Confidential Clinic Energy Survey

Village (Clinic) survey for energy

Questionnaire number:

Surveyor/Enumerator

1. Date of survey:
   Date/Month/1997
2. Name of Clinic Represantative:................................ ....
3. Sex of respondend:
   1. Male 2. Female
4. Age of representative:
   1. 20s 2. 30s 3. 40s 4. 50s 5. 60s +
5. Name of Clinic ....
6. Name of district ....
7. Name of province..
8. Sector of your clinic
   1. Large Scale Commercial Farm LSCF
   2. Resettlement Area Farm (RAF)
   3. Small Scale Commercial Farm (SSCF)
   4. Parastated Government Farm (PGF)
   5. Communal Land Farm (CLF)
   6. Urban

9. Type of electrification of the clinic
   1. Fully unelectrified
   2. Photovoltaic (PV) electrified
   3. Grid electrified

!0. Population in the Catchment area of the Clinic.......................

A. Characteristics of the clinic

11.

111. How many employees work at the Clinic ? ....
112. Total Number of nurses (SRN+SCN)...........
113. Total Number of nurse aid...........
114. Total number of Environmental Helth Technitian............
115. Total number of other employee

14. Number of major building of clinic (Exclude toilets, incinerator, washing room, staff's dwelling)...................

15. Rooms and facilities of them

	Facility of Room	Number
1501	Consulting	
1502	Waiting	
1503	Consulting	
1504	Injection	
1505	Staff's	
1506	Delivery	
1507	Atenatal	
1508	Treatment	
1509	Refrigerator	

	Facility of room	Number
1510	Pharmacy storage	
1511	Linen storage	
1512	Disinfection	
1513	Male ward	
1514	Female ward	
1515	Sluice	
1516	Shower	
1517	Utility	
1518	Other	

16. Availability of following facilities in use

	Facility	1. Availability	2. Reason see ***
		Yes 1 No 2	Reason of out
		Fill 1 or 2	
1601			
1602			
1603			

1. Lack of water
2. Facility broken
3. Lack of sewage
4. No necessary

17. Is there any medical doctor's visit?
1. Yes 2. No

171. If Yes, fill the average frequency. Around ......times per ...... months

18. Average number of monthly out patient in 1996 (Fill number) Around............../month

19. Top five diseases at your clinic in 1996.
191.........192................193. ....194............195..............

1. Acute respiratory infectories
2. Diarrhea
3. Injuries
4. Malaria
5. Respiratory disease
6. Skin diseases
7. Signs, symptoms, and ill-defined
8. Sexual transmittance diseases
9. Tonsillitis
10. Others

11. 20. Average number of deliveries a month in 1996. Around ..../month

B. All Clinics: Electric appliances and energy used

15. Appliances used

Appliance	Number	Number of Hours used/Day	Power (Watts)	Source of Power*** See below
eg. Radio	1	8	9	4
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

1510 For sorce of power, please use one of the following:

1. Grid Electricity 2. PV Electric 3. Diesel
4. Dry Battery 5. Kerosene/Paraffin 6. Gas
7. Other (Specify)

16. Sources of energy used

(A) For All Clinics: Source of Energy for 1996, Average consumption per month

	A: Firewood	B: Parrafin	C:Diesel	D: Petrol	E: Electricity	F: Gas See below
Units/month	barrow/Cart	litre	litre	litre	KWh	Kg
1 Cost per month $						
2 Average time (hr) used/day						
3 Used for Car						
4 For Motorcycle						
5 For Truck						
6 For Cooking						
7 For Lighting						
8 For Generator						
9 Others						

16 (B) For Option F: Gas, Give the Following:

1. Average Life Of a Bottle
2. Mass (kg) of A bottle
3. Number of Bottles used/Day

16 (C) For Grid, Solar and Generator Electrified Clinics only: Supply of electricity

Supplied by	Grid	PV	Generator
Single Phase	1=yes 2=No	na	na
Three Phase	1=yes 2=No	na	na
Supplied Volt			
Supplied Amp			
Supplied Watts			

na=not applicable

17. ALL Clinics: Source of water for Clinic uses including Drinking

	Volumes m^3/day
Quantity spent a day (1996)	
Total cost in 1996	
From piped inside	
From piped outside	
From river/ stream/ dam	
From communal tap	
From well protected	
From well unprotected	
From others Specify	

17 b The distance from your source of water (m)

1 On premises
2 Shorter than 500m
3 500 to 1,000 m
4 More than 1,000 m

18. Priorities of the Clinic (Including energy)

181. What are the 5 most important things for your Clinic? List up the top five items according to your priority.

1. Budgetary Money
2. Medicine
3. Water
4. Fuel
5. Electricity
6. Refrigirator
7. Safety
8. Ambulance
9. Telephone
10. Wireles Telephone
11. More Staff
12. Education/Training
13. Drainage Facility
14. Doctors Visit
15 Entertainment
16. Housing
17. Others

182. What is your clinics priority for energy sources? List up the top five items according to your priority.

1. Firewood
2. Paraffin
3. Electricity by grid
4. Electricity by PV
5. Electricity by engine generator
6. Dry battery
7. Gas
8. Coal
9. Others

PV ELECTRIFIED CLINICS ONLY
UNELECTRIFIED AND GRID ELECTRIFIED CLINICS GO TO Q20

C. Photovoltaic (PV) system

19. For Clinics already installed PV system

1901. Date of PV installation 1. Month............. 2. Year 19.....

1902. Capacity of installed PV system.................. watts

1903. Arrangement for buying PV system
1. Bought by one time paying
2. Initial payment and repaying of loan
3. Others, specify

1904. Investment amount of whole PV system including initial installation work which you have (had) to pay
Arround Z$................

1905. Total repayment period
1. year(s) 2. month(s)

1906. Repayment stage
1. Already repaid
2. Under repaying
3. Repaying will start soon

1907. Rate of repayment of loan Z$......per............(select from below)
1. Month 2. Quarterly repaying
3. Half yearly 4. Yearly repaying
5. Others, then specify

1908. Amount of money to maintain PV system apart from loan repayment (Fill numbers)
1. Around Z$.............../Year
2. Around Z$................ / month

1909. Appliances connected to PV system
1. Fluorescent tube(s) 2. Incandescent bulb(s)
3. Radio 4. Black /white TV
5. Color TV 6. Others, then specify

1910. From what time to what time PV lighting is used a day?
From..........pm. to..........pm

1911. Maintenance of PV System. Who is doing maintenance work for PV system ?
1. Clinic Head Nurse 2. Other Nurse
3. Paid Person 4. Envronmental Health Technician 5. Other

1912. Total number of faults which you called for the maintenance company after installation till the end of May 1997 Around ....times

1913. Frequency of faults for which you called for the maintenance company after installation till the end of May 1997. Average around ....times/ month

1914. Total number of days that PV system couldn't be used due to low voltage after installation till the end of May 1997 Around .... days

1915. Type of faults you have experienced (Fill up to five)

1. Break down of PV panel
2. Inclination, break down of stem (pole) for solar panel
3. Appliances connected do (did) not work
4. Shorter available hours a day compared to the initial start up days
5. Fluctuation of voltage when in use
6. Disconnection, loose connection of wire at the terminal of battery
7. Corrosion of the battery terminal
8. Shut down by over use of appliances
9. Level down of pure water in the battery
10. Almost no use due to no sunshine during daytime
11. Stolen
12. Others, specify

1916 State the kind of changes in daily life that your Clinic has experienced after installation of PV system ? (Fill up to five)

1. Easy care of handling delivery at night time
2. Easy care of handling the urgent patients at night time
3. Easy receiving of patients necessary to stay in the ward at night
4. Giving the public health education to the villagers at night become
5. Giving the education for the family planning to the villagers at night become easier
6. Safety of clinics at night (easy to notice snakes, animals, injurious insects, intruder
7. Sleeping hours decreased
8. Bit by mosquito, injurious insects, etc. Increased
9. Employees became lazy
10. Fundamentally almost no change
11. Others

1917. Extent of satisfaction : Are you currently satisfied with PV system ?

1. Satisfied very much
2. Just about (nearly satisfied) due to less capacity than clinic's needs
3. Just about (nearly satisfied) due to a rather high burden of repaying the loan.
4. Not satisfied, but not unsatisfied
5. Nearly unsatisfied due to higher burden of repaying the loan.
6. Nearly unsatisfied due to high frequency of faults on the system
7. Unsatisfied

1918. Fill all the names of PV system companies you know

UNELECTRIFIED AND PV ELECTRIFIED HHDS ONLY
Please skip question 20 to 23 for the grid electrified clinics

D. Future installation and/or expansion of PV system

20. Please list 5 future installaltions in your plans for future electrification by PV and/or expansion of PV by use of following appliances

1. Fluorescent tube	2. Incandescent bulb
3. Electric stand	4. refrigerator
5. Electric fry pan	6. Electric toaster
7. Electric food processor	8. Electric fan
9. Radio	10. Radio cassette
11. TV	12. Battery charger
13. Others, specify	

21. What is your priority in future PV electrification and/or expansion plan using 25 watts PV system? (Fill according to your priority based on the expense shown below. Necessary expense: Z$ 20,000 by single payment
Z$ 8,800/year for three (3) years
Appliances to be used: 12 fluorescent and outlets for radio or black/white TV

1. 12 fluorescent tubes
2. 6 fluorescent tubes and consents for radio or black/white TV
3. Minimum Florescent and outlets for Radio and TV
4. Others, specify

22. Payable amount in case of electrification by 2 electric lamps
Fill the amount of money (monthly basis) which you feel you can pay for item 1 to 5. Fill the amount of money for item f.

1. What would be expensive price for you ie unacceptable price for solar PV system, but still pay anyway?: Around Z$............ ..../m
2. OK (acceptable) to pay, but little bit too cheap and begin to worry about quality (not expensive) Around Z$...... /m
3. Too expensive to pay, we won't electrify: Around Z$ ..../m
4. Too cheap that makes me worry about quality: Around Z$................/m
5. Payable monthly cost: Around Z$ ..../m
6. Payable initial investment (indoor wiring and battery): Around Z$ ....
7. Are you willing to purchase PV system in future ? 1: Yes 2: No
8. If Not, Under what condition, would you want to buy PV system ?

23. Any other comment for PV electrification:

ALL CLINICS
E Operating Costs
24. How has the tendency of the gross total annual income of your clinic in 1996 in compared to that in 1995 changed ? (Here, the gross total annual income contain all cash income before deduction of tax and all income in kind.)

1. Increased
2. Almost no change
3. Decreased

25. How has the tendency of the gross total annual consumption expenditure of your clinic in 1996 in compared to that in 1995 changed?

1. Increased
2. Almost no change
3. Decreased

26. How much was the gross total annual income of your clinic in 1996 ?

27. Sources of income for clinic (Fill the selected up to five)

1. Budget from Supporting Organisation
2. Remittance
3. Transfers
4. Donations
5. Income from the Patient
6. Income in Kind
7. Borrowing
8. Others

28. Average gross monthly operating Cost in 1996 (Fill number)

2801. Personnel fee Around Z$........../m
2802. Medicine Around Z$ ..../m
2803. Electricity Around Z$........../m
2804. Fuel (Paraffin, kerosene, gasoline, gas, wood, etc.) Around Z$................/m
2805. Photovoltaic (PV) Around Z$ ..../m
2806. Dry battery Around Z$...................../m
2807. Others Around Z$...................../m
2808. Total Around Z$ .... /m

29. Disposal income

291. Did you make any savings in 1996 ? 1. Yes 2. No

292.How much money did you save ?

293. How much did you save at the end of May 1997 ?

294. Where do you save your deposit ?

1. Bank
2. Other banking organization
3. By yourself
4. Others

Thank you very much for your cooperation.

30. Surveyor's confidential comment

Confidential Household Energy Survey

Village (Household) survey for energy

Questionnaire number:

Surveyor/Enumerator

1. Date of survey:
   Date/Month/1997
2. Family Name:...

3. Sex of respondend:
   1. Male
   2. Female

4. Age of representative:
   1. 20s 2. 30s
   3. 40s 4. 50s
   5. 60s +

5. Name of village...

6. Name of district..

7. Name of province..

8. Sector of your village

   1. Large Scale Commercial Farm LSCF
   2. Resettlement Area Farm (RAF)
   3. Small Scale Commercial Farm (SSCF)
   4. Parastated Government Farm (PGF)
   5. Communal Land Farm (CLF)
   6. Urban

9. Type of electrification of the household

   1. Fully unelectrified
   2. Photovoltaic (PV) electrified
   3. Grid electrified

A. Characteristics of the family

11. Family size: How many people live and eat together in your home ? ....

111. How many of the above are economically active (able bodied)?........................

112. How many other members of your family work separately out of your village?...:...........

For the following questions 12 and 13, use the options:

1. Own agriculture
2. Own stock farming
3. Agriculture for others
4. Stock farming for others
5. Services
6. Mining & construction
7. Manufacturing
8. Education
9. Business & finance
10. Machine operators
11. Law & security
12. Clerks & secretaries
13. Transport
14. Director & manager
15. Government officials
16. Others, specify

12. Job category of family household head ....

13. Job of family members other than family Head. (Please include non-resident members that contribute to the well being of the family. Fill in up to five different job categories if possible).........................

14. House

141. Total number of traditional houses (Fill number)

142. Total number of other type/ morden type houses (Fill number)

143. Total number of rooms of other type/ morden type houses (Fill number)............

144. Main material of wall of other type/ morden type house

1. Concrete/Brick
2. Metal
3. Traditional
4. Wood
5. Other specitfy

145. Main material of roof of other type house than traditional one

1. Concrete
2. Metal
3. Slate
4. Traditional
5. Thatch
6. Wood
7. Other

B. All Households: Eleciric appliances and energy used

15. Appliances used

Appliance	**Number**	**Number of Hours used/Day**	**Power (Watts)**	**Source of Power*** See below**
eg. Radio	1	8	9	4
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

15 i0 For sorce of power, please use one of the following:

1. Grid Electricity 2. PV Electric 3. Diesel
4. Dry Battery 5. Kerosene/Paraffin 6. Gas
7. Other (Specify)

16. Sources of energy used

(A) For All Households: Source of Energy for 1996, Average consumption per month

	A: Firewood	**B: Parrafin**	**C:Diesel**	**D: Petrol**	**E: Electricity**	**F: Gas *** See below**
Units/month	barrow/Cart	litre	litre	litre	KWh	Kg
1 Cost per month $						
2 Average time (hr) used/day						
3 Used for Car						
4 For Motorcycle						
5 For Truck						
6 For Cooking						
7 For Lighting						
8 For Generator						
9 Others						

16 (B) For Option F: Gas, Give the Following:

1. Average Life Of a Bottle
2. Mass (kg) of A bottle
3. Number of Bottles used/Day

16 (C) For Grid, Solar and Generator Electrified Households only: Supply of electricity

Supplied by	Grid	PV	Generator
Single Phase	1=yes 2=No	na	na
Three Phase	1=yes 2=No	na	na
Supplied Volt			
Supplied Amp			
Supplied Watts			

na=not applicable

17. ALL Households: Source of water for Household uses including Drinking

	Volumes m^3/day
Quantity spent a day (1996)	
Total cost in 1996	
From piped inside	
From piped outside	
From river/ stream/ dam	
From communal tap	
From well protected	
From well unprotected	
From others Specify	

17 b The distance from your source of water (m)

1 On premises
2 Shorter than 500m
3 500 to 1,000 m
4 More than 1,000 m

18. Priorities of the family (Including energy)

181. What are the 5 most important things for your family life ? List up the top five items according to your priority.

1. Money	2. Food	3. Water
4. Fuel	5. Electricity	6. Health
7. Safety	8. Clothing	9. Footwear
10. Religion	11. Education	12. Job
13. Entertainment	14. Social relations	15. Relatives
16. Friends	17. Transportation tools	18. Property
19. Housing	20. Others	

182. What is your family's priority for energy sources? List up the top five items according to your priority.

1. Firewood	2. Paraffin
3. Electricity by grid	4. Electricity by PV
5. Electricity by engine generator	6. Dry battery
7. Gas	8. Coal
9. Others	

PV ELECTRIFIED HOUSEHOLDS ONLY
UNELECTRIFIED AND GRID ELECTRIFIED HOUSEHOLDS GO TO Q20
C. Photovoltaic (PV) system

19. For Households already installed PV system

1901. Date of PV installation 1. Month.............. 2. Year 19......

1902. Capacity of installed PV system.................... watts

1903. Arrangement for buying PV system
1. Bought by one time paying
2. Initial payment and repaying of loan
3. Others, specify

1904. Investment amount of whole PV system including initial installation work which you have (had) to pay Arround Z$.................

1905. Total repayment period 1. year(s) 2. month(s)

1906. Repayment stage
1. Already repaid
2. Under repaying
3. Repaying will start soon

1907. Rate of repayment of loan Z$......per.............(select from below)
 1. Month 2. Quarterly repaying
 3. Half yearly 4. Yearly repaying
 5. Others, then specify

1908. Amount of money to maintain PV system apart from loan repayment (Fill numbers)
 1. Around Z$ /Year
 2. Around Z$ / month

1909. Appliances connected to PV system
 1. Fluorescent tube(s) 2. Incandescent bulb(s)
 3. Radio 4. Black /white TV
 5. Color TV 6. Others, then specify

1910. From what time to what time PV lighting is used a day? From...........pm. to...........pm

1911. Maintenance of PV System. Who is doing maintenance work for PV system ?
 1. Family member 2. relative
 3. Paid Person 4. Others, specify

1912. Total number of faults which you called for the maintenance company after installation till the end of May 1997 Around ....times

1913. Frequency of faults for which you called for the maintenance company after installation till the end of May 1997. Average around ....times/ month

1914. Total number of days that PV system couldn't be used due to low voltage after installation till the end of May 1997 Around .... days

1915. Type of faults you have experienced (Fill up to five)
 1. Break down of PV panel
 2. Inclination, break down of stem (pole) for solar panel
 3. Appliances connected do (did) not work
 4. Shorter available hours a day compared to the initial start up days
 5. Fluctuation of voltage when in use
 6. Disconnection, loose connection of wire at the terminal of battery
 7. Corrosion of the battery terminal
 8. Shut down by over use of appliances
 9. Level down of pure water in the battery
 10. Almost no use due to no sunshine during daytime
 11. Stolen
 12. Others, specify

1916 State the kind of changes in daily life that your family has experienced after installation of PV system ? (Fill up to five)
 1. Dinner time became much joyful
 2. Family's interests to the outside world became wider
 3. Cooking at night became easier
 4. Completing homework became easier for school children
 5. Hours for the entertainment (such as by watching TV, listening radio etc.) became longer

6. Working at home at night (such as knitting, sewing etc.) became easier
7. Home parties with relatives, and /or other families increased
8. Safety of houses at night (easy to notice snakes, animals, injurious insects, intruder etc.)
9. Sleeping hours decreased
10. Bit by mosquito, injurious insects, etc. increased
11. Family became lazy
12. Fundamentally almost no change
13. Others

1917. **Extent of satisfaction :** Are you currently satisfied with PV system ?

1. Satisfied very much
2. Just about (nearly satisfied) due to less capacity than family's needs
3. Just about (nearly satisfied) due to a rather high burden of repaying the loan.
4. Not satisfied, but not unsatisfied
5. Nearly unsatisfied due to higher burden of repaying the loan.
6. Nearly unsatisfied due to high frequency of faults on the system
7. Unsatisfied

1918. Fill all the names of PV system companies you know

UNELECTRIFIED AND PV ELECTRIFIED HHDS ONLY
Please skip question 20 to 23 for the grid electrified households

D. Future installation and/or expansion of PV system

20. Please list 5 future installaltions in your plans for future electrification by PV and/or expansion of PV by use of following appliances

1. Fluorescent tube
2. Incandescent bulb
3. Electric stand
4. refrigerator
5. Electric fry pan
6. Electric toaster
7. Electric food processor
8. Electric fan
9. Radio
10. Radio cassette
11. TV
12. Battery charger
13. Others, specify

21. What is your priority in future PV electrification and/or expansion plan using 25 watts PV system? (Fill according to your priority based on the expense shown below. Necessary expense: Z$ 5,000 - 6,000 by single payment
Z$ 2,200 - 2,600 /year for three (3) years
Appliances to be used: Two fluorescent tubes or combination of one fluorescent tube and one outlet for radio or black/white TV

1. Two fluorescent tubes
2. One fluorescent tube and one consent for radio or black/white TV
3. One outlet for TV only
4. Others, specify

22. Payable amount in case of electrification by 2 electric lamps
Fill the amount of money (monthly basis) which you feel you can pay for item 1 to 5. Fill the amount of money for item f.

1. What would be expensive price for you ie unacceptable price for solar PV system, but still pay anyway?: Around Z$................../m
2. OK (acceptable) to pay, but little bit too cheap and begin to worry about quality (not expensive) Around Z$...... /m
3. Too expensive to pay, we won't electrify: Around Z$ . .../m
4. Too cheap that makes me worry about quality: Around Z$................/m
5. Payable monthly cost: Around Z$ ..../m
6. Payable initial investment (indoor wiring and battery): Around Z$ ....
7. Are you willing to purchase PV system in future ? 1: Yes 2: No
8. If Not, Under what condition, would you want to buy PV system ?

23. Any other comment for PV electrification:

ALL HOUSEHOLDS
E Living conditions

24. How has the tendency of the gross total annual income of your family in 1996 in compared to that in 1995 changed ? (Here, the gross total annual income contain all cash income (by selling agricultural products, stock farming, wages, remittances, household enterprise sales, transfers, etc.) before deduction of tax and all income in kind.)

1. Increased
2. Almost no change
3. Decreased

25. How has the tendency of the gross total annual consumption expenditure of your family in 1996 in compared to that in 1995 changed?

1. Increased
2. Almost no change
3. Decreased

26. How much was the gross total annual income of your family in 1996 ? Z$.............................

27. Sources of income for family life (Fill the selected up to five)

1. Farming income including selling agricultural products and stock farming
2. Remittance
3. Wages including job for piece job.
4. Household enterprise sales
5. Income in kind
6. Transfers including pensions, social welfare etc.
7. Properties
8. Donation received from the public, relatives, neighbor, etc.
9. Borrowing
10. Others, specify

28. Average gross monthly consumption expenditure (Fill number)
  - 2801. Food Around Z$.........../m
  - 2802. Drinking water Around Z$......./m
  - 2803. Electricity Around Z$.........../m
  - 2804. Fuel (Paraffin, kerosene, gasoline, gas, wood, etc.) Around Z$................./m
  - 2805. Photovoltaic (PV) Around Z$ ..../m
  - 2806. Dry battery Around Z$...................../m
  - 2807. Clothing Around Z$ ..../m
  - 2808. Education Around Z$ ..../m
  - 2809. Entertainment (including beer) Arround Z$........../Month
  - 2810. Others Around Z$...................../m
  - 2811. Total Around Z$ .... /m

29. Disposal income

291. Did you make any savings in 1996 ? 1. Yes 2. No

292.How much money did you save ?

293. How much did you save at the end of May 1997 ?

294. Where do you save your deposit ?
  1. Bank
  2. Other banking organization
  3. By yourself
  4. Others

Thank you very much for your cooperation.

30. Surveyor's confidential comment

Confidential School Energy Survey

Village survey for energy (School)

Background Information

0. Interviewer's Name

1. Date of survey (Fill number) Date................ Month 1997

2. Name of school Head..

3. Sex: 1. Male 2. Female

4. Age of representative/respondend..

5. Name of school ....

Type of School
1 .Primary 2 Secondary

6. Name of village ....

7. Name of district..

8. Name of province..

9. Sector of your village (Fill the alphabet)

   1. Large Scale Commercial Farm (LSCF)
   2. Small Scale Commercial Farm (SSCF)
   3. Communal Land Farm (CLF)
   4. Resettlement Area Farm (RAF)
   5. Parastated Government Farm (PGF)
   6. Urban

10. Type of electrification of the school

   1. Fully unelectrified
   2. Photovoltaic (PV) electrified
   3. Grid electrified

11. Population of villages in catchment area .. ..

A. Characteristics of the school

13 School size: How many employees work totally in your school ? (Fill number) ....

14. Total number of pupils/students, and classrooms (Fill number) ....

		a	b		c	d
		Primary School			Secondary School	
		Pupil	Classroom		Student	Classroom
141	Grade 1			Form 1		
142	Grade 2			Form 2		
143	Grade 3			Form 3		
144	Grade 4			Form 4		
145	Grade 5			Form 5		
146	Grade 6			Form 6		
147	Grade 7					
148	Adult					
149	Total					

15 Does your school have two classrooms a day (Hot Seater) system ?
1. Yes 2. No

16 School start time and closing time (Fill number by 24 hr system)

Start Closing

161 In case of one time classroom a day system a........... b.................

162 In case of two time classrooms a day system: First a .... b................
Second c............ d................

17 Average homework frequency and average necessary hours to do (Fill the number)
ONCE PER...........DAY(S)

Necessary hours: Express by expected hours (1: 1 hour, 2: 2hours etc.)

		Primary School			Secondary School	
		Frequency	Nes. Hrs		Frequency	Nes. Hrs
161	Grade 1			Form 1		
162	Grade 2			Form 2		
163	Grade 3			Form 3		
164	Grade 4			Form 4		
165	Grade 5			Form 5		
166	Grade 6			Form 6		
167	Grade 7					
168	Adult					
169	Total					

Note: Nes. Hrs = Necessary hours to complete homework for pupil/student

B. Electric appliances and energy used

All Schools: Electric appliances and energy used
15. Appliances used

Appliance	Number	Number of Hours used/Day	Power (Watts)	Source of Power*** See below
eg. Radio	1	8	9	4
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				

1510 For sorce of power, please use one of the following:
1. Grid Electricity 2. PV Electric 3. Diesel
4. Dry Battery 5. Kerosene/Paraffin 6. Gas
7. Other (Specify)

16. ALL SCHOOLS: Sources of energy used
(A) For All Schools: Source of Energy for 1996, Average consumption per month

	A: Firewood	B: Parrafin	C:Diesel	D: Petrol	E: Electricirty	F: Gas See below
Units/month	barrow/Cart	litre	litre	litre	KWh	Kg
1 Cost per month $						
2 Average time (hr) used/day						
3 Used for Car						
4 For Motorcycle						
5 For Truck						
6 For Cooking						
7 For Lighting						
8 For Generator						
9 Others						

16 (B) For Option F: Gas, Give the Following:
1. Average Life Of a Bottle
2. Mass (kg) of A bottle
3. Number of Bottles used/Day

16 (C) For Grid, Solar and Generator Electrified Schools only: Supply of electricity

Supplied by	Grid	PV	Generator
Single Phase	1=yes 2=No	na	na
Three Phase	1=yes 2=No	na	na
Supplied Volt			
Supplied Amp			
Supplied Watts			

na=not applicable

17. ALL Schools: Source of water for School uses including Drinking

	Volumes m^3/day
Quantity spent a day (1996)	
Total cost in 1996	
From piped inside	
From piped outside	
From river/ stream/ dam	
From communal tap	
From well protected	
From well unprotected	
From others Specify	

17 b The distance from your source of water (m)

1 On premises
2 Shorter than 500m
3 500 to 1,000 m
4 More than 1,000 m

20. Priorities for the School (including Energy)

201. What is the most important thing for your school ? List up the top five items according to your priority by selected numbers.

1. Budgetary money
2. Classroom (Building)
3. Water
4. Fuel
5. Electricity
6. Lighting
7. Text book
8. Reference books
9. Library
10. Teachers
11. Re- education/re-training of teachers
12. Telephone
13. Wireless telephone
14. Gymnasium
15. Drainage facility
16. Entertainment
17. Others

202. What is your school's priority for energy source? List up the top five items according to your priority.

1. Firewood
2. Paraffin
3. Electricity by grid
4. Electricity by PV
5. Electricity by engine generator
6. Dry battery
7. Gas
8. Coal
9. Others

C. PV ELECTRIFIED SCHOOLS ONLY: Photovoltaic (PV) system

21. School already installed PV system

2101. Date of PV installation (Fill number) 1. Month .... 2. Year 19.....

2102. Capacity of installed PV system (Fill number) ....watts

2103. Arrangement for buying PV system
1. Bought by one time paying
2. Initial payment and repaying of loan
3. Others, then specify

2104. Investment amount of whole PV system including initial installation work which you have (had) to pay (Fill number) Around Z$

2105. Total repayment period (Fill number) a. ....year(s) b. .... month(s)

2106. Repayment stage
1. Already repaid
2. Under repaying
3. Repaying will start soon

2107. Rate of repayment of loan (Fill figure in a and put the alphabet in b) a. Z$ /b.
1. Monthly repaying
2. Quarterly repaying
3. Half yearly repaying
4. Yearly repaying
5. Others, then specify

2108. Amount of money to maintain PV system except loan repayment (Fill numbers)
1. Around Z$................ /Year 2. Around Z$ ..../ month

2109. Appliances connected to PV system

1. Fluorescent tube(s)
2. Incandescent bulb(s)
3. Radio
4. Black /white TV
5. Color TV
6. Others, then specify

2110. From what time to what time PV lighting is used a day? From............pm. to................pm

2111. Maintenance of PV System. Who is doing maintenance work for PV system ?

1. School representative
2. Head master
3. Teachers
4. Administrative
5. Others, specify

2112. Total number of faults which you called for the maintenance company after installation till the end of May 1997. Around .... times

2113. Frequency of faults for which you called for the maintenance company after installation till the end of May 1997. Average around .... times/ month

2114. Total number of days that PV system couldn't be used due to low voltage after installation till the end of May 1997. Around ....days

2115. Top Five Type of faults you have experienced

1. Break down of PV panel
2. Inclination, break down of stem (pole) for solar panel
3. Appliances connected do (did) not work
4. Shorter available hours a day compared with the initial start up days
5. Fluctuation of voltage when in use
6. Disconnection, loose connection of wire at the terminal of battery
7. Corrosion of the battery terminal
8. Shut down by over use of appliances
9. Level down of pure water in the battery
10. Almost no use due to no sunshine during daytime
11. Stolen
12. Others, specify

2116. What kind of changes in shool life employees have experienced after installation of PV system ?. List the top 5

1. Teachers' preparation of lessons for next day became easier
2. Receiving the consultation for education from the pupil/student's family in the evening became easier
3. Progress of lessons became faster
4. Adult education class in the evening was availabl
5. Offering room (s) for villagers meeting in the evening became easier
6. Safety of school at night (easy to notice snakes, animals, injurious insects, etc.) increased
7. Bit by mosquito injurious insects, etc. increased
8. Working time for employee especially it for teacher became longer
9. Budgetary burden became heavier
10. Employee became heavier
11. Fundamentally almost no change
12. Others, specify

2117. Extent of satisfaction. Are you currently satisfied with PV system ?

1. Satisfied very much
2. Just about (nearly satisfied) due to less capacity than school's needs
3. Just about (nearly satisfied) due to a rather high burden of repaying the loan.
4. Not satisfied, but not unsatisfied
5. Nearly unsatisfied due to higher burden of repaying the loan.
6. Nearly unsatisfied due to high frequency of faults on the system
7. Unsatisfied, specify why?

2118. Fill all the name of PV system companies you know

a.	b.
c.	d.
e.	f.

D. Future installation and/or expansion of PV system
Please skip question 22 to 25 for the grid electrified schools

22. Your plans for future electrification by PV and/or expansion of PV by use of following appliances

1. Fluorescent tube
2. Incandescent bulb
3. Electric stand
4. Refrigerator
5. Electric fan
6. Radio
7. Radio cassette
8. TV
9. Others, specify
10.

23. What is your priority in future PV electrification and/or expansion plan using 165 watts PV system?

Necessary expense: Around Z$ 20,000 by single payment
Around Z$ 8,800 /year for three (3) years
Appliances to be used: Around twelve fluorescent tubes and outlets for radio and or TV
Priority:

1. Twelve fluorescent tubes
2. Six fluorescent tubes and many outlets for radio or TV
3. Minimum fluorescent tubes and many outlets for TV
4. Others

24. Payable amount in case of PV electrification by 12 fluorescent tubes and outlets for radio/TV.

1. What would be expensive price for you?: Around Z$............/m
2. OK (acceptable) to pay, but little bit cheap (not expensive) Around Z$............./m
3. Too expensive to pay, we won't electrify: Around Z$ .... /m
4. Too cheap that makes me worry about quality: Around Z$............./m
5. Payable monthly cost: Around Z$........... /m
6. Payable initial investment (indoor wiring and battery): Around Z$ ....

. Are you willing to purchase PV system in future ? 1: Yes 2: No

If Yes, Under what condition, would you want to buy PV system ?

25 Any other comment for PV electrification:

E Operating costs

26. How about the tendency of the gross total annual income of your school in 1996 in compared with that in 1995 ? Here, the gross total annual income contain all cash income (by budget from the supporting organization of your schools, donation, remittances, transfers, etc._)before deduction of tax and all income in kind.

1. Increased
2. Almost no change
3. Decreased

27. How about the tendency of the gross total annual expenditure (= operating cost) of your School in 1996 in compared with that in 1995 ?

1. Increased
2. Almost no change
3. Decreased

28. How about the gross total annual income of your schools in 1996 ? ....

29. Sources of income for your school (Fill the selected up to five)

1. Budget from the supporting organization of your shool
2. Remittance
3. Transfer
4. Donation
5. Income in kind
6. Borrowing
7. Others, specify

30. Average gross monthly operating cost in 1996 (Fill number)

3001. Personnel fee (Excuding Ministry of Education Staff	Around Z$.... ..... /m
3005 PV	Around Z$......./m
3002. Electricity	Around Z$ ..../m
3006. Dry battery	Around Z$.........../m
3003. Fuel (Paraffin, kerosene, gasoline gas, wood, etc.)	Around Z$........./m
3007. Others	Around Z$......... /m
3008. Total	Around Z$......... /m

31. Disposable income at your school

311. Did you make any savings in 1996

1. Yes 2. No

312.How much money did your school save ? Z$............................

313. How much did you save at the end of May 1997 ?Z$...................... ....

314. Where do you save your deposit ?

1. Bank 2. Other banking organization
3. By yourself 4. Others

Thank you very much for your cooperation.

32. Surveyor's confidential comment

APPENDIX - 2

TRAINING COURSE

TRAINING COURSE FOR SOLAR PHOTOVOLTAIC FIELD TECHNICIANS

JICA

Prepared by : The Japan International Cooeration Agency Solar Team

For Kwekwe Technical College, Kwekwe, Zimbabwe

1997

CHAPTER 1

SOLAR PHOTOVOLTAIC SYSTEMS

WHAT IS A SOLAR PHOTOVOLTAIC SYSTEM?

A solar photovoltaic unit turns sunlight into electricity. The more sun there is, the more electricity is produced. When it is a rainy day, little electricity is made. At night, no electricity is produced even if the moon is very bright. Because electric lights are needed when the sun is not shining, electricity made during sunny days is stored in a battery. Electricity can be drawn from the battery at any time to do useful things like operate lights, refrigerators and videos.

WATER SYSTEMS AND SOLAR SYSTEMS: A SIMILAR IDEA

Understanding a solar system seems difficult at first. Electricity can not be seen and measurements must be made with complicated looking instruments. To help in understanding an electric system, it is useful to compare it with a water system.

The water system that acts most like a solar photovoltaic system is a rainwater collection system. The amount of water collected by a rainwater collection system changes with the weather. There are days with much rain and days with none so that some days much water is collected and on others none is collected. In the same way, the amount of electricity made by a solar system changes according to the weather. There are days with bright sun when a lot of electricity is created and others with little sun when little electricity is made. Sometimes it rains for many days, other times it is dry for many days. Sometimes it is sunny for many days and other times it is cloudy for many days. So the output of both rainwater collection systems and solar systems depends on the patterns of the weather.

Not only do rainwater collection systems and solar PV systems act much alike, they have similar parts.

The main parts of a rainwater system are:

- ✓ THE ROOF COLLECTION AREA
- ✓ A STORAGE TANK
- ✓ PIPES TO CARRY WATER TO AND FROM THE TANK
- ✓ VALVES ON PIPES TO CONTROL THE FLOW OF WATER
- ✓ APPLIANCES (LIKE A SHOWER) FOR USING THE WATER

The main parts of a PV system are:

- ✓ THE COLLECTOR PANEL
- ✓ THE STORAGE BATTERY
- ✓ WIRES TO CARRY THE ELECTRICITY TO AND FROM THE BATTERY
- ✓ A CONTROLLER TO CONTROL THE FLOW OF ELECTRICITY
- ✓ APPLIANCES (LIKE LIGHTS) FOR USING THE ELECTRICITY

Each part of the rainwater system does a job similar to a part in the PV system.

Collection

The solar panel collects sunlight and converts it into electricity. It is often mounted on a roof but it can be placed anywhere there is sun. In a rainwater system the equivalent part is the house roof. If we think of electricity as being like water, then the roof collects rainwater like the solar panel collects sunlight. The roof collects water that falls from the sky so it can be stored for later use. The solar panel collects sunlight that comes from the sky so it can be stored for later use as electricity. The bigger the roof, the more water that is collected when it rains. The bigger the PV panel the more solar energy that is collected during the day. If it rains hard, a lot of water is collected in a short time and if it rains lightly, only a little is collected in the same time. If the sun shines brightly, a lot of electricity is collected in a short time and if it is cloudy only a little is collected in the same time. If it doesn't rain, no water is collected and if it is night, no solar energy is collected. So you see that the idea behind having a roof area for rainwater collection is almost the same as the idea of having a solar PV panel for sun energy collection.

Storage

Water is needed when it is not raining and electricity is needed when the sun is not shining. Both a rainwater collection system and a solar PV system must have storage. The battery in a photovoltaic system does a job like the storage tank of a water system. The storage tank allows the use of water for some time after it quits raining. The battery allows the use of electricity for some time after the sun goes down.

If it rains a lot and no one uses much water, the storage tank fills up to capacity. If the sun shines a lot and there is little use of electricity then the battery becomes full of electricity and we say it is charged.

If people use water when there is little rain, the water level in the tank gradually falls and soon the tank becomes empty. If people use electricity when there is little sun, the amount of electricity in the battery gradually falls and soon the battery has no more electricity and we say it is discharged.

SOMETHING VERY IMPORTANT TO KNOW ABOUT SOLAR UNITS

If people use water from the tank faster than rain falling on the roof collection area refills it, the tank will run dry and people will have to wait until it rains again before they have water. If people use electricity faster than the sun shining on the photovoltaic panels can refill the battery with electricity, then the battery will run out of electricity and become discharged and the people will have to wait for the sun to recharge it.

Flow Control

Water storage tanks have valves on their outlet pipes to control the use of water. Photovoltaic systems have a controller between the battery and appliances to control their use of electricity. Such a controller is called a discharge controller because it controls the amount of electricity coming out, or discharging, from the battery. A water tank may not be damaged by being drained until empty but a battery can be damaged if too much electricity is drawn from it. The discharge controller prevents damage to the battery from too much discharge.

Some water storage tanks also have valves on their inlet to prevent them from becoming too full and overflowing. Most photovoltaic systems have a controller between the panel and the battery to keep the battery from receiving too much electricity. It is called a charge controller because it controls the amount of energy going into, or charging, the battery. Batteries can be damaged from too much charge, so the charge controller is needed to prevent damage from over charging.

Usually the charge controller and the discharge controller are combined into one box which is simply called the controller.

Transport

Both water and electricity have to be moved from place to place. To move water from one place to another, pipes are used. To move electricity from one place to another wires are used. Big pipes let water flow more easily than small pipes and are needed when large amounts of water are to be moved quickly. Big wires let electricity flow more easily than small wires and are used when large amounts of electricity is to be moved quickly.

If pipes are not connected together properly, they leak and all the water does not get to the other end of the pipe where it is needed. If wires are not connected together properly, all the electricity does not get to the appliance end of the wire where it is needed.

Appliances

The devices that make use of the water from the rainwater system or of the electricity from the photovoltaic system are called appliances. For rainwater collection systems, there is often only one appliance attached to the system: a tap. Some more complicated water systems may include other appliances such as flush toilets and showers. Appliances that use a lot of water, like flush toilets, only work well if connected to a water system that is designed for them. If a flush toilet is attached to a water system designed for a simple water tap, it probably will not work properly and the storage tank may run dry quickly.

With solar photovoltaic systems, many units have only one appliance: lights. But it is possible to connect other appliances like radios, videos, pumps and refrigerators if the photovoltaic system is designed for them. But if a refrigerator, pump or video is connected to a solar photovoltaic system designed only for lights, it will not work properly and the battery will be discharged quickly.

CHAPTER 2

ELECTRICITY

INTRODUCTION

People usually have some difficulty in understanding electricity because it is invisible. Fortunately, electricity has many things in common with water so understanding how water acts in a water system helps us understand how electricity acts in a PV system.

To understand a water system, there are a few things that we have to know. We must know things like how much water is there, how much force is pushing water through the pipes and how much water is flowing through the pipes over a period of time. These important things that we can measure in a water system are like things that are important to measure with electricity.

PRESSURE

Water pressure is a measure of the force that pushes water through a pipe. Each country has its own method of describing pressure. Units like pounds per square inch, Pascals and kilograms per square metre are used. Though they have different names, they all are a measure of water force. One common measure of water pressure is kilograms per square centimetre. A water pressure of 1/3 kilogram per square centimetre is very low and is what might be found at the outlet to a rainwater storage tank sitting on the ground. A pressure of 10 kilograms per square centimetre is high and might be found at the outlet of a pump driven by a diesel engine. It takes a lot of force to move water through long pipes so high pressures are needed when water must be moved long distances. Low pressures are all right when the water is being used very close to the storage tank.

Electrical pressure is the force that pushes electricity through a wire. Fortunately, the measure of electrical pressure is the same everywhere. It is measured in Volts. An electrical pressure of 1-1/2 volts is low and is the electrical pressure provided by one dry cell like is used in an electric torch or radio. An electrical pressure of 240 Volts is fairly high and is the pressure found at city electrical power points. High voltages are needed to move electricity long distances or for running large appliances.

VOLUME

The amount of water in a tank is its volume. Many different measures of volume are popular. The gallon is a measure of volume used in some countries. Another common measure of volume is litres. A household rainwater tank may hold 4000 litres. Another measure of volume is cubic metres. One cubic metre is the same volume as 1000 litres.

There are several measures of electrical volume too. One measure of electricity volume is the Coulomb. A torch cell may hold an electrical volume of 1500 Coulombs. A solar battery may hold an electrical volume of 360,000 Coulombs. Another more common measure of electricity volume is the Ampere-hour. An electrical volume of one Ampere-hour is the same as an electrical volume of 3600 Coulombs so a battery holding 360,000 Coulombs also holds 100 Ampere-hours.

FLOW RATE

When water moves through a pipe, it is said to flow. The *volume* of water (like gallons, litres and cubic metres) that flows through a pipe in one unit of *time* (like one second, one minute or one hour) is called the flow rate. It is often measured in litres per minute. A pipe from a rainwater tank may have a flow rate of 10 litres per minute when a tap is turned on while a pump driven by a diesel engine may provide a water flow rate of 1000 litres per minute.

When electricity moves through a wire, it is sometimes said to flow just like water but usually it is said to have a current instead of a flow rate. So electricity moving through a wire is a current and electrical current is measured in Amperes. One Ampere is a volume of one Coulomb flowing through a wire over a time of one second. It is a one Coulomb per second flow rate. One Ampere is also the average current flowing through a wire when one Ampere-hour of electricity volume flows through a wire over a period of one hour. The current which flows through a solar powered light may be one Ampere while that needed to run a large solar powered video may be thirty Amperes.

RESISTANCE

Electricity flows through wires like water flows through pipes. Pipes allow water to be carried from one place to another just as wires allow electricity to be carried from place to place. The longer the pipe or wire the more difficult it is to move water or electricity from the source to the user.

With water, the longer the pipe the lower the flow of water that a particular pressure can push through the pipe. For a given pressure, a very long pipe will have a much lower flow of water than a short one of the same size. This is because the longer the pipe, the more difficult it is to push water through the pipe. It is just as though a very long pipe pushes back with a force against the flow of water. This force that opposes the flow of water is called flow resistance or simply resistance. The resistance to water flow in a pipe increases in step with the length of a pipe, so a pipe twice as long pushes back twice as hard. It has a resistance of twice as much.

It is also harder to push water through a small pipe than a big one. The back force (resistance) *increases* in step with the *decrease* in the amount of room there is for water flow in a pipe. The room for flow is also called cross sectional area. It is usually measured in square inches or square centimetres. If a pipe has a cross section of five square centimetres, it will (for an equal length of pipe) have twice the resistance to water flow as a pipe that is ten square centimetres in cross section area.

Be sure that the difference between diameter of pipe and cross sectional area of pipe is understood. The diameter is the distance across the end of the pipe. The cross sectional area is the total room available across the end of the pipe for water to flow. It is important to realise that if you double the diameter of a pipe, the cross sectional area of that pipe is made *four* times, not two times, larger. The reason is that when you increase the diameter of the pipe in one direction, the diameter is increased in the other direction too because the pipe is round. If you doubled the diameter of the pipe in only one direction and therefore doubled the cross section area, the pipe would not be round, it would be a flattened oval. This means that if you have a hundred metres of 20mm diameter pipe and you change to 40mm diameter pipe, the pipe resistance falls by a factor of *four* because the cross sectional area of the 40mm pipe is four times that of the 20mm pipe.

Electricity flowing through a wire acts in the same way as water flowing through a pipe. If the wire length is doubled, the resistance of the wire is also doubled and it is twice as difficult to force electricity through the wire. If the wire size (cross section area) is cut in half, the resistance is doubled and it is two times harder to push electricity through the wire.

With water, if the pressure stays the same and the pipe length is doubled, the flow rate is cut in half. Another way of saying the same thing is that if we want to maintain the *same* flow rate through a pipe whose length has doubled (thereby doubling its resistance to flow), we have to *double* the pressure.

Looking at it differently, if we find that for some reason we have to increase the length of a pipe to double what it started with and can't change the pressure forcing the water through the pipe, then the only way we will be able to keep the same flow rate as before is by cutting the resistance in half. To do that we can lay another pipe of the same size along side the first one and connect them together. That gives double the room for water to flow and cuts the resistance to flow in half. Another way is to take out the old pipe and put in a single new pipe with double the cross sectional area of the old one.

This relationship can be stated as follows:

Water Pressure equals **Flow rate** times **Resistance**

or another way:

Water Flow rate equals **Pressure** divided by **Flow Resistance**

or a third way:

Water Flow Resistance equals **Pressure** divided by **Flow rate**

Therefore if you know any two of the three terms, flow resistance, pressure or flow rate, you can calculate the third easily.

Electricity acts the same way. If wire length (resistance) is doubled and the Voltage (electrical pressure) kept the same, the Amperes flowing (electrical flow rate) are cut in half. If the Voltage is kept the same and the wire length doubled we can have the same current only by cutting the wire resistance in half. This can be done by doubling up the wire with another of the same size or by replacing the old small wire with one having twice the cross sectional area of the first one.

There is no common measurement term for pipe resistance but the unit used in measuring electrical resistance is the Ohm. The interaction between electrical pressure in Volts, electrical flow rate in Amperes and flow resistance in Ohms is:

Voltage equals Amperes time Ohms
Which is the electrical equivalent of:
Water Pressure equals **Flow Rate** times **Flow Resistance**

or another way:

Amperes equals Voltage divided by Ohms
Which is the electrical equivalent of:
Water Flow Rate equals **Pressure** divided by **Flow Resistance**

or a third way:

Ohms equals Voltage divided by Amperes
Which is the electrical equivalent of:
Water Flow Resistance equals **Pressure** divided by **Flow Rate**

Therefore if you know any two of the three: Amperes, Volts or Ohms, you can always calculate the third.

Examples:

A Voltage of 12 Volts forces a current of 4 Amperes through an unknown resistance. What is the resistance in Ohms?

Resistance = Volts/Amperes

= 12/4

= 3 Ohms

A resistance of 6 ohms is placed across a voltage of 24 Volts. What current flows?

Current = Volts/Ohms

= 24/6

= 4 Amperes

A resistance of 3 ohms is measured to have a current of 2 Amperes flowing through it. What voltage is there across the resistance?

Voltage = Amperes X Ohms

= 2 X 3

= 6 Volts

POWER

Power is the ability to do work. A machine with lots of power can do lots of work. Anyone living near the ocean knows the power of moving water. If you have ever had to swim against an outflowing tide, you know there is power in even slowly moving water. If the water volume is high and the flow rapid, as with high breakers along the reef, the power is great and can break bones or even kill.

If you place your hand in flowing water, you can feel the stream of water pushing your hand. The flow of water is producing a small amount of power. If the water is under high pressure or there is a large volume of water flowing, the pressure on your hand is greater and we can say there is more power. In fact, the power increases if either the water pressure or the water flow rate increases.

Think about the water flow from the faucet on a rainwater tank. If the faucet is just barely turned on and there is little flow, the force on your hand under the tap is low. If you turn the tap open all the way, the power is greater. The power increases exactly as the flow rate increases. If the flow rate doubles, the power doubles.

Also, if the tank is nearly empty and the pressure very low, the force on your hand is also low. If the tank is full and the water pressure high, the force is also high. The power provided by the flow of water increases exactly as the pressure increases. If the pressure doubles, the power doubles.

So the power from a stream of water increases both with increased flow rate and increased pressure. If both the pressure and the flow rate double, the total power is raised by four times, twice due to the doubling of flow rate and twice again for the doubling of pressure. In fact, the power can be said to be changed as the change in the flow rate and the pressure multiplied together.

Examples with numbers:

Suppose:

Flow rate doubles and the pressure triples

2 times 3 = 6

The power goes up six times

Suppose:

Flow rate doubles and the pressure is cut in half

2 times 1/2 = 1

and the power is the same.

Electrical power works the same way. If the pressure (Volts) doubles and the flow rate (Amperes) stays the same, the power doubles. If the current triples and the voltage stays the same, the power triples. If the voltage doubles and the current triples, the power goes up six times. Electrical power equals the flow rate in Amperes times the pressure in Volts.

The measure used for electrical power is the Watt. One Watt is the power produced by a current of one Ampere driven by an electrical pressure of one Volt. If the electrical pressure of a photovoltaic system is 12 Volts and it operates a light which uses two Amperes, the power used is:

12V times 2A = 24 Watts

Remember that electrical power in Watts is the Voltage times the Amperage just like water power is pressure times flow rate.

Examples:

A video uses 30 Amperes at 12 Volts. Its power requirement is:

30 Amperes X 12 Volts = 360 Watts

A pump uses 10 Amperes at 48 Volts. Its power requirement is:

10 A X 48 V = 480 Watts

A light uses 1.5 Amperes at 12 Volts. Its power requirement is:

1.5 A X 12 V = 18 W

Notice that you can use this relationship between Watts, Volts and Amperes to calculate backwards too:

If a 24 Watt light is connected to a 12 Volt source of electricity, how much current will flow?

12 Volts times ???? Amperes = 24 Watts

24 W / 12 V = 2 A

So if we know the power in Watts we will get the Amperes if we divide Watts by Volts. If we know Watts, we can get Volts if we divide Watts by Amperes.

If a 120 Watt refrigerator operates on a current of 10 Amperes, what voltage is present?

???? Volts times 10 Amperes = 120 Watts

120 W / 10 A = 12 V

ENERGY

The terms power and energy are often confused. Power is the *ability* to do work. Energy is the total actual work that is done. A large, strong man has a lot of power but if he is lazy and sleeps all day, he does little work and produces little energy.

To see the difference between power and energy, think of a car and a motorcycle. The power for their motors is rated in horsepower. A 40 horsepower car motor has ten times the power of a 4 horsepower motorcycle. You might think that the 40 horsepower motor provides ten times the energy of the 4 horsepower unit but that is not so. Remember that energy is a measure of actual work done. Even though something is powerful, there may be little work done because the power is used only for a short time. The very strong man who sleeps all day does much less work than a weak man who labours all day. A 40 horse motor operated for a few minutes moves the car only a short distance while a 4 horse motor operated all day will move the motorcycle a long distance. The energy produced depends on both the power available and the length of time the power is applied. Multiplying power times the time the power is used gives energy. Since the electrical measure of power is the Watt, in electrical terms energy is measured as Watts times hours or Watt-hours.

An electrical device that delivers a power of five Watts for two hours provides 5 X 2 = 10 Watt-hours of energy. If a light requires 20 Watts to operate and is run for four hours, the energy used is 20 X 4 = 80 Watt-hours.

Because it is *energy* which is provided to the battery by the solar panels and *energy* which goes to the appliances from the battery, it is the flow of *energy*, not power, that determines how large the panels and batteries must be. An appliance, like a small light, that uses little energy in an hour can operate many hours from a charged battery. An appliance that uses much energy in an hour, like a freezer, will operate only a short time from the same charged battery.

CIRCUITS

A piping system for a rainwater system may be simply a short pipe with a tap at the end or it may have many branches going to many places. The pipe and its connections can be called the water circuit. For the water to flow all the way from the tank to the appliance there must be a continuous pipe connecting them. If the pipe is disconnected or broken, the water will not flow to the appliance and it will not work.

If a picture is drawn of a water circuit, it shows the water source, the pipe paths and connections and the appliances. The drawing is called a plumbing circuit diagram. On that diagram you can trace the flow of water from source to appliance.

Like water circuits, electrical circuits for PV systems can be very simple such as a wire running directly from a battery to a light. A circuit can also be complex with several batteries and many appliances all connected together. When electrical elements, like batteries, resistances, motors and appliances are connected together with wires, an electrical circuit is created. For an electrical circuit to function, there must be a continuous path for the electricity to flow. If a continuous path does not exist, then we say that the circuit is *open*. If the continuous path is present, then the circuit is *closed*. Electricity will flow through a closed circuit but will not flow through an open circuit. A switch is an electrical device which allows you to open or close a circuit to turn the electricity on or off.

There is one big difference between the way a water and an electrical circuit works. A water circuit usually ends with the appliance and the water flowing away into a drain somewhere. In an electrical circuit, the electricity cannot flow outside of a wire so there must be a wire to carry electricity away from the appliance just as there is one to carry electricity to the appliance. This *return* wire goes back to the power source where the returned electricity is pumped back up to full voltage and sent back out to the appliance. In an electrical circuit, the electricity must have a continuous path not only to the appliance but from the appliance back to the source as well. If the path is broken at any place, the flow of electricity stops.

Polarity

It makes a difference to most solar powered appliances which way the electricity flows. If you connect a flush toilet backward, it will not work and if you connect a solar light backward it probably will not work either. With a water appliance the inlet pipe is usually clearly marked. The same is true of connections in a solar system. The markings are usually + and – or spelled out as positive or negative. The + side is called the positive pole and the - side the negative pole. The arrangement of + and – is called the polarity of the unit. The polarity is simply a way of showing the direction of the electricity flow. Appliances usually have their + pole connected to the + pole of the battery and the – to the –.

It is always important to know and observe polarity when making connections in a PV electrical system. Connecting the wrong poles together can cause damage, a fire or even an explosion.

Series Circuits

When electrical elements are connected end to end, they are said to be connected in series. To connect two wires in series, one end of one wire is connected to one end of the second wire creating a single wire as long as the two put together. This is like connecting two short pipes to create one longer pipe. Notice that the resistance of the resulting long wire (or pipe) is the sum of the resistances of the individual wires (or pipes).

If a long pipe is made by connecting shorter pipes end to end, any water that goes into one end must pass through all the pipe sections to get to the other end. The same flow rate is present everywhere in the circuit. Electricity entering one end of series connected electrical components will all pass through each component to get to the other end. A basic characteristic of series connected electrical circuits is that:

All components in a series circuit have the same electrical current (Amperes) flowing through them. The voltage across each individual component will vary according to the characteristics of that component.

If we stack water tanks one over the other, the pressure available from the bottom tank will increase. In PV systems batteries and panels are often connected in series to increase the available voltage. If two 12V batteries producing 10 Amperes are connected in series, 24V is produced at 10 Amperes. If three 18V panels each producing 3 Amperes are connected in series, 54V at 3A is produced. The voltage from series connected batteries or panels is the sum of the individual voltages. The Amperes produced is the same as that produced by one unit.

Parallel Circuits

When electrical components are connected side by side, they are said to be connected in parallel. To connect two wires in parallel, one end of each wire is connected together then the other ends of each wire is connected together. The result is two wires side by side with the two ends tied together.

This is like laying two small pipes side by side then connecting them together at both ends. When water is turned on, part of the water flows through one pipe and part through the other. The flow is split. If one pipe is large and the other one small, more water will flow through the large pipe than the small one. This is true because the same pressure is present on both pipes but their resistances are different. The same thing happens in a parallel electrical circuit, the flow is split among each of the branches according to the flow resistance of each branch. A basic characteristic of parallel connected electrical circuits is that:

All components connected in parallel have the same voltage across their terminals. The electrical current (Amperes) flowing through each component will vary according to the electrical characteristics of the components.

If several water tanks are set side by side and interconnected, the pressure will be the same as from one tank but the flow of water will be increased. In PV systems batteries and panels are often connected in parallel to increase the available current. If two 12V batteries which can produce 10 Amperes are connected in parallel, 12V is produced with a possible 20 Amperes of current. If three 18V panels each producing 3 Amperes are connected in parallel, 18V at 9A is produced. The voltage from parallel connected batteries or panels is the same as that produced by one unit. The Amperes produced is the sum of the individual currents.

ALTERNATING CURRENT (AC)

The electricity that we have discussed so far can be thought of as flowing directly from a source (like a battery) through wires to the point of use (like a light). This form of electrical flow is called Direct Current or DC.

Solar panels, storage batteries and torch batteries all produce DC electricity. Notice that none of these sources of electricity have any moving parts.

The electrical power provided by engine driven rotating generators ranging from the smallest portable generator up to the very largest city power plant is usually not direct current. It is usually Alternating Current. This type of electrical power flows in one direction for a short time then reverses to flow in the other direction an equally short time before reversing again. This type of electrical power is called Alternating Current (AC) because the electricity is constantly alternating its direction of flow. The flow starts in one direction, say from the source to the appliance, then reverses to flow in the opposite direction then starts going the original direction again. This forward then backward repetition of direction is called a cycle and the number of cycles that occur in one second is called the AC frequency. The measurement term for frequency is the Hertz which is simply the number of directional change cycles per second for the electricity. Power plant frequencies are either 50 Hertz or 60 Hertz (Hz) according to what power standards a country observes.

Alternating Current power can be converted to Direct Current using what is called a rectifier. Direct Current can also be converted to Alternating Current using an inverter. These conversions cannot be made without the loss of some power and unless care is taken, the power produced is of a poor quality.

The laws governing electrical flow in Direct Current systems also apply to Alternating Current systems but with some added complexities caused by the constantly changing flow of electricity. Calculations which are exact for DC may be only approximate for AC unless complicated correction formulas are included in the calculations.

Unlike DC, AC has no polarity. That is because polarity indicates the direction of electricity flow and in an AC system, the flow reverses many times a second.

Which is better, AC or DC power? Both have advantages and disadvantages. AC is more commonly used in large power systems both because it is easily produced by big rotating machines and because it is easy to change from one voltage level to another, an important factor in large power distribution systems. DC power is generally more efficient to transport and use but more difficult to produce in large quantities and operating voltages are not easily changed. The decision whether to use AC or DC is usually based on what technology is to be used to create the power. Home appliances built to operate on DC do exactly the same job as ones designed to work on AC and both are widely available. Since solar panels produce DC, that is the usual choice for solar PV system operation. In a few cases where appliances are not readily available for DC operation an inverter to convert solar generated DC to AC may be used. Such conversions should be avoided when possible because of the added cost of the inverter and its use of additional electrical energy.

CONCLUSION

Electrical systems are like water systems in many ways. Pressure, flow rate, power and resistance all act in the same way for water and electricity.

Any time there is a problem understanding an electrical system it is a good idea to think about how a similar water system would act. Even in troubleshooting a solar electrical system, thinking about it as though it was a water system often helps in deciding what is wrong.

CHAPTER 3

PHOTOVOLTAIC PANELS

INTRODUCTION

In a photovoltaic system, the part that converts sunlight to electricity is called a photovoltaic panel. It is expensive and very hard to make but simple to use. All that you have to do to make electricity is to place it in the sun.

PANEL CONSTRUCTION

Most solar panels normally used for rural power production are made up of a number of individual cells. The cells may be round, square or some other shape.

AMORPHOUS PANELS

Some panels, called amorphous silicon panels, do not have individual cells but still can charge a 12 V battery. These panels are not recommended for rural electrification use because they do not last as long as the panels with individual cells yet cost about the same for the same power rating.

Each cell produces about one-half Volt no matter what their size. The amount of Amperes a cell can produce depends on its size with larger cells producing more Amperes.

Since each cell only produces about one-half volt, many cells will have to be connected in series to produce a high enough voltage to charge a 12 V battery. Usually there are from 30 to 36 of these cells on a panel which is intended to charge a 12 V battery. This makes sure the maximum Voltage from the panel is high enough to charge a 12 V battery.

Because panels having less than 33 cells do not properly charge a 12 V lighting system battery in the tropics, no panels should be used that do not have at least 33 cells and 34 to 36 cell panels are better. Most panels from good manufacturers now use 36 cells and that is recommended for all tropical installations.

Panels with more than 36 cells will work fine. Unfortunately, they cost more and do not provide any advantage over 36 cell units. Therefore, their higher cost is not justified for 12 V battery charging.

THE EFFECT OF PANEL AREA ON ELECTRICITY OUTPUT

The same way a large roof collects more water than a small one, the larger the solar panel the more electricity is produced. If you double the amount of surface covered by panels the electrical power output in Watts is doubled.

THE EFFECT OF SUNLIGHT BRIGHTNESS ON ELECTRICITY OUTPUT

The harder it rains, the more water you get from a roof. Photovoltaic panels work the same way with the sun. The more sunlight there is falling on the panel, the more electricity is produced.

THE EFFECT OF PANEL DIRECTION ON ELECTRICITY OUTPUT

If you are standing in a rain storm with a strong wind blowing, the side of you facing the wind gets much wetter than the side away from the wind. To get the most electricity from a solar panel it must be pointed towards the sun.

THE EFFECT OF HEAT ON ELECTRICITY OUTPUT

You work better if you are not too hot. Solar panels also work best when kept cool. The hotter the panel is the less power it provides.

MAXIMISING THE ELECTRICITY OUTPUT FROM A SOLAR PANEL

Because photovoltaic panels are expensive, you want to get as much electricity out of them as you can. Electricity from a solar panel is greatest when:

✓ ***THE BRIGHTEST SUNLIGHT FALLS ON THE PANEL***

The brightest sun is where there is no shade. Solar panels lose most of their electricity output when even a small part of the panel is in the shade. It is very important that solar panels are placed where the sun will shine on them from at least 0900 to 1500 without any shade at all.

✓ ***THE PANEL POINTS TOWARD THE SUN***

The most electricity will come from the panel when it points directly toward the sun. But because the sun keeps moving across the sky from morning to night the panel would have to move to always point directly toward the sun. That is not practical in most places and the best we can do is to fix the panel so it is pointing in the direction where the sun is located when it is the brightest. The sun is brightest at noon. The best mounting for a solar panel is with a tilt toward the equator equal to the latitude of the location. A panel located at a site with a latitude of 18 degrees south of the equator would be best mounted with a tilt of 18 degrees toward the north. A panel mounted on the equator should have a tilt of 5 degrees toward any direction. A small tilt is always needed to let rain wash off dirt that is on the panel.

✓ ***THE PANEL IS KEPT AS COOL AS POSSIBLE***

Because solar panels must be in the bright sun, it is hard to keep them from getting hot. It helps if solar panels are mounted so wind can blow over both the top and bottom of the panels. That means they should not be mounted right on a roof but at least ten centimetres above the roof so air can move all around the panel and keep it from getting too hot.

TO GET THE MOST FROM SOLAR PANELS FOLLOW THREE RULES

Rule 1: There should be no shade on the panel between 0900 and 1500.

Rule 2: Tilt the panel an angle in degrees equal to the latitude of the site though it should never be tilted less than 5 degrees from horizontal. The panel should face north for sites south of the equator and it should face south for sites north of the equator.

Rule 3: Mount the panel at least 10 centimetres above other surfaces so air can easily cool the back of the panel.

PROPER MOUNTING OF PANELS

Because solar panels are expensive and easily broken, it is important that they be mounted solidly so they cannot be loosened by the wind and blown away. Nails are not good enough to hold panels in place very long. Screws or bolts made of materials which will not corrode should be used to attach solar panels and to hold together the frame that is made to mount the panels to a building.

ARRAYS OF MORE THAN ONE PANEL

Most people want more power than can be provided by a single solar PV panel. To increase the power available, panels may be connected together. There are two ways panels can be connected together: series connections and parallel connections.

Series Connecting Panels

When more voltage than can be provided by a single panel is needed, additional panels are connected in series. If one panel provides 18 Volts, two in series will provide 18 + 18 or 36 Volts. Three in series will provide 3 X 18 or 54 Volts. For each of these 18 V panels connected in series to other panels, the voltage will go up another 18 Volts.

The Amperes provided by panels in series is the same as that provided by one panel because the same electricity flows through all the panels as they are connected in one long line. Each panel increases the electrical pressure but the flow stays the same as one panel. Since power in Watts equals Volts times Amperes, the power increases as panels are added.

Parallel Connecting Panels

When the voltage from a single panel is fine but more current is needed, panels can be connected in parallel. If one panel provides 2 Amperes in bright sun, two in parallel will provide 2 + 2 or 4 Amperes. For each of these 2 Ampere panels connected in parallel, an extra 2 Amperes will be produced.

In parallel connected panels, the voltage remains the same as one panel but the Amperes increases with each added panel. Since power in Watts equals Volts times Amperes, the power increases as panels are added.

Notice that for both series and parallel connected panels, the power increases as the number of panels in increased. Two panels in parallel produce the same power as two panels in series, it is just that the Voltage and Amperages are different.

Series - Parallel Connections

Solar PV systems to power refrigerators and other large appliances often use a 24 Volt battery instead of a 12 V battery. Some even use 48 Volt batteries. Since solar panels almost always are designed to charge 12 V batteries, two have to be connected in series to charge a 24 V battery and four have to be connected in series to charge a 48 V battery.. Many times, more Amperes are needed than can be provided by one panel, so it is necessary to connect panels in parallel as well. This combination of series and parallel connections can be extended to as high a Voltage as needed by adding more panels in series and as high an Amperage as is needed by adding more panels in parallel.

There are many different ways of correctly connecting a large number of panels to get a desired Voltage and a desired Amperage. You can connect panels in series until the desired voltage is reached then connect other series connected sets of panels in parallel until the desired Amperage is reached.

You can also connect panels in parallel to get the Amperes needed then connect other similar groups of parallel connected panels in series to get the desired voltage. Perhaps this should be called parallel-series connection but it really doesn't matter since the end Voltage and Amperage is the same as series-parallel connections.

THE IMPORTANCE OF GOOD PANEL CONNECTIONS

The solar panels are the source of all electricity in the PV system. If the wires are not clean and tightly connected to the panels, some of the electricity will be lost and the system will not work right. Always be sure that connecting wires are clean and that the screws which connect the wires to the panels are also clean and are properly tightened.

CHAPTER 4

BATTERY

CHARACTERISTICS

The battery stores electricity produced by the solar panel for later use. It is an important part of solar systems which need to have electricity at night when the solar panel is not producing electricity.

The battery is one of the most expensive parts of the solar system. It also has the shortest life and is the part most easily damaged by poor maintenance or improper use. The most important thing a PV technician can learn is how to take care of batteries and how to tell if the people using a PV system are causing battery damage through improper use.

The type of battery usually used in a solar system is what is called a *Lead-Acid* battery. That is its name because the main material it is made of is lead and the battery contains acid. The acid is called Sulphuric Acid and can burn holes in clothes, burn skin and especially hurt the eyes. For that reason, you should be very careful around Lead-Acid batteries and not spill the acid, get it in your eyes or on your skin. If it is spilled or comes in contact with your skin or eyes, immediately wash it off with lots of water.

Lead-Acid batteries are made up of cells. Each cell produces about 2 Volts. A 12 Volt battery has six 2 Volt cells connected in series. A 24 Volt battery has twelve 2 Volt cells. The cells may all be contained in a single plastic case like a car battery or they may be separate.

Most batteries used for solar systems have removable caps on top so you can test the cells and add water when it is needed. They are called *open cell* or *flooded cell* batteries. Some batteries are sealed and cannot be maintained except at the factory. They are called *maintenance free* or *sealed* batteries. That type of battery has a smooth top and no filler caps. If that type of battery is provided for your solar systems, there is nothing you can do to maintain it except keep the connections tight, the case clean and be sure the user of the system is not using it improperly. Maintenance free batteries are more expensive than open cell batteries of the same capacity. Field tests have shown that maintenance free batteries do not last as long as open cell batteries that are properly maintained. Maintenance free batteries should only be used where no one is trained to properly maintain the open cell type batteries.

Of all the parts of a solar system, the battery requires the most care. It must be checked regularly to be sure the liquid level is correct and only the purest water added if it is low. If properly maintained, a battery has a life of five to seven years. If poorly maintained or if the electricity system is used improperly the battery may have to be replaced much sooner.

THE SOLAR SYSTEM BATTERY IS SPECIAL

Although the solar battery may look like the battery used in automobiles, tractors and trucks, inside it is very different. Batteries used for vehicles are designed to provide large amounts of power in short spurts while solar batteries are designed to provide a small amount of power continuously for many hours.

A car battery is like a fast, short distance runner. It produces a lot of effort for a short time.

A solar battery is like a long distance runner. It provides a moderate amount of energy continuously for a long time.

A good long distance runner is usually tall, thin and has long legs. A good sprinter usually has a compact and powerfully built body. If a long distance runner is forced to sprint, he will not be very fast and may be injured. If a sprinter is entered in a long distance race, he will be slow and may not even finish the race.

In the same way, if a solar system battery is used to attempt to start a tractor, car or truck it will work poorly and may be badly damaged. If a battery made for use in a car, truck or tractor is used in a solar system it will not last nearly as long as the battery made especially for solar systems. You should *never* allow a solar system battery to be used for any other purpose. If you must use an automotive type battery in a solar system, do not expect it to last very long. If you use a solar battery to start cars or tractors, it will not last long either.

TYPE OF BATTERY

Several types of batteries are made. The type best suited for most solar systems is called a deep discharge battery. It is called that because it is especially designed to deliver most of its power slowly without any damage.

The most common battery type made is the starting battery. It is designed to provide lots of power for a short time in order to start engines. That battery is easily damaged by taking too much power from it over a long period of time. Though the starting type battery is cheaper than the deep discharge battery, it will not last long when used in a PV system and replacements be much more expensive in the long run.

ABILITY TO STORE ELECTRICITY

Batteries are classed according to how much electricity they can store. The measure used is the Ampere-Hour (AH). If a battery delivers one Ampere of current continuously for 100 hours it has provided 100 Ampere-hours. If a battery delivers 10 Amperes continuously for 10 hours, it is also delivering 100 Ampere hours. If 5 Amperes is delivered continuously for 20 hours, that is 100 Ampere hours too. Ampere-hours are therefore equal to the continuous current being delivered times the number of hours it is delivered. If a current of 7 Amperes is delivered for 6 hours, that will be 6 X 7 = 42 AH.

If a battery is rated at 100 Ampere-hours, that means it can be expected to deliver 1 Ampere for 100 hours, or 10 Amperes for 10 hours, 5 Amperes for 20 hours or any combination of Amperes and hours that equal 100 when multiplied together.

When selecting a replacement battery, it should never have a lower Ampere hour rating than the one originally installed. If the battery is a deep discharge type of battery, then the replacement does not need to be higher in rating than the original battery.

Starting type (automotive) batteries are never the best choice for solar systems but if it is impossible to obtain a deep discharge type of battery and a starting battery has to be used, always obtain one at least twice as big as the solar battery originally installed. If the original battery shipped with the solar system had a 105 AH rating and you have to replace it with an automotive type of battery, the replacement should have a rated capacity of at least 210 AH. Even with the larger battery, it will not last as long as a proper deep discharge type, but at least it should last several years.

If an open cell type of solar battery is to be replaced with a maintenance free type of solar battery, it should be half again as large as the open cell battery it is replacing. So if the original open cell battery had a capacity of 100 Ampere hours, a solar type maintenance free battery to replace it should have a capacity of at least 150 Ampere hours.

THE DIFFERENCE BETWEEN A BATTERY FULL OF ELECTRICITY (CHARGED) AND ONE EMPTY (DISCHARGED)

We can easily tell if a water tank is full or empty. It is not so easy to tell if a battery is full or empty of electricity since we cannot see electricity. To tell if a battery is full or not it is necessary to use a tester.

There are two types of testers to tell how much electricity a battery contains. The most common tester checks the acid in the battery and tests it for its strength. The stronger the acid in the battery, the more electricity is stored in the battery. The strength of the acid is measured by a device called a hydrometer.

A hydrometer is a glass tube with a special float in it. The battery acid is sucked up into the tube by squeezing a bulb on top. The float then rises to the top of the liquid. On the float are markings which tell how strong the acid is. If the float rises high in the liquid, then the battery is full. If it floats low, the battery is low and if it rises part way, the battery is partly full of electricity.

The hydrometer measurement is like a float gauge on a water tank. In a water tank if the float is high, the water is high. If it is low, the water level is also low.

In a battery, if the hydrometer float is high the battery charge is high. If it floats low, the charge level is low.

A second way to check the amount of electricity in a battery is to use a meter which measures the Voltage of the battery. When a water tank is full, there is a higher pressure at the outlet tap than if the tank is low on water. With a battery, if it is full of electricity, the voltage is higher than if it is low on electricity.

Water pressure is highest when the storage tank is full. Electrical pressure (Voltage) in a storage battery is highest when the battery is fully charged.

A battery rated at 12 Volts will actually measure over 13 Volts when it is fully charged and less than 11 Volts when it is getting low on charge. A battery has very little charge left in it if its Voltage falls below 10 Volts. In normal use, the battery should never be discharged to a Voltage less than 11.5 Volts.

Since the difference between the Voltage of a low battery (11.5 V) and a full battery (13.5 V) is only 2 Volts, a high sensitivity Voltmeter must be used to tell the difference accurately.

Voltage level is the easiest way to check the charge in a battery but accurate Voltage measuring meters are expensive and easily damaged. For routine checks it is usually better to use a cheap hydrometer.

INSTALLING A NEW BATTERY

The special acid used in storage batteries is called electrolyte. To install a battery that comes with electrolyte (acid) already in it, first be sure the acid level is correct, then simply connect the battery and allow it to charge from the solar panel at least two sunny days before turning on any lights or other appliances. If a new battery arrives filled with acid but one or more of the cells is low on electrolyte, add only acid (*not* water) before connecting the battery to the solar system.

If a new battery is delivered with some acid already in the cells, fill the cells with acid if any are low and connect it to the solar system. Let the solar system charge the battery for at least two sunny days before using any electricity.

If the new battery arrives with no liquid in the cells, the cells must be filled with battery acid. Because the battery acid may harm eyes, skin and clothes it is important to handle the acid carefully.

IMPORTANT: If acid gets on the skin, eyes or clothes immediately wash off the acid with lots of clean water.

Fill the battery slowly and be very careful not to spill any acid. You should fill each cell so slowly that you can count to at least to thirty in the time it takes to fill one cell. It is best to put a little acid in one cell, then put some in another cell and rotate through all the cells before adding more to the first cell. This will insure that you are not filling the cells to fast.

If the battery comes with filling instructions, follow them carefully. If no instructions are provided, fill the cells so the acid covers the plates in the cell but is below the bottom of the fill opening.

Notice that the battery becomes warm after it is filled. That is normal but it can become dangerously hot if it is filled too fast so always fill slowly and carefully.

A newly filled battery should be immediately connected to the solar system and allowed to sit and charge for at least two sunny days before any electricity is used.

The battery should be installed in a plastic or wooden box which has holes near the top to allow air to reach the battery. Never use a metal box because the acid will cause the metal to corrode.

The battery should be installed on a hard, level surface. It should not be placed where small children can reach it because they may be burned by the acid. Place the battery where it is not likely to be turned over accidentally.

The wires should be firmly attached using bolts. Never use spring clips or just wrap the wire around the posts. Paint the terminals with thick oil or grease to prevent corrosion. Do not paint the oil or grease anywhere but on the battery terminals.

BATTERY MAINTENANCE

There are three things that need to be done to properly maintain a solar system battery:

Maintenance Step 1

Keep the battery clean. If the top of the battery becomes dirty corrosion will begin to be a problem and electricity will begin to leak from the battery connections through the dirt. To clean the battery, use only fresh water and a rag. Because it is likely that a little acid will be found on the battery, be careful not to touch your eyes with hands or rags that have touched the battery. Wash all rags and your hands in fresh water when you are finished. Recoat the terminals with thick oil or grease after cleaning.

Maintenance Step 2

Test each cell with the hydrometer. All the cells should be about the same when measured with the hydrometer. If one or more are much different from the others, it is likely that the battery is beginning to fail. A failing battery may continue to be used as long as the system is functioning but the battery should be watched more carefully in the future to see if it is getting worse.

Sometimes there will not be enough electrolyte in a battery cell to suck enough into the hydrometer to get a reading. In that case, add pure, clean, fresh water until the cell is filled to the proper level. Wait at least one day before taking a reading with the hydrometer after filling with water.

Maintenance Step 3

Keep the battery cells full of electrolyte. The battery cells should be checked at least once a month and special, high purity fresh water added if the liquid is below the correct level. After the battery is once filled with acid, you should *never* add more acid unless the battery has been turned over and the acid spilled out. As long as the acid has never spilled out of the cells in the battery, add only pure, fresh water, *never more acid*. The water put in the battery must be pure, clean and fresh or the battery life may be shortened.

Do not fill the cells so the water is to the top of the fill holes. If you do, as the battery is charged, electrolyte will be forced out and acid will spread over the top of the battery. The electrolyte should always cover the thin plates you can see if you look into the fill holes but should not be so full as to come up into the fill hole itself. Usually there is a mark on the side of the battery or an indicator in the fill hole which shows the proper level for the electrolyte.

Battery caps should not be kept very tight though they must always be in place except when you are checking the battery. Battery caps have a small hole to let the cell breathe. If that hole is plugged, the cell may crack or explode. If a cap is lost or broken and a proper replacement cap is not immediately available, use a sheet of plastic to cover the hole. Remember to never plug the hole tightly because the cell must get air to operate. Never use paper, wood, cork or metal to cover the fill holes, only plastic or glass.

If water has to be added more than once each month to all the battery cells, it is likely that the system controller is not operating properly. It should be replaced and returned for adjustment or repair.

If water has to be added often to one or two cells but not the rest of the cells, the battery is weakening and will probably have to be replaced soon.

SAFETY AROUND BATTERIES

Although the Voltage of a battery is not enough to cause harm, if a piece of metal is placed across the terminals of a charged battery, there is enough power in the battery to cause a large, hot spark to jump which could cause a fire.

Never lay anything on top of a battery except plastic or glass.

The acid in a battery is not strong enough to cause immediate burns to the skin and no harm will probably be done if it is washed off immediately. To get rid of the acid, lots of water must be used for washing.

Getting acid in the eyes is particularly dangerous. It will cause eye damage and sometimes blindness. When filling a battery, do not look into the fill hole while acid or water is being added. After handling, filling or testing a battery, be careful not to touch your eyes before washing your hands. If any acid gets into the eyes, wash them with lots of water actually immersing your head in a bucket of water or dunking in a pool if possible.

When the battery is connected, it sometimes produces a gas which will explode if a flame is near. Never smoke or light matches, or use an open flame lantern around a battery, particularly when checking or filling the cells.

CHAPTER 5

CONTROLLERS

INTRODUCTION

In a water system, it is sometimes important that a storage tank not become too full or too empty. A valve can be installed to turn off the water coming into the tank when the tank gets full. Another valve can be installed which prevents water from leaving the tank when it gets too low. These two valves control the amount of water in the tank.

In a solar system, an electricity valve is usually installed to keep the battery from getting too full. This is called a charge controller. Another valve is installed to keep the battery from completely running out of electricity. That is called a discharge controller. These electricity valves control the amount of electricity in the battery.

CHARGE CONTROLLER

Without a charge controller the panels can force too much electricity into the battery and cause it to be overcharged. When a battery is overcharged, it loses water rapidly, it gets hot and may be damaged. A charge controller works like a valve on a rainwater collection system that prevents the water tank from overflowing.

The charge controller must be connected between the panels and the battery. It works by constantly checking the voltage of the battery and if the battery voltage is so high that it shows that the battery is full, the controller automatically disconnects the panels so no more electricity will be forced into the already full battery.

DISCHARGE CONTROLLER

The discharge controller keeps the appliances from taking too much electricity out of the battery and causing it to become too discharged. When a battery is too discharged, it loses some of its ability to be recharged and becomes weakened and its life shortened. A discharge control is like a valve on a rainwater collection system that keeps you from taking all the water from the tank.

The discharge controller must be connected between the battery and the appliances. It works by continuously checking the voltage of the battery and if the battery voltage is so low that it shows that the battery is almost empty, the controller automatically disconnects the appliances so no more electricity can be taken from the nearly empty battery.

COMBINED CHARGE AND DISCHARGE CONTROLLERS

Many times a charge controller and a discharge controller are together in the same box. You can usually tell what kind of controller is present in a box by looking to see what connections there are. If the controller box has connections that go to the panels, it usually means that it includes a charge controller. If the box has connections that go to the appliances, it usually means that it includes a discharge controller. All controllers are connected to the battery.

INSTALLATION AND MAINTENANCE OF CONTROLLERS

Wire the controller into the circuit according to the instructions which are provided by the supplier of the controller. It is very important that you connect the right wires to the right terminals. The positive wire from the battery must be connected to the positive battery terminal on the controller. The positive terminal from the panels must be connected to the positive panel terminal on the controller. If the controller is wired incorrectly it will not work and the controller and the battery may be damaged. Long wires between the controller and the battery may cause problems since it is more difficult for the controller to measure the charge in the battery from a long distance. It is best if the wire between the controller and the battery is no more than two metres long.

When installed properly, controllers rarely fail. Controllers can be damaged by incorrect wiring, connection to too large appliances, too much heat, insects, water and animals. The controller should be solidly mounted in a cool place out of the sun and rain and as close to the battery as is practical. The connections should be made according to the instructions and all connection screws tightened correctly. If new appliances are added, be sure the controller can handle the extra power without damage.

If a controller does not work properly, always replace it with a good one and send in the bad one for repair. Never wire around the controller. Never change the controller adjustments. The adjustments tell the control circuits when the battery is full and when it is empty. Without special equipment and techniques, you cannot set them properly. If you change the adjustments without the proper equipment and techniques the system may appear to work but you will cause damage to the battery and greatly shorten its life.

SUMMARY

The charge and discharge controller protect the expensive battery from damage due to too much electricity being forced into it or from too much electricity being taken from it. Though you may be able to get a little more electricity from a battery by wiring around the controller, the battery will wear out much sooner. If you need more electricity, it is much better to add another panel instead of wiring around the controller. If a controller fails and bad connections are not the problem, replace it rather than trying to fix it.

CHAPTER 6

WIRE SIZING AND SELECTION

INTRODUCTION

If a water system is installed using pipes that are too small, water pressure will be lost in the pipes. By the time the water reaches the user, the pressure may be so low that not enough comes out to be useful. The reason for the loss of pressure is that the small pipe has too high a resistance and a lot of the pressure is used up just keeping the water flowing in the pipe.

In an electrical system, if the wires are too small, voltage is lost and appliances may not be able to get enough electricity to work properly. The reason for the loss of voltage is that the wires have too high a resistance and a lot of the voltage is used up just keeping the electricity moving in the wire.

A common reason for poor performance of solar systems is wiring that is too small. It is very important to know that the wiring used for a 12V solar installation must be much larger than wire used to carry the same amount of power at 240V from a city electrical system. Electrical technicians trained to work on city electrical systems often install wire that would work fine at 240V but works poorly at the 12V found in a PV system.

Wire connecting appliances in a solar installation must be larger than wire used for the same size appliances operating from 240 Volt AC power.

THE RELATION OF SIZE TO POWER LOSS

Pipe Size. Water flows easily through a big pipe but not a small pipe. The smaller the pipe, the more difficult it is to force water through it. To make water flow through a pipe, there must be force behind it. That force is the water pressure. To move a certain amount of water each day through a big pipe takes less pressure than through a small pipe. Since the power needed to move the water is the pressure times the flow rate, a small pipe will require more power than a big pipe to make the same amount of water move through the pipe in a day. Power costs money. To save power, bigger pipes can be installed. But big pipes cost more money than small ones. When designing a water system, the designer has to compare the cost of bigger pipe and the cost of the extra power necessary to force water through smaller pipes.

Wire Size. The same problem exists with solar electrical systems. The smaller the wire, the more electrical pressure (Voltage) must be available to force a certain current through the wire. To get increased Voltage, more batteries and panels must be installed at considerable extra cost. If we put in very big wires, the voltage needed to push the electricity through the wires is low, but the cost of the wires becomes high. The right size of wire is that which provides the best compromise between the cost of larger wire and increased wiring costs to lower losses and the cost of more panels and batteries needed to overcome wire losses.

THE RELATION OF LENGTH TO POWER LOSS

Pipe length. The longer a pipe, the more difficult it is to force water through it. To move a certain amount of water each day through a short pipe takes less pressure than through a long pipe of the same size. Since the power needed to move the water is the pressure times the flow rate, using a long pipe will require more power to move the same amount of water than using a short one. Power costs money. To save power, pipes should be as short as possible.

Wire length. The same problem exists with solar electrical systems. More electrical pressure (Volts) must be present to force a certain current (Amperes) through a long wire than a short one of the same size. To get this increased voltage, more batteries and panels must be installed at considerable extra cost. To save cost, wires should be kept as short as possible.

VOLTAGE DROPS FROM WIRING

The reason for the power loss in wire is its resistance (Ohms). It takes force (Volts) to push electricity through the wire and the more resistance the wire has, the more force must be used. The amount of Voltage necessary to push the electricity through a wire is called the voltage drop of the wire. It is called voltage drop because the voltage at the battery end of the wire is higher than that at the appliance end by the amount needed to push the electricity through the wire. There is a drop in voltage due to the wire resistance.

It takes more force to push a lot of electricity through a wire than to push a small amount. Therefore, the voltage drop in a wire increases as the electricity flow (Amperes) increases. The exact voltage drop caused by the wire equals the Amperes being pushed through the wire times the wire resistance in Ohms.

The three things which determine the loss of power in a wire are the amount of electricity (Amperes) which have to flow, the wire size and wire length.

An appliance requires a certain number of Amperes to operate properly. It is the appliance that determines the Amperes which must flow in the wire connecting the appliance and the battery.

Wire length and Voltage Drop: Since wire resistance increases as wire length increases, the shorter the wire, the better. If the voltage drop between the battery and an appliance is 2 Volts with a ten metre wire, shortening the wire to 5 metres will cut the voltage drop in half to only 1 Volt. Not only does a shorter wire make more Volts available to the appliance, it also cuts the cost of the wire so a double advantage is gained. This leads to:

WIRING RULE 1: Never put in longer wires than are absolutely necessary.

Wire Size and Voltage Drop. Since resistance decreases as wire size increases, the voltage drop in the wires goes down and wire size goes up. Doubling the size of the wire cuts the wire voltage loss in half. But doubling the wire size will increase the cost of the wire. A good method to use to be sure that the wire is big enough for the PV system to work properly but not too big and excessively expensive is to allow the wire to lose some voltage but not so much as to cause problems with appliance operation. This leads to:

WIRING RULE 2: The maximum voltage drop for a 12 Volt solar system wiring should not exceed 0.5 Volts.

TYPES OF WIRE

Although the size of the wire is the most basic specification, there are several different types of wire available in the standard sizes.

Conductor Type

The metal core that carries the electricity is called the conductor. Although large wires are sometimes made with aluminium conductors, wire used for home and small commercial applications is always copper. Even if aluminium wire is available at no cost, never use it in house wiring because unless it is installed with special, difficult to obtain connectors and in a special manner, it will not last very long.

For house wiring, solid copper wire is often used. It consists of a single solid copper conductor inside an insulating sleeve. Solid wire is usually the cheapest but it is stiff and if bent back and forth enough times it will break.

Some wire is made up of many small wires all bunched together inside the insulating sleeve. It is called stranded wire because it is made up of many small strands of wire. Though each strand is very small, enough strands are bunched together to make the total wire area equal to that of a solid wire. If each strand is, for example, $0.1mm^2$ in size, then 25 strands will be used in a $2.5mm^2$ wire. The main advantage of stranded wire is its flexibility. The more strands in the conductor, the more flexible the wire. Most appliance power cords have a stranded wire. Very large electrical wires are also stranded simply because a single solid wire would be too hard to bend.

Electrically, there is no difference between equal sizes of stranded and solid wire. Solid wire is cheaper and fine for permanent installations. Stranded wire is usually best for any application where the wire is not permanently fixed in place.

Insulation

Insulation on a wire is mainly intended to prevent accidental electrical connections so no electricity is lost through leakage to the material surrounding the wire. Insulation also is for safety. At the low voltages of a solar system, electrical shock is not likely but burns or a house fire can be caused if inadequately insulated wires are shorted.

Another function of insulation in some wires is to combine several conductors into one unit. Since all electrical circuits require one wire going to the load from the power source and another returning, it is common for house wiring to include two separate conductors combined into one insulating sheath. This is called two conductor wire. Three conductors or more are also available though for solar systems usually two are all that is needed. Multiple conductor wire has two layers of insulation. The exterior insulation holds the several wires together and the interior insulation is a layer around each individual wire. For house wiring, two conductor wire is much more convenient to install than running two single conductor wires.

Insulation also protects the wire from damage. Heavy, abrasion resistant insulation is used for wiring that is to be moved often or may be stepped on or run over by vehicles. Special insulation is needed for wires that are to be buried or exposed to sunlight and the weather.

When buying wire, make sure that the insulation is right for the job. If the wire is to be exposed to the weather, as is the case for connecting solar panels, it is important that the insulation be designed for exposure to sunlight and to rain. Standard indoor house wiring will become hard and crack open if exposed to sunlight for long periods. If the wire is to be buried, the insulation must be of a type designed to resist the fungus and moisture always present in the ground. Again, standard indoor house wiring will be ruined by long burial.

WIRING RULE 3

Always use the right kind of wire for the job. Buried wire must have underground rated insulation. Wire exposed to sunlight must have exterior grade insulation. Wire with interior grade insulation may only be used inside a building, neither buried nor exposed to the sun for long periods.

CHOOSING THE CORRECT SIZE OF WIRE

At the end of this chapter is a table to help you determine the size wire to use in a 12V PV installation. These wire sizes are NOT correct for PV systems that are not 12V.

Looking at the tables you can see that there are two things that must be known in order to correctly choose the proper wire size:

The distance in meters along the path of the wire.

The number of Amperes which must flow through the wire.

Distance Along the Path of the Wire: The length must be measured along the actual path the wire will take all the way from the appliance to the battery.

Using The Wire Sizing Table For Wiring Appliances

It is very easy to use the table when a battery is connected by a wire to a single appliance. First the appliance Amperes or Watts must be determined. This is usually printed on the appliance though sometimes it can only be found on specification sheets packed with the appliance. Starting at the top, move down the Watts/Amperes column until you find the first row having the number of Watts or Amperes equal to or higher than the appliance rating.

DISTANCE MEASUREMENT

Distance is always measured along the actual path the wire follows in the installation. Side branches to switches or extra wire needed to go around doors and windows must be included in the total distance between the battery and appliance. Even though the wire you are connecting may be connected to a controller instead of going all the way to the battery, the measurement of distance for figuring wire size must go all the way from the appliance to the battery.

Then in the table, go across the row for the appropriate Watt/Ampere value until you reach a wire length equal to or longer than the wire length you need.

Go straight up to the top of the table and read the wire size directly.

EXAMPLE #1:

A wire run of 7 metres is required between a battery and a 60 Watt fan operating off of 12 Volts. What standard European wire size is needed? What American Wire size?

Distance between battery and appliance is 7 metres

Watts = 60

System Voltage = 12 V.

Using the 12V Metric wire table, go down the Watts column to 60. Go across on that line. First you come to 6 metres. That is too short since the actual value is 7. Keep going across the page. The next distance is 10 metres. That is larger than 7 so it can be used. Go up that column and you see that the wire size is $4mm^2$

Though we can use the exact wire sizes that we calculate from the table, we can also use any larger wire too. If a larger wire is used, the actual power loss is less so there will be a slight improvement in the operation of the solar system.

The two most common wire sizes are $1.5mm^2$ and $2.5mm^2$. The difference in cost between the two wire sizes is not large when compared to the overall cost of the solar system but the losses in the larger wire are significantly lower. For best performance, it is best to use the $2.5mm^2$ even though a smaller wire is given by the table as being acceptable.

WIRING RULE 4

Do not use wire smaller than 2.5mm2 for any solar installation.

Wire Sizing For Appliances With Motors

The Watts or Amperes listed on an appliance is its electricity use while in normal, continuous operation. For example, a refrigerator may show a power requirement of 60 Watts at 12 Volts. That means when it is running continuously, it will need to receive 5 Amperes of current from the battery. Electric motors, however, require extra current to start. When an electric motor is first turned on it may require several times the Amperes as it uses when running. Since the voltage drop in the wire increases as the Amperes through the wire increases, a motor which is starting and drawing extra Amperes from the battery may cause such a large voltage drop in the wire that it can cause problems with the appliance, particularly when the battery is partially discharged and its voltage low. To prevent this problem, wires running to appliances with motors (refrigerators, washers and pumps for example) should be at least twice as large as the size given in the wire table. Note that an exception to this rule is the wire running to electric fans. Fans do not require the large extra starting current and therefore do not need the oversized wire.

WIRING RULE 5

Wires from the battery to a refrigerator, pump, washing machine or other appliance with a motor should be at least twice as large as the wire table shows.

Wire Table For Panel To Battery Connections

Voltage drop problems can occur in the wires connecting solar panels to batteries.

The number of Amperes the wire must carry is not constant. It changes with the amount of charge in the battery, the size of the panels and the brightness of the sun. The wire size should be that which will pass the maximum amperes the panels will produce. The maximum panel Amperes is assumed to be:

Maximum Panel Amperes = Wp rating/15 for charging a 12V battery

Thus a 90Wp panel can be assumed to produce a maximum of 90Wp divided by 15 = 6 Amperes. Where there is more than one panel, the Amperes of each are added together. Thus if there were two 90Wp panels, the Amperes would be (6+6) = 12 Amperes

If the table requires a wire size larger than is available, several smaller wires can be combined into one large one.

EXAMPLE #2:

A 12V solar system uses 3 panels to operate a health centre. Each has a rating of 45Wp. The panels are mounted on the roof and the distance between the panels and the battery along the wire path will be 12 metres. Using the wire table, what size wire is needed?

First, estimate the maximum Amperes from the Panels:

Maximum Amperes = Wp rating / 15 = 45/15 = 3 Amperes. Therefore, three panels will produce (3A+3A+3A)= 9 Amperes

Then go down the Ampere column until you reach 9 Amperes, then go across to the 12 Metre panel to battery distance column and read 6 mm^2 as the minimum wire size to use.

SUMMARY

Wire is usually the lowest cost part of a solar electric system but if the wrong wire is used it can keep the more expensive parts of the solar system from working properly. Remember that electricity from a solar system is different from that found in cities where there is a central electricity utility. The wires normally used for house wiring in the city are often too small for a solar system.

It is very important to select the right size of wire and the proper type of insulation for the wire. If the wrong size wire is used, the appliances may not work right. If the wrong type of insulation is chosen, the wire may develop electrical losses or may be the cause of electrical fires due to insulation failure.

CHAPTER 7

SYSTEM SIZING

INTRODUCTION

For a solar photovoltaic system to work properly, the size of the panels and the battery must be matched with the energy needs of the appliances. Because panels and batteries are expensive, it is common to try to save money by installing too few panels or too small a battery. That is very poor practice and does not really save money because a system that is too small for the appliances does not work right and the battery will have to be replaced often.

Sizing PV systems for homes is not difficult if it is known what appliances will be used and how long they will operate each day. Because all the power must come from the panels, it is most important that they be large enough to provide the energy needed even when there are some cloudy days.

CALCULATING THE PROPER PANEL SIZE

Appliances use energy measured in Watt-hours and panels produce energy measured in Watt-hours. Watt-hours of energy are like litres of engine fuel. When five litres of fuel are needed to go from one place to another in a car, if only four litres of fuel are provided the motor will stop before the trip is completed. In a solar system, if an appliance needs 100 Watt-hours a day to work properly, if only 80 Watt-hours are produced by the panels, then the appliance will quit working early in the day.

ELECTRICITY LOSSES

If the fuel line leaks in the car, you will need more fuel in your travels. With a PV system there are always electricity leaks and even if the panels produce a full 100 Watt-hours a day it will not be enough to power appliances needing 100 Watt-hours a day because some of the energy from the panels is lost before it can get to the appliances.

In most solar PV systems, the energy from the panels is first stored in a battery before being sent to the appliances. There is always some energy lost in the battery. That lost energy must be provided by the panels but never gets to the appliances. Also, a little energy is always lost in the wires and controller even though the wires are the proper size and the controller is working correctly. It is reasonable to say that for every 100 Watt-hours needed by the appliances, at least 130 Watt-hours must be provided by the panels. The extra 30 Watt-hours is lost in the battery, wires and controller.

Calculating Appliance Watt-hours used each day

To compute the number of Watt-hours needed each day from the panels, first compute the number of Watt-hours needed each day by the appliances. Then add to that the number of Watt-hours lost before the energy gets to the appliances.

To compute appliance Watt-hours, multiply the number of Watts needed to operate the appliance times the number of hours the appliance is used each day.

Example #1:

If a 10 Watt light is turned on two hours a day, then the energy used is:

10 Watts X 2 hours = 20 Watt-hours per day

If a 120 Watt fan is operated 3 hours a day, the energy used is:

120 X 3 = 360 Watt-hours per day.

Always figure the energy used per day because the solar panels work on a daily cycle. Sometimes an appliance is used more on some days than on others, in a church for example. Then compute the Watt-hours needed per week and divide that by 7 to get the Watt-hours per day.

Example #2:

A 20 Watt light in a church is used on Wednesday night for three hours and Saturday night for four hours. The rest of the week it is not used. The Light will use:

20 Watts X 3 = 60 Watt-hours on Wednesday

20 Watts X 4 = 80 Watt-hours on Saturday

So the light uses 60 + 80 = 140 Watt-hours per week. There are seven days in a week, so the light uses 140 divided by 7 = 20 Watt-hours per day on the average.

So far, we have assumed there is only one appliance. Usually there are several. We have to know the total energy needed by all the appliances each day. To get that, find the Watt-hours needed per day by each appliance and add them all together.

Example #3:

A house has three lights. One is 20 Watts and is used three hours a day. The second is 10 Watts and is used 4 hours a day. The third is 2 Watts and is used 9 hours a day. The total Watt-hours used by the three lights in a day is:

20 Watts X 3 hours = 60 Watt hours per day

plus:

10 Watts X 4 hours = 40 Watt hours per day

plus:

2 Watts X 9 hours = 18 Watt hours per day

The total energy used is

60 + 40 + 18 = 118 Watt-hours per day.

Calculating total Watt-hours needed from the panels each day

Once the Watt-hours used by the appliances is known, the Watt-hours that must be provided each day by the panels will be appliance Watt-hours plus the Watt-hours lost in the wires, battery and controller. It is reasonable to estimate that for every 100 Watt-hours used by the appliances, the panels have to produce 130 Watt-hours. Therefore to calculate the number of Watt-hours that have to be produced by the panels each day, multiply the Watt-hours used by the appliances times 1.3.

Example #4:

The appliances in a house require 100 Watt hours per day. The panels will have to produce:

100 Watt-hours X 1.3 = 130 Watt-hours per day

of which 30 Watt-hours will be lost in the system and 100 used by the appliances.

Example #5:

A fan uses 200 Watt-hours in a day. The panels will have to produce:

200 X 1.3 = 260 Watt-hours each day

of which 60 Watt-hours will be lost in the system and 200 used by the fan.

Estimating the energy output from a solar panel

Photovoltaic panels come in different sizes. The larger the panel, the more energy in Watt-hours it will produce. Panel manufacturers rate the size of their panels by the maximum Watts of power that they will produce. This is called panel peak Watts. On manufacturer's data sheets, panel peak Watts is usually shown as Wp. Some common panel sizes are 35 Wp, 42 Wp, 47 Wp and 55 Wp. Since the peak Watts produced depends not only on the size of the panel but also on the brightness of the sunlight striking the panel, you cannot get Watt-hours by multiplying peak-Watts times the hours the sun is shining because the brightness of the sun is constantly changing as it moves in the sky. Also, clouds reduce panel output so in a cloudy climate there will be less energy produced by a panel than in a sunny climate.

Fortunately there have been many measurements made of panel energy output which can be used to estimate panel energy production. Those measurements tell us that it is reasonable to estimate that a 35 peak Watt solar panel will provide 120 Watt-hours per day on the average in a typical Pacific island climate. On very clear days the panel will produce more, on cloudier days less, but over many days, the average panel output from a 35 peak Watt panel will be about 120 Watt-hours.

If a bigger panel is used there will be more energy output. If the panel is twice as big and rated at 70 peak Watts, then it will produce twice as many Watt-hours per day as a 35 Watt panel. To estimate how many Watt-hours a particular panel will provide in a typical

Pacific Island climate, divide the actual panel peak-Watt rating by 35 then multiply times 120 which is the average daily output of a 35 peak Watt panel.

Example #6:

The number of Watt-hours expected to be produced by a 55 peak-Watt panel in a typical Pacific Island climate is:

55/35 X 120 = 188.57 Watt-hours per day

The 55 Watt panel produces 55/35 = 1.57 times as much energy as a 35 Watt panel. The 35 Watt panel produces 120 Watt-hours per day, so the 55 Watt unit provides 188.57 Watt hours per day.

Example #7

About how many Watt-hours per day will a 47 Watt panel produce in a typical Pacific Island climate?

47/35 X 120 = 161.14 Watt-hours per day.

Determining the number of panels needed

If two panels are connected together, twice as many Watt-hours will be produced. Three panels will produce three times the Watt-hours one panel produces. Watt-hours produced are the same whether the panels are connected in series or in parallel.

To find the number of panels needed to operate the appliances, find the number of Watt-hours which must be provided by the panels and divide that by the number of Watt-hours one panel will produce.

Example #8:

Appliances in a house need 200 Watt-hours a day to operate. How many 42 peak Watt panels will be needed if the climate is a typical Pacific Island climate?

The panels must produce 200 Watts plus the energy lost in the system:

200 X 1.3 = 260 panel Watt-hours per day.

One 42 Watt panel can be expected to produce:

42/35 X 120 = 144 Watt-hours per day

Therefore it will take:

260/144 = 1.81 panels to do the job.

Since we cannot take a saw and cut a panel to smaller size to get 0.81 panels, there will have to be at least 2 panels installed. One panel will not be enough.

Example #9:

A video system which needs 200 Watts to operate is used four hours a week. How many 35 peak Watt panels will be needed to provide enough energy?

200 Watts X 4 hours = 800 Watt-hours per week

800/7 = 114.29 Watt-hours per day

So 114.29 Watt-hours/day is required by the appliances

114.29 X 1.3 = 148.58 Watt-hours per day

and 148.58 Watt-hours/day must be provided by the panels.

One 35 Watt panel produces:

35/35 X 120 = 120 Watt hours per day.

148.58/120 = 1.24 panels will be needed

There cannot be a fractional part of a panel, so 2 panels will have to be installed for there to be enough energy to run the video as needed.

Summary of panel sizing calculations

Step 1). Calculate the Watt-hours per day for each appliance used.

Step 2). Add the Watt-hours needed for all appliances together to get the total Watt-hours per day which must be delivered to the appliances.

Step 3). Multiply the total appliance Watt-hours per day times 1.3 to get the total Watt-hours per day which must be provided by the panels.

Step 4). Calculate the Watt-hours per day produced by one panel by dividing the panel peak Watt rating by 35 and multiplying the answer times 120.

Step 5). Divide the total Watt-hours per day which must be provided by the panels by the number of Watt-hours per day produced by one panel. Increase any fractional part of the result to the next highest full number and that will be the number of panels required.

Example #10:

A house has the following appliance usage:

One 18 Watt light used 4 hours per day

One 60 Watt fan used 2 hours per day

One 75 Watt refrigerator that runs 12 hours a day

The system will be powered by 40 peak Watt panels. How many panels will be needed if the climate is a typical sunny Pacific Island climate?

Step 1).

Light: 18 X 4 = 72 Watt-hours per day

Fan: 60 X 2 = 120 Watt-hours per day

Refrigerator: 75 X 12 = 900 Watt-hours per day

Step 2).

Total Appliance use = 72 + 120 + 900

= 1092 Watt hours per day.

Step 3).

Panel energy needed = 1.3 X 1092

= 1419.6 Watt-hours per day

Step 4).

Watt-hours per day per panel = 40/35 X 120

= 137.14 Watt-hours per day per panel.

Step 5).

Number of panels needed = 1419.6 / 137.14

= 10.35 panels. Actual requirement

= 11 panels.

The number of panels calculated by this method is the minimum number. If more panels are installed, the system will perform somewhat better and battery life will be improved. If less panels are used, the system may not work at all during cloudy periods and battery life will be shortened.

BATTERY SIZE DETERMINATION

A battery is needed because the appliances use electricity at different times and rates than the panels produce. For the system to work properly, the battery must be large enough to store sufficient energy to operate the appliances at night and on cloudy days. Also, for the battery to last a long time, it should not be discharged too much too often. In sizing a battery, it is important to install one large enough to operate the appliances for at least five days without recharging.

The rule for battery size is to install a battery which has five times as much capacity as will be needed to operate the appliances for one day.

Remembering that battery life depends on how much discharge takes place before a recharge, another way of looking at this rule is to say that the battery should be large enough so that one day's use of the appliances will discharge it no more than one-fifth of its full charge. This limited discharge before recharging will help the battery last a long time.

In purchasing a battery, the voltage and the Ampere-hour rating must be known. Usually for a solar PV system in a home the voltage will be either 12 V or 24 V. The size in Ampere-hours will depend on the energy requirements of the appliances.

Since the battery should store five times the energy the appliances use in one day, the Watt-hour capacity needed in the battery is the total appliance Watt-hour per day requirement times five.

Because battery manufacturers rate their battery in Ampere-hours, not Watt hours, it is necessary to convert the calculated Watt-hour storage to Ampere-hours. Since Watts equals Volts times Amperes, dividing Watt-hours by the battery voltage gives Ampere-hours.

Example #11:

The total appliance Watt-hour per day requirement for a house system using a 12 V battery is 260 Watt-hours per day. The total Watt-hours which the battery should store will be:

5 X 260 = 1300 Watt-hours

Once the total Watt-hour capacity of the battery is known, the Ampere-hour capacity can be calculated by dividing Watt-hours by battery Volts:

1300 Watt-hours / 12 V = 108.33 Ampere-hours.

For this example, the battery chosen should be a 12V deep-discharge type battery with at least a 108.33 Ah rating.

Remember that if a deep-discharge type of battery absolutely cannot be found and it is necessary to use an automobile type of battery, choose one with at least twice the Ampere-hour capacity as would be correct for the deep-discharge battery. In the example above, a car battery would have to have a rated capacity of at least 108.33 X 2 = 216.66 Ah to have a useful life in excess of a year or so. Even then, it will not last nearly as long as a deep-discharge type battery.

Summary of battery size calculations

Step 1). Compute the Watt-hours per day used by each appliance.

Step 2). Total the Watt-hours per day used by all appliances.

Step 3). Multiply the total appliance Watt-hours per day by five.

Step 4). Divide the answer obtained in Step 3. by the battery Voltage. The result will be the required Ampere-hour capacity of a deep-discharge type battery. If an automobile battery must be used, choose one with at least double the Ampere-hour capacity calculated for the deep-discharge type of battery.

Example #12:

A house with a 12 V solar system has the following appliance uses:

One 18 Watt light used 4 hours per day

One 60 Watt fan used 2 hours per day

One 75 Watt refrigerator that runs 12 hours a day

What battery capacity will be needed?

Step 1).

Light: 18 X 4 = 72 Watt-hours per day

Fan: 60 X 2 = 120 Watt-hours per day

Refrigerator: 75 X 12 = 900 Watt-hours per day

Step 2).

Total Appliance use:

72 + 120 + 900 = 1092 Watt hours per day.

Step 3).

Total Appliance Watt-hours X 5 = 1092 X 5

= 5460 Watt-hours

Step 4).

Divide Watt-hours by battery voltage

5460 / 12 = 455 Ampere hours

If a car type battery is used, it should be double that or:

455 X 2 = 910 AH.

So for the house in the example, a deep-discharge battery of at least 455 AH should be used.

SYSTEM MODIFICATIONS AND SIZING

The size of the panels and the battery are both determined by the Watt-hours consumed by the appliances. Watt-hours used by appliances changes when appliances are added or removed from the system and when appliances are used more or less each day. Having more panels and a bigger battery than is needed is not a problem. It is a big problem, however, when the panels and battery are too small.

It is common for people to add appliances to an existing PV system. If that is done, the system will not continue to operate properly unless the panels and battery are large enough to provide the extra Watt-hours. Any time a new appliance is added or an old appliance replaced by a new one, it is important to recalculate the correct panel and battery sizes and to increase the system capacity to handle any increased load.

Even if the appliances are not changed, using the appliances more will increase the energy used and make it necessary to add panels or a larger battery to keep the system working properly. It is common for people to under estimate the amount of time lights or other appliances will be used. If the PV system size is calculated using estimates of appliance use that are too low, then the system will not be large enough and will not work well.

Too small a system will run out of power when the weather is cloudy and will cause batteries to fail more often. Any time a PV system is not working properly always check to be sure that the panels and battery are large enough to provide the Watt-hours actually needed to operate the appliances. If the system is too small, you must either increase the number of panels or reduce the energy needed by appliances by reducing their number or their time of use. A larger battery may also be needed, but installing a larger battery without first installing more panels will not help. If you do not increase the number of panels, the system will continue to work poorly and batteries will fail often.

SUMMARY

Many of the problems with solar PV systems are caused by not having enough panels or large enough batteries to provide needed energy. Unless the system is sized correctly, the power will fail during cloudy weather and the battery will have to be replaced more often than should be the case.

Though a smaller system is cheaper at first it is more expensive in the long term. Trying to save money by installing too few panels or too small a battery only leads to a system which is unreliable and has a high maintenance cost.