points

$B = 1.362$
$A = 0.004$
$r = 0.998$

The conclusion is that now

the Kipp readings are 36% higher than the Haenni,
the linear correlation is very good,
the Modas zero is one count too high, 4 W m^{-2}.

This correction has NOT been incorporated in the data of the field observation or their evaluation for the following reasons.

1. one may suppose a gradually increasing deviation from the ideal response due to aging of the sensor.

   It is no longer possible to reconstruct this development.

2. the hypothetical aging process is not visible as a trend of the irradiation data. The time series is short, but a 30% change could still be visible.

3. the aging process of the sensor may have been accelerated due to the particular mounting. The backplate of the sensor was connected to the flange of the angle bar by means of epoxy.

4. at the time of the reporting the voltage standard is not available to check the calibration of the integrator.

Comparison of Haenni #11 vs. Kipp #22

Date	Time	Haenni #11 x (kWh m^{-2})	Kipp #22 y (kWh m^{-2})
21 Feb 1987	8:40 - 9:10	0.24	0.294
	9:10 - 11:10	1.22	1.474
	11:10 - 11:40	0.16	0.512
	11:40 - 12:10	0.23	0.347
23 Feb 1987	12:10 - 9:10	6.0	8.213
	9:10 - 9:40	0.26	0.322
	9:40 - 10:10	0.24	0.392
	10:10 - 10:40	0.23	0.327
	10:40 - 11:10	0.34	0.464
	11:10 - 11:40	0.19	0.247
	11:40 - 2:10	0.66	0.891
	2:10 - 2:40	0.06	0.067
	3:40 - 3:10	0.05	0.052
	3:10 - 3:40	0.04	0.062
	3:40 - 4:10	0.04	0.047
24 Feb 1987	4:10 - 8:10	0.36	0.381
	8:10 - 9:10	0.33	0.479
	9:10 - 9:40	0.23	0.297
	9:40 - 11:10	0.65	0.917

Kipp #22 readings are 36% higher than Haenni #11.

Photocells for Village Water Systems

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1 Introduction

1.1 Background

The country does not avail of large traditional energy sources. With its location between roughly 5° and 25° latitude solar energy irradiation is high and rather evenly distributed over the year. Thus the sun may be a source of energy for other than only biological applications. Clouds reduce direct insolation but may increase the diffuse one. This effect may vary much with local conditions, because convective cloud formations affect certain spots more than others.

The network of solar observations is rather thin, 3 or 4 stations were operational in the country in 1982. Thus the solar irradiation map is insufficiently detailed for actual investments. This irradiation map should ideally contain information about the temporal distribution of intensities because the efficiency of certain applications may depend on this intensity. Small installations may indicate the economic value of a given detail of the irradiation map.

The advent of photocells made the conversion of irradiated energy technically possible. The predicted decrease of the price of these photocells points to a possible new source of energy which has the great advantage to be renewable. Thus the idea ripened to acquire practical experience with some solar energy systems, especially in terms of usable amounts of energy where system's response depends on threshold intensities. Avoidance of storage of electrical energy will require the storage of the final product. Some practical experience with the storage volume needed to assure a uninterrupted supply, is then desirable.

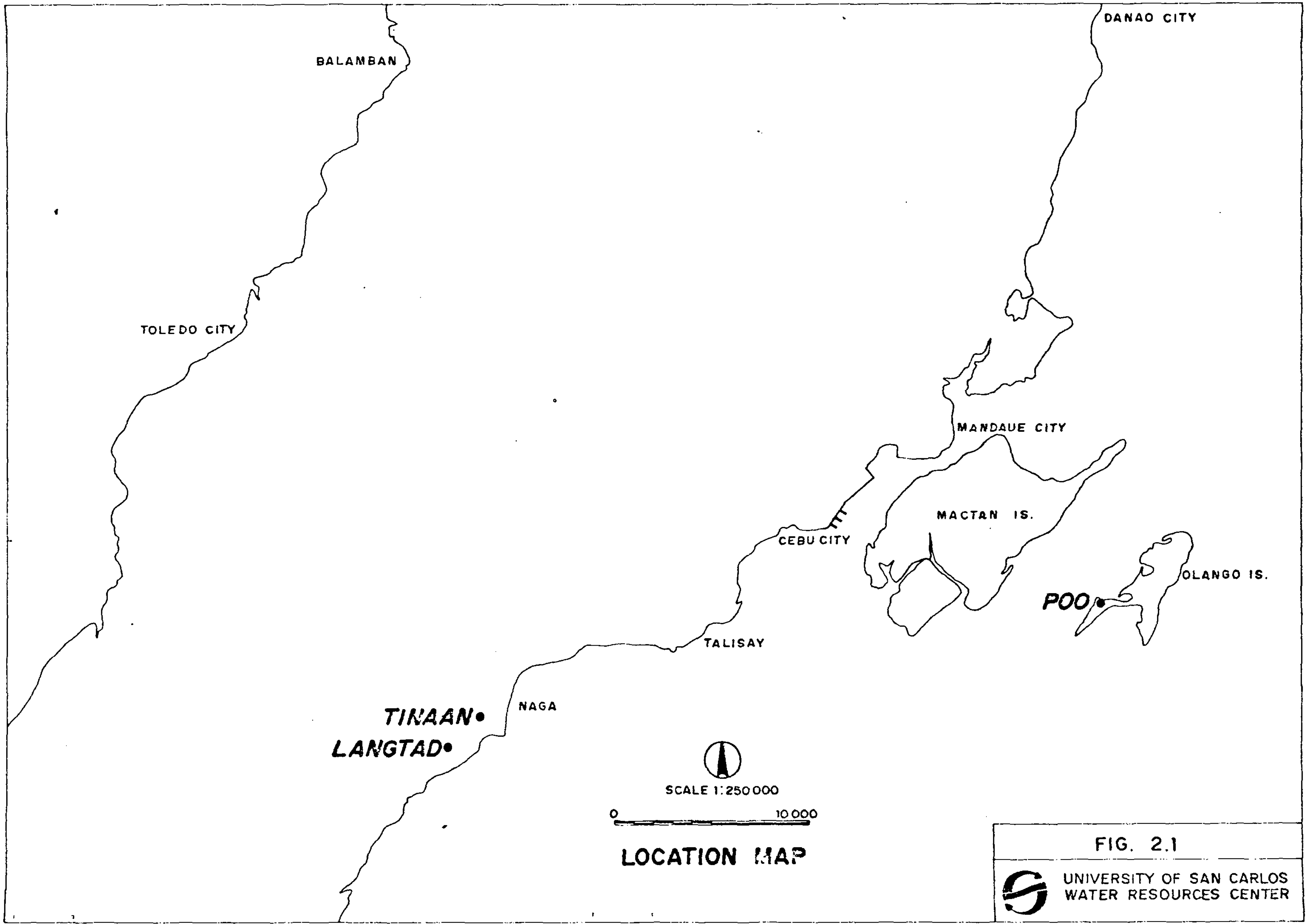
These general ideas have been combined in a practical application: water supply for small communities of 1000 to 2000 people.

1.2 Village Water Supply

The location of villages is not always determined by the availability of sufficient drinking water. When a spring is situated at the right place, gravity can be used as source of energy to transport the water from source to user. Where distances are not too long, water can be hand-carried. One encounters also a further development especially when distances are longer than 1 kilometer: motorized transport of water containers, from 20 liter-cans to tank trucks. The ultimate system consists of transport and distribution pipes fed by motorized pumps. Particularly villages which require some 10 to 20 m^3 water per day which has to be transported between 1 and 3 km seem to be communities for which photocells can supply the required energy in an economic way, when gravity cannot be utilized.

The order of magnitude requirements of such installations is less than 1000 W. When one namely assumes a dynamic head of 20 meters and 20 m^3 water delivered per day, some 4 million joules are needed. This energy when distributed over 4 hours of daily effective sunshine requires about 660 W installed power assuming again a 50% energy conversion by the pump.

In this analysis only basic fresh water requirements have been considered: 10 liters per head per day. Availability of water for bathing and washing is presupposed. This may be brackish surface water.



LOCATION MAP

FIG. 2.1

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2 Aims

2.1 General Aim

Based on such general ideas a project proposal was composed to collect the information which is necessary to optimalize the system's design. Although the data collection was centered around a water supply system, it is thought that much of the information can be used for other systems too.

The Memorandum of Agreement (dated 06 September 1982) expresses this in the following way:

a. To determine and assess the suitability of utilizing solar-powered pumping systems in providing the water needs of a rural community.

b. To install and monitor the performance of a water system using a solar-powered pump in a selected rural site.

c. To gather techno-economic data necessary to optimize the array size, capacity and reservoir volume in terms of quantity and time-distribution of solar energy supply and water demands.

d. To study the social acceptance of a solar system.

This Memorandum was based on the Proposal which used the following summary in 1979:

It is proposed to install a small watersystem for about 2,000 people. The system consists of a well, a pump which is powered by photovoltaic cells and buffered by a groundwater reservoir, a 3 km gravity-fed transport pipeline and two or three public faucets. A back-up power system, consisting of a 2 to 3 kW engine-driven electric generator together with a power conditioning unit will also be installed to provide the electrical power to the motor/pump set whenever the PV system is not viable to deliver the required daily water supply. The PV system can be rendered useless or inadequate in case it breaks down or whenever poor weather condition prevails respectively. This pilot installation will provide the data which are necessary to optimize the array size, pump capacity and reservoir volume in terms of quantity and time-distribution of solar energy supply and water demand.

2.2 Specific Aims

The equipment started arriving in May 1984 and the system was operational on 27 December 1984. The site is barrio Poo on Olango Island, Lapulapu City. See Fig.2.1. During this long gestation period the Aims as described in the Memorandum of Agreement were expressed in the three following areas of interest. This reformulation was strongly influenced by the experiences with 2 other similar installations in Langtad and Tinaan, Naga, Cebu. See Figure 2.1. These systems were sponsored by Shell Philippines and were operational in September 1983 and April 1984 respectively. The aims and field operations coincided sufficiently so that for report and evaluation the 3 systems are described together.

2.2.1 The Amount of Usable Solar Energy and Its Time Distribution.

It has been observed that some PV pumping systems do not produce any water when the insolation intensity is below a certain threshold expressed in watts per square meter ($W\ m^{-2}$). Other systems may have similar thresholds of operation, so it was considered interesting to evaluate the daily time distribution of the irradiated power. The non-utilization of low power energy is typical for centrifugal pumps. Jack pumps and other mechanical devices may also not develop a sufficient torque under low power conditions. For co-generating AC systems it may be interesting to know how much can be gained by utilizing the low power energy. Batteries can be used to boost starting torques, but they are an additional investment and operational expense.

The time distribution of the supply of energy over the day and over the month may help to adjust the storage (of energy or of final product) to specific local conditions. A mountain range westward of the site may cause afternoon cloud formations which effectively intercept the irradiation from early afternoon on. It is not known to the researchers in how far this convective cloud formation has been studied, especially in relation with the interception of direct irradiation, resp. increase of global radiation.

2.2.2 The Efficiency of the Energy Conversion

Photocells have many potential areas of application, because electricity may be considered as a high quality type of energy. The practical application of the Project is pumping of drinking water. In order to make the observations more generally useful, the generated electrical power was observed. This gives figures on the efficiency of the solar-to-electric energy transformation. The observation of volume and head then shows the efficiency of the pump-motor combination.

2.2.3 The Social and Economic Acceptability

Although the sun rises everyday with the accuracy of a clock, the amount of irradiated energy fluctuates with much less predictability. It was considered practical to observe the willingness of the users to adapt to these fluctuations.

In principle, a large storage volume can even out such fluctuations, but the costs are high, possibly unnecessarily so. In one location people are used to pay for the drinking water. The recording of the flow of money may indicate better at what price photocells are economically viable as source of energy.

3 Means

In order to evaluate available energy and performance or efficiency of the systems the following observations were considered necessary. They are grouped under Irradiation and Efficiency.

3.1 Irradiation

The incoming solar radiation (irradiation) must be measured in its totality and in its detailed time distribution. It was planned to utilize a radiation recorder, which has essentially the same spectral and spatial sensitivity as the photocells. It proved to be practical to make hourly observations of power and energy intensities in addition to the recorders. Complications arise when the sensor is placed in the plane of the photocell array. These complications are multiplied when the array is movable to be able to track the sun. The time series provide the data for size and for response thresholds. The instantaneous values are used for the determination of efficiencies, response thresholds and quality changes.

It is necessary to evaluate the irradiation observations with understanding of the differences in sensitivities between sensors and photocells. The main parameters are directionality and spectral response.

3.2 Efficiency

One may distinguish the following efficiencies of the different energy transformations:

from solar radiation to electric energy : E_{hv},
from electric energy to mechanical energy : E_{vm},
from solar radiation to mechanical energy : E_{hm}.

Theoretically, $E_{hm} = E_{hv} \times E_{vm}$, but the partial efficiencies are not always available. Also the combination of observational errors in such derived formula makes a direct calculation of E_{hm} preferable.

3.2.1 The observation of E_{hv} is fundamental for any evaluation of photocell performance. It requires:

- instantaneous observations of irradiation (W m^{-2} times the area of the photocells),
- instantaneous observations of closed circuit DC voltage and current (V_{cc} and I_{cc} respectively),
- eventually instantaneous observations of DC power (W_{cc})

In formula:

$$E_{hv} \times (W\ m^{-2}) \times \text{area} = V_{cc}\ I_{cc},\ \text{resp.} = W_{cc}.$$

All these observations must be made simultaneously.

3.2.2 The E_{vm} is specific for the given application: pumping water. Its observation requires:

- instantaneous pumping rate in $m^3\ sec^{-1}$,
- instantaneous pumping head in m_h,
- instantaneous friction loss in piping in m_f,

E_{vm} includes the pump properties, the pipeline lay-out and even the converter and AC motor combination.

In formula:

$$E_{vm}\ V_{cc}\ I_{cc} = 9800 \times (m^3\ sec^{-1}) \times (m_h + m_f)$$

Again, all observations must be made simultaneously.

3.2.3 The E_{hm} again is specific for the choosen application: pumping of water. Its observation requires:

- integrated irradiated energy in joules m^{-2} multiplied with array area in m^2. The integration time may be a month, a day, or shorter. At one minute simultaneity problems show up.
- integrated volume of pumped water in m^3, using the same integration periods as for the solar irradiation,
- average pumping head ($m_{h,av}$) in meters,
- average frictional loss ($m_{f,av}$) in meters.

In formula:

$$E_{hm} \times (\text{joules}\ m^{-2}) \times (m^2) = 9800 \times (m^3) \times (m_h + m_f)_{av}.$$

Again, all observations must be made simultaneously.

3.2.4 The performance of the panels and their possible change of quality can be observed with little additional effort: interrupting switches can be placed in the DC lines so that instantaneous values of short circuit currents (I_{sc}) and open circuit voltages (V_{oc}) can be observed. These values can be compared with the instantaneous irradiation values and can give a picture about panel performance against specifications or about panel deterioration in time.

3.2.5 Finally, the panel temperature was observed together with the air temperature, insolation and closed circuit currents to evaluate the manufacturers specifications.

3.3 Social and Economic Evaluation

3.3.1 Acceptability

In order to gain information about required dimensions of the system a survey was needed to count the number of users. A more reliable count requires some kind of mapping of the houses. With very little extra effort such map can be used to estimate the distances from where people prefer to go to the PV system as compared with the preference to go to available handpumps. Handpumps are customary, so if a clear preference is shown for the PV pump, it may be explained as if the PV pump is considered by the user as an improvement. The user always has to count with the possibility that the reservoir may be empty on a rainy day, an eventuality which does not exist with the handpump.

The irregularity of the sunshine can be equalized by a large storage reservoir. Some educated guess lead to a design of a volume equal to 150% of the average daily production which also was more or less guess work. Observations of the volume of water in storage can be used to check how correct the guesses were. It should be noted here that the users understood the operation of the system quite soon, so that the use of water was restricted once the storage ran low and clouds or time of the day did not promise new supply soon. Such restrictions are not too severe, because on cloudy, i.e. cool and rainy, days the demand for bath and laundry water decreases naturally.

3.2.2 Economics

In barrio Poo on Olango Island people were provided with fresh water by tricycles. The road runs around a bay which is flooded at high tide. The distance along the road is about 2.4 km. The charge for a 20 liters container was P1.50 at the time of the construction. For obvious reasons it was not considered wise to supply the water free of charge. A strong technical argument is that on this island fresh water should be used judiciously. And water will not be saved, if it is given for free. Initially a price of P0.25 was agreed for 20 liters, a price which was soon raised to P0.50. Tickets are sold in a small store so that at the water distribution point no money is required and thus no problems will come up in relation with change.

As the installation was experimental, it was not considered fair to take the cash out the community which generates it. It was kept in a bank account to prevent loss and it will be used for improvements in the barrio. In the meantime, the development of the bank account gives the hard facts of the economic potentials.

4 Implementation

4.1 The Installations

Due to some steady promotional work and some lucky circumstances 3 solar powered pumping systems could be evaluated. The systems are described in sequence of initial operation.

4.1.1 Langtad, Naga

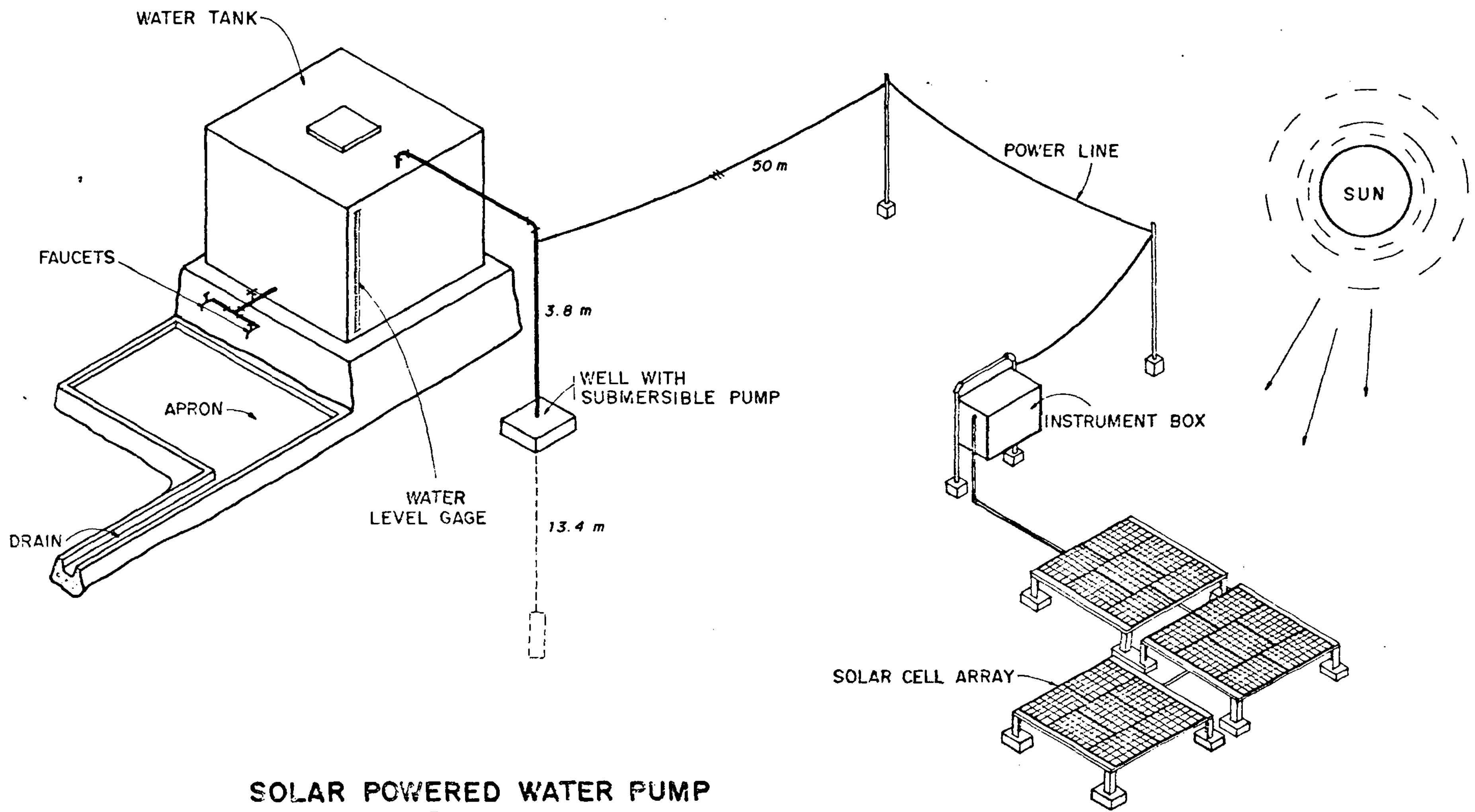
In Langtad, an abandoned open dug well was drilled deeper and provided with a cover. The site was choosen because of its central location in relation with the users. In addition, the well had served satisfactorily, what lead to the conclusion that there would be enough water. A design pumping rate of 1 liter per second was required to produce about 15 cubic meters water per day. A cursory survey had shown that there were some 250 people in the area, who use about 15 m^3 per day. It turned out that the upper portion of the aquifer could not sustain a pumping rate of 1 L sec^{-1}. The lower sandy formation can sustain this rate very well. For evaluation purposes, this situation was not ideal: at pumping rates smaller than 0.4 L sec^{-1} the water level steadied at 13.5 *m* below the surface while at higher pumping rates the water level dropped to 18.5 *m* below the surface.

A reservoir of 13 m^3 could be constructed close to the well. The area around the well was fit for washing, etc. This consideration was important, because the system would probably not stay. It could (and actually has been) replaced by a standard handpump.

At about 30 m distance a field free from shade was available for the panels. The electric line from source to submersible pump was 50 m long. This distance between array and pump is not ideal, but was caused by the given well location which is too shaded for the array.

In most actual systems it is expected that the well site is remote from the distribution point. Thus the shade, preferred for a distribution point, will not interfere with the openess which is required for the solar collector areas.

A plan of the site is given in Figure 4.1. Figure 4.2 shows the circuits to measure the electric parameters.



SOLAR POWERED WATER PUMP
LANGTAD , NAGA

FIG. 4.1

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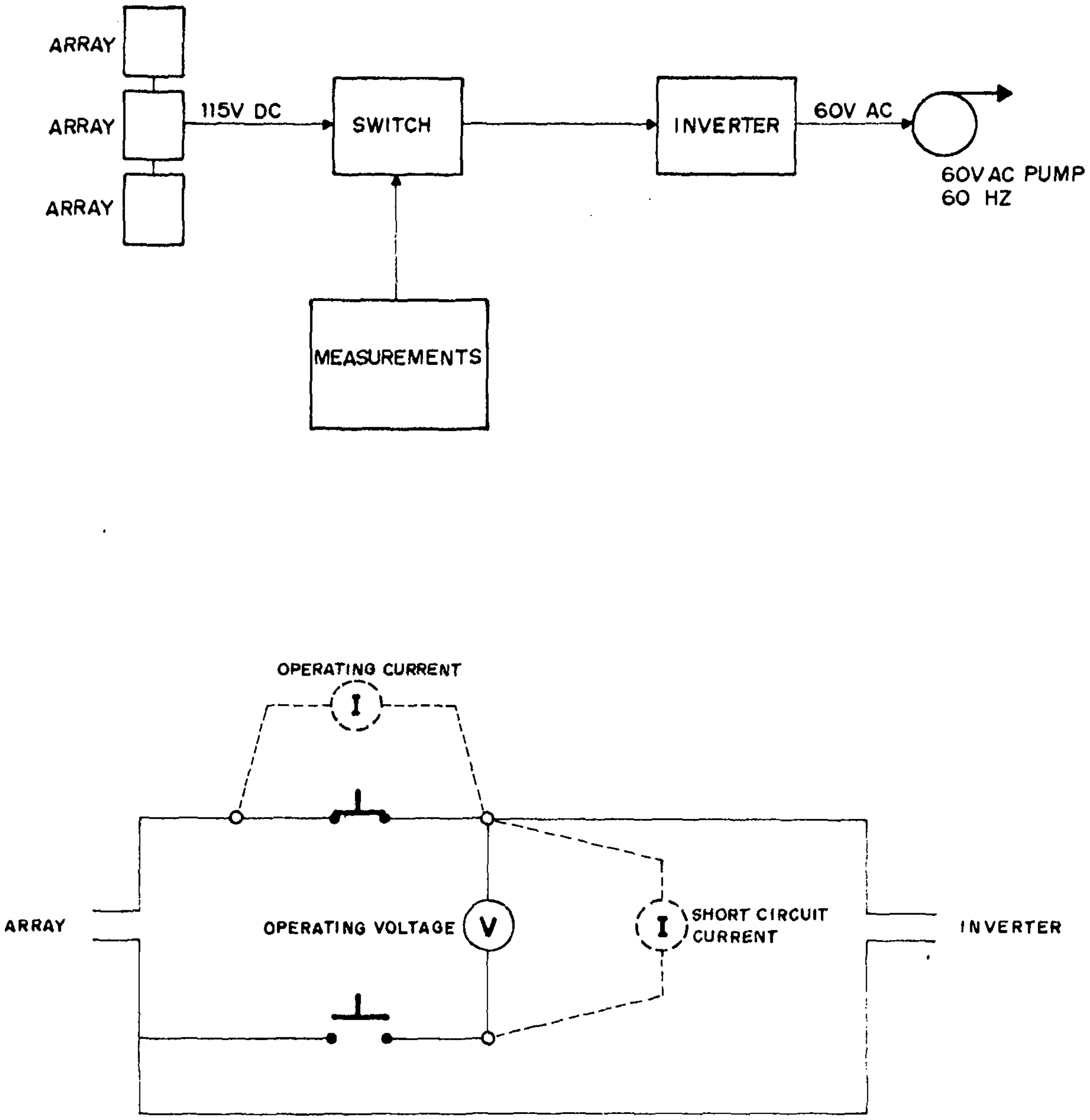

MEASUREMENT DIAGRAM
LANGTAD, NAGA

FIG. 4.2

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Specifications of the Panels

manufacturer	Holecsol
material	monocrystalline silicon
peak power	$W_p = 33$ W
open circuit voltage	$V_{oc} = 16.7$ to 20 V DC
short circuit current	$I_{sc} = 2.5$ A
dimensions	0.60 m x 0.90 m

Specifications of the Array

7 panels in series, 3 series in parallel

$W_p = 693$ W

$V_{oc} = 117$ to 140 V DC

$I_{sc} = 7.5$ A

tilt : 10°, facing South, fixed.

Specifications of Inverter

manufacturer : Grundfos

input voltage : 100 to 150 V DC

output voltage : 60 V AC, 3 phase, 6 to 60 Hz

power : 1500 W

short circuit protected

Specifications of Pump

manufacturer : Grundfos

type : submersible, 3 phase, 60 V AC

number of pump elements : 7

capacity : 1 L sec^{-1}

Head

static : 17.2 m

pumping : elevation 17.2 m to 22.6 m

friction 0 m to 1 m

total 17.2 m to 23.6 m

Volume of Reservoir 13 m^3

Instruments

multimeter

manufacturer : UNIVOLT

model : DT-845 #01

ranges : 0 to 750 V DC, 0.2 to 10 A

solarimeter

manufacturer : HAENNI MESSGERAETE

model : Solar 118

sensor : #01 installed in plane of array

reads instantaneous power in W m^{-2} or

integrated energy in kWh m^{-2}

thermometer
manufacturer : COMARK
model : 17320 A
sensor 1 : thermocouple taped between back cover and photocell
sensor 2 : thermocouple in free air

watermeter in production line
manufacturer : KIWA
model : BR 14062855
diameter : 50 mm
capacity : 15 m^3 hr^{-1}

watermeter in distribution line
manufacturer : LIBERTY
model : LMC
diameter : 25 mm
capacity : 10 m^3 hr^{-1}

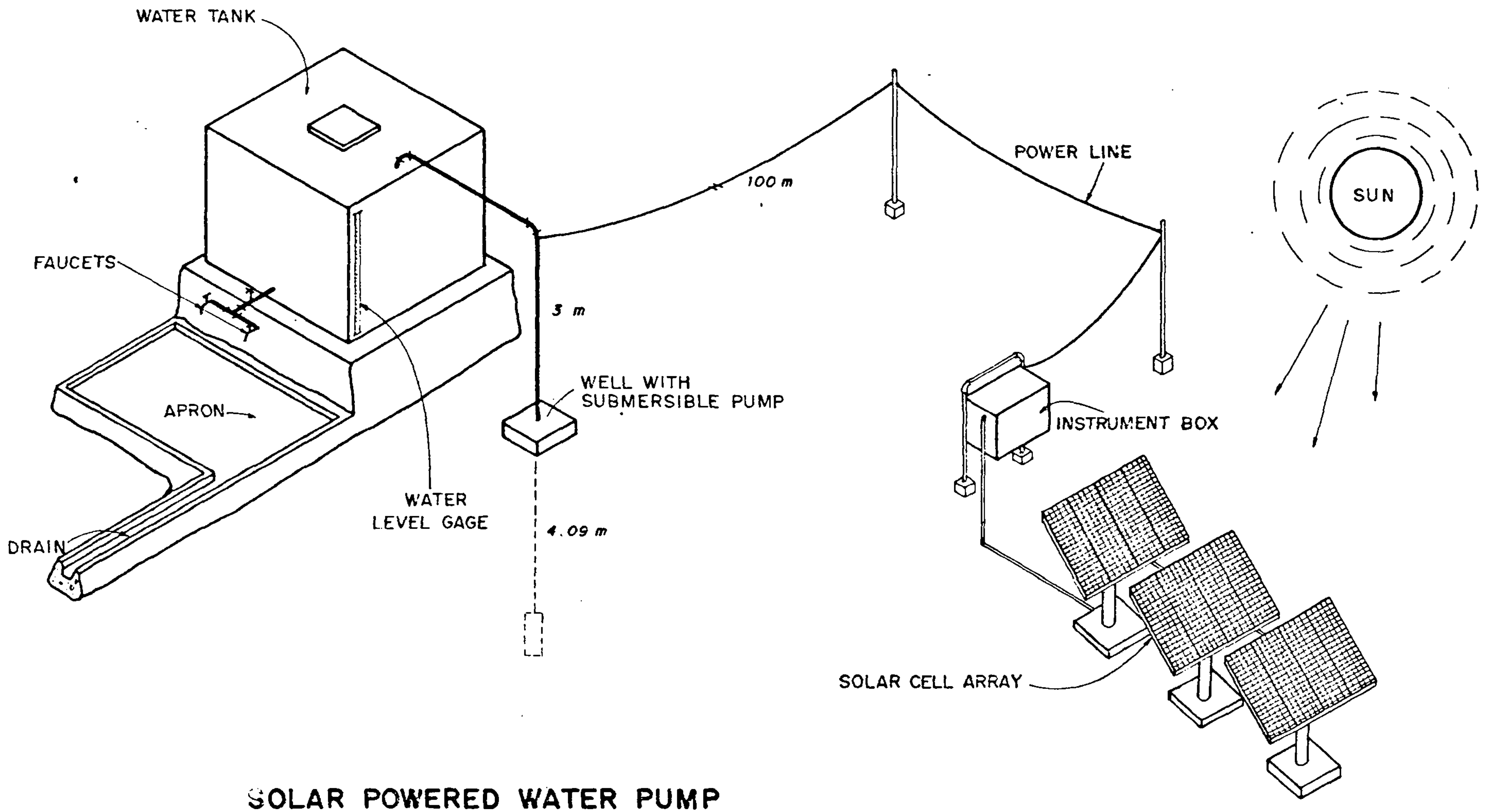
waterlevel indicator (well)
manufacturer : Ott
model : KL 50

waterlevel indicator (reservoir)
float : Plastic buoy
readings : in m^3 (approximate)

4.1.2 Tinaan, Naga

In Tinaan, a well was drilled in a thick sand formation. The site was choosen because of its central location in relation to the users. The location of the photocells is at some distance because of shade. As in Langtad the distribution point was choosen centrally in a shaded location. The well was drilled in this place so that if the system would be taken out, it could be replaced by a handpump and the well further utilized. The design pumping rate was arbirarily choosen as 1 L sec^{-1} against 15 m head. The well can sustain this pumping rate with very little drawdown, 0.7 m. Surplus water was partly utilized for irrigation of gardens with pepper, onions, beans. The distance between array and pump was 90 m which resulted in 100 m electric wire. This distance is the result of considerations given to the well-users and requirements of waste water drain.

A plan of the site is given in Figure 4.3. Figure 4.4 shows the circuits to measure the electric parameters.



SOLAR POWERED WATER PUMP
TINAAN , NAGA

FIG. 4.3

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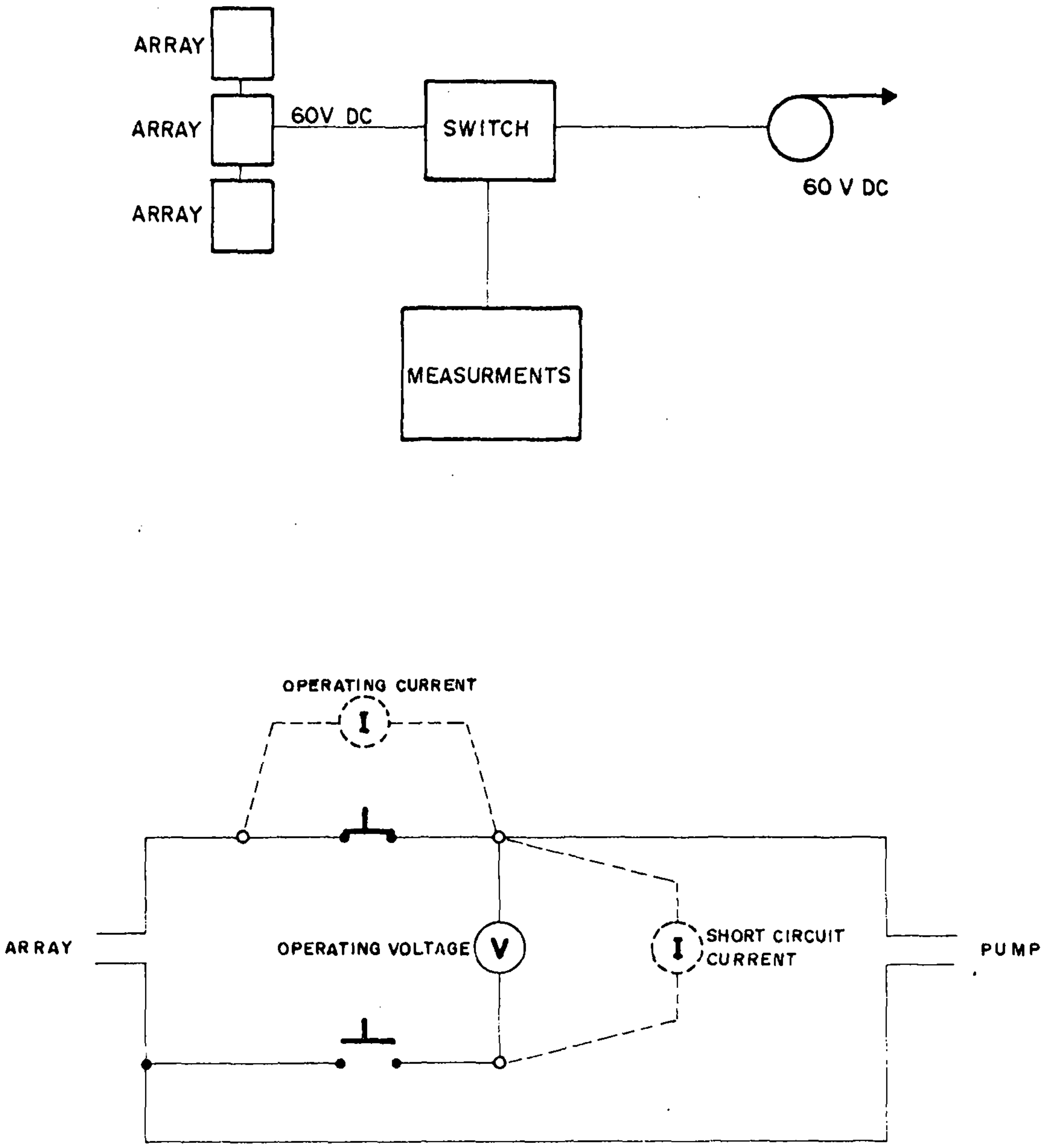

MEASUREMENT DIAGRAM
TINAAN, NAGA

FIG. 4.4

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Specifications of the Panels

manufacturer	ARCO Solar
material	Single crystal silicon
peak power	$W_p = 43$ W
open circuit voltage	$V_{oc} = 21.7$ V DC
short circuit current	$I_{sc} = 2.7$ A
dimensions	1.22 m x 0.305 m

Specifications of the Array

4 panels in series, 3 series in parallel

$W_p = 516$ W
$V_{oc} = 86.8$ V DC
$I_{sc} = 8.1$ A
tilt : 10°, facing South, adjustable.

Specifications of Pump

manufacturer : JACUZZI BROS.
type : submersible, 60 V DC
model : ZZ 4" series
number of pump elements : 7
capacity : 1 L sec^{-1}

Head

static : 7.0 m
pumping : elevation 7.0 m to 7.7 m
friction 0 m to 0.9 m

total 7.0 m to 8.6 m

Volume of Reservoir 13 m^3

Instruments

multimeter
manufacturer : UNIVOLT
model : DT-845 #02
ranges : 0 to 750 V DC, 0.2 to 10 A

solarimeter
manufacturer : HAENNI MESSGERAETE
model : Solar 118
sensor : #02 installed in plane of array/adjustable

reads instantaneous power in W m^{-2} or
integrated energy in kWh m^{-2}

watermeter in production line
manufacturer : KIWA
model : BR 14062855
diameter : 50 mm
capacity : 15 m^3 hr^{-1}

watermeter in distribution line
manufacturer : LIBERTY
model : LMC
diameter : 25 mm
capacity : 10 m^3 hr^{-1}

waterlevel indicator (well)
manufacturer : Ott
model : KL 50

waterlevel indicator (reservoir)
float : Plastic looking glass
readings : in m^3 (approximate)

4.1.3 Poo, Olango Island

In Poo, a reservoir of 20 m^3 was constructed at the distribution point. The well is at the other end of 1500 m pipeline. The well was drilled in the same general area from where the water was taken by the tricycle drivers. Here it was possible to keep the distance between well and array short, 15 m. The pipeline had to be non-corrosive because it would be in contact with sea water over half its length. Polybutelene was the choice. The pipeline is buried, except for 400 meters where it crosses a bay which is dry except for high floods. This stretch is weighed down by means of concrete blocks.

The site plan is given in Figure 4.5. Figure 4.6 shows the electrical circuits.

Specifications of the Panels

manufacturer	SOLAVOLT
material	Polycrystalline silicon
peak power	W_p = 36.6 W
open circuit voltage	V_{oc} = 17.9 V DC
short circuit current	I_{sc} = 2.6 A
dimensions	1.22 m x 0.36 m

Specifications of the Array
4 panels in series, 3 series in parallel
W_p = 439 W
V_{oc} = 72 V DC
I_{sc} = 7.8 A
tilt : 10°, facing South, adjustable.

Specifications of Pump
manufacturer : JACUZZI BROS.
type : submersible, 60 V DC
model : ZZ 4" series
number of pump elements : 7
capacity : 1 L sec^{-1}

Head
static : 5.8 m
pumping : elevation 5.8 m to 6.1 m
friction 0 m to 9 m
total 5.8 m to 15.1 m

Volume of Reservoir 22 m^3

Instruments

multimeter
manufacturer : BOSS INSTRUMENTS
ranges : 0 to 90 V DC, 0 to 12 A, 0 to 500 W

solarimeter
manufacturer : LI-COR
model : LI-200 SB
sensor : #05
directly connected to Rustrak chart recorder.

thermometer : thermocouple
directly connected to Rustrak chart recorder.

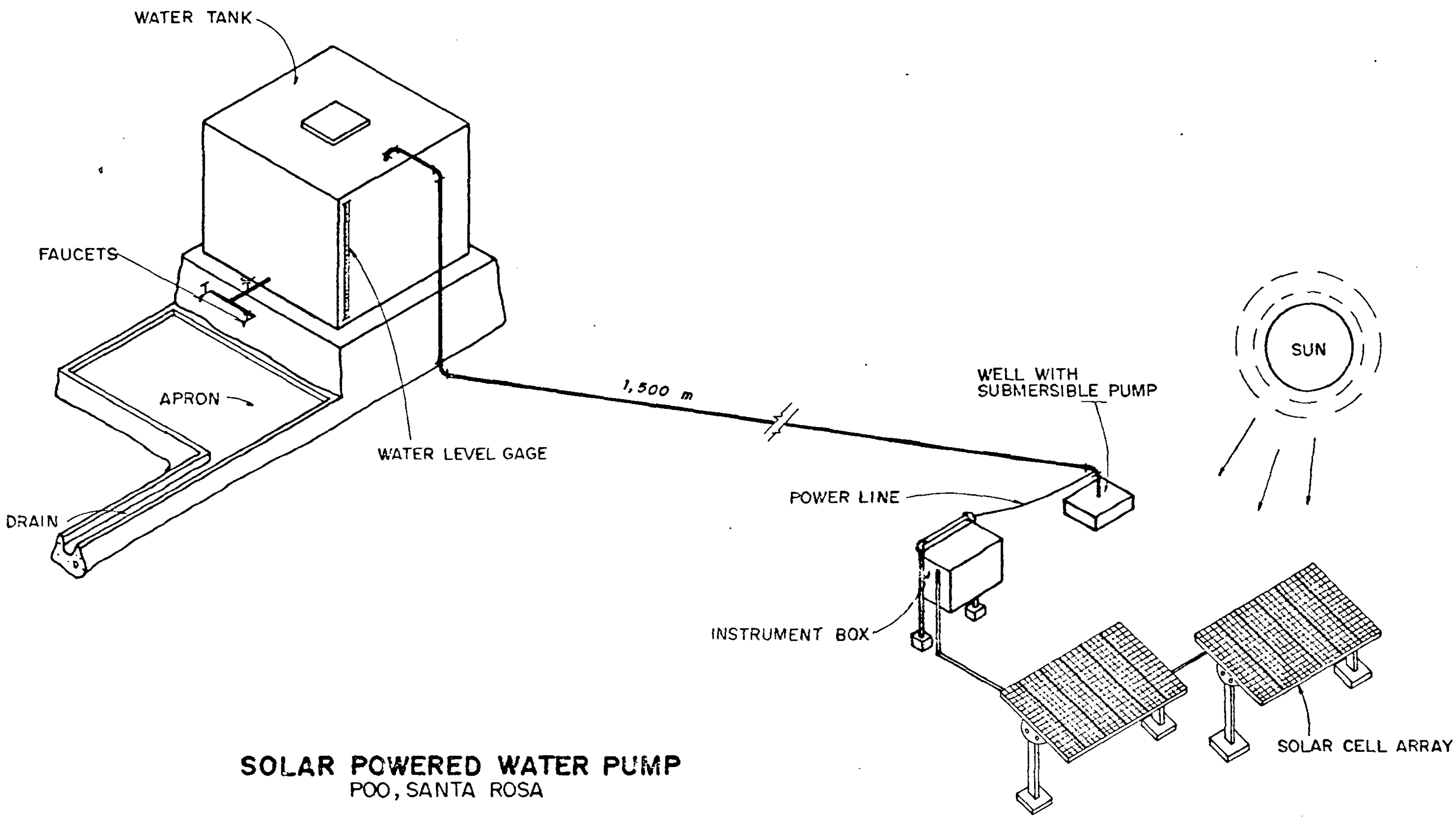
watermeter in production line
diameter : 2"

watermeter in distribution line
diameter : 1"

waterlevel indicator (well)
manufacturer : Ott
model : KL 50

waterlevel indicator (reservoir)
float : Plastic looking glass
readings : in m^3 (approximate)

An overview of the technical data is given in Table 4.1.



SOLAR POWERED WATER PUMP
POO, SANTA ROSA

FIG. 4.5

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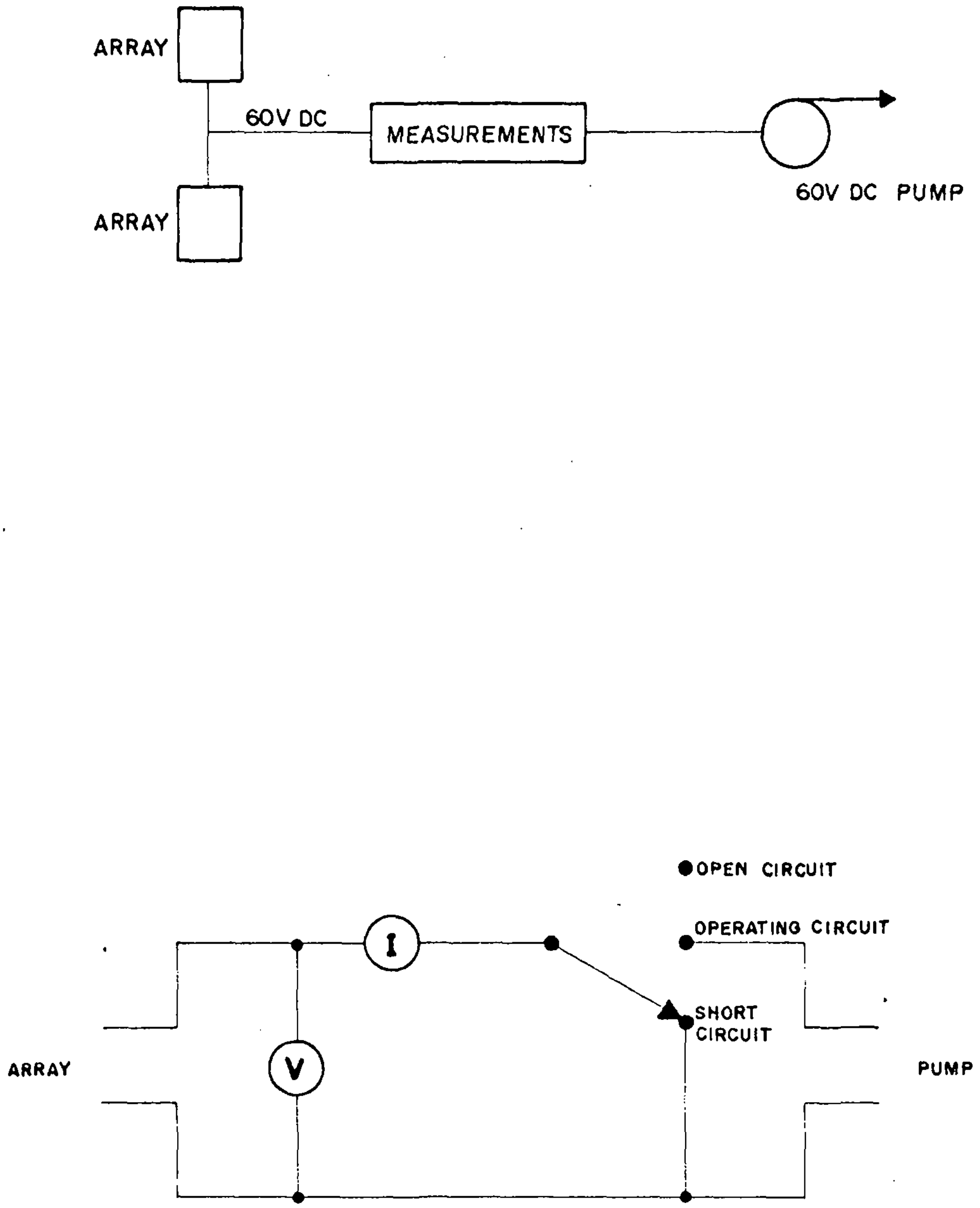

MEASUREMENT DIAGRAM
POO, SANTA ROSA

FIG. 4.6

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TABLE 4.1

SUMMARY OF TECHNICAL DATA

	LANGTAD	TINAAN	POD
No. of Panels	3 x 7	3 x 4	3 x 4
Manufacturer	HOLECSOL	ARCO SOLAR	SOLAVOLT
Peak DC Power	693	516	480
Module Voc	16.7-20 V "depending on insolation"	21.5 - 18V (21°-60°)	17 V at 50°
Module Isc	2.5 A	2.7 A	2.6 A
Module Peak Power	33 W	43 W	36.6 W
Submersible Pump	GRUNDFOS	JACUZZI	JACUZZI
area:			
Panels	8.4 m^2	4.46 m^2	5.22 m^3
Sum of Cells	21x 40x 0.01 = 8.40 m^2	12x 36x 0.01 = 4.32 m^2	12x33x 0.01 = 3.96 m^2
Exposed Semi-conductor	0.74 x 7.56 = 5.59 m^2	0.84 x 4.32 = 3.63 m^2	0.62 x 3.96 = 2.49 m^2
Total head	[(17.2 to 22.6)+(0 to 1)]	[7.69+(0 to 1)]	[6.0 + (0 to 9)]
Pumping Rate	1.0 $l\ sec^{-1}$	1.0 $l\ sec^{-1}$	0.8 $l\ sec^{-1}$
Max. day prod.	24.2 m^3	32.8 m^3	22.7 m^3
Min. Required Insolation	360 $W\ m^{-2}$	120 $W\ m^{-2}$	150 $W\ m^{-2}$
Cable Length	50 m	100 m	15 m
Storage Tank	13 m^3	13 m^3	20 m^3
Average Month Production	449 m^3	642 m^3	85 m^3 *)
No. of People Affected	600	250	1500

*) due to restrictions on pumping time.

It is worth to note the differences between panel area, photocell area and area of exposed semiconductor.

The photocell area (Sum of Cells) is used in the evaluation of the observations.

4.2 Calibration

The purpose of the study is among others an evaluation of the differences of the systems. The absolute calibration of the different instruments was not known. Rather early in the operations some instruments malfunctioned, so that some meters temporarily had to be used in different locations. Thus comparisons between instruments became important in order to make the observations consistent.

4.2.1 Calibration of Irradiation Meters

The calibration was performed by placing the sensors of the different meters side by side. The observations of the two Haenni meters are compiled in Table 4.2.

Table 4.2
Comparison of HAENNI #1 and HAENNI #2

Date	Time	HAENNI #2 $(W\ m^{-2})$	HAENNI #1 $(W\ m^{-2})$	Date	Time	HAENNI #2 $(W\ m^{-2})$	HAENNI #1 $(W\ m^{-2})$
Feb 18 85	7:00	70	78		12:00	843	967
	8:00	103	136		1:00	815	940
	9:00	565	647		2:00	770	812
	11:00	509	623		3:00	575	654
	12:00	882	999		4:00	362	415
	1:00	848	973		5:00	105	95
	2:00	724	838				
	3:00	331	436	Feb 21 85	7:00	59	67
	5:00	113	124		8:00	370	419
					9:00	583	659
19	7:00	51	58		10:00	723	828
	8:00	379	420		11:00	768	878
	9:00	603	698		12:00	791	909
	10:00	730	846		1:00	668	640
	11:00	821	750		2:00	131	154
	12:00	907	1035		3:00	159	182
	1:00	478	630		4:00	168	213
	2:00	740	775		5:00	95	119
	3:00	573	657				
	4:00	348	392	22	7:00	6	49
	5:00	122	110		8:00	153	172
					9:00	316	364
20	7:00	84	87		10:00	677	794
	8:00	347	427		11:00	385	328
	9:00	538	654		12:00	777	807
	10:00	719	795		1:00	377	474
	11:00	806	929		2:00	291	348

Haenni #02 has been used in Tinaan, while Haenni #01 was assigned to Langtad.

The Table shows that on the average Haenni #02 reads 12% lower than Haenni #01. The field irradiation values of Tinaan have been multiplied by 1.12 in order to make comparisons easier.

A linear regression analysis gives essentially the same result:

$$(\#01) = 1.11 \times (\#02) + 8.2$$
$$R = 0.9902.$$

In January 1987 the possibility arose to compare Haenni #01 with a Kipp thermopile. The results are described in "Important Remark on Absolute Values". Because of the substantial differences this evaluation has been inserted following the Table of Contents. The irradiation as measured during the Project is 36% lower than this standard.

The comparison between the Haenni #01 and the Li-Cor with Rustrak recorder was made by identifying smooth portions of the track in the field and recording simultaneous Haenni #01 integrations in kWh m^{-2}. The identified tracks were later planimetered. The data are compiled in Table 4.4. The Li-Cor reads on the average 8% higher than the Haenni #01. For the comparison of observations the Poo values have been used as observed because of possible errors in planimetering.

Table 4.4
Comparison of Haenni #1 and Li-Cor

	TIME	LICOR (kWh/m^{-2})	HAENNI (kWh/m^{-2})
April 18, 1985	11:00 - 1:00	1.805	1.91
	1:00 - 3:00	1.624	1.37
	3:00 - 5:00	1.022	0.79
19	6:00 - 8:00	0.511	0.47
	8:00 -10:00	0.842	0.85
	10:00 -12:00	1.293	1.28
	12:00 - 2:00	1.594	1.64
	2:00 - 5:00	0.902	0.97
20	6:00 - 8:00	0.361	0.28
	8:00 -10:00	1.053	0.94
	10:00 -12:00	1.98	1.53
	12:00 - 2:00	1.113	1.08
	2:00 - 5:00	0.541	0.45
21	8:00 -10:00	1.564	1.18
	12:00 - 2:00	2.045	1.81
	3:00 - 5:00	0.457	0.43
22	10:00 -11:00	0.902	0.88
	12:00 - 2:00	1.119	0.83
	2:00 - 3:00	0.902	0.67
	4:00 - 5:00	0.277	0.28
25	7:00 - 9:00	1.029	1.94
	9:00 -11:00	1.599	1.55
	11:00 - 1:00	2.04	1.84
	1:00 - 3:00	1.624	1.46
	3:00 - 5:00	0.397	0.32
26	7:00 - 9:00	0.577	0.42
	9:00 -11:00	1.564	1.6
	11:00 - 1:00	2.021	1.72
	1:00 - 3:00	0.457	0.36
	3:00 - 5:00	0.331	0.24
30	7:00 - 9:00	0.962	0.88
	9:00 -11:00	1.54	1.39
	11:00 - 1:00	1.805	1.73
	1:00 - 3:00	1.624	1.44
	3:00 - 5:00	0.782	0.73

4.2.2 Check of Multimeters

The multimeters have been compared with one so-called laboratory standard of USC Physics Department, Fluke, Model 8000 A, serial #0800797. The current and voltage readings are tabulated in Tables 4.5 and 4.6 respectively.

The field meter reads on the average 0.55 V lower than the laboratory meter. The current radings are 0.02 A higher. These differences have been neglected.

Table 4.5
Comparison of Current Meters
Field instrument: UNIVOLT DT-845 #01
Lab instrument : Fluke 8000 A

Test Point	Univolt (A)	Fluke (A)
1	0.05	0.05
2	0.10	0.09
3	0.15	0.14
4	0.20	0.18
5	0.25	0.23
6	0.30	0.28
7	0.35	0.33
8	0.40	0.38
9	0.45	0.42
10	0.50	0.47
11	0.55	0.52
12	0.60	0.57
13	0.65	0.62
14	0.70	0.68
15	0.75	0.72
16	0.80	0.78
17	0.85	0.82
18	0.90	0.87
19	0.95	0.93
20	1.00	0.97

Table 4.6
Comparison of Volt Meters
File instrument: UNIVOLT DT-845 #01
Lab instrument : Fluke 8000 A

No.	Fluke (V)	Univolt (V)	No.	Fluke (V)	Univolt (V)
1	1.00	0.930	20	18.00	17.660
2	2.00	1.798	21	19.00	18.600
3	2.50	2.350	22	20.00	19.470
4	3.00	2.780	23	21.00	20.410
5	3.50	3.240	24	22.00	21.300
6	4.00	3.700	25	23.00	22.300
7	5.00	4.646	26	24.00	23.200
8	6.00	5.560	27	25.00	24.100
9	7.00	6.480	28	26.00	25.000
10	8.00	7.410	29	27.00	26.000
11	9.00	8.340	30	28.00	27.900
12	10.00	9.260	31	29.00	28.800
13	11.00	10.190	32	30.00	29.700
14	12.00	11.110	33	35.00	34.300
15	13.00	12.030	34	40.00	39.000
16	14.00	13.870	35	45.00	44.600
17	15.00	14.290	36	50.00	48.200
18	16.00	14.820	37	55.00	53.900
19	17.00	15.750	38	60.00	59.500

4.2.3 Comparison of Water Meters

The watermeters have been compared by connecting them in series. It was possible to always mount these meters in pipes which were straight over more than 10 pipe diameters before and after the meter. In this way, turbulence is expected to have a negligible influence on the readings. The observations have been compiled in Table 4.7.

The conclusion is that one has to accept an inaccuracy of the volume observations of 6%.

The flowmeter connected to the recorder in Poo started malfunctioning after a few days in the field. Recordings were apparently normal up to 0.7 L sec^{-1} flow rate. Above this rate the electronics seemed to be saturated. Local technicians were badly handicapped by the lack of detailed diagrams. Repeated requests for additional information were not answered by the supplier.

Table 4.7
Comparison of Poo Flowmeters

Pumpsite meter = X
Tanksite meter = Y

Reading	X (m^3)	Y (m^3)
1	0.43	0.4936
2	0.4244	0.4228
3	0.6095	0.6575
4	0.5789	0.5537
5	0.7853	0.8153
6	0.4628	0.4603
7	0.3577	0.3736
8	1.2327	1.3369
9	0.5932	0.4973
10	0.4422	0.4436
11	0.4985	0.5026
12	0.4877	0.483

It is clear that in situations where comparisons are made with the intention to distinguish between sites and between systems, it becomes very important to select meters which will not add a few poorly defined variables. This condition becomes more urgent where differences of not more than 10% can be expected. Such small differences are important given the relatively high initial costs of the systems being studied. Thus either the meters must be very stable, a property which is not claimed by manufacturers of irradiation meters with semiconductor sensors, or a stable standard must be readily accessible. The acquisition of two Kipp thermopiles has satisfied this last condition, but somewhat late in the Project.

4.3 Operations

All systems had a local operator who was instructed to make a number of observations on an hourly basis. In Langtad and Tinaan one person per site could perform all the functions expecially because there was no detailed control of the consumption. In Poo the payment of the water required a collector besides the operator who made observations at the remote pump site.

USC-WRC provided about twice per month a supervisor who made additional and more precise observations in addition to a general inspection of the installations.

4.3.1 Operations in Langtad and Tinaan

4.3.1.1 The Operator

The two systems had the same sponsor, so the operations were nearly identical. The operator made the following hourly observations, see Fig. 4.8 as an example. The description of the different items follows:

Figure 4.8

SITE OPERATORS VILLAGE WATER SUPPLY HOURLY DATA SHEET

Site: ___________ Date: _______
Pump: ___________

Time	Depth	Flow Readings		Flow L/M	Tank Vol. m^3	Insolation		Volts	Amps	Temp.		Remarks
		(1)	(2)			Inst W/m^2	Cum kWhr			Air °C	Cell °C	
6												
7												
8												
9												
10												
11												
12												
1												
2												
3												
4												
5												
6												

Total Insolation: ____ kWhr/m^2

Final Volume in Tank: ____ m^3
Total Flow into Tank: ____ m^3
Out of Tank: ____ m^3

Insolation, Inst.: instantaneous irradiation

the solarimeter permits this reading in W m^{-2}

Insolation, Cum. : accumulated energy

the solarimeter integrates, thus the difference between readings is the energy in kWh m^{-2} collected in the time interval under consideration.

electric quantities

Volts, Amps: V_{cc} and I_{cc} from which electric power is calculated,

Flow Readings: watermeter readings

the watermeters integrate, thus differences between readings indicate the volume over a given interval. One meter registers the production, the other meter gives the consumption. Two meters are necessary because pumping continues, even when the reservoir is full and overflowing. The production meter gives the information which is needed for the calculation of the efficiency of the pump. The consumption meter gives the data to analyze the consumption pattern.

Tank Vol.: gage reading

Although not very accurate the level gage of the reservoir is a cross check of the recording of the watermeters. Its main purpose is to warn when storage runs low on a cloudy day.

Temperature

the temperature of the panels and of the air eventually indicates the temperature dependence of the energy conversion.

Depth

water level in the well below the measuring point, expressed in meters.

4.3.1.2 The Supervisor

The supervisor made on the average twice per month an additional set of observations in Langtad and about once per month in Tinaan. These data are considered of higher quality, but they also constitute a cross check on the operator's performance. An example is given in Figure 4.9.

The description of the different items is essentially the same as for the Operators Sheet. The following are special:

O/C Volt, S/C Amp.: V_{oc} and I_{sc} from which changes in panel performance may be deduced.

Figure 4.9
SUPERVISORS VILLAGE WATER SUPPLY HOURLY DATA SHEET

Site: _______
Pump: _______

Date: _______

Time	Depth m	Water Flow Readings 1*	2*	Flow L/M	Tank Vol. m^3	Insolation Inst W/m^2	Cum kWhr	Volt	Amp	O/C Volt	S/C Amp	Temp Air °C	Cell °C	Hyd Power watts	Elec Power watts	W-W Eff %
6																
7																
8																
9																
10																
11																
12																
1																
2																
3																
4																
5																
6																

Total Insolation: _____ kWhr m^{-2}

Final Vol. in Tank: _____ m^3
Total Flow into Tank: _____ m^3
Out of Tank: _____ m^3

Note: even on clear days the short term variations of irradiation are remarkably large: 10% per 30 sec is no exception. This fact has influence on combinations of instantaneous readings: the potential and current readings cannot be made exactly simultaneously with the irradiation readings. The result is a spread in the efficiency values which hopefully averages out.

4.3.2 Operations at Poo

4.3.2.1 The Operator

Due to the distance between the well and the distribution point two operators were needed. One operator made hourly readings, see Figure 4.10. The description of the different items follows on the next page:

Figure 4.10
SITE OPERATOR HOURLY DATA SHEET

Site __________ Date ______

Time	Depth	Volts		Amps		Watts	Remarks
		R	S/C	R	S/C		
7:00							
8:00							
9:00							
10:00							
11:00							
12:00							
1:00							
2:00							
3:00							
4:00							
5:00							

depth		water level below measuring point in meters
volts	R	closed circuit voltage
	OC	open circuit voltage
ampere	R	closed circuit current
	SC	short circuit current
watts		reading of a DC watt meter
remarks		here is indicated when the pump is disconnected. This column has frequently been used to record the instantaneous solar power and the accumulated solar energy in W m^{-2}, respectively kWh m^{-2} by means of the Haenni Solar 118 #01.

4.3.2.2 The Water Distributor

The other operator recorded the water meter and the water level indicator of the reservoir, see Figure 4.11. This operator collects the tickets as payment for the water.

Figure 4.11
WATER DISTRIBUTION HOURLY DATA SHEET

Site: ___________ Date: _______

Time	Meter Reading Gal	Consumption Gal	Storage Volume	Remarks
6:00				
7:00				
8:00				
9:00				
10:00				
11:00				
12:00				
1:00				
2:00				
3:00				
4:00				
5:00				
6:00				

5. Data and Interpretations

5.1 Usable Solar Energy

5.1.1 Irradiation

In Langtad the sensor was mounted in the plane of the panels which has a tilt of 10° off the horizontal. The panels were in fixed position.

In Tinaan the sensor was mounted in the plane of the panels which has a tilt of 10° off the horizontal. The three arrays could be adjusted for manual tracking. According to the cosine law full tracking should result in 36% more irradiated energy. The increase in air mass in the early morning and late afternoon reduces the gain.

Hills towards the west of both locations intercept the sun after 5:30, when not much useful energy can be collected anyhow. Afternoon clouds over these hills intercept a more significant part of the theoretically available sunshine.

In Poo the arrays were mounted as in Tinaan, but the sensor was placed horizontally. The stripchart recorder produced curves in squares about 50 mm × 50 mm for one day. The resolution of these graphs is too small for anything else than semi-quantitative analysis.

From the observer's records the daily observed irradiated energy in kWh m^{-2} has been tabulated in Table A.1. Monthly averages have been calculated, see Table 5.1.

The tracking in Tinaan was manual. Spot checks showed that the observer was faithful up to 80%. Instrument failures limited the possibilities of concurrent observations in Tinaan, Langtad and Poo.

The fixed Langtad configuration was preferred for irradiation observations. As a result the Langtad series is nearly complete, but the Tinaan series, which started in May 1984 only, shows many gaps. March 1984 had all solarimeters out. August 1985 shows an erratic behavior of the solarimeter. The Poo data did not permit correlations of time series, but a number of individual days have been compared.

Table 5.1
Average Daily Irradiation and Production
Summary of Table A.1

Month	LANGTAD		TINAAN		POO
	Radiation (kWh m^{-2})	Production (m^3)	Radiation (kWh m^{-2})	Production (m^3)	Radiation (kWh m^{-2})
Nov 1983	3.6				
Dec 1983	3.2	6.4			
Jan 1984	3.5	10.6			
Feb 1984	3.4	11.3			
Mar 1984					
Apr 1984	5.0	17.7			
May 1984	4.7	16.8	5.6	25.8	
Jun 1984	3.8	13.0	4.2	22.0	
Jul 1984	4.1	14.7	4.5	24.0	
Aug 1984	3.7	12.1	4.4	21.5	
Sep 1984	4.3	15.6	4.9	20.6	
Oct 1984	3.5	11.8		18.3	
Nov 1984	4.0	14.4		21.8	
Dec 1984	3.3	11.4		17.4	
Jan 1985	3.4	12.4		18.2	3.7
Feb 1985	4.4	17.1		23.0	4.9
Mar 1985	5.0	20.0	5.3	19.7*	5.5
Apr 1985	4.6	18.2		12.5*	5.1
May 1985	4.1	16.0			
Jun 1985	3.6	13.1	3.7		3.9
Jul 1985	3.5	13.4	3.8	20.5	4.3
Aug 1985				24.9	4.4
Observation Average:	3.9	14.0	4.6	18.1	4.5
12-Month Average: (May-April)	4.1	15.0		20.4	

* Only 2 out of 3 Tinaan arrays were operating

N.B. Radiation values are probably low in Tables 5.1, 5.2 and 5.3.

In the period of observation, November 1983 till August 1985, the daily average irradiated energy fluctuated

between 0.1 kWh m^{-2}, 16 January 1985
and 6.1 kWh m^{-2}, 2 April 1984

the daily irradiation, averaged over a month, fluctuated

between 3.2 kWh m^{-2}, December 1983
and 5.1 kWh m^{-2}, March 1985.

the average daily irradiation between May 1984 and April 1985 is 4.1 kWh m^{-2}.

Theoretically, one might expect in first approximation:

average duration of irradiation	12 hours/day,
maximum irradiation	1000 W m^{-2},
maximum irradiation/day (cosine law)	7.7 kWh m^{-2}.

The clouds and the larger-than-one airmass early and late in the day are responsible for the fact that the average observed value is about 50% of the maximum as calculated above.

No attempt was made to determine if this period had an average cloudiness, or not, as observed by the meteorological station of the weatherbureau in Cebu.

The effect of tracking in the 8 months where the data allow comparison, shows an increase of 11% of the irradiation on the plane of the array.

The monthly totals, which are derived from Table A.1, are compiled in Table 5.2 to give an impresssion of how much energy is received per square meter. The Langtad observations show that a square meter received an average of 120 kWh per month with a minimum of 100 kWh (-17%) and a maximum of 157 kWh (+31%).

5.1.2 Time Distribution

The irradiated energy per square meter was observed in Langtad and Tinaan every hour. The hourly readings of Langtad are given in Table A.2. The hourly readings of Tinaan contain many gaps because of malfunctionings of one or the other of the available solarimeters. Also the not-perfect tracking caused unreliable points. Thus the Tinaan hourly data have not been printed.

Table 5.2
Total Monthly Irradiation and Production
Derivation from Table A.1

Month	LANGTAD		TINAAN	
	Radiation (kWh m^{-2})	Production (m^3)	Radiation (kWh m^{-2})	Production (m^3)
Nov 1983	109			
Dec 1984	100	197		
Jan 1984	107	330		
Feb 1984	101	328		
Mar 1984				
Apr 1984	149	532		
May 1984	147	522	175	799
Jun 1984	113	390	126	659
Jul 1984	126	455	140	743
Aug 1984	113	375	136	666
Sep 1984	128	469	146	619
Oct 1984	108	365		567
Nov 1984	119	431		653
Dec 1984	103	354		539
Jan 1985	105	385		564
Feb 1985	124	480	117	645
Mar 1985	157	619	164	609*
Apr 1985	137	545		**
May 1985	129	497		**
Jun 1985	107	393	111	513
Jul 1985	109	416	119	635
Aug 1985				772
Observation Average:	120	425	124	642
12-Month Average: (May-April)	123	449		642

* Only 2 out of 3 Tinaan arrays were operating
** Pump malfunction in Tinaan

A summary of the monthly averages of energy which is irradiated is given in Table 5.3. In the column under e.g. 12 is recorded the difference between the two readings of collected energy at 12:00 and 11:00 respectively. The value marked under 7 represents the energy which is irradiated from 5:00 until sunset of the previous day and from sunrise till 7:00 of the running day.

The distribution is definitely skewed towards the morning. This is different from a temperature distribution. The reasons are clear: first, the irradiation measurement is instantaneous while the air temperature follows the soil temperature which in its turn lags the irradiation; second, cloud formation is most of the time an afternoon affair. A tentative conclusion is that when no ideal site can be located, preference should be given to a site which is open towards the east in order to catch the morning sun. The monthly averages are represented in histograms in Figures 5.1 and 5.2.

It is also important to note that the average hourly maximum is only 70% of the theoretical maximum value of 1 kWh m^{-2} as derived from the maximum irradiation power which is 1 kWh m^{-2}. Clouds are responsible.

Table 5.3
Average Hourly Irradiation
(kWh m^{-2})
Langtad
Summary of Table A.2

Month/ Time	7	8	9	10	11	12	1	2	3	4	5
Feb 1984	0.04	0.12	0.26	0.40	0.52	0.50	0.54	0.44	0.34	0.20	0.10
Apr 1984	0.08	0.22	0.45	0.61	0.69	0.74	0.68	0.68	0.51	0.30	0.08
May 1984	0.10	0.24	0.48	0.62	0.71	0.66	0.67	0.62	0.42	0.23	0.09
Jun 1984	0.11	0.19	0.37	0.48	0.51	0.55	0.57	0.52	0.32	0.20	0.08
Jul 1984	0.08	0.18	0.38	0.51	0.55	0.65	0.60	0.53	0.38	0.19	0.09
Aug 1984	0.08	0.18	0.36	0.48	0.53	0.53	0.46	0.45	0.36	0.20	0.11
Sep 1984	0.09	0.24	0.39	0.60	0.59	0.72	0.61	0.49	0.34	0.20	0.09
Oct 1984	0.04	0.21	0.38	0.48	0.53	0.50	0.47	0.39	0.29	0.15	0.05
Nov 1984	0.02	0.22	0.40	0.54	0.56	0.59	0.50	0.53	0.36	0.20	0.07
Dec 1984	0.04	0.17	0.31	0.44	0.48	0.46	0.44	0.44	0.34	0.18	0.06
Jan 1985	0.02	0.15	0.29	0.40	0.47	0.47	0.48	0.45	0.35	0.22	0.11
Feb 1985	0.04	0.15	0.34	0.54	0.59	0.66	0.65	0.57	0.48	0.31	0.17
Mar 1985	0.06	0.17	0.42	0.61	0.73	0.74	0.71	0.70	0.50	0.33	0.14
Apr 1985	0.08	0.20	0.45	0.63	0.70	0.68	0.61	0.55	0.38	0.26	0.10
May 1985	0.10	0.25	0.41	0.58	0.64	0.64	0.53	0.44	0.37	0.20	0.12
Jun 1985	0.09	0.16	0.33	0.45	0.53	0.54	0.51	0.43	0.36	0.19	0.07
Jul 1985	0.08	0.18	0.36	0.43	0.47	0.52	0.50	0.44	0.34	0.19	0.07
Average:	0.07	0.19	0.38	0.52	0.58	0.60	0.56	0.51	0.38	0.22	0.09

* March 1984 no data.

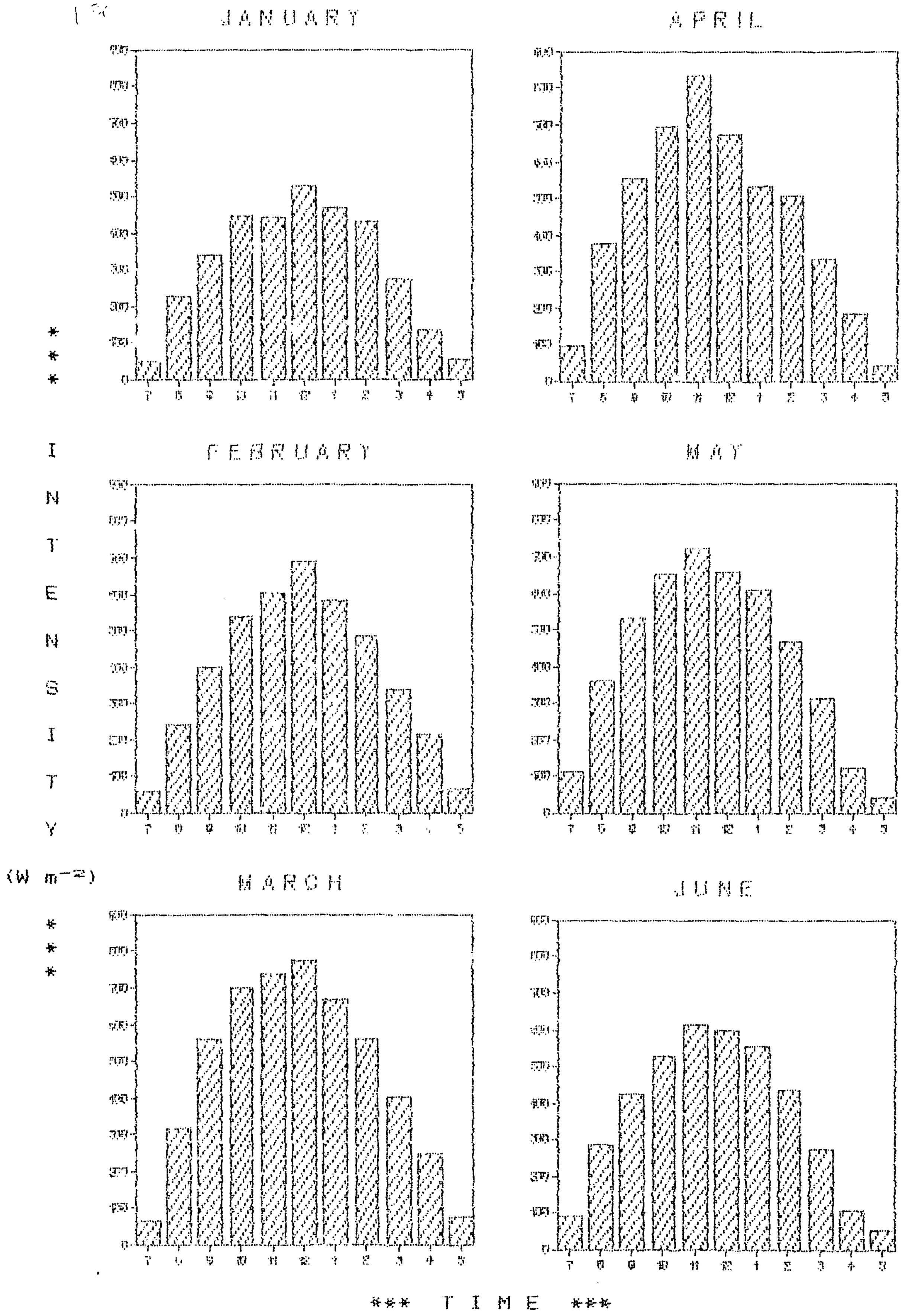


Figure 5.1 Daily Irradiation Distribution

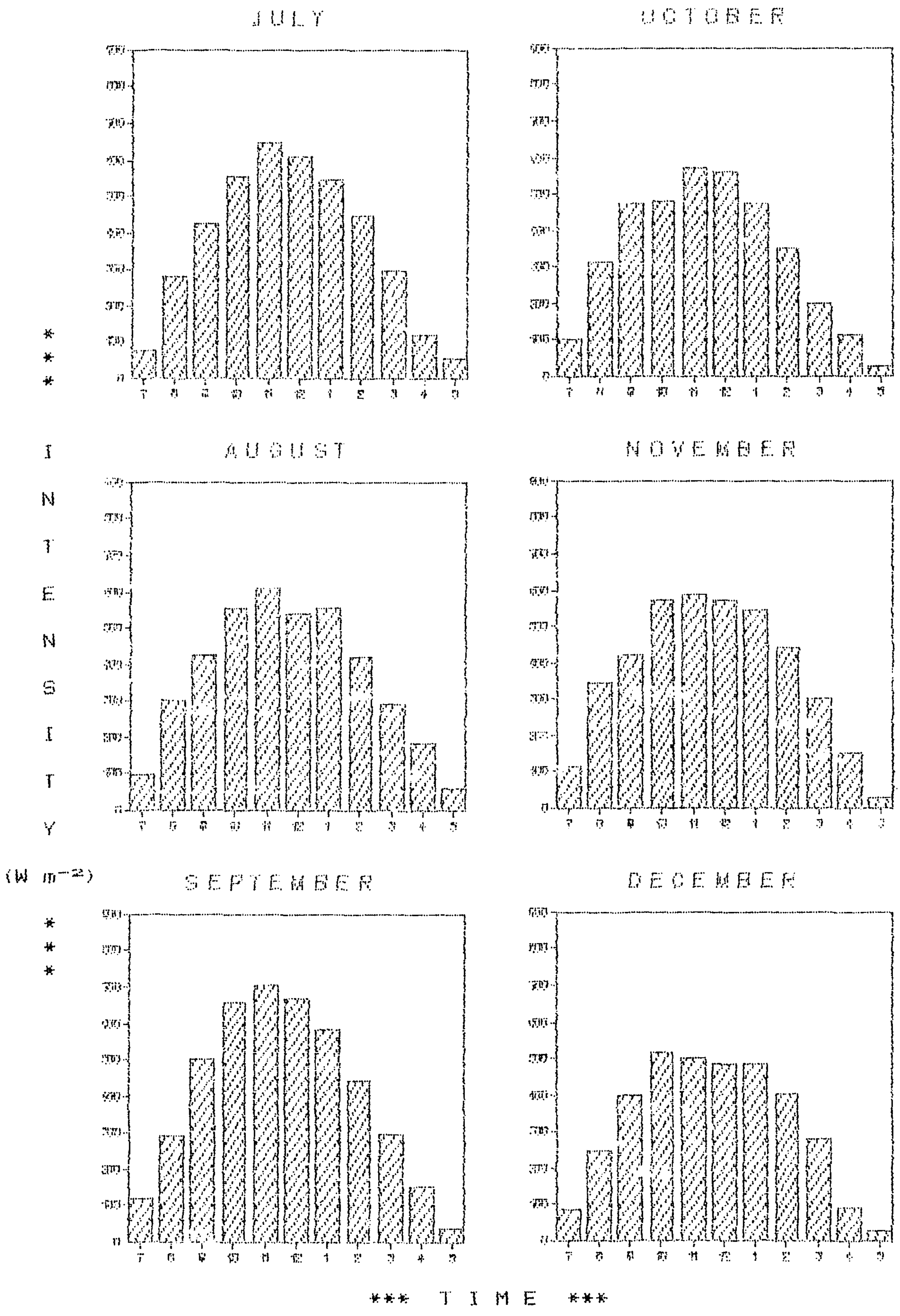


Figure 5.2 Daily Irradiation Distribution

5.1.3 Threshold Irradiation and Usable Energy

An initial statement must be made. The irradiation sensors register all incoming energy, also the low intensity energy of early morning and late afternoon which partly can be recovered by tracking, and the low irradiation of cloudy days.

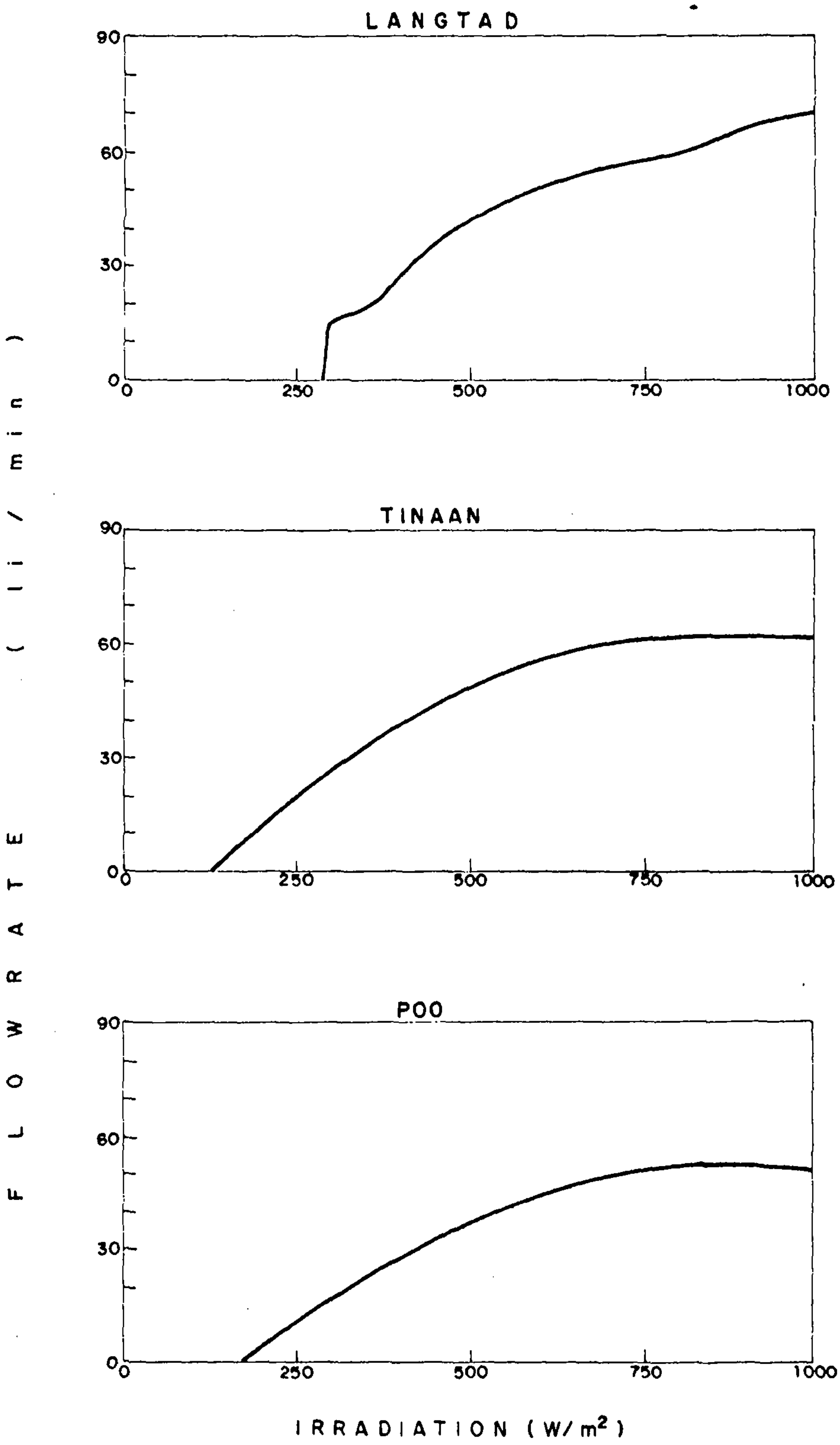
In Langtad, the inverter was equipped with a cut-off mechanism which reduced the pump rotation drastically as soon as the irradiation fell below a certain threshold. The aim is to reduce mechanical wear once the available energy drops so low that no significant production is possible. This threshold value is about 300 W m^{-2}. Namely the more reliable supervisor's observations, see Table C.1, show that the pumping rate is 0 L sec^{-1} as long as irradiation is below 300 W m^{-2}, which pumping rate jumps to some 15 L min^{-1} as soon as the irradiation rises over 300 W m^{-2}. The question then is if this cut-off reduces the wear significantly to justify the extra costs of the circuitry and the lower rate of utilization of the irradiation.

The small irregularities in these observations are largely due to fluctuations in the irradiation during the observation periods of about 5 minutes. Note that the pumping rates are derived from water meter readings made at 60 seconds intervals, while the irradiation was read on digital meters (with 2 seconds integration time) directly before or after the water meter readings. Ideally one needs concurrent readings of meters with identical integration periods.

In Tinaan or Poo the supervisor's sheets, Tables C.2 and C.3 do not give such distinct discontinuity in the irradiation-pump rate diagram. The non-regulated DC causes a lower pump rotation with lower irradiation. Thus the pump rate decreases gradually until at a much lower irradiation level, about 200 W m^{-2}, the centrifugal pump loses its effectivity. Figure 5.3 illustrates this behavior.

Once figures are available about the amount of energy which the sun irradiates, it becomes important to determine the fraction which is efficiently used. This fraction depends on the system. Thus the collected data were analyzed for the different systems.

In a first approach one multiplies the irradiation as tabulated in Table 5.2 with the active area of the photocells to determine the collected energy. However, manufacturers do not specify the active area of their photocells. The leads which are necessary to collect the photocurrent, cover namely an appreciable part of the surface of the cell, confer Table 4.1. But this is



IRRADIATION VS. FLOWRATE

FIG. 5.3

correct for direct radiation only, the diffuse radiation may still activate electrons in the shade of the leads. A check of the geometric area of the cells revealed that manufacturers have sufficiently standardized the cell area to accept that one cell covers 0.01 m^2. To cut a possibly long discussion short, the active area of a panel has been defined as the number of cells per panel times 0.01 m^2. Thus the 3 sites have 8.40m^2 resp. 4.32m^2 and 3.96 m^2 as area of photocells, based on their respective installed number of cell. Taking then a 12-months average (Table 5.2), the Langtad system received

123 × 8.40 = 1033 kWh per month in the plane of the cells.

The tracking in Tinaan produced 11% more irradiation in the plane of the photocells. Thus the Tinaan system received in the plane of the cells:

$$1.11 \times 123 \times 4.32 = 578 \text{ kWh per month.}$$

The effect of this irradiation is in Langtad a 12-months average of 449 m^3 water per month. The average height over which this volume has been lifted is 20.2 m. The peculiar properties of the well made it difficult to measure this value with an accuracy better than 10%. Thus this volume water acquired

$$449 \times 9800 \times 20.2 = 8.9 \times 10^7 \text{ joules.}$$

The average systems efficiency is then

$$\frac{8.9 \times 10^7}{1033 \times 3.6 \times 10^6} = 2.4\%.$$

The Tinaan data do not permit an efficiency calculation over 12 contiguous months. The 9 months with enough data miss some of the dark and some of the sunny months and may give an acceptable average. The irradiation over these months averages 137 kWh m^{-2} and the production 654 m^3. With an average lift of 8.5 m the acquired energy was

$$654 \times 9800 \times 8.5 = 5.4 \times 10^7 \text{ joules.}$$

The available energy was 592 kWh or 2.13 × 10^9 joules.

This gives a system's efficiency of 2.6%.

5.1.4 Remarks about Ohmic Losses

The higher efficiency of the Langtad system can be partially explained by the lower electric losses of the 3-phase AC system as compared with the other DC systems.

The system of Langtad used 3 wires, AWG 12, 3-phase Y circuit, to transport 693 W over 80 m. No data about the power factor, or losses in the inverter are available. For the calculation the optimistic assumption has been made that the power factor equals one, but that no power is lost in the inverter. The supposedly high power factor results in a low current and low ohmic loss which compensates the assumed no-loss condition of the inverter. The conclusion is that the current is 231 W/60 V = 3.9 A per wire and the energy loss is 3 x 14.8 x 0.44 = 19.6 W (about 3% of 693 W), at peak irradiation.

The system in Tinaan used 2 wires, AGW 12, to transport 516 W DC at 60 V over 90 m. The current is 516 W/60 V = 8.6 A and the energy loss is 2 x 74.0 x 0.50 = 74 W (about 14% of 516 W).

In Poo the system used only 10 m wire to transport the electrical energy. This corresponds with 7.0 W loss of energy (about 1.5% of 480 W).

From the calculations it becomes clear that special efforts must be made in small systems to keep the ohmic losses low.

For small systems the use of a regulated inverter may be debatable. It is not clear if the extra cost of an inverter balances the better use of the solar energy. This is especially true when the inverter does not produce a standard voltage and thus still requires a special electric motor. The regulated inverter and its consequence, a better utilization of the solar energy, points the way to future developments. Even if the inconvenience of carbon brushes in submersible DC motors is not considered, the nearly 100 years of experience with AC cannot easily be overtaken.

5.2 Efficiency of the Energy Conversion

The small global efficiencies make a further analysis desirable. For this analysis is available a large volume of operator's data, hourly readings over more than one year, and a smaller volume of higher quality supervisor's data, hourly readings over some 30 days. The operator's data are utilized through daily total or averages while the supervisor's data are entered as individual data points in the corresponding formula.

5.2.1 Conversion of Solar to Electrical Energy

From the large volume of data collected by the operator it was possible to calculate the efficiency of the conversion of irradiation to electricity. Instantaneous values of irradiation, closed circuit voltage and current were read every hour. The efficiency is calculated by the following formula:

$$\text{efficiency} = \frac{\text{voltage} \times \text{current}}{\text{irradiation} \times \text{active area.}}$$

The results of the calculations are given in Table 5.4, for Langtad with 8.4 m^2 and for Tinaan with 4.3 m^2.

This is a summary of Table B.1 to B.3 and B.5 to B.7 respectively.

The quality of the meters, the weakness of the observers and the distraction of the data handlers resulted in efficiencies of less than 0% or more than 20%. Such values are obviously erroneous and were not included in the computation of the averages.

Similar observations have been made in all three stations by better trained supervisors. Their observations are given in Annex C.1, C.2 and C.3.

The efficiencies calculated by means of these data are given in Table 5.5,

for Langtad	covering	33 days,
for Tinaan	covering	16 days,
for Poo	covering	10 days.

The spread of these efficiency values in each station is much less. Correspondingly one is inclined to attribute more confidence to these values. These efficiency values are 6.0%, 9.0% and 8.5% respectively. Again note the low efficiency at low irradiation.

It has not been possible to explain the systematic large difference in efficiencies based respectively on operator's and supervisor's data. The original supposition that errors caused by lack of training would cancel out, on the large number, has not been proven correct.

Table 5.4
Efficiency of Energy Conversion
Solar Irradiation to Electrical Energy

Langtad Overall Average: 5.8%

Month/Time	7	8	9	10	11	12	1	2	3	4	5
Feb 1984	2.6	5	6	5.9	6.1	6.3	5.4	5.2	4.6	3.9	2.4
May 1984	3.6	5.9	6.8	6.6	6.4	6.4	6.5	6.2	5.6	5.2	2.6
Jun 1984	4.2	5.9	6.4	7.1	6.6	6.7	6.9	6.4	5.1	4.5	3.2
Jul 1984	3.5	5.9	6.5	6.7	6.6	6.6	6.9	6.4	6	5.4	3
Aug 1984	4.2	5.8	6.5	6.4	7	6.8	6.6	6.4	5.9	4.7	3
Sep 1984	4.9	6.9	6.5	6.9	6.9	6.8	6.2	6.3	5.4	4.5	2.6
Oct 1984	4	6.2	6.2	6.7	6.6	6.6	6.5	5.8	5.2	4.8	2.1
Nov 1984	3.6	5.3	6.2	6.8	6.2	6	6.2	5.9	5.4	4	1.8
Dec 1984	3.9	6.2	6.6	6.7	6.4	6.4	6.4	6.4	5.7	4.5	1.6
Jan 1985	4.5	7.5	8	7.1	8	6.8	7.6	6.4	6.1	5.2	3.4
Feb 1985	3	6.4	6.8	6.9	6.8	6.9	7.3	6.2	6.6	5.7	3.1
Mar 1985	3.1	5.9	7	7.1	6.9	7.1	7	6.7	4.4	6.3	4
Apr 1985	4.4	6.6	7.7	7.3	6.7	7	6.3	7.3	7.2	6.4	4.5
Average:	3.8	6.1	6.7	6.8	6.7	6.7	6.6	6.3	5.6	5	2.9

Tinaan Overall Average: 6.6%

May 1984	7.8	8.5	9.0	8.7	9.0	7.8	8.7	7.7	6.8	5.5	4.3
Jun 1984	5.8	8.5	9.4	9.3	7.8	8.7	7.7	6.5	5.4	3.6	1.7
Aug 1984	5.4	6.9	7.8	8.5	8.1	8.0	8.2	7.8	5.8	5.2	3.0
Sep 1984	6.5	8.5	8.8	7.8	8.5	8.2	7.8	6.4	5.8	5.2	1.9
Oct 1984	2.3	7.8	7.4	9.3	9.1	7.8	8.0	7.4	5.5	4.5	0.1
Nov 1984	4.5	9.0	8.2	8.5	8.5	8.5	7.2	7.2	7.2	5.8	0.4
Dec 1984	3.0	4.5	7.1	7.7	7.4	5.8	6.5	7.5	6.5	6.5	2.3
Jan 1985	2.2	2.5	6.2	5.9	4.6	6.5	8.1	6.7	5.8	4.9	1.2
Feb 1985	1.4	5.6	5.2	5.8	6.5	8.1	6.8	7.4	5.9	4.6	0.1
Mar 1985	5.4	8.1	8.5	8.1	8.2	8.1	7.2	6.8	7.1	7.2	3.8
Jun 1985	3.8	5.9	6.5	6.8	7.7	7.4	7.2	6.1	5.4	4.5	2.0
Jul 1985	6.9	8.2	8.7	8.5	8.1	8.2	8.0	7.5	7.2	7.2	3.0
Aug 1985	7.8	9.4	9.4	7.5	8.8	8.5	8.2	9.1	8.0	7.4	5.1
Average:	4.8	7.2	7.8	7.8	7.8	7.8	7.7	7.2	6.4	5.6	2.3

Note: Efficiencies less than zero and greater that 20 have been deleted before computing the average.

Table 5.5
Efficiency of Energy Conversion
Solar Irradiation to Electrical Energy

Langtad Supervisor

Date/Time	7	8	9	10	11	12	1	2	3	4	5	Ave.
29 Feb 1984		6.8	6.8	6.8	7.0	7.0	7.5	3.7	6.5	5.7	0.0	5.8
15 Apr 1984		7.2	6.4	6.6	7.9	7.3	0.0	0.0	0.0	0.0	0.0	3.5
28 Apr 1984	3.7	7.6	6.7	6.6	6.4	6.4	6.5	6.5	6.4	4.2	2.9	5.9
05 May 1984	3.6	6.4	6.6	6.7	6.7	6.5	6.6	4.5	5.8	4.0	11.2	6.3
12 May 1984	2.5	6.2	6.6	6.7	6.4	6.4	6.5	6.0	6.2	6.0	3.1	5.7
19 May 1984	5.1	5.7	6.8	6.8	6.8	6.8	6.7	6.4	3.9	4.4	2.7	5.6
26 May 1984	5.1	3.4	6.8	6.7	6.7	6.5	6.7	6.7	6.6	8.0	3.4	6.0
02 Jun 1984		5.5	5.2	6.8	6.7	6.7	6.5	6.3	6.4	3.8	2.2	5.6
09 Jun 1984	4.2	4.0	5.4	7.0	6.8	6.7	6.8	6.8	6.8	4.0	1.7	5.4
16 Jun 1984	4.5	5.8	7.1	6.8	6.4	7.3	15.1	7.3	7.0	5.0	4.4	7.0
23 Jun 1984	3.6	6.2	6.8	6.5	6.8	7.2	7.0	6.6	6.2	4.6	3.5	5.9
07 Jul 1984	4.3	7.8	7.3	7.1	6.8	6.8	6.8	6.9	7.2	4.7	2.5	6.2
14 Jul 1984	1.9	6.6	6.7	6.8	6.8	6.8	6.7	6.8	5.2	5.2	4.1	5.8
21 Jul 1984	3.5	6.5	6.9	6.9	6.8	6.7	6.7	5.3	5.2	9.1	1.7	5.9
28 Jul 1984	3.0	4.8	7.3	7.3	9.4	5.0	4.5	8.8	6.8	4.9	3.2	5.9
18 Aug 1984	4.5	6.8	7.1	7.3	7.6	6.6	7.6	9.8	7.4	5.5	3.5	6.7
25 Aug 1984	3.8	6.6	7.0	7.1	10.5	6.0	0.7	6.8	6.0	6.4	1.1	5.6
03 Nov 1984	1.7	6.8	6.9	6.9	5.9	7.8	5.5	7.1	3.8	4.5	1.7	5.4
10 Nov 1984	2.8	4.2	7.1	7.0	7.6	5.9	6.2	5.8	7.0	4.2	1.2	5.4
12 Jan 1985	4.2	7.0	7.2	6.8	4.8	8.0	7.6	4.5	4.1	8.0	4.5	6.0
19 Jan 1985	4.9	8.2	8.2	8.2	7.7	7.7	7.5	7.6	3.5	2.7	2.5	6.3
29 Jan 1985	1.7	6.9	7.8	6.4	7.7	7.4	7.4	7.9	5.3	5.1	3.4	6.1
02 Feb 1985	3.4	6.8	7.3	7.2	7.6	6.3	5.4	7.3	6.7	2.7	4.5	5.9
09 Feb 1985	1.8	6.4	7.1	7.3	7.3	7.1	7.2	7.3	7.3	5.0	5.4	6.3
16 Feb 1985	4.2	5.0	6.6	6.5	6.8	6.1	7.3	7.2	6.4	5.6	3.8	5.9
23 Feb 1985	4.6	6.5	7.2	7.3	7.0	7.3	6.9	7.2	7.3	14.4	0.8	6.9
02 Mar 1985	2.1	3.4	7.3	7.3	7.2	7.1	9.5	6.4	7.5	6.2	3.8	6.2
09 Mar 1985	3.3	6.7	7.3	7.3	7.2	7.3	7.3	6.7	7.0	5.4	2.8	6.2
16 Mar 1985	2.6	5.0	7.2	4.3	7.2	7.1	12.6	2.4	7.4	3.2	3.7	5.7
23 Mar 1985	4.3	5.9	7.2	7.3	7.1	7.1	6.3	7.3	6.9	4.8	2.3	6.0
30 Mar 1985	2.3	7.3	2.5	7.3	7.3	7.1	7.3	6.8	5.8	4.0	4.5	5.6
06 Apr 1985	2.9	6.9	7.3	7.3	7.6	7.3	5.2	7.2	7.1	6.4	2.5	6.2
22 Oct 1985	0.0	6.8	7.1	7.2	7.0	7.0	4.3	7.2	7.2	5.9	0.0	5.9
Average:	3.5	6.2	6.8	6.9	7.1	6.8	6.9	6.6	6.3	5.4	3.3	6.0

Table 5.5 (continued)
Efficiency of Energy Conversion
Solar Irradiation to Electrical Energy

Tinaan Supervisor

Date/Time	7	8	9	10	11	12	1	2	3	4	5	Ave.
08 Jul 1984		10.1		9.9	10.6	10.6	11.2					10.4
14 Jul 1984		13.7	10.3	9.9	10.0	9.8	9.4	10.0	4.1	5.3		9.2
29 Jul 1984		8.5	10.0	10.4	10.3	6.2	9.4	8.0	10.0			9.1
31 Oct 1984				10.9	9.0	10.7	9.9	6.2	5.5	4.1	0.7	7.2
18 Nov 1984			11.0	9.8	9.4	9.8	9.4	6.9	5.5	5.3	4.4	7.9
03 Feb 1985		12.9	14.0		9.9	10.1	4.9	10.3	9.9	8.8	6.6	9.7
10 Feb 1985			9.8	5.1			9.0	9.2	9.3	5.1		7.9
17 Feb 1985		14.9	11.6	5.9	6.2	13.1	9.4		9.9	11.1	7.0	9.9
10 Mar 1985	7.3	9.9	9.1	7.3	6.7	7.3	5.9	7.5	4.7	4.3		6.9
17 Mar 1985		11.1	7.6	8.6	6.3	9.4	11.2	8.8	6.3			8.7
14 Apr 1985		7.4	3.7	8.2	7.2	6.6	12.1	6.3	9.3	5.1		7.3
04 Aug 1985	7.0	11.0	10.0	9.3	7.4	4.7	5.9	13.5	11.1	6.9		8.7
11 Aug 1985		5.0	8.1	11.9	10.0	9.7	10.1	13.7	9.9	13.5		10.3
18 Aug 1985		10.7	10.1	10.7	9.7	9.3	9.8	12.1	9.4	3.5		9.4
23 Oct 1985	11.8	11.0	9.9	10.3	9.3	9.4	8.7	10.3	10.7	10.9	10.0	10.3
17 Nov 1985		11.2	12.7	12.5	11.0	13.3	13.0	5.3	3.8	4.1		9.7
Average:	8.7	10.3	9.8	9.3	8.6	9.2	9.2	9.1	8.2	6.9	5.7	9.0

Poo Supervisor

Date/Time	7	8	9	10	11	12	1	2	3	4	5	Ave.
26 Feb 1985	5.3	6.0	6.1	8.5	7.2	7.2	8.0	7.2	8.0	7.8	6.1	7.1
28 Feb 1985	6.2	8.0	6.1	7.9	7.3	8.3	8.1	9.1	7.7	8.2	6.4	7.5
25 Mar 1985	7.0	8.1	8.5	9.2	10.2	10.5	9.6	11.0	11.2	10.3	2.8	9.0
21 May 1985	8.7	9.6	9.6	10.4	10.4	11.3	10.3	10.2	7.2	3.4	3.0	8.5
22 May 1985	7.2	10.5	11.1	9.8	10.2	7.4	9.6	9.6	11.1	8.4	8.3	9.4
29 Sep 1985	6.8	10.0	6.4	7.3	10.6	9.3	9.1	6.5	8.4	6.8	10.1	8.3
09 Oct 1985	3.1	4.5	3.8	8.0	9.5	11.2	10.0					7.2
20 Oct 1985		9.9	9.1	9.6	8.7	8.8	9.2	10.5	11.2	8.8	8.4	9.4
27 Oct 1985			10.3	9.9	9.2	9.2	9.6	11.0	10.6	11.8		9.1
16 Nov 1985		7.2	10.6	10.8	11.1	11.9	10.9	7.8	7.0	7.0		9.3
Average:	6.3	8.2	8.2	9.1	9.4	9.5	9.4	9.2	9.2	8.1	6.4	8.5

5.2.2 Conversion of Electrical to Mechanical Energy

Water acquires energy when lifted according to the formula:

energy = mass x "g" x head.

In the same way the energy lost by friction can be formulated as:

energy = mass x "g" x head

in which formula the head is calculated by means of the Hazen-Williams formula. In both cases the flow rates were used so that actually mechanical power was calculated. This can then easily be compared with the electrical power, which is found by multiplying instantaneous current with voltage. A problem in the field arose from the fact that the water meters had to be observed over 60 seconds during which the irradiation and thus the current fluctuated. Thus a clear cause of errors was introduced by comparing an average value, flow rate, with instantaneous values, voltage and current. Analogue meters permit accurate readings of averages by experienced observers. The actual digital solarimeter made this averaging more difficult. It seems that there is a tendency to record the higher values. The result is an efficiency which is at the low side.

The efficiency is calculated by the following formula:

$$\text{efficiency} = \frac{\text{mass} \times \text{"g"} \times \text{head}}{\text{voltage} \times \text{current}},$$

The results of the calculations are given in Table 5.6. Table B.4 and B.8 give the hourly observations which are required for these calculations.

A few values smaller than 0% or larger than 90% have been omitted in the calculations as clearly caused by instrument or human error.

A striking difference is that in Langtad there are periods that the pump does not run as can be seen from the efficiency being zero. The inverter is arranged so that the pump stops when the available energy is such that hardly any water would be pumped. This arrangement saves the mechanical parts of the pump. But when the pump operates, its efficiency is about twice the efficiency of the DC pump of Tinaan.

Table 5.6
Efficiency of Energy Conversion
Electrical to Mechanical Energy

Langtad Overall Average: 30.6%

Month/Time	7	8	9	10	11	12	1	2	3	4	5
Feb 1984	0.0	12.0	26.0	31.8	33.7	32.8	30.3	29.6	15.1	5.0	0.0
Apr 1984	0.0	35.1	43.4	41.5	40.8	38.4	37.6	36.9	22.2	2.3	0.0
May 1984	0.0	36.1	49.2	45.7	47.2	40.4	42.7	38.2	24.0	0.0	0.0
Jun 1984	0.0	23.8	37.6	40.4	40.3	40.3	36.7	25.1	15.4	0.0	0.0
Jul 1984	0.0	23.2	36.9	41.3	41.0	42.8	39.5	34.3	18.3	1.3	0.0
Aug 1984	0.0	21.9	36.7	40.4	40.8	35.2	42.1	31.0	13.9	2.6	0.0
Oct 1984	0.0	23.9	37.6	39.1	37.1	33.3	30.1	16.9	5.2	0.0	0.0
Nov 1984	0.0	32.5	37.7	39.3	36.9	40.2	30.7	31.7	20.5	0.0	0.0
Dec 1984	0.0	24.7	31.2	33.6	37.6	25.6	30.7	27.7	18.8	0.0	0.0
Jan 1985	0.0	18.2	22.8	33.8	34.8	39.3	26.5	24.2	18.1	0.0	0.0
Feb 1985	0.0	33.5	45.0	40.2	43.0	44.5	36.7	35.5	28.9	7.7	0.0
Mar 1985	0.0	35.1	47.9	46.5	42.0	40.2	35.9	36.8	30.4	12.4	0.0
Apr 1985	0.0	38.4	47.7	41.2	43.7	39.3	42.1	36.3	32.8	4.5	0.0
Average:	0.0	27.6	38.4	39.6	39.9	37.8	35.5	31.1	20.3	2.8	0.0

Tinaan Overall Average: 26.1%

May 1984	40.3	26.2	23.3	22.1	22.4	25.0	25.2	27.7	40.4	31.7	19.2
Jun 1984	38.5	32.9	32.2	28.9	40.1	38.7	44.0	45.7	25.5	28.6	11.1
Aug 1984	21.8	30.3	29.9	26.2	31.4	30.0	27.2	32.0	33.5	15.8	9.2
Sep 1984	30.1	25.9	27.0	25.5	22.8	22.9	21.6	19.7	27.0	16.5	2.7
Oct 1984	34.1	37.1	21.7	35.2	27.5	26.3	38.0	39.8	33.2	22.1	3.0
Nov 1984	31.7	20.8	26.8	24.3	33.1	23.3	30.2	29.2	27.6	28.0	0.0
Dec 1984	31.5	41.6	27.8	28.2	29.6	30.7	21.6	30.5	30.6	30.4	4.9
Feb 1985	29.4	39.9	24.1	21.4	30.4	20.7	23.8	25.4	21.4	21.3	24.4
Mar 1985	33.7	26.4	32.9	26.7	28.2	33.8	33.2	34.8	28.0	25.1	12.7
Apr 1985	10.4	22.9	28.2	28.7	29.2	31.1	22.2	19.8	13.4	12.8	2.6
May 1985	18.6	22.3	24.9	28.8	32.9	28.3	22.2	18.8	16.6	8.9	0.0
Jun 1985	16.2	26.8	36.3	33.3	29.6	27.4	28.3	31.3	46.3	11.8	12.3
Jul 1985	19.3	23.4	21.0	19.0	21.5	25.9	27.6	26.6	24.3	29.3	15.0
Aug 1985	28.2	30.0	28.4	28.9	25.6	30.2	27.4	30.0	33.0	24.0	24.1
Average	27.4	29.0	27.5	26.9	28.9	28.2	28.0	29.4	28.6	21.9	10.1

The supervisor's observation produced Table 5.7. The small number of data is caused by the fact that not everytime all meters were simultaneously operational.

Table 5.7
Efficiency of Energy Conversion
Electrical to Mechanical Energy

Date/Time	7	8	9	10	11	12	1	2	3	4	5	Ave.
Langtad									Supervisor			
15 Apr 1984		20	34	36	38	33						32
05 May 1984		38	41	50	46	43	39					43
12 May 1984		39	41	44	43	46	43	31	30			40
16 Jun 1984			37	44	47	38	33	41	38			40
02 Mar 1985		36	45	48	42	41	43	46	42			43
09 Mar 1985		41	45	42	47	45	43		46			44
30 Mar 1985		37		45	49	42	40					43
Average:		35	41	44	45	41	40	39	39			41
Tinaan									Supervisor			
31 Oct 1984					25	41	23	28	30			29
18 Nov 1984		29	20	18	19	18	42	29				25
03 Feb 1984			21	18	17	55	17	17	52			28
14 Apr 1984					22	30	22	11	17	14	22	20
10 Mar 1984			23	24	26	22	23	56	29	31	36	30
17 Mar 1984			15	50	57	64	36	26	39	62		44
11 Aug 1984				57	18	20	19	19	20	21	11	23
18 Aug 1984			18	20	19	20	18	20	22	30		21
Average:		29	19	31	25	34	25	26	30	32	23	27
Poo									Supervisor			
21 May 85			32	30	27	27	25	27	28	56	57	34
22 May 85			35	30	29	28	47	34	30	27		33
29 Sep 85		29	26	24	30	23	25	28	68	68	34	36
20 Oct 85		30	30	29	29	28	28	29	32	43	54	33
27 Oct 85					27	27	28		28	34	33	30
Average:		30	31	28	28	27	31	30	37	46	45	33

5.2.3 Conversion of Solar to Mechanical Energy

The collected data permitted the calculation of the overall efficiency by relating the hourly collected irradiation with the hourly produced volume of water. This gives probably the best evaluation of the system's performance. The reasons are that human errors are much reduced:

a. the readings are cumulative, no averaging is required,

b. a late reading, i.e. a too long integration time, affects irradiation and volume readings in a proportional way and does not affect the efficiency value.

The uncertainty caused by the varying head in the Langtad well remains. It is estimated that this may result in an uncertainty of 5% of the final figures.

The uncertainty introduced by solar and water meters error remains too.

The results of the calculation are found in Table 5.8.

The efficiencies, 1.5% and 1.3% respectively, differ markedly from the efficiencies calculated by means of the supervisor's observations. The results are tabulated in Table 5.9 as 2.2% and 2.6% respectively. It should be noted that actual instrumentation does not permit to definitely chose between AC or DC systems.

5.2.4 Stability of Panel Performance

As indicated above short circuit currents and open circuit voltages have been recorded at many instances. Also a few I-V curves at constant irradiation have been observed. Over the 2-years period of observation no changes could observed. It is planned to observe I-V curves once a year to check if changes in the cell performance will become observable.

5.2.5 Influence of Panel Temperature on Performance

Temperatures have been measured. They reached around noon 65°C on clear days. It was not possible to see changes in performance attributable to the temperature. This is understandable as only above 60°C an appreciable influence may be expected.

Table 5.8
Efficiency of Energy Conversion
Solar Irradiation to Mechanical Energy

Langtad — Overall Average: 1.5%

Month	7	8	9	19	11	12	1	2	3	4	5
Feb 1984	0.0	0.5	1.2	1.4	1.5	1.5	1.5	1.3	0.7	0.2	0.0
May 1984	0.0	1.7	2.4	2.1	2.1	1.8	2.0	1.7	1.0	0.0	0.0
Jun 1984	0.0	1.1	1.7	2.0	1.9	1.9	1.8	1.2	0.7	0.0	0.0
Jul 1984	0.0	1.0	1.7	2.0	1.9	2.0	1.9	1.7	0.9	0.1	0.0
Aug 1984	0.0	1.0	1.7	2.0	2.1	1.8	1.9	1.5	0.7	0.1	0.0
Sep 1984	0.0	1.5	2.0	2.1	2.1	2.1	1.5	1.2	0.9	0.1	0.0
Oct 1984	0.0	1.2	1.8	2.0	1.7	1.8	1.4	0.7	0.2	0.0	0.0
Nov 1984	0.0	1.6	1.7	2.0	1.9	1.7	1.4	1.5	0.9	0.0	0.0
Dec 1984	0.0	1.2	1.4	1.7	1.7	1.3	1.5	1.4	0.9	0.0	0.0
Jan 1985	0.0	0.9	1.2	1.7	1.8	1.9	1.5	1.2	0.9	0.0	0.0
Feb 1985	0.0	1.7	2.1	2.1	2.1	2.1	1.9	1.7	1.5	0.5	0.0
Mar 1985	0.0	1.5	2.3	2.2	2.1	2.0	1.8	1.7	1.5	0.6	0.0
Apr 1985	0.0	1.9	2.5	2.2	2.1	1.9	1.7	1.7	1.2	0.1	0.0
May 1985	0.0	2.0	2.1	2.3	2.1	1.8	1.5	1.2	1.1	0.0	0.0
Jun 1985	0.0	1.0	2.0	2.1	2.0	2.1	1.7	1.6	0.8	0.0	0.0
Jul 1985	0.0	1.2	2.0	2.0	1.8	1.8	1.7	1.4	1.2	0.0	0.0
Average:	0.0	1.3	1.9	2.0	1.9	1.9	1.7	1.4	0.9	0.2	0.0

Tinaan — Overall Average: 1.3%

May 1984	1.9	1.4	1.3	1.2	1.3	1.3	1.3	1.3	1.6	1.1	0.7
Jun 1984	1.7	1.6	1.8	1.7	1.7	1.8	1.7	1.6	1.0	1.2	0.4
Jul 1984	1.4	1.4	1.4	1.3	1.6	1.6	1.3	1.4	1.2	0.8	0.5
Aug 1984	1.2	1.3	1.4	1.4	1.3	1.4	1.4	1.4	1.6	0.7	0.6
Sep 1984	2.4	1.4	1.4	1.4	1.2	1.2	1.1	1.0	1.2	0.7	0.2
Nov 1984	3.1	1.6	1.4	1.2	1.7	1.2	1.3	1.2	1.2	1.4	1.6
Dec 1984	1.2	1.3	1.4	1.4	1.7	1.6	1.2	1.6	1.7	1.1	0.2
Mar 1985	1.1	1.6	1.4	1.3	1.4	1.7	1.6	1.7	1.3	1.2	0.5
Apr 1985	0.6	1.0	1.2	1.1	1.2	1.3	0.5	0.6	0.2	0.5	0.2
Jun 1985	0.8	1.4	1.8	1.8	1.7	1.6	1.6	1.3	1.8	1.7	0.7
Jul 1985	1.1	1.3	1.3	1.1	1.4	1.6	1.4	1.3	1.2	1.3	0.6
Aug 1985	1.7	1.8	1.6	1.4	1.4	1.4	1.3	1.4	1.6	1.2	1.2
Average:	1.6	1.4	1.4	1.3	1.4	1.4	1.3	1.3	1.3	1.1	0.6

Table 5.9
Efficiency of Energy Conversion
Solar Irradiation to Mechanical Energy

Langtad									Supervisor		
Date/Time	7	8	9	10	11	12	1	2	3	4	5	Ave.
15 Apr 84			2.4	2.1	1.6	1.8	1.9	2.1	3.0	0.4		1.9
05 May 84		0.2	2.8	0.6	1.6	2.3	1.8	5.1	4.0			2.3
12 May 84		0.3	3.0	2.6	2.6	2.6	2.4	2.3	1.8	1.7		2.1
16 Jun 84		0.5	1.2	2.8	2.8	3.6	1.6	2.5	2.3	0.7		2.0
02 Mar 85		0.2	1.8	2.9	3.0	2.8	2.9	2.6	2.4			2.3
09 Mar 85		0.3	6.4	2.6	3.5	3.1	2.5	1.6	2.2			2.7
30 Mar 85		1.9	1.9	3.4	3.0	3.0	3.0	2.6	1.2	1.7		2.4
Average:		0.6	2.8	2.4	2.6	2.7	2.3	2.6	2.4	1.2		2.2

Tinaan									Supervisor			
31 Oct 84				0.5	3.0	1.0	2.5	4.8				2.4
18 Nov 84			4.2	1.3	2.4	1.1						2.3
03 Feb 84			3.1	2.5	3.5	2.9	3.5	2.1				3.0
10 Mar 85		1.7	3.3	2.3	2.9	1.8	1.6	4.4				2.5
17 Mar 85		0.7	2.7	1.6	2.1	3.1						2.0
14 Apr 85				6.4	4.1	1.7	1.9	4.2				3.7
11 Aug 85			1.3	1.8	1.2	3.8	1.7	2.7	2.6			2.1
18 Aug 85			2.7	5.6	3.3	2.6	2.0	2.6				3.2
Average:		1.2	2.9	2.7	2.9	2.3	2.1	3.5	2.6			2.6

Poo												
21 May 85		1.8	4.9	2.4	2.1	3.2	2.7	2.7	2.9	3.0	1.4	2.7
22 May 85		1.2	1.4	1.9	1.2	2.7	2.6	2.3	2.1	1.6		1.9
29 Sep 85		1.4	3.1	3.5	3.2	2.6	3.1	3.2	3.8	4.0	3.1	3.1
20 Oct 85					3.3	2.6	3.1	2.8	3.5	4.5	2.9	3.2
27 Oct 85				2.2	2.6	3.3	3.5	2.8	3.9	3.1		3.1
Average:		1.4	3.1	2.6	2.4	2.9	3.0	2.8	3.2	3.2	2.4	2.8

5.3 Social and Economic Acceptability

5.3.1 Social Aspects

The two installations in Langtad and Tinaan where originally intended to evaluate the technical aspects only. Accessability for potential customers was an important asset. Furthermore, the installations were introduced to the users as temporary test set-ups.

In Langtad the users appreciated the solar pump to the extent that they bypassed a not efficient handpump to walk about 100 meters more to the solar pump. However, the number of houses around the array started to increase in the beginning of 1986. Thus the landowner expected more income from this parcel. So the people chose a sturdy handpump which costs about P150.00 per year for maintenance above a more luxurious, but also more expensive solar pump. The landowner expected namely some P700.00 per year as lease. The unfamiliarity of the solar pump contributed to this decision.

In Tinaan the solar pump brought water at a point about 300 meters away from the existing supply. Only a relatively small portion of the users saw the walking distance reduced to nearly nothing. The solar pump was intensively used for the laundry, a sign that the automatic pumping was appreciated. But after the observation period, when the landowner started talking about payment for the land lease, the people found it better to fall back on their original supply. The owner intends to install a pump of about 5 kW to supply a sitio at about 0.5 km distance. Thus the new well would be fully utilized. The experiment caused at least some lasting improvement on the site.

The installation in Poo was from its beginning intended to replace another expensive water supply system. Drinking water was provided to this barrio by motorized tricycles at a cost of P1.50 per can of 20 liters, i.e. for P75.00 per cubic meter. Such conditions are not uncommon in places where freshwater wells can be found only at 2 or more kilometers distance. The acceptability of the system is understandable, when one considers that the price of the water is now P0.50 per 20 liters. An educated guess is that people spend about the same amount of money, thus that they use about 3 times more freshwater than before. For washing and bathing brackish to salt water was used and it still is. The use of rainwater has been expanded.

A more detailed financial analysis is discussed under 5.3.3. Its conclusion is that at a rate of P25.00 per cubic meter systems of 1 kW are viable, when panels plus pump go for $7.00 per peak watt and total pumping head is less than 20 meters.

5.3.2 Storage and Production

The technical aspect of an irregular time distribution of the irradiation must be solved by storage. Under the given conditions no electrical storage was attempted, because a ground level water tank is cheaper in acquisition and lasts longer than an equivalent battery.

Absolutely no data were available about irradiation distribution. Also the information about human consumption is qualitative only. So it was mainly guess work to design reservoirs of 150% of calculated daily production.

The reservoir in Langtad turned out to be 13 m^3 only, the result of a misunderstanding between the 3 involved parties: sponsor, contractor and designer. This reservoir had reasonably well bridged the gaps of low insolation in its first 6 months. So the decision was made to construct in Tinaan a similarly seized reservoir. In Poo the decision was made to follow the 150% rule, thus a reservoir of 22 m^3 was built.

The determination of the reservoir size was based on the following assumptions:

daily domestic consumption a low, but sometimes observed value,	40 liters
daily human consumption a probably high figure,	10 liters
longest series of sun-less days	2 days.

In this scenario everybody should have his domestic needs satisfied at the moment when in the afternoon the storage is reduced to 25% of the daily consumption. If the use of water at that instant is limited to human consumption only, a sun-less period of two days can be bridged.

At the other end of the range it is not very probable that more than two consecutive days of extreme insolation occur. Such days will bring a peak in the consumption too, so that waste of water will seldom occur. Thus average consumption will be matched with average supply.

In Table 5.10 the days of less than 2 kWh m^{-2}, i.e. less than 50% of the average irradiation have been compiled over a period of 630 days. Only once two consecutive

Table 5.10
LOW IRRADIATION DAYS
(less than 2.01 kWh m^{-2})

	LANGTAD		TINAAN	
Date	Radiation	Production	Radiation	Production
10 Nov 83	1.6	0.09		
18 Nov 83	1.9	0.21		
20 Nov 83	1.4			
21 Nov 83	1.8	0.47		
08 Dec 83	1.2	1.89		
14 Dec 83	1.0			
20 Dec 83	1.7	4.58		
27 Dec 83	1.4	1.01		
10 Jan 84	1.9	0.00		
12 Jan 84	1.9	1.34		
15 Jan 84	1.7	3.39		
17 Jan 84	1.3	0.43		
28 Jan 84	1.4	0.64		
29 Jan 84	1.6	2.92		
11 Feb 84	1.2	0.04		
19 Feb 84	1.4	0.34		
23 Feb 84	1.8	0.00		
26 Jun 84	1.5	0.00	1.3	4.29
23 Nov 84	1.6	0.00		5.80
26 Nov 84	1.6	4.75		7.70
30 Nov 84	1.2	0.00		2.51
08 Dec 84	1.6	2.91		2.45
14 Dec 84	0.5	2.86		0.00
15 Dec 84	0.3	0.00		0.00
17 Dec 84	0.9	2.35		1.09
18 Dec 84	2.0	2.10		12.50
01 Jan 85	1.2	4.87		2.26
05 Jan 85	1.8	2.31		7.48
15 Jan 85	1.5	0.95		8.60
16 Jan 85	0.1	1.97		0.00
24 Jan 85	1.9	1.03		12.88
25 Feb 85	1.5	0.33	1.4	6.17
17 Apr 85	2.0	5.46		6.20
19 Jun 85	1.9	0.00	1.5	
21 Jun 85	1.5		1.4	
09 Jul 85	1.8		1.6	8.30
10 Jul 85	1.3		1.1	3.57
14 Jul 85	1.4		1.5	
16 Jul 85	1.7		2.0	11.82
19 Jul 85	0.8		0.6	0.00

days did not produce any water. There were 5 other instances of two consecutive days with less than 50% of average insolation. The above mentioned restriction rule was at the time not implemented in Langtad. Consequently people had to rely on the neighboring pump. However, implementation of this rule would have helped the people over these dark days.

A special note may be added. During and after the typhoon of September 1984 Langtad and Tinaan had pumped water, which was not true for most of Metro Cebu for several days, because the electric grid was badly damaged.

The available production figures are compiled in Table 5.11. Installed power and total head are given for better comparison.

Table 5.11
Comparison of Production with Power

	Langtad	Tinaan	Poo
average monthly production	425 m^3	606 m^3	153 m^3
installed power	693 W	516 W	480 W
head	15 to 21 m	6 m	8 to 14 m

5.3.3 Economics

The prevailing condition in Poo offered the possibility to test the economic viability of photovoltaic pumping systems. The people in that locality were namely used to pay for fresh water. The island conditions do not permit to waste freshwater. Thus it was possible and desirable to sell water but at a reduced price.

The price reduction was from P1.50 to P0.50 per can. The increase of gasoline prices since the start of the project caused in adjacent barrios an increase from P1.50 to P2.00 per can in 1985.

The minimum collection system requires a money collector at the distribution point. Actually, tickets were sold which are good for 20 liters water. In this way, no cash is required at the distribution point. The extra costs are: a bonus for the ticket seller and expenses for printing. The tickets provide a certain check and permit additional demand analyses.

A basic journal records the financial activities. There is some money required for notebooks and pencils, even the trip to the bank to deposit the collections, cost money. A savings passbook is the official document which proves the financial status.

A summary of the activities is given in Table 5.12. The observations show the following:

1. the water consumption is higher during the dry season than during the wet season, as there is less rainwater available in the dry season,
2. the difference between the pumped volume of water and the sold water is 18%, explained by some losses, some freeloading and some incorrect container measurements,
3. the salaries of collector and seller are quite reasonable,
4. the net income is P 7,700.- in the first year,
   P 9,400.- in the second year.

The pressure to keep the income high and the expenses low is very small. An improvement of the financial performance seems thus possible. It must also be observed that the system can produce two times more water. The pump is switched of when the reservoir is full in order not to waste freshwater.

The Poo system actually produces P9,000.00 per year which with 10% interest and 20 years amortization represents P76,622.00 investment. If the potential production were sold, this system would produce P27,000.- per year corresponding with P230,000.- investment.

The actual investment in the system can be placed at:

photocells with pump ($7.- per Wp)	P 60,000.00
well, pipeline, reservoir	100,000.00
design, supervision	10,000.00
TOTAL	P170,000.00

Table 5.12
Poo Photovoltaic Installation
Monthly Financial Summary

Month	Water Prod m^3	Ticket Sales m^3	Gross Income (Pesos)	Salaries (Pesos)	Expenses Printing (Pesos)	Sundry (Pesos)
1985						
Jan	Free	Free				
Feb	252.00	189.60	2,181.00	600.00		94.00
Mar	277.00	241.90	1,564.00	900.00		101.00
Apr	183.00	199.10	2,542.00	900.00		434.00
May	160.00	152.10	3,500.00	1,260.00		719.00
Jun	188.00	120.30	2,500.00	900.00		100.00
Jul	81.00	59.10	1,000.00	450.00		50.00
Aug	130.00	118.80	3,000.00	1,350.00		100.00
Sep	78.00	60.10	500.00	450.00	510.00	
Oct	56.00	48.30	1,500.00	1,350.00		560.00
Nov	81.00	43.00	500.00	450.00		
Dec	72.00	59.98	1,500.00	1,350.00		
Subtotal	1558.00	1292.28	20,287.00	9,960.00	510.00	2,064.00
1986						
Jan			1,000.00	1,200.00		68.50
Feb			2,761.00	1,200.00		40.00
Mar			2,010.00	1,200.00		233.35
Apr			2,900.00	1,200.00		163.00
May			5,349.00	1,200.00	510.00	935.61
Jun			2,475.00	1,200.00		160.00
Jul			2,150.00	1,200.00		40.00
Aug			1,500.00	1,200.00		130.00
Sep			2,405.00	1,200.00		747.40
Oct			1,500.00	1,200.00		40.00
Nov			1,055.00	1,200.00		12.50
Dec			2,000.00	1,200.00		227.58
Subtotal	2125.00	1726.59	27,105.00	14,400.00	510.00	2,797.94

YEARLY FINANCIAL SUMMARY

Year	Prod m^3	Sales m^3	Diff %	Gross (Pesos)	Expenses (Pesos)	Net (Pesos)
1985	1558.00	1292.28	17.06	20,287.00	12,534.00	7,753.00
1986	2125.00	1726.59	18.75	27,105.00	17,707.94	9,397.06

6 Conclusions

The observations show that Cebu receives an average of 4.1 kWh m^{-2} day^{-1} which is relatively evenly distributed over the year. The high point is 5.0 kWh m^{-2} day^{-1} in March-April, the low 3.2 kWh m^{-2} day^{-1} in December-January. This value has been obtained by a fixed silicon sensor tilted 10° with respect to the horizontal.

The number of days with less than 50% of the average irradiation is low, 40 on 600. Such days hardly ever come in pairs, 6 pairs were recorded in the period of observation and only 2 pairs had the two days with less than 25% of the average irradiation. A full day's storage combined with emergency rationing will then bridge such low irradiation periods.

Convective cloud formation over hills or land areas have a noticeable influence on the irradiation. The hourly irradiation figures show namely that in stations close to the hills more energy is received before noon than in the afternoon. This effect explains also the higher irradiation in Poo, which lays about 20 km east from anappreciable land area.

Considering the many variables in pump systems stable and accurate, 1%, instruments are required in order to be able to compare different systems under different field conditions. A compromise where reliable working standards are available in a central work station is only a second best solutión, because transport and interchange of instruments usually add a few uncertainties. Meters which satisfy the requirements under field conditions, are not so easily found.

The acquisition of reliable irradiation data has improved considerably in the Central Visayas to the point that comparative calibrations have been reduced to the acceptance of a protocol.

The low-power cut-off is debatable for small pumps: the extra costs may not balance the savings on pumps. In addition, a certain quantity of energy is not utilized. From the other side inverters give access to the existing range of AC meters and offer the possibility of reduced energy losses where long electric lines cannot be avoided.

The reliability of the pump systems is such that special stand-by provisions are considered superfluous.

It has been proven that systems below 1 kW are economically viable. The conditions are that the location does not have access to the electric grid and that the people are used to pay P25.- per m^3 water.

5 Conclusions

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