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Project Proposal

for the

INTRODUCTION AND PROMOTION OF PHOTOVOLTAIC ELECTRICITY TECHNOLOGY IN SIERRA LEONE

prepared for

UNIDO

United Nations Industrial Development Organization
Vienna International Centre
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by

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1. Preface

The Government of Sierra Leone and the UNDP Office in Freetown requested UNIDO to carry out an analysis and assessment of the possibilities for introduction and promotion of solar energy technologies in the country, as a possible solution to the critical power supply problem in the country. The UNIDO mission visited Sierra Leone from 23-30 November 1991.

The almost total reliance of Sierra Leone on imported oil to meet its energy needs, the foreign exchange situation of the country and the resultant oil procurement problems, together with the abundance of solar radiation on the country, create favourable conditions for the exploitation and development of solar energy in Sierra Leone.

Despite the higher initial cost, solar photovoltaic electricity has all the qualities that make it attractive as a power supply source, especially for rural areas in developing countries where the central electricity grid infrastructure is poor-to-non-existent and technical expertise is normally not readily available. Photovoltaic electricity is almost maintenance free and is very convenient to use: solar radiation (the fuel) is freely available: etc.

The present report, which is based on the findings of the UNIDO mission that visited Sierra Leone, constitutes a pilot program for the introduction and promotion of solar energy technologies in Sierra Leone, including the building up of a nucleus of local capabilities and expertise in the core areas of design, planning, construction, operation, repair and maintenance of solar photovoltaic electricity systems.

The sites for the pilot projects were selected in consultation with, or at the specific request of, either the UNDP office in Freetown or the UNICEF office in Freetown. The three health facilities (Port Loko District Vaccine Distribution Centre, Masiaka Community Health Centre and Taiama Community Health Centre) were at the request of UNICEF while the Njala University College Hospital was at the request of the UNDP. The choice of Fourah Bay College (Department of Electrical Engineering) and the National Power Authority Training Centre as training sites for development of local capabilities for solar energy application was based on visits by the UNIDO mission to the two facilities and discussions with local authorities in Freetown.

It was the understanding of the misssion that funding for the project would be made possible by UNDP and UNICEF offices in Freetown.

2. Introduction and Background

Total gross energy consumption in Sierra Leone is estimated at 1.16 million tons of oil equivalent (TOE), of which 0.213 million TOE is commercial energy. This is equivalent to a per capita commercial energy consumption of 0.058 TOE. Following a 3 per cent per year growth rate in the 1970s, consumption of petroleum products declined from 172,000 tons in 1980 to 161,000 tons in 1989 - caused by declining availability of foreign exchange and procurement problems. Today, the supply of petroleum products is extremely irregular and unreliable.

According to available data on the consumption pattern, the transport sector is the major consumer of petroleum products, accounting for 49 per cent; household consumption is estimated at 24 per cent; industry, 15 per cent: agriculture, 6 per cent; and mining, 6 per cent.

This report has been prepared by UNIDO consultant, Dipl.-Ing. Hans Blank, a solar energy specialist, and is based on the energy assessment mission undertaken in Sierra Leone together with UNIDO staff member, Mr. George Tabah, Industrial Development Officer. The author is presently employed as assistant head of the Department for Renewable Energy Resources and Rational Energy Use at Bayernwerk AG, a major German Utility, which is heavily involved in the development of solar energy applications through its major share holding in SOLAR WASSERSTOFF BAYERN GmbH and its joint venture partners, SIEMENS SOLAR and SIEMENS AG. Through purchasing and integrating ARCO SOLAR in the USA (now being called SIEMENS SOLAR INDUSTRIES), SIEMENS SOLAR became the world's largest manufacturer for photovoltaic equipment. The technical inputs for this proposal were generated with the support of SIEMENS SOLAR. The sun position diagram in the appendix was calculated by IWR, Germany.

The public sector electricity (power) supply to Sierra Leone comes from hydro and thermal power stations. The industry sector, including commercial enterprises, consumes 40 per cent of the electricity supply, followed by the mining sector, 38 per cent, and households, 22 per cent. In the provinces only Bo, Kenema, Njala and Lungi are supplied with electricity.

Production of electricity declined steadily from 1983 to 1986 from 244 GWh per year to some 180 GWh/a. In 1989/90 the public power supply system comprised 72 MW of installed capacity, of which less than 20 MW was in operation, generating approximately 70 GWh annually. The transmission and distribution losses are estimated at 35-40 per cent. Approximately 2 MW of the total supply comes from hydropower.

The energy situation in Freetown is extremely serious. The electrical grid supplying Freetown, once mainly powered by large diesel generators, has not operated reliably since 1987, due to technical problems. Since then, electricity is only available randomly, and for periods of only 2-3 hours per week in some cases. Under such conditions the industry sector, and those very few households that can afford it, rely almost entirely on private small-size emergency generators or larger stand-alone systems fuelled with diesel oil or gasoline. Private electric generator units are estimated to produce up to 60 MW. But given that the average monthly salary for workers varies between US $ 12 - US $ 25, it is obvious that the average person cannot afford to own/operate a private generator.

The main, and by far largest, energy source for most households in Sierra Leone is firewood and charcoal which are the chief fuels for cooking. Statistics indicate that the growth rate for annual production of firewood between the years 1983-1986 was about 2 per cent per annum, resulting in a yearly consumption of nearly 8 million m^3 in 1986, rising to an estimate for 1992 of almost 9 mio.m^3/year (950.000 TOE of firewood and 40.000 TOE of charcoal). The ecological consequences of this deforestation are immeasurable.

The energy situation in Sierra Leone is likely to remain critical for some time yet. Due to a lack of spare parts, the large generators are still out of order and will probably remain so for a while - although there are on-going discussions with the World Bank for assistance in the maintenance and rehabilitation of the power generation facilities. Also, discussions are being held to rehabilitate the Kingtom hydropower station by the EEC and Germany's GTZ on an emergency basis. No one knows for certain when these efforts will materialize. Also, Italy is funding a 70 MW hydropower station at Bumbuna to supply Freetown; however, completion is not anticipated for still some time.

In addition, the grid infrastructure in Freetown is in very poor state and deteriorating each day, as material is being taken away all the time. The grid infrastructure in the provinces is just as bad, if not worse. In the rural areas, grid infrastructure is practically non-existent. Supplying electricity to the rural areas from the national or central grid would require, in the first place, providing the necessary infrastructure in the rural areas, and connecting these to the national/central grid. In view of the very difficult foreign exchange situation being faced by the country, this arrangement will take a long time to realize.

Because of the foregoing uncertainties regarding the present electricity supply systems in the country, it has become necessary to examine other energy options, especially a renewable energy option such as solar energy. The proliferation of, and dependence on, small private stand-alone electric power generators in the country is, in the long run, uneconomical. And as generators depend on diesel or gasoline, the supply of which is not guaranteed in Sierra Leone (as explained earlier), the generators themselves become unreliable as a viable electric energy option.

In fact, for rural areas, isolated villages and townships with small and scattered populations, decentralized electricity supply systems based on photovoltaic solar plants would be the most effective way of meeting their electricity needs. The costs involved in transmitting power make grid connection uneconomic for small and isolated habitations which invariably have only small electrical loads. Given the country's financial situation, stand-alone photovoltaic electricity generation would be a natural option for rural and remote locations.

3. The UNIDO Mission

In the light of the above, the Government of Sierra Leone, through the UNDP office in Freetown, requested UNIDO's assistance in carrying out an analysis and assessment of the possibilities of introducing and promoting the application of solar energy in the country - particularly in the rural areas. It was intended that, based on the findings of the UNIDO assessment mission, a number of pilot activities would be initiated on solar energy applications, and lead eventually to the wide-scale application of solar energy technologies in the country.

The UNIDO mission consisting of UNIDO staff member, Mr. George Tabah, Industrial Development Officer, Industrial Technology Development Division, and UNIDO Consultant Dipl.-Ing. Hans Blank, Solar Energy Expert, visited Sierra Leone from 23-30 November 1991.

At the outset, the mission met with the UNDP Resident Representative a.i., Mrs. Zara Nuru, who briefed on the energy situation in the country, and especially the very critical and deteriorating situation with respect to the electricity supply. She felt that solar energy provided the best option to the energy problem, particularly for the rural area, and especially for the rural health facilities - most of which either do not have any electricity supply at all or have to depend on diesel generators running all day.

The UNDP Resident Representative a.i. indicated that the UNDP would be willing to provide financial assistance towards an integrated program for the introduction and promotion of solar energy in the country. She suggested that the mission should, inter alia, (I) visit the Njala University College Health Clinic and assess the possible application of solar energy there, and (II) visit the UNICEF office in Freetown to discuss with them possible solar energy applications in rural health clinics.

In the absence of Mr. Mohammed Jalloh, the UNICEF Representative, the mission was received by Dr. Isaac Egboja. He explained that, as part of the Expanded Programme on Immunization (EPI), UNICEF was running a number of district vaccine distribution centres in the provinces. To keep the vaccines refrigerated, the centres are equipped with stand-alone diesel generators which run practically 24 hours a day. Maintenance and supply of fuel were always problematic.

He also referred to the electricity problem faced by rural health facilities. A large majority of these rural health centres do not have any lighting at all, even though they frequently have to handle emergency cases at night. He felt that it would be necessary to provide them with at least minimum lighting in the key areas, e.g. consulting room, delivery room, vaccination room, dispensary; etc.

Dr. Egboja indicated that UNICEF was very much interested in the solar energy option and that they (UNICEF) would be prepared to finance a pilot program of solar energy application at three (3) rural health facilities:

I) Port Loko District Vaccine Distribution Centre

II) Masiaka Community Health Centre

III) Taiama Community Health Centre

On the basis of the above meetings and discussions, the UNIDO mission visited the Njala University College Hospital, the Masiaka Community Health Centre and the Taiama Community Health Centre to evaluate and determine their minimum lighting requirements. Detailed information about the Port Loko District Vaccine Distribution Centre was provided by the UNICEF officer in charge of power supply, and has been used in preparing the solar power requirements of the Centre.

An integrated program for the introduction and promotion of solar photovoltaic electricity supply systems in the country must include the development of the necessary manpower, technical skills and capabilities for the design, planning, construction, operation, repair and maintenance of the solar equipment. Two levels of manpower skills/capabilities are envisaged:

(i) higher level skills for the design, planning and construction of solar photovoltaic systems. This level of skills is to be developed at the Fourah Bay College, Department of Electrical Engineering.

(ii) middle level technician skills for the operation, repair and maintenance of solar equipment. Training for this level of skills is to be carried out at the National Power Authority Training Centre.

For this reason, the present proposal also includes a training component at Fourah Bay College, Department of Electrical Engineering, and at the National Power Authority Training Centre, for development of the necessary local capabilities in support of the solar photovoltaic program.

4. Solar Insolation Data for Sierra Leone

During the visit, it was not possible to collect recent data on solar insolation in Sierra Leone. To achieve a data basis for the layout of the different systems, two approaches were possible. The first one was to proceed from insolation data compiled by M.W. Baradas in 1979. The values are calculated by means of a linear equation with regression parameters gained from short term measurements and observations during a period in 1979. The results for Freetown and Njala are shown in Table 1.

	J	F	M	A	M	J	J	A	S	O	N	D
Freetown:	4.45	4.72	4.28	4.83	4.5	3.99	3.24	[illegible]	3.72	4.24	4.11	4.05
Njala:	4.20	4.51	4.57	4.44	4.33	3.95	3.23	3.00	3.49	4.07	3.95	3.86

Table 1: Average daily solar insolation on a horizontal surface in kWh/m²d (M.W. Baradas, 79)

The average annual insolation values resulting are 4.17 kWh/m²d for Freetown and 3.97 kWh/m²d for Njala.

The second approach, which was finally used for the dimensioning of the systems, was to use a computerized data base from SIEMENS SOLAR, which is continuously supplied with actual worldwide meteorological data. The nearest location to the site, where weather data also considering microclimatic influence were available, was Lungi.

Latitude: 8.62°N / Longitude: 13.20°W

The values used for the energy calculation are shown in Table 2.

Month	Insulation in kWh/m²d Horizontal	On Panel	Average Daily Output in Wh per module M 55 (PV module type chosen for the proposal)
Jan	5.18	5.83	196
Feb	5.65	6.11	205
Mar	5.95	6.11	205
Apr	5.79	5.66	190
May	5.18	4.91	164
Jun	4.73	4.44	148
Jul	4.02	3.84	128
Aug	3.87	3.78	127
Sep	4.38	4.42	149
Oct	5.00	5.28	178
Nov	4.86	5.40	182
Dec	4.68	5.33	179

Table 2: Average daily insolation on a horizontal surface, on the PV panels (tilt angle 15° South) and daily output in Wh (system efficiency considered)

The insolation on the tilted surface is calculated from the values on the horizontal surface according to a calculation model from Lui/Jordan. The optimum tilt angle for the month of August with the lowest insolation during the rainy season would be about horizontal, the annual energy yield, however, is better with south orientation. In the practical realization of the projects, the tilt angle and orientation also depends on site conditions.

A tilt angle of less than 15° is also not to be recommended because of substantially more dirt collection on the modules, which reduces their energy output.

The tilt angle for the solar panels can be chosen according to the calculatory annual optimum in all the rural projects, where there is no existing building structure to be considered. Particularely in the case of Fouran Bay College, the orientation has to be chosen following the building to be supplied.

As the radiation during the rainy season is predominantly diffuse and the location is pretty close to the equator, the reduction due to this constraint is not very significant. Outside the rainy season, the insolated solar energy can always be considered sufficient to meet the demand as the design is performed for the worst case.

For general purposes, a sun position diagram calculated for Freetown is added as an appendix. It was kindly calculated by an engineer of the German utility RWE. It supports the choice of the orientation of solar collectors, PV modules, etc. An application sheet, which explains the use, is also included.

5. Project Proposal

5.1. Main Components of the Proposed PV Systems

Solar radiant energy can be converted directly into electricity (DC) by means of semiconductor materials, so-called solar cells. The process whereby solar cells convert light rays directly into electricity is called photovoltaics (PV). PV plays an important role in the sector of electricity generation from renewable energy sources. It operates without moving parts, without noise and without emissions.

For energy relevant applications, a large number of solar cells are connected with each other and thus form the main component of a solar electric energy supply system. PV systems in the kW power range can for all practical purposes be considered as small power plants. Such plants can either be operated in parallel to an electric grid in a fuel saver mode or as decentralized stand alone systems with storage capacity.

Figure 1 showes the principle structure of a photovoltaic stand alone system with battery storage.

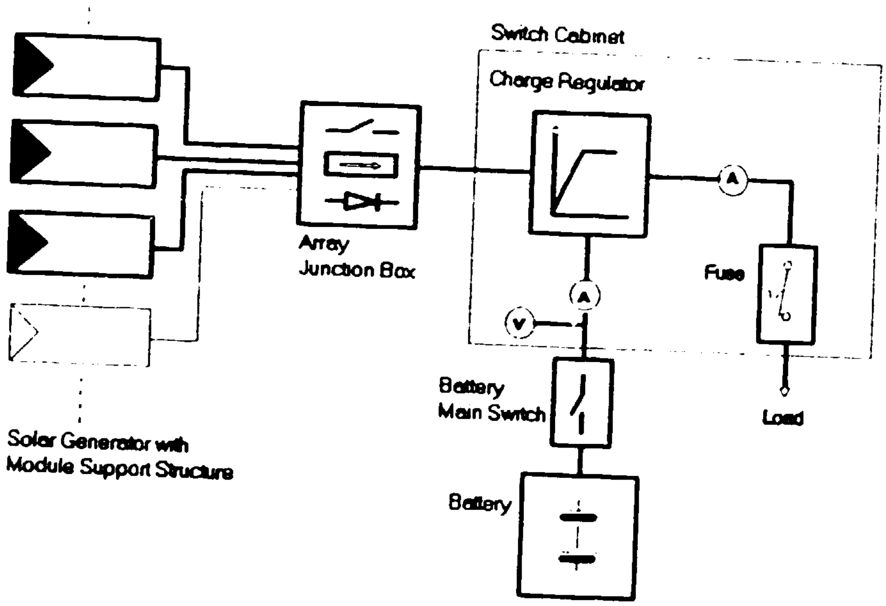


Figure 1: Principle structure of a photovoltaic stand alone system with battery storage

A stand alone PV system, as is proposed in all 6 projects, consists of the following main components:

- Solar Generator with Module Support Structure
- Array Junction Box
- Control Unit incl. Battery Charge Regulator
- Battery Storage
- Installation Material

The proposed solar generators consist of a fixed amount of so-called PV solar modules (proposed type: SSI M 55, most frequently used worldwide) with a nominal power of 53 W_p (Watt peak) at standard test conditions (insolation: 1000 W/m², cell temperature: 25°C, air mass coefficient: 1.5). The number of modules depends on the designed plant power.

A single module generates a DC-voltage sufficient to charge a 12 V battery even under high ambient temperature conditions. To achieve a higher system voltage, a serial connection of modules, a so-called string, is necessary. The desired rated current is reached by parallel operation of several PV strings.

The module support structures, on which the single modules are mounted, are made of anodized aluminum. The mounting feet are made from galvanized steel to provide optimal protection against corrosion. For a reliable and durable plant, the design has to meet several requirements like sturdiness against wind loads, sufficient ventilation for the modules and of course system compatibility. The proposed support structure can hold a maximum of eight solar modules M 55 and can be adjusted to tilt angles between 15° and 65° against horizontal. It is designed to withstand wind speeds of up to 200 km/h (125 mph) and can be attached easily to standard foundations.

In the array junction box, the parallel strings are interconnected to a common output terminal that leads to the charge regulator. The different strings are decoupled by diodes against reverse currents. In case of atmospheric overvoltages due to lightning, protection is assured by using two overvoltage protection devices (varistors). A power switch is integrated to make maintenance and service more comfortable and fulfill security guide-lines. The case is made of UV-resistant Polyethylen with a high grade of protection (IP 55).

The charge regulator is a very important component. It protects the battery from being overcharged or from being too deeply discharged. In this way it maintains the storage capacity of the battery at a high level by conserving the charge as overcharging and deep discharging shorten the lifetime of a battery. Overcharging also causes gassing of the battery and evaporation of the electrolyte.

If the battery voltage drops below a certain threshold, the charge regulator disconnects the load from the battery. When the battery voltage increases again, the regulator reconnects the load automatically. The units work as shunt regulators with extremely low losses. The proposed TM version is built to operate in extreme climates from -25 to 80°C and a relative humidity up to 90 %. (Note: Humidity inside switch cabinets in operation is always lower than outside!)

In addition, the charge regulator incorporates three relays which can switch the following control signals:

(i) - Signal contact for deep discharge (load cut-off pre-set voltage level).

(ii) - Pre-fault warning for low voltage (pre-adjustable according to specific needs).

(iii) - Signal contact for over-voltage (pre-set voltage level).

The second signal, which gives a warning in case of low battery voltage, is particularely important for the users at Fourah Bay College. If the batteries would get discharged too much, for example through more operation of the equipment than quoted for the design or through periods of extraordinary low insolation during rainy season, the staff could decide to switch off part of the equipment.

Local system condition indication is displayed on the front side of the switch cabinets or charge units by LED's. Potential free contacts are provided for external monitoring purposes. The battery voltage as well as the charge or discharge current can be shown on a LCD display.

The charge regulator is integrated into the control unit, which also contains a voltmeter, two ampere meters, the input and output terminals and an output switch. The compartment is made out of steel and is designed for internal wall mounting, the grade of protection is IP 55.

Solar energy generation in general is 'supply controlled' meaning that the solar light determines the production. To meet demand side requirements, energy storage is necessary for example to provide electricity during nighttime. Battery storage is the most economic solution for this need and plant size.

The proposed battery type 'bloc' is a lead acid model especially developed for application in industrial systems with low self-discharge rates. The expected lifetime is more than 8 years, when operation and service is carried out in accordance with the regulations of the manufacturer.

All necessary cable and connecting material shall be provided for the interconnection of the solar array, the charge regulator, the battery and the load.

Heavy rubber cable of type H07 RN-F or better shall be used, to ensure the best electrical and mechanical reliability possible. The cable cross-section of the cables shall be dependent on the allowable voltage drops and the lengths between the components.

The interconnection cable between the array junction box and the control unit shall be of heavy duty energy type NYCWY. Internal connections in the control room shall be designed with cable type NYY.

It is strongly recommended to always protect the PV arrays by a fence.

5.2. National Capabilities Development Program for Solar Energy Applications

5.2.1. Training Aspects

The successful introduction of new technologies to a developing country requires the training of local staff. Photovoltaic electricity generating equipment is no exception. It is considered most essential to implement such projects on a partnership basis. This means that the final users of the installations participate in the execution of the projects as soon as possible also being involved in the design process.

The following skills are considered necessary to plan, build and operate photovoltaic energy supply systems:

- Detailed analysis and evaluation of the energy demand, including the identification of energy saving opportunities to be carried out before the new system is put into operation.

- Civil works skills, to lay concrete foundations for the support structures or to prepare buildings for PV integration

- Mechanical design and assembly of the support structures, taking into account the appropriate safety considerations and the effects of natural phenomena such as wind, rain or snow.

- Electro-technical design and installation of the system following relevant safety standards and regulations (wiring, electronic controls, batteries, battery management, inverters, low energy applications, etc.)

Training of staff has to include the understanding of the single plant components, subsystems, and, of course, the interaction of the components as a complete system. Regular maintenance requirements as well as skills to repair the equipment have to be tought.

It is strongly recommended that a PV Energy Task Force will be established within the Department of Electrical Engineering even before the project equipment is delivered to Sierra Leone. The leader (or someone who will be intimately involved with the project) should be sent to the system manufacturer to be trained in advance for about 2-3 weeks in setting up and starting up of the plants. At various stages of the project a representative of the system supplier shall visit Sierra Leone. It is also recommended to include a local expert in building and operating the plants. This will be particularely important when trouble shooting becomes necessary.

The training aspect for the engineers and students of the college, as well as, the technicians at the NPA Training Centre will be fostered by their early integration in building and operating the plants. Having student manpower support during the setting up of the proposed projects will also cut down the installation cost considerably.

The involvement of a local expert should also be considered for supervising.

5.2.2. The Fourah Bay College Project

In the assessment of the UNIDO mission, the Department of Electrical Engineering appears to be the best suited place to develop the manpower for introduction of PV technology to Sierra Leone, as the topic can be included in the teaching curriculum of the department.

The actual installation of a PV system in the department will support the training program by having students perform practical work within the project. This hands-on approach will bring general benefit to the students as they learn to operate the PV electrical equipment and will be a substancial part of their training.

This practical, hands-on approach will ensure the success of the project. The training staff, including the head of the department, were very excited about the possibilities of the training program and were very supportive to the UNIDO mission during the visit. For a successful introduction of photovoltaics technology to Sierra Leone, the development of the necessary local capabilities is a 'conditio sine qua non'!

As already stated, the Department of Electrical Engineering should establish a PV Energy Task Force to coordinate the planning and building of all the 6 projects. This would not only provide optimal conditions for on-the-job training but would also bring local work force to the project through the use of students. The head of the Task Force should preferably be an engineer from the department with good qualification and a practical approach. He will be expected to undergo a 2-3 weeks training course at the system supplier in advance of the start of the project. In order to ensure continuity of the program, it should be clarified beforehand, that he will stay with the department for at least 5 years after the PV project is installed.

The basis for the design of the system and power dimensioning besides the weather data is a load profile prepared by the staff members of the Department of Electrical Engineering. It also points out in detail the requirements of the different user sectors like lighting, computer operation, etc.

Also included in the proposal is the erection of a computerized measuring station for solar insolation and temperature. It consists of a pyranometer to register gobal insolation, a PT-100 temperature sensor, a data logger with RS 232 interface and the necessary software for data evaluation on a PC. Long term climatic data, which are very useful for planning purposes, are not readily available in the country. Experience in Germany, as in many other developed countries, has shown that computer aided measuring activities should be a part of the training program at universities.

Table 3 displays an overview of the technical data and the estimated energy demand for Fourah Bay College, Dept. of Electrical Engineering (as provided by the Department).

	Power Consumption each/W /	Daily Operation /h/d /	Days per Week /d/week /	Energy Consumption /kWh/d /48 V-level
220 Volt AC Loads:				
10 PCs	150	4.5	5	7.94
6 Oscilloscopes	50	3	4	1.07
4 Patch Boards	200	3	4	2.82
1 Power Electronics	250	3	3	0.88
1 Comms Kit	250	3	3	0.88
1 Function Generator	50	3	4	0.18
4 Power Supplies	220	3	4	3.11
1 Photocopier	450)*	6.5	5	3.44
1 Laser Printer	450)*	6.5	5	3.44
12 Volt DC Loads:				
20 Fans	12	4	5	0.96
65 Lights	11	3	5	2.15

)*: Average Power Consumption. Peak Power approx. 1.4 - 1.5 kW

Table 3: Requested Items and Estimated Power and Energy Demand for Fourah Bay College

The electricity users' side is split up into 2 levels. 220 V AC for standard equipment and 12 V DC for special low energy equipment, which is available for several applications. Thus two voltage transformers, one DC/AC inverter and one DC/DC converter will be used to change the battery voltage into 220 V AC resp. 12 V DC. The battery storage voltage level shall be 48 V in accordance to the design of the DC/AC inverter and the DC/DC converter. The respective average inverter/converter efficiencies are 85% and 80%.

The maximum total energy consumption, when all items are operated during the estimated daily time period, is 20.2 kWh per day on the 220 V level and 3.5 kWh per day on the 12 V level. The peak power adding up all appliances is 6.8 kW on the 220 V level and 955 W on the 12 V level. Both power values will probably not be reached in practice, as the instruments and lights will not all be switched on at the same time. The resulting electricity consumption on the 48 V battery side (taking inverter/converter efficiencies into account) results in 28.13 kWh/d or 586 Ah/d.

As the space on the campus is limited and the solar plants can only be delivered in certain power steps due to the string-by-string parallel arrangement of the PV modules according to the voltage and current requirements, it is suggested to slightly cut the original planning value for energy consumption e.g. by operating all ten PCs for only 4.5 h/d in average or as long as the battery is not discharged too low. This would also create an energy awareness which is always necessary for a stand alone solar system user. A major advantage is the low or near zero energy demand during weekends, during which the batteries of the fully automatic plant can be recharged.

Table 4 shows the calculated daily energy consumption in kWh on the 48 V battery level over the week, which was basis for the plant design. The different values represent the fact, that not all the equipment is operated every day and for equal times.

Mon	Tue	Wed	Thu	Fri	Sat	Sun
23.59	28.13	28.13	28.13	23.76	0	0

Table 4: Calculated Daily Energy Consumption for the Fourah Bay College Project

The average daily consumption value including Saturdays and Sundays with no load is 18.82 kWh/d. As the designed battery system provides full autonomy for nearly 5 days, even the minimum average solar gain of 19.1 kWh/d is sufficient to fully charge the batteries over the weekend, although during weekdays, the solar energy yield is lower than the expected energy consumption.

In times of higher insolation, the electric appliances can be operated correspondingly longer based on operational experience.

Technical scope of supply:

According to the requested power the proposed photovoltaic system, in order to provide sufficient energy also during the rainy season, consists of the following main components, which where described in detail earlier:

- 152 solar modules type SSI M 55, 53 W_p each, at standard test conditions (total peak power: 8056 W_p)

- 19 module support structures designed for 8 modules each

- 5 array junction boxes

- 1 Control unit
  completely prewired and factory tested consisting of:

  2 control cabinets, 5 charge regulators, 5 DC/DC switching regulators,
  1 battery voltmeter, 1 ampere meter for charge/discharge current,
  1 ampere meter for the load current, input and output terminals, output fuse

- 1 battery bank with 2500 Ah (C_{10}) consisting of 24 cell units type OPZS, 2 V per cell, dry pre-charged with recombiner vent plugs, service and installation material, safety accessories and 4 battery support structures

- 1 battery main switch (IP 65, for wall mounting)

- installation material
  - -- 750 m H07RN-F 1x2.5 mm²
  - -- 200 m NYCWY 4x35 mm²
  - -- 40 m NYY 1x50 mm²
  - -- 100 m H03VV-F 2x0.75 mm²

- 1 Inverter, 48 VDC/220 VAC, 5 kVA, trapezodial output waveform

- 1 documentation set incl. system description, parts list, installation and detail drawings, wiring and control diagrams, installation and maintenance guide

- 20 ceiling fans, 12 V, 12 W

- 65 lighting points, 12 V, 13 W (incl. ballast losses), incl. housing, low energy type

- building wiring system material
  - -- 100 swithes
  - -- 30 socket-outlets
  - -- 1 load distribution box
  - -- 5000 m cabling material NYM 3x1.5 mm²
  - -- fixing parts necessary for correct installation

5.2.3. The NPA Training Centre Project

The National Power Authority Training Centre is located in downtown Freetown in the Kissy section. It is supported by the German aid organization, GTZ. It is proposed to set up a small photovoltaic plant there in order to integrate PV technology courses in the mid-level training of technicians which is conducted there. This level of training will complement the high level training at Fourah Bay College. The objective of the NPA Training Centre course will be to train technicians who are able to visually control, maintain and repair PV systems.

The NPA Training Centre PV plant should be installed in an open, modular way and clearly arranged in order to underline the modular character of such a system. In this case, the variable tilt angle of the module support structures is useful to also try out different angles and study the resulting different energy outputs.

As low energy consumption equipment, 2 lamps and a refrigerator especially designed for solar systems is suggested. Further examples can be added later. The calculated daily energy consumption for the suggested equipment is approx. 1 kWh on a 24 V level. the battery storage capacity provides 5 days full autonomy. Thus, if the system will not be used during weekends, the useful energy during work days and particularly during periods of high solar insolation will be higher.

The PV Energy Task Force shall be closely associated with the design and construction of the NPA Training Centre project in order to ensure the co-ordination of the 2 training programs - at Fourah Bay College and at the NPA Training Centre.

The exact site within the training centre has not yet been determined. it should be chosen together with the local staff of GTZ and Fourah Bay College.

Technical scope of supply:

The resulting proposed photovoltaic system consists of the following main components:

- 8 solar modules type SSI M 55, 53 W_p each, at standard test conditions

- 1 module support structure for 8 modules max.

- 1 array junction box

- 1 Control unit
  completely prewired and factory tested consisting of:

  1 control cabinet, 1 charge regulator,
  1 battery voltmeter, 1 ampere meter for charge/discharge current
  1 ampere meter for the load current, input and output terminals, output fuse

- 1 battery bank with 200 Ah (C_{10}) consisting of 6 battery units, bloc type, 4 V per unit, dry pre-charged with recombiner vent plugs, service and installation material, safety accessories and 1 battery support structure

- 1 battery main switch (IP 65, for wall mounting)

- installation material
  - -- 40 m H07RN-F 1x2.5 mm²
  - -- 40 m NYCWY 4x16 mm²
  - -- 40 m NYY 1x50 mm²
  - -- 20 m H03VV-F 2x0.75 mm²

- 1 documentation set incl. system description, parts list, installation and detail drawings, wiring and control diagrams, installation and maintenance guide

- 1 refrigerator, 24 V, 55-60 W, capacity 100 litres

- 2 lighting points, 24 V, 13 W incl. housing, low energy type

- building wiring system material
  - -- 5 swithes
  - -- 1 socket-outlet
  - -- 1 load distribution box
  - -- 50 m cabling material NYM 3x1.5 mm²
  - -- fixing parts necessary for correct installation

5.3. Medical Centres' Support Program

During a visit at the UNICEF headquaters in Freetown, which was initiated by the local UNDP representative, the necessity to provide some of the medical stations in the country with an independent solar power supply, was expressed. The UNIDO mission was requested to visit selected rural health facilities and assess the possibilities to install solar power supply systems there. The following four locations were selected for initiation of the solar energy program:

- Njala Hospital
- Taiama Community Health Centre
- Masiaka Community Health Centre
- Port Loko Central Vaccine Storage

After investigation of the 4 installations within a 1-day round trip, all suggested centres were considered to be in urgent need for solar energy supply, as it is the only way to realize a secured electricity supply for them.

The following chapters describe the proposed solar systems for the 4 facilities. Again it is emphasized, that the PV Energy Task Force should be involved closely in the execution of these projects.

5.3.1. Njala Hospital

The Njala University College hospital consists of a single floor square building arangement and contains, among others, 3 doctor's offices, 1 administration office, 1 laboratory, 1 operation theatre, 6 wards, 1 vaccination room, 1 "under five" wing and several utility and service rooms. It serves the health/medical needs of the 800-900 students who study in the university as well as of the surrounding rural population, up to a radius of about 30 km.

The hospital is suffering from lack of electricity and water. Most of the electrical appliances are not working any more because of not having been used for a long time. The resident medical doctors informed the UNIDO mission that quite often, surgeries or births have to be conducted during the night with candle light because of no electricity. The refrigerator for blood storage is very old, too big and surely using too much energy, when operating. Due to the high humidity, a lot of the equipment was mouldy and rusty due to their not being used for lack of electricity.

It would be extremely helpful to also provide the hospital with some basic supply of new medical equipment incl. refrigerators. It is most of the time less expensive to replace inefficient appliances instead of covering their high energy demand by costly photovoltaics.

Also in this project, the PV Energy Task Force should be involved in preparing the site, building and starting up the plant and providing maintenance. In a project like this, where the absence of electricity can be the difference between life and death, the benefits of an independent power supply system become most obvious.

During the visit of the hospital, the basic and minimum energy requirements summarized in Table 5 were identified:

	Power Consumption each /W/	Daily Operation h/d
4 Lights	15	5
25 Lights	13	5
55 Lights	11	5
12 Ceiling Fans	12	12
2 Refrigerators	36	24
1 Vaccine Fridge	50	24
Miscellaneous	100	5

Table 5: Electrical Appliances Required in Njala Hospital

Adding up these consumption values, the average daily electricity demand for the designed plant results in 10.85 kWh/d on the 24 V battery level. During rainy season, the lowest daily energy yield of the proposed PV plant is calculated to be 10.87 kWh/d, the demand can therfore always be met. In addition to this, extra medical equipment can be operated during periods of higher insolation without difficulty

For water supply, it is suggested to set up an independent water pumping system, a so-called Solar Jack Pump, which is available as a proven unit off the shelf.

Technical scope of supply:

The resulting proposed photovoltaic system consists of the following main components:

- 88 solar modules type SSI M 55, 53 W_P, at standard test conditions

- 11 module support structures for 8 modules each

- 6 array junction boxes

- 1 Control unit
  completely prewired and factory tested consisting of:

  1 control cabinet, 6 charge regulators,
  1 battery voltmeter, 1 ampere meter for charge/discharge current,
  1 ampere meter for the load current, input and output terminals, fuse
  1 DC/DC switching regulator, 24/12 V DC, 20 A

- 1 battery bank with 2000 Ah (C_{10}) consisting of 12 battery cell units. bloc type. 2 V per unit. dry pre-charged with recombiner vent plugs. service and installation material. safety accessories and 2 battery support structures

- 1 battery main switch (IP 65. for wall mounting)

- installation material
  - -- 450 m H07RN-F 1x2.5 mm²
  - -- 360 m NYCWY 4x35 mm²
  - -- 40 m NYY 1x50 mm²
  - -- 120 m H03VV-F 2x0.75 mm²

- 1 documentation set incl. system description. parts list. installation and detail drawings. wiring and control diagrams. installation and maintenance guide

- 12 Ceiling Fans. 12 V. 12 W

- 2 refrigerators. 24 V. 36 W

- 1 vaccine fridge. 100 ltr., UNICEF cold chain Standard E3/Rf.4 Class A

- 55 lighting points. 24 V. 11 W incl. housing. low energy type

- 25 lighting points. 24 V. 13 W incl. housing. low energy type

- 4 lighting points. 24 V. 15 W incl. housing. low energy type

- building wiring system material
  - -- 110 swithes
  - -- 20 socket outlets
  - -- 1 load distribution box
  - -- 5100 m cabling material NYM 3x1.5 mm²
  - -- fixing parts necessary for correct installation

- 1 solar pumping system consisting of
  - -- 2 solar modules. 53 W_p. 1 module support structure for up to 4 modules.
  - -- 1 Solar Jack submersible pump
  - -- 1 high-level water tank

- 1 parabolic dish solar cooker. type "falco". for sterilizing purposes

5.3.2. Taiama Health Centre

Taiama is a relatively small settlement. There are however several villages in the area which rely on the Taiama Heath Centre for medical care. The centre consists of 2 ground level buildings connected by a roofed porch. Nearby is another building in which a health assistant or health officer lives.

This building is already equipped with a solar system and the occupant was enjoying the benefits like electric light and enough water pumped into a storage tank on the roof.

The following list of equipment could be drawn up for the centre:

- 7 lights, 13 Watts each, 10.5 h/d, 7 d/week operation

- 1 Solar Jack Pumping System incl. high-level water tank

The plumbing in the rooms is still in place, although it will probably need to be overhauled. The proposed system can cover a daily energy demand of 960 Wh on the 24 V level, which is the requirement calculated from the above figures, even during rainy season. In February and March, the solar energy gain even tops in 1.6 kWh/d. It is proposed that there will be also a 24 V wall outlet installed in the treatment room, which can supply future small medical equipment. The modular setup of the PV systems would also allow an extension, if needed.

Technical scope of supply:

The recommended photovoltaic system consists of the following main components:

- 8 solar modules type SSI M 55, 53 W_p each, at standard test conditions

- 1 module support structure for 8 modules

- 1 array junction box

- 1 Control unit
  completely prewired and factory tested consisting of:

  1 control cabinet, 1 charge regulator,
  1 battery voltmeter, 1 ampere meter for charge/discharge current,
  1 ampere meter for the load current, input and output terminals, fuse

- 1 battery bank with 200 Ah (C_{10}) consisting of 6 battery units, bloc type, 4 V per unit, dry pre-charged with recombiner vent plugs, service and installation material, safety accessories and 1 battery support structure

- 1 battery main switch (IP 65, for wall mounting)

- installation material
  -- 40 m H07RN-F 1x2.5 mm²
  -- 40 m NYCWY 4x16 mm²
  -- 40 m NYY 1x50 mm²
  -- 120 m H03VV-F 2x0.75 mm²

- 1 documentation set incl. system description, parts list, installation and detail drawings, wiring and control diagrams, installation and maintenance guide

- 7 lighting points, 24 V, 13 W incl. housing, low energy type

- building wiring system material
  - -- 2 swithes
  - -- 1 load distribution box
  - -- 150 m cabling material NYM 3x1.5 mm²
  - -- fixing parts necessary for correct installation

- 1 solar pumping system consisting of
  - -- 2 solar modules, 53 W_p, 1 module support structure for up to 4 modules.
  - -- 1 Solar Jack submersible pump
  - -- 1 high-level water tank

5.3.3. Masiaka Health Centre

Masiaka Health centre is situated approx. 70 km east of Freetown, on the way to Njala. The situation is quite similar to the one in Taiama. the station seemed to be a bit less crowded. The Taiama Health Centre has a well with a functioning hand pump. but which could also be equipped with an electric pump. A storage vessel. which was once installed. was broken down and needs to be replaced.

The list of applications therefore is identical to the previous one. it can be considered as a basic package solution for a rural health centre including water supply. when a well is existing.

Technical scope of supply:

The recommended photovoltaic system for Masiaka consists of the following main components:

- 8 solar modules type SSI M 55. 53 W_p each. at standard test conditions

- 1 module support structure for 8 modules

- 1 array junction box

- 1 Control unit
  completely prewired and factory tested consisting of:

  1 control cabinet, 1 charge regulator,
  1 battery voltmeter, 1 ampere meter for charge/discharge current,
  1 ampere meter for the load current. input and output terminals, fuse

- 1 battery bank with 200 Ah (C_{10}) consisting of 6 battery units. bloc type, 4 V per unit. dry pre-charged with recombiner vent plugs. service and installation material. safety accessories and 1 battery support structure

- 1 battery main switch (IP 65. for wall mounting)

- installation material
  - -- 40 m H07RN-F 1x2.5 mm²
  - -- 40 m NYCWY 4x16 mm²
  - -- 40 m NYY 1x50 mm²
  - -- 120 m H03VV-F 2x0.75 mm²

- 1 documentation set incl. system description, parts list, installation and detail drawings, wiring and control diagrams, installation and maintenance guide

- 7 lighting points, 24 V, 13 W incl. housing, low energy type

- building wiring system material
  - -- 7 swithes
  - -- 1 socket-outlet
  - -- 1 load distribution box
  - -- 150 m cabling material NYM 3x1.5 mm^2
  - -- fixing parts necessary for correct installation

- 1 solar pumping system consisting of
  - -- 2 solar modules, 53 W_p, 1 module support structure for up to 4 modules.
  - -- 1 Solar Jack submersible pump
  - -- 1 high-level water tank

5.3.4. Port Loko District Vaccine Distribution Centre

Port Loko is located approx. 100 km north east from Freetown. The Port Loko District Vaccine Distribution Centre serves as the base for distributing vaccine to a larger district. Therefore its main energy demand is for cooling and lighting. As the existing 3 refrigerators consume 200 W each, it is suggested to replace them with low energy, high efficient UNICEF-approved vaccine refrigerators, which are included in the proposal. This investment is, in the long run, more economical than building a larger PV array.

The centre is dependent on electricity from diesel generators. The risk is high that, due to fuel supply problems, the vaccine stock is in danger of getting spoiled. A secured electricity supply by PV power would definitely improve this situation and eliminate the dependence on fossil fuel.

The following technical items are suggested:

- 3 vaccine refrigerators, 100 ltr., 50 Watts each, 24 h/d, 7 d/week

- 3 lights, 13 Watts each, 5 h/d, 7d/week

The calculated daily electricity consumption for the suggested equipment is 3.79 kWh/d on the 24 V level. As the energy yield in the worst case is calculated to be close to 4 kWh/d, extra equipment can even be operated during periods of high solar insolation.

Technical scope of supply:

The recommended photovoltaic system for the Port Loko District Vaccine Distribution Centre consists of the following main components:

- 32 solar modules type SSI M 55, 53 W_p each, at standard test conditions

- 4 module support structures for 8 modules each

- 2 array junction boxes

- 1 Control unit
  completely prewired and factory tested consisting of:

  1 control cabinet, 2 charge regulators, 1 DC/DC switching regulator, 24/12 V, 20 A
  1 battery voltmeter, 1 ampere meter for charge/discharge current,
  1 ampere meter for the load current, input and output terminals, output fuse

- 1 battery bank with 700 Ah (C_{10}), consisting of 12 battery cell units, bloc type, 2 V per unit, dry pre-charged with recombiner vent plugs, service and installation material, safety accessories and 2 battery support structures

- 1 battery main switch (IP 65, for wall mounting)

- installation material
  - -- 160 m H07RN-F 1x2.5 mm²
  - -- 80 m NYCWY 4x35 mm²
  - -- 40 m NYY 1x50 mm²
  - -- 40 m H03VV-F 2x0.75 mm²

- 1 documentation set incl. system description, parts list, installation and detail drawings, wiring and control diagrams, installation and maintenance guide

- 3 lighting points, 24 V, 13 W incl. housing, low energy type

- 3 vaccine refrigerators, 12 V, UNICEF cold chain standard E3/Rf.4, Class A, gross volume 100 litres each, freezer gross volume 27 litres

- building wiring system material
  - -- 6 swithes
  - -- 1 socket-outlet
  - -- 1 load distribution box
  - -- 50 m cabling material NYM 3x1.5 mm²
  - -- fixing parts necessary for correct installation

The total cost of the 6 proposed projects is summarized in chapter 6.

6. Total Scope of Equipment and Cost Estimation for the Proposal

The complete equipment for all 6 projects shall be shipped to Freetown in 20 ft. containers, probably 3 units, which will serve as site storage rooms after unloading. As the transport back to Europe is more expensive than the purchase of the containers, it is suggested to leave them in Sierra Leone.

After a general approval of the project by UNIDO, UNDP and UNICEF, a detailed plant design has to be carried out with emphasis to parts or sub-systems, that are not standard or have to be built in Sierra Leone. It has to be organized in detail and with strong support of the PV Energy Task Force of Fourah Bay College. (How and when the plant will be set up and how, for example, concrete foundations will be prepared to carry the support structures.)

The PV solar systems are designed in a modular way, where all components including installation material shall be delivered from the PV system manufacturer. Proceeding like this ensures that the overall plant design and construction will be correct and logical. Splitting up the system delivery to several suppliers would also increase engineering expenditure considerably.

More detailed work is required concerning the integration of the PV panels on the roof of the building of the Department of Electrical Engineering at Fourah Bay College. A civil work specialist, maybe available within the administration of the college, has to be involved. A static calculation of the loads has to be performed.

The 6 systems are designed to meet the electrical energy requirements as listed in Table 6 even during periods of lowest solar insulation in August during the rainy season.

	useful energy / kWh/d /	batt. voltage level / Volts /	$Watt_{peak}$ PV power / Watts /
Fourah Bay College	28.13	48	8056
NPA Training Centre	0.96	24	424
Njala Hospital	10.85	24	4664
Taiama Centre	0.96	24	424
Masiaka Centre	0.96	24	424
Port Loko Centre	3.79	24	1696

Table 6: Maximum daily energy consumption on the battery side, battery/array voltage level and installed PV peak power

The total suggested number of modules type SSI M55 is 296. This does not include the 3 pump systems, which consist of 2 modules each.

The prices of the complete PV systems, net, CIF Freetown, excluding concrete foundations, installation and additional starting up capacities can be estimated as listed below, they are originally calculated in DM and are transfered into US $ with an exchange rate of 1.60 DM/$:

National Capabilities Development Program for Solar Energy Application

Fourah Bay College:	$ 181.000.-
NPA Training Centre:	$ 16.800.-

Medical Centres' Support Program

Njala Hospital:	$ 115,500.-
Taiama Health Centre:	$ 19.500.-
Masiaka Health Centre:	$ 19,500.-
Port Loko Vaccine Distr. Centre:	$ 48,800.-
Total cost for all systems CIF Freetown:	$ 401,100.-

Table 7 shows the estimated cost distribution for the main sub-systems and deliveries for the 6 projects:

	Fourah Bay College	NPA Training Centre	Njala Hospital	Taiama Centre	Masiaka Centre	[illegible] Storage
PV Generator incl. Support Structures and Array Junction Box	64,000	3,700	39,000	3,700	3,700	14,000
Control Unit incl. DC-DC Converters	18,200	4,700	12,500	4,800	4,800	7,600
Battery System	46,500	3,400	21,600	3,400	3,400	8,600
Inverter	13,100	/	[illegible]	[illegible]	[illegible]	[illegible]
Installation Material incl. Electrical Equipment and Building Wiring System	22,600	1,700	29,000	1,400	1,400	11,500
Solar Water Pumping System	/	/	2,900	2,900	2,900	/
Documentation and Engineering	4,900	200	2,500	200	200	1,700
Supervising (Duration in Work Days)	7,900 (7)	2,300 (2)	4,500 (4)	2,300 (2)	2,300 (2)	3,400 (3)
Transport CIF Freetown	3,800	800	3,500	800	800	2,000
Total Project Costs	**181,000**	**16,800**	**115,500**	**19,500**	**19,500**	**48,800**

Table 7: Estimated Cost Distribution for the 6 Projects (in US $)

The total amount of $ 401,100.- includes one man month (20 work days) of a specialist sent from the system deliverer to start up the project in Sierra Leone.

It must be emphasized once more, that before a detailed plant engineering can be carried out by the supplier of the system, a site measurement has to be performed in order to determine exact plant locations, distances for wiring, installation material requirements, etc.

The cost for the concrete foundations for the medical support program can roughly be estimated to be US $ 5,500.- in total, for the NPA Training Centre, the cost would be approx. $ 400.-. These are illustrative estimates based on European experience under normal conditions but higher labour costs.

For Fourah Bay College, a very rough illustrative figure for the costs of foundations and additional roof-top support structures would be approx. $ 20,000.-.

It is suggested to include funds for project management, man power support, transport of equipment within Sierra Leone, a 2-week training program for one, preferably two engineers from Sierra Leone at the system manufacturer, etc.

7. Time Schedule for Project Execution

The Schedule for the project depends very much on the decision processes within UNIDO, UNDP and UNICEF. After general approval, a design engineer has to spend approx. 2 weeks in Sierra Leone to clarify technical details and in particular the location of the PV array at Fourah Bay College.

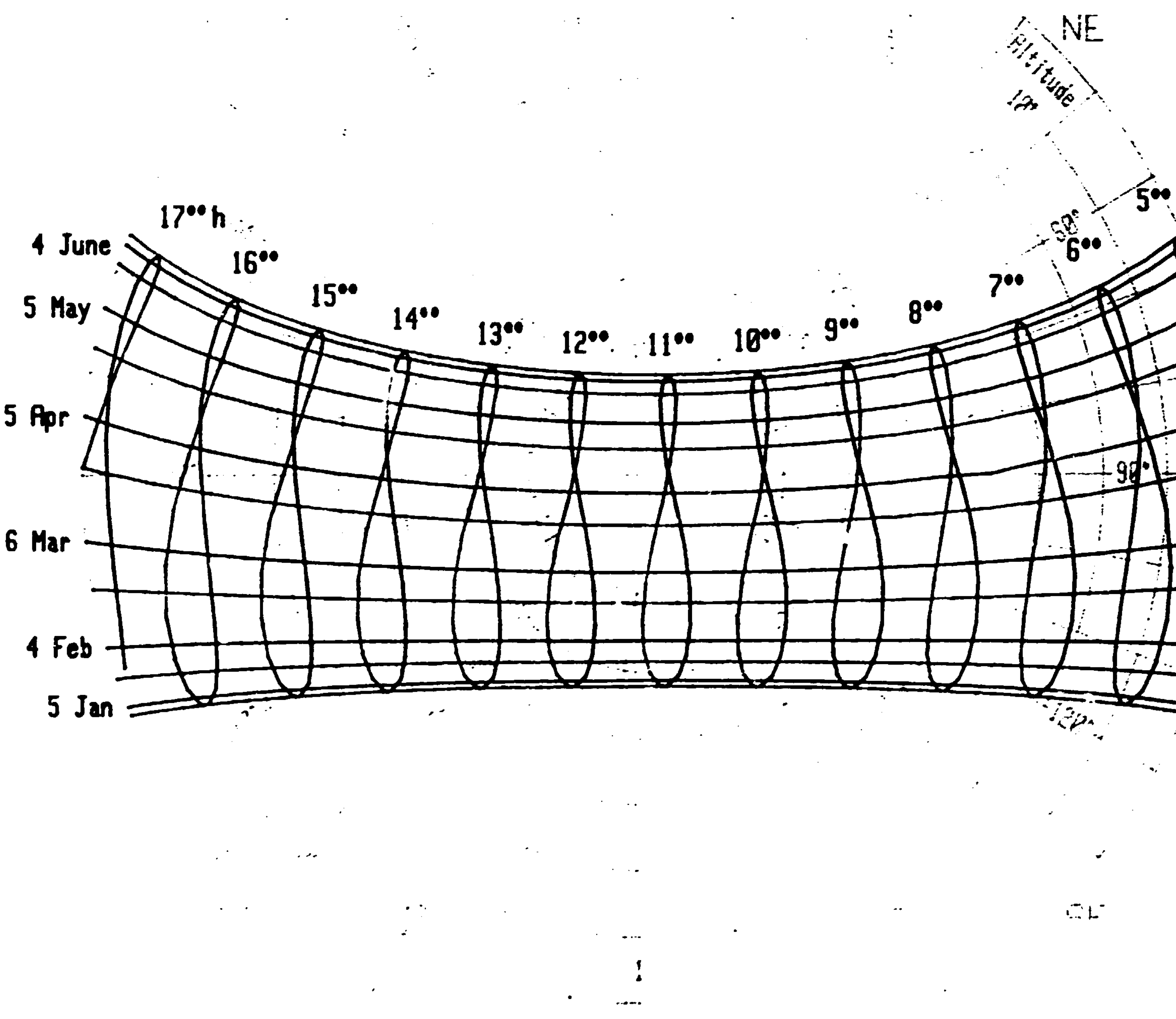
After approval of the project, delivery of the complete equipment ex-works will take approx. 16 weeks from receipt of technically and commercially clarified order. It would be most effective to pursue the training program for local engineers in Europe at the beginning of this 16 week period.

Transport of equipment to Sierra Leone is estimated to take about 4 weeks. The progress of the plant installation and start up depends very much on the amount of support by the "PV Energy Task Force".

As probably only 2 systems can be erected at the same time, the total installation time can be in the order of 6 months. This means, that from kick off on, the whole project will take 12 to 14 months, if no major obstacles occur. A realistic schedule, however, would be 18-24 months.

RWE sun-position-diagram
Freetown (Sierra Leone)

8°30' latitude north, 13°17' longitude east, time reference meridian 0°00' longitude east

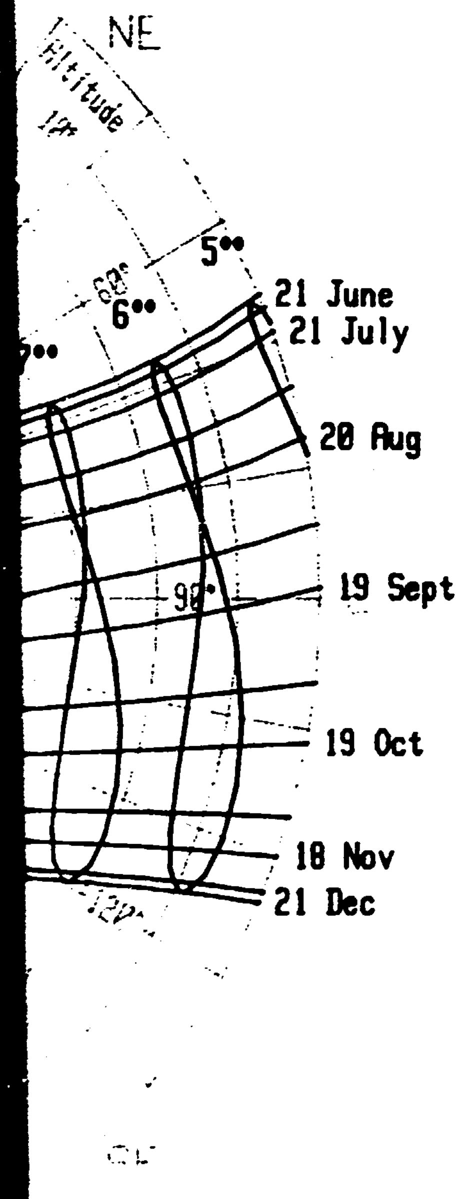


SECTION 1

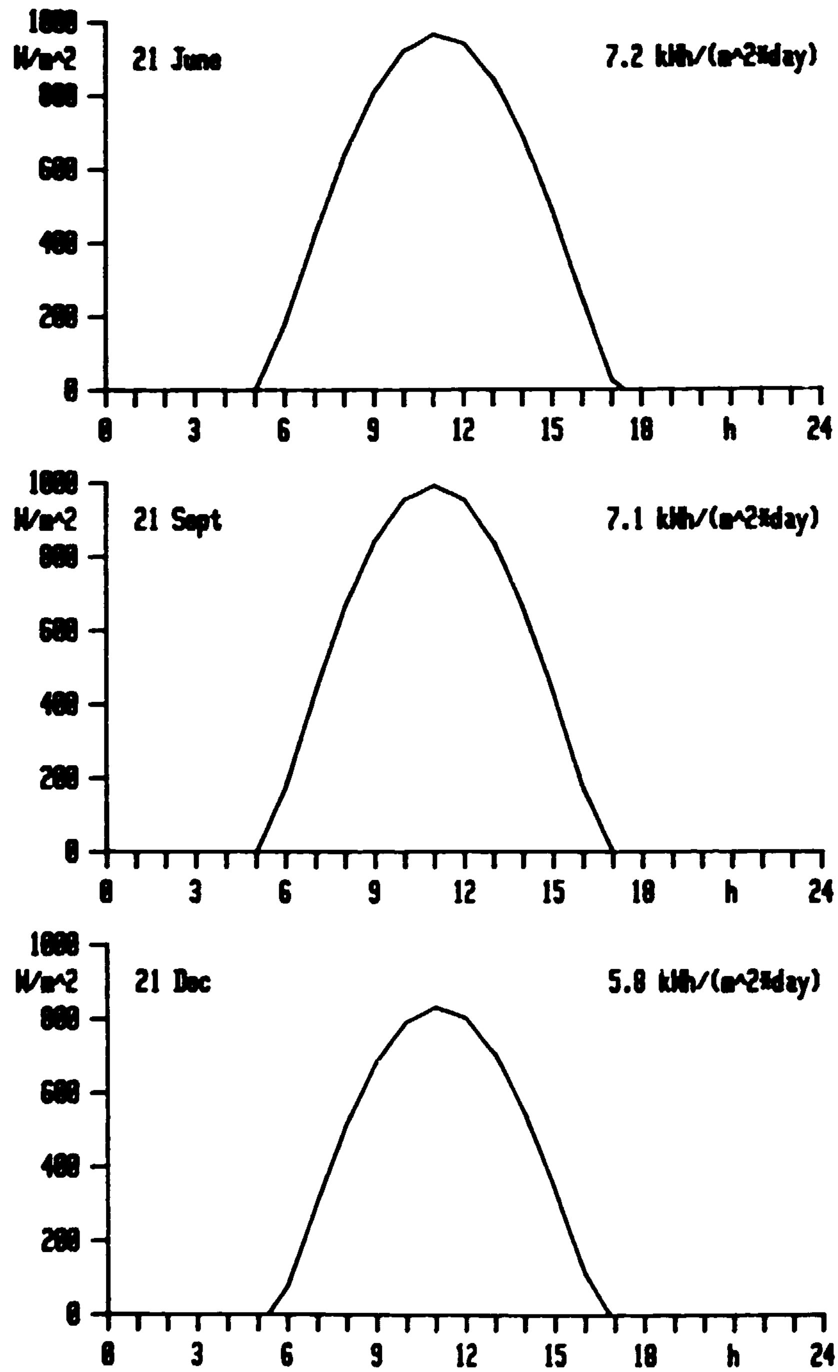
am

e)

0' longitude east



Global irradiance on a horizontal surface
for days with highest, mean and lowest
sun position at cloudless sky
(turbidity factor 5)



RWE Energie
Aktiengesellschaft
Head Office, Dept. Anwendungstechnik
Kruppstraße 5, D-4300 Essen 1, FRG

RWE sun position diagram

The daily and annual motion of the sun is determined by the rotation of the earth around its axis, by the elliptical orbit of the earth around the sun and by the inclination of the earth's axis to the orbital plane (obliquity of the ecliptic). To our knowledge, the RWE sun position diagram is the first accurate descriptive depiction of the position of the sun since by means of a computer programme it takes all these influences into account and it can be drawn up for any locality on earth at the click of a button. For the locality desired, its geographical coordinates (degrees of longitude and latitude) and the time reference meridian, i. e. the degree of longitude to which the standard time refers, have only to be indicated.

The position of the sun can be ascertained by means of the orange coordinate system (polar diagram) as direction angle of the sun (azimuth) and altitude of the sun (elevation) from the violet and green curves of the movement of the sun which are arc-shaped and run from east to west. For each specified day the sunrise and sunset can be read at the respective boundary points of the daily curves (altitude 0°) in terms of time and direction angle as far as the daily curves do not present a closed shape as in the polar regions. Furthermore the sun position diagram is a simple aid to ascertain the insolation or shading conditions and the duration of shadings at any locality.

The availability of these relationships is a prerequisite for accurate calculations of the energy-related effects of shadings to be taken, e. g. for constructing a house or the planned photovoltaic research installation of RWE.

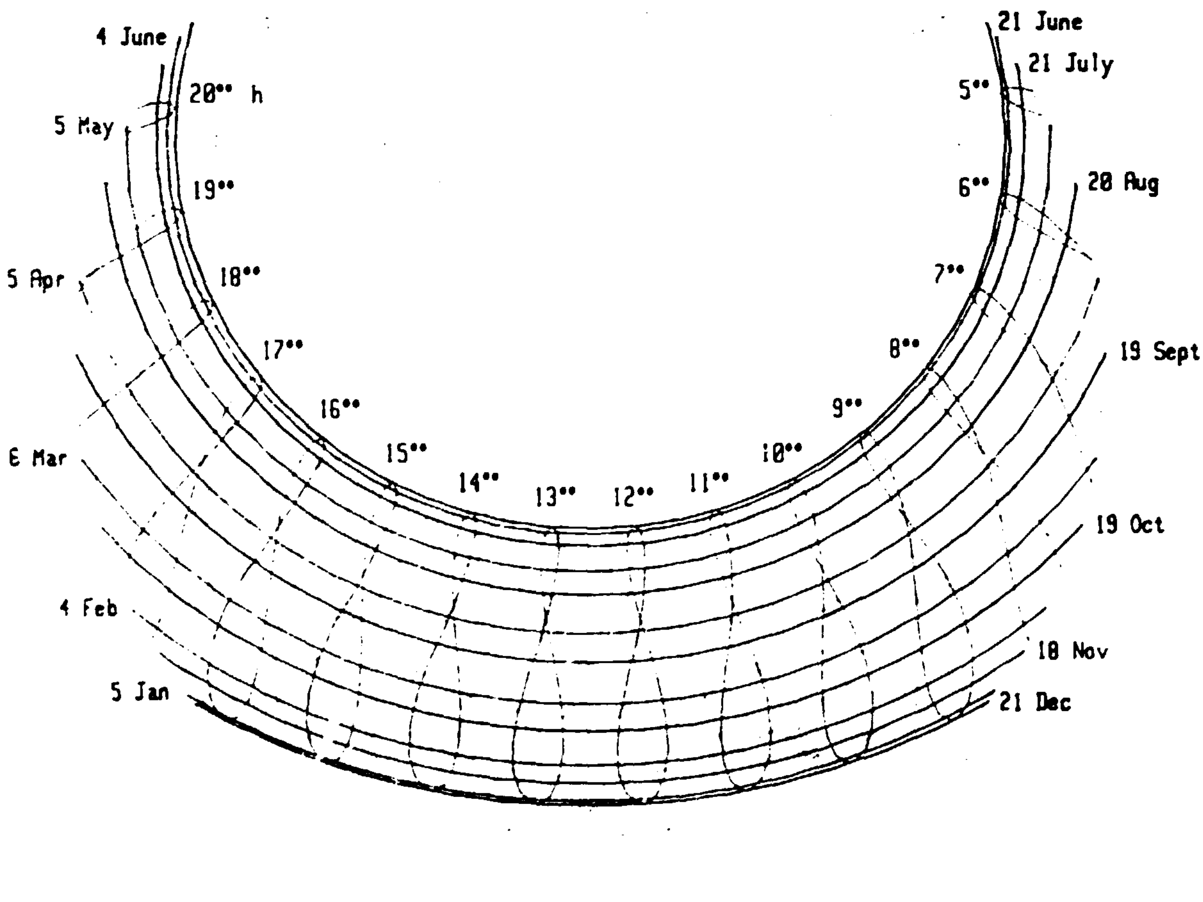
This folder shows the sun position diagrams for three towns in Central, North and South Europe and for the especially prominent sites of the North Pole and equator. In addition, it contains definitions of essential terms and some examples of application of the sun position diagram.

RWE

Rheinisch-Westfälisches Elektrizitätswerk AG, Abt. Anwendungstechnik, Kruppstraße 5, 4300 Essen 1

RWE sun position diagram
Essen

51°25' latitude north, 6°57' longitude east, time reference meridian 15°00' longitude east



Application of the RWE sun position diagram

Structure of the diagram

The position of the sun in the sky is described by means of the orange polar diagram the centre of which represents the stand of the viewer. The movement of the sun for particular days is entered in this coordinate system from the east to the west in arc-shaped daily curves (violet for the first six months, green for the second six months).

The computer programme ascertains for the locality desired the day showing the highest sun position and the day showing the lowest sun position at noon (in the example Essen, 21 June, 21 December) and enters as boundary curves the associated daily curves of the movement of the sun for these days. At intervals of 30 days each, further daily curves of the movement of the sun are entered. Contrary to this, an interval of only approx. 15 days to the neighbouring curves of another colour is left for the two boundary curves of 21 June and 21 December. For the locality concerned, there are no sun positions outside this field.

Loop-shaped hourly curves have been entered to ascertain the sun position for the full hours with the colour violet also applying to the first six months and green to the second six months. The loop shape of the hourly curves is attributable to the elliptical orbit and the obliquity of the ecliptic (s. also "Definition of essential terms"). The times refer to the time reference meridian indicated in each case, e. g. to the zone time of the locality in question (for example Essen locality: European Mean Time, 15° longitude east).

Ascertainment of the sun position

The intersections of the daily curves with the hourly curves of the same colour indicate the position of the sun by day and hour. In the orange coordinate system (polar diagram), the position of the sun can be read as direction angle of the sun (azimuth) and altitude of the sun (elevation).

Example ① (Essen locality)

What is the position of the sun on 19 September at 9.00 h?
The following result is obtained from the intersection of the two related green curves:

direction (azimuth) 121°
altitude above horizon 24°

The position of the sun for days and times other than those specified can be ascertained by interpolation. Attention must be paid to the fact that during the first six months interpolation is effected in the area of the violet daily and hourly curves and in the second six months between the green curves.

Sunrise and sunset

Sunrise and sunset can be read for each specified day at the respective boundary points of the daily curves (altitude 0°), in terms of time and direction angle.

Example ② (Essen locality)

At what time is sunrise and sunset on 4 February?
By interpolation:

sunrise 8.10 h
sunset 17.20 h

North Pole locality

For the North Pole, the daily curves have a circular shape where the sun does not set all the day long. As can be seen from the diagram, the sun is over the horizon between 23 March and 20 September. The sun is not visible on all the other days.

A part of the daily curves of the movement of the sun have also a closed shape at all localities situated between the Arctic Circle and the North Pole (example Hammerfest) and between the Antarctic Circle and the South Pole. During these days the sun is above the horizon.

Ascertainment of shadings

By means of the RWE sun position diagram, such periods within a year can be determined in which a particular locality is shaded due to horizon superelevations of the environment – hills, mountains, trees, structures. To this purpose the area covering the sky and rising above the horizontal plane of the locality is entered in the polar diagram. Ascertainment of the area covering the sky and the entry in the RWE sun position diagram are explained by the opposite example (house and tree). The lower edge of a garden window as high as a room, was chosen as locality (P).

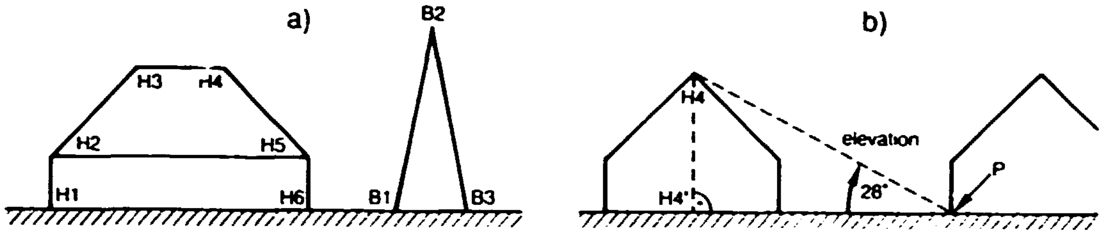
From the layout (c) the azimuths of prominent corner points of the border line between the sky and the objects casting shadows are ascertained (H1 – H6, B1 – B3). The lengths required for the calculation are attained from vertical intersections (b) of the locality and the respective corner point – in the example the corner point H4. From the corner point H4 the perpendicular is dropped to the horizontal plane and the perpendicular point H4´ is attained. The elevation angle can be calculated from the line segment H4 – H4´ and the distance H4´ – P.

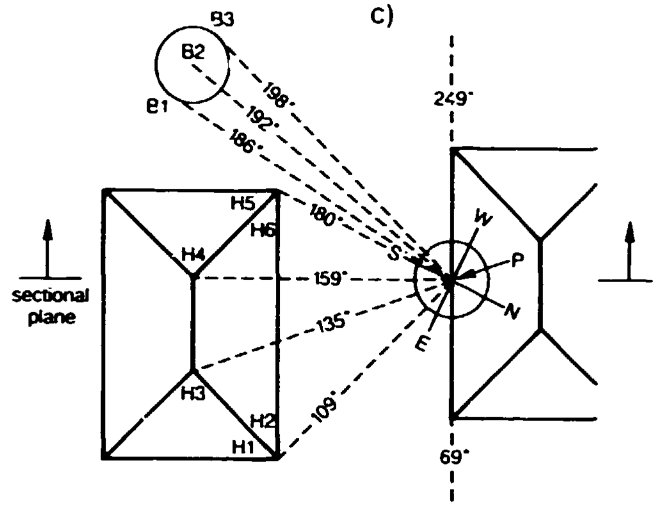
The elevation angles of all other corner points are ascertained in the same way from (supposed) vertical intersections and entered in the polar diagram to the respective azimuths. By means of drawing lines between neighbouring corner points in the polar diagram, the course of the border line between the sky and the environment is attained.

The example shows an additional border line that is due to the shading by the house wall where the garden window is situated. This border line runs in the straight line of the house wall on the azimuths of 69° and 249° through the locality.

The hatched areas pointing outwards between the border lines and the elevation angle of 0° mark the area covering the sky for the selected locality in the polar diagram.

Shadings occur in such periods where the hatched areas and the area of the daily motion lines are overlapping – e. g. on 19 October from 9.10 h to 11.05 h and from 17.00 h to 17.25 h.





Example for ascertaining shadings caused by a house and a tree

a) view from the locality P on the house and the tree

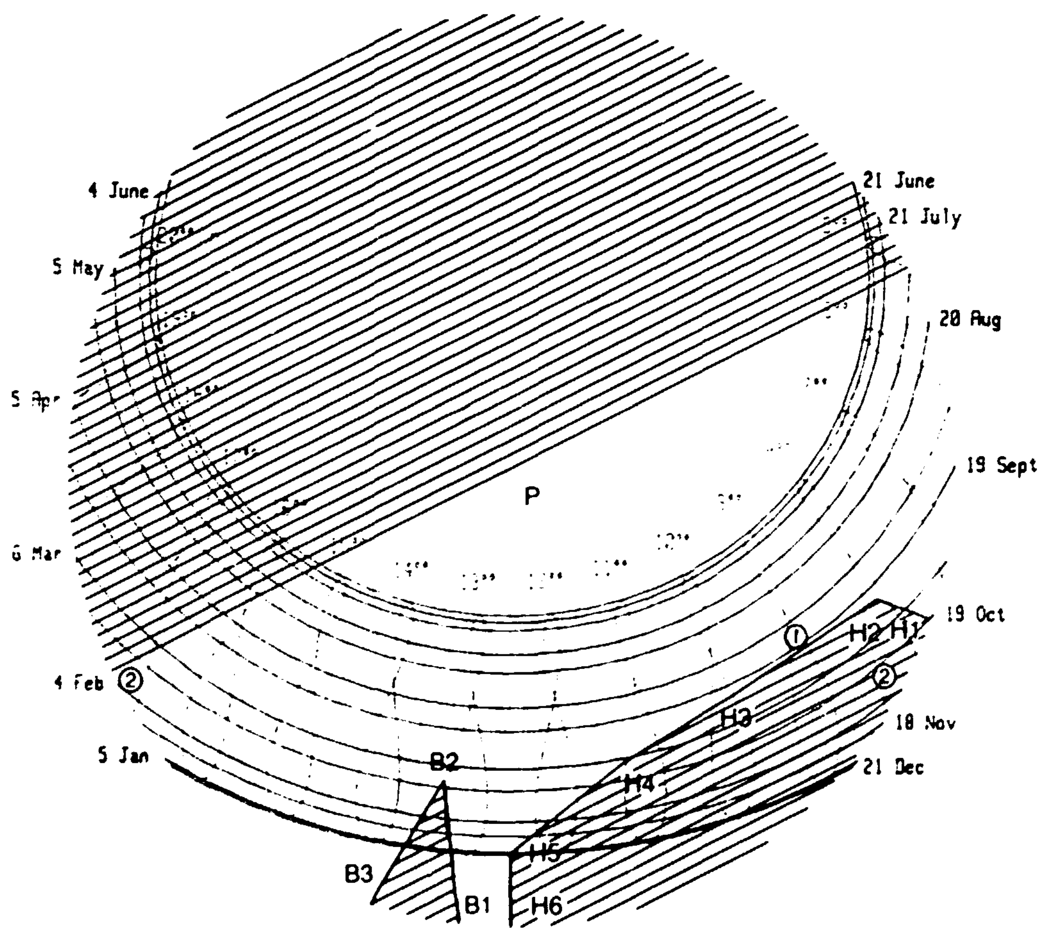
b) section of the locality P and the corner point H4

c) layout with the azimuths of the corner points

d) entry of the horizon superelevation in a sun position diagram of Essen locality

.d) RWE sun position diagram Essen

51°25' latitude north, 6°57' longitude east, time reference meridian 15°00 longitude east



Definition of essential terms

In the so-called horizon system the **position of the sun** is formed by the azimuth angle and the altitude (Fig. a).

The **altitude** is the angle with which the observer sees the sun above the horizon. This angle ist also called elevation and is between 0° and 90°.

The **azimuth** indicates the direction angle of the sun which is measured clockwise in the horizon plane starting from north. This angle is between 0° and 360°: its graduation is identic with that of a compass (north: 0°, east: 90°).

The **sun position diagram** shows these two angles in a polar diagram. (A **polar diagram** is an even coordinate system where the position of a point is defined by its distance to the centre and by its polar angle.) The outer circle of the sun position diagram represents the horizon. The centre is identic with the vertical above the observer's localitiy. The altitude of the sun results from the distance to the centre. The azimuth angle of the sun is identic with the polar angle in the sun position diagram.

The time defined by the sun position observed, when noon always coincides with the sun on the celestial meridian, is called the **apparent solar time**. Exact measurements show that the hours of this time during the course of a year are not of exactly the same length. Taking as the fixed time scale the mean value of the hours of the apparent solar time for all the year, we will get the **mean solar time** also called local solar time.

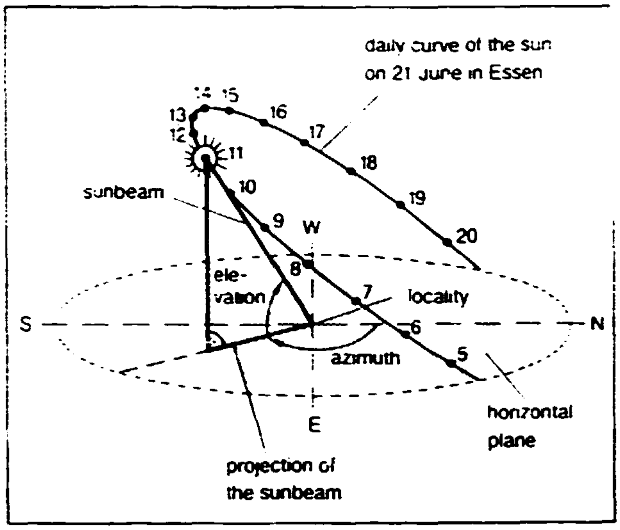
The mentioned difference between the apparent solar time and the mean solar time is called the **equation of time**. There are two reasons for it.

First, the path of the earth is an ellipse which is not passed with a uniform speed. According to Kepler's Laws, the sun is in a focus of the ellipse and the polar vector drawn from the earth passes the same areas in the same periods (Fig. b). That is the reason why the days are somewhat shorter when the earth is closer to the sun than they would be if the earth were more distant from the sun. This time correction shows an all-year period (Fig. d).

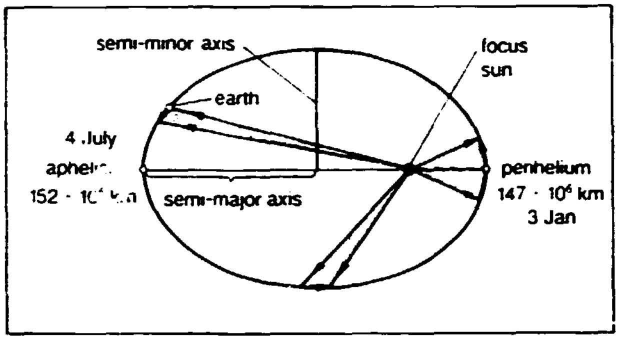
The second reason is the **obliquity of the ecliptic** that means the fact that the **ecliptic** in which the earth moves around the sun in an elliptical orbit is making an angle of 23° 27′ with the equator of the earth (Fig. c). Since the sun appears to move in the ecliptic, time, however, is measured alongside the equator, deviations between the apparent and the mean solar time with a half-year period result (Fig. d).

To eliminate the disadvantage of different times for closely neighbouring localities situated on various geographical longitudes, each locality on earth is assigned to a **time zone**. In every zone a uniform time (zone time) is valid where the mean solar time of the associated **time reference meridian** is applicable. The degrees of longitude are determined in steps of 15° as time reference meridians starting from the prime meridian – e. g. Federal Republic of Germany 15° east, European Mean time.

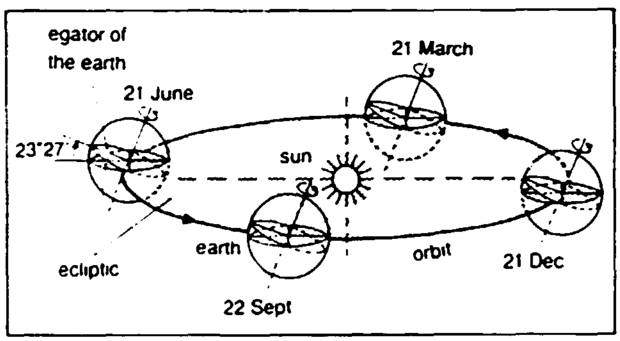
The loop-shaped hourly curves in the sun position diagram indicating the zone time for the locality in question is due to the equation of time.



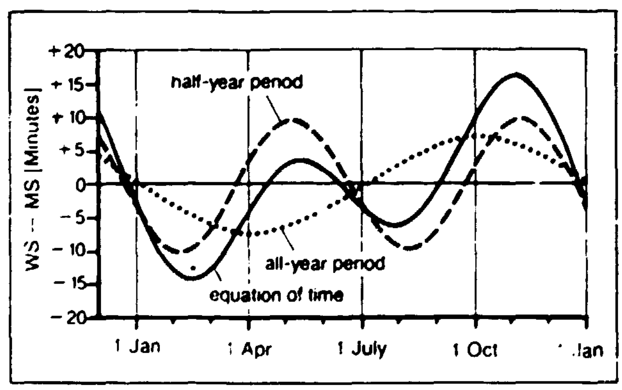
a) Definition of azimuth and elevation of the sun position



b) Kepler's model of the elliptical path of the earth around the sun

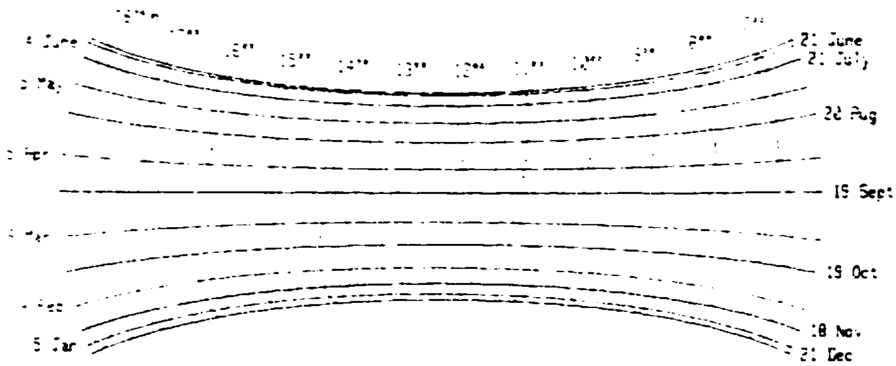


c) Definition of the obliquity of the ecliptic of 23° 27′



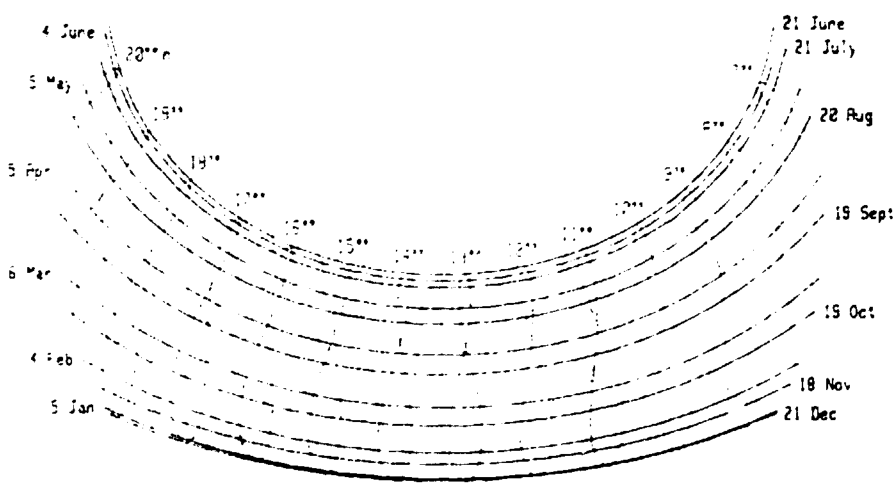
d) Representation of the time equation from the overlapping of two curves with all-year and half-year periods

RWE sun position diagram
Equator



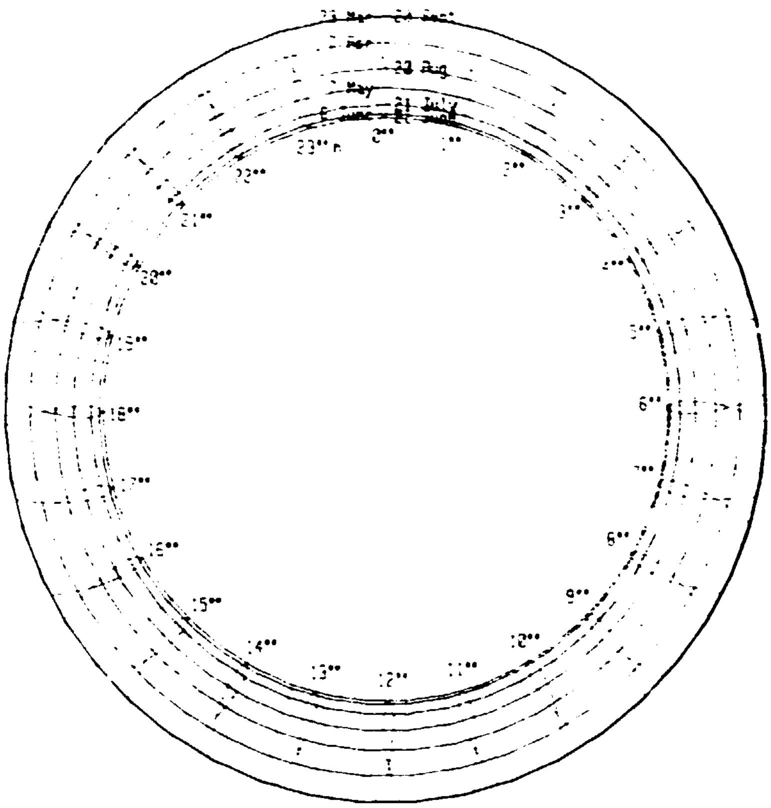
RWE sun position diagram
Gibraltar

36°25 latitude north, 5°21 longitude west, time reference meridian 15°22 longitude east



RWE sun position diagram
North Pole

90°00 latitude north, 0°00 longitude east, time reference meridian 0°00 longitude east



RWE sun position diagram
Hammerfest

70°40 latitude north, 23°44 longitude east, time reference meridian 15°00 longitude east