SOLAR RURAL ELECTRIFICATION IN TUNISIA

Approach and Practical Experience (Volume 2)

Agence pour la Maîtrise de l'Energie (AME)

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH

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National Agency for Renewable Energies

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9.1. Understanding the technology - long-term experience

9.1.1. Interrelationship of components

A Solar Home System (SHS) is composed of five elements (*Fig. 9-24*):

- the photovoltaic module, which takes up solar energy and transforms it into electricity;
- the battery, which stores this electrical energy, and supplies it later to the consumers;
- the electricity consuming equipment (radio, television set, lamps);
- the charge regulator, which controls the transmission of the electricity to the consumers and protects these elements;
- cables, supports for modules (to fix them on the roof) and switches, plugs, sockets, etc.

SHS in Tunisia operate at a voltage of 12V. Therefore, it is necessary to install an adapter to select the appropriate voltage for the type of radio used.

There is a relationship between the energy generated (depending on the power of the PV module and the solar radiation), the capacity of the energy store (the battery) and the quantity of consumable energy (power and time of use of the consumers).

The battery, managed by the charge regulator, is at the centre of the system. It is also the component which has the greatest influence on the long-term operational costs of an SHS.

Let us now regard the cycle of charging and discharging the battery on a sunny day:

Early in the morning, the battery is in a partly discharged state. After sunrise, electricity is generated and starts to recharge the battery. In the afternoon, when the radio and television start to work, the battery is simultaneously charged and discharged. When the battery is completely charged, the charge regulator stops further injection of solar electricity into the battery. In the evening, the battery is discharged (television, radio, lighting).

During a day with little or no sunshine, the discharging cycle is the same, but there is no or only little charging of the battery. So, the following day the cycle starts again with the battery emptier than on the previous morning. If there are several consecutive days without sunshine, the battery becomes more and more empty, until the charge regulator stops electricity consumption in order to avoid a deep discharge of the battery, which would have a negative effect on its potential lifetime.

When the days become sunny again, the battery is recharged, the charge regulator puts the system into operation again, and the normal cycle restarts.

The length of time that an SHS can operate on days without sunlight is called the <u>autonomy</u> of the system. Generally, the configuration of an SHS should be designed for an autonomy of three days.

There are several factors influencing the autonomy:

- First, the *capacity of the battery* must be sufficient. Otherwise, every evening it will be emptied to the limit.
- After several months of operation, the discharge process of the battery becomes more rapid, the autonomy of the battery is reduced. This effect is called the *ageing of the battery*. The ageing effect, which is progressive, results in more and more frequent cut-offs by the charge regulator in order to prevent a deep discharge. Finally, the PV system comes to a complete standstill.
- The *charge regulator* has to be well adapted to the characteristics of the battery. For example, it has to ensure that the battery is completely charged.
- The *power of the PV module* also influences the autonomy. If the power is too low, in relation to the capacity of the battery, the solar electricity generated will not be able to charge the battery completely, especially if - as is the case in winter - solar radiation is low and the number of hours of sunshine is reduced due to clouds.
- The *user* himself might extend the autonomy of his SHS, if he adapts his electricity consumption to the offer of solar energy.

The deeper the battery is regularly discharged, the more its potential lifetime (expressed in number of cycles of charge and discharge) is reduced.

Fig. 9-1 shows the results of standardised long-term tests for four different types of solar batteries: starting from the low duty battery (for use in leisure applications, such as caravans or holiday houses), up to very high-duty batteries for applications of very high performance at sites with difficult access - example: alarm signals for aeroplanes at the top of masts of high-voltage power lines.

The characteristics of the batteries used for the national programme in Tunisia correspond (from top to bottom) to the second (tubular - batteries) or the third curve (batteries with thick plates). The characteristic curves of TV - or starter batteries for lorries will even lie beyond the fourth curve of the diagram.

The diagram also shows that the lifetime of the battery (expressed in number of cycles) regularly discharged by only 10% of its nominal capacity will be between 2.5 and four times longer than that of a battery regularly discharged by 60%.

This explains why in Chile, where according to */9-1/* the discharge rate of the SHS-batteries is generally low, even low-quality batteries (car batteries) may achieve the same lifetime as solar batteries with thick plates in Tunisia, where the regular electricity consumption is considerably higher.

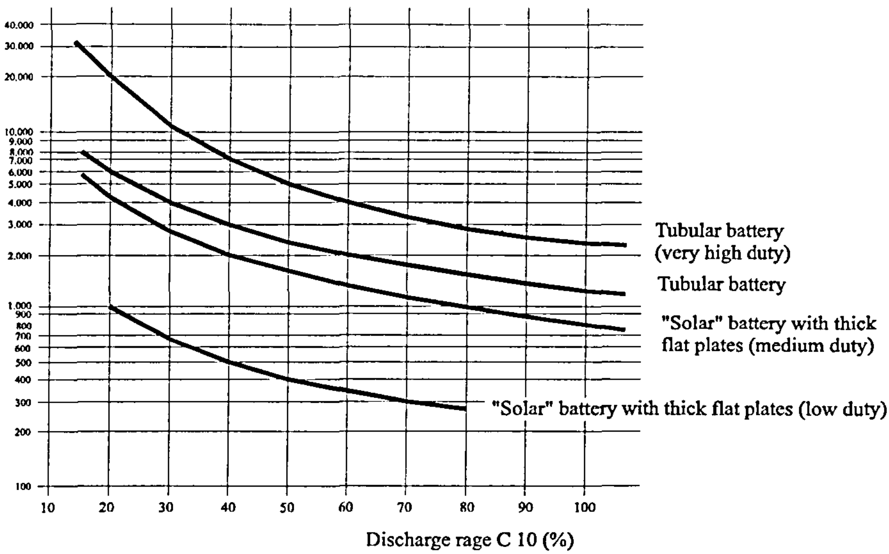


Fig. 9-1: Lifetime of four types of solar batteries (expressed in number of cycles in relation to the discharge rate). Source: Hoppecke (Germany)

9.1.2. The four SHS monitored by data acquisition systems

Some data characterising the performance and the services offered by SHS (solar radiation, electricity generated and consumed, and time of operation of the appliances - lamps, TV/radio) was to be collected by means of long-term measurements and analysed. For this reason and in co-operation with scientists of the National Technical University of Tunis (ENIT), SEP installed four data acquisition systems (MODAS, producer: NES) in different user households. The SHS had been installed in the framework of the pilot dissemination phase.

The characteristics of the four SHS were the following:

System Number	Delegation Sector	Charge Regulator	PV Module(s)	Battery	Lamps, Ballast	Television set	Radio
KEF-42	Kef-East Dyr El Kef	HELIOS LR 12/2	one module, SIEMENS 53 Wp	ASSAD TV 90, 12 V, 90 Ah (TV battery)	two lamps of 18W; ballast HELIOS, SVE	black and white; 21 W dc	-.-
KEF-32	Kef-East Dyr El Kef	HELIOS LR 12/2	one module, SIEMENS 53 Wp	TUDOR MOROCCO 12 V, 80 Ah (starter battery for vans)	two lamps of 18 W; ballast SVE	black and white; 14 W dc	-.-
KEF-53	Ksour Ksour I	HELIOS LR 12/2	one module, SIEMENS 53 Wp	TUDOR TUNISIA, 12 V, 90 Ah (thick flat plates)	two lamps of 18 W; ballast SVE	black and white; 40 W ac., used in dc	radio-cassettes 9V
KEF-07	Kef-East Dyr El Kef	HELIOS LR 12/2	two modules, SIEMENS2 x 53 Wp	two units TUDOR TUNISIA 12 V; 2 x 90 Ah (thick flat plates)	five lamps of 18 W; of 18 W; SVE	black and white; 14 W dc	radio/ cassette deck 6V

Tab. 9-1 : SHS analysed by MODAS: configurations

Three of the four SHS monitored were in the same sector, at a distance of up to five kilometres apart. The fourth, at Ksour, is about 40 kilometres away from the others.

Each data acquisition system had at its disposal four canals and thus was able to measure four physical characteristics. Two of the canals were used to measure the electricity of the consumers (lamps and television sets), whereas the fourth measured the global irradiation on the surface of the PV modules, directed to the South with an inclination of 45° (see plan in *Fig. 9-2*).

The data were automatically registered on a diskette. Each month, the diskette was changed and the data processed and evaluated.

Taking into account the great amount of data registered, only some extracts can be reproduced here.

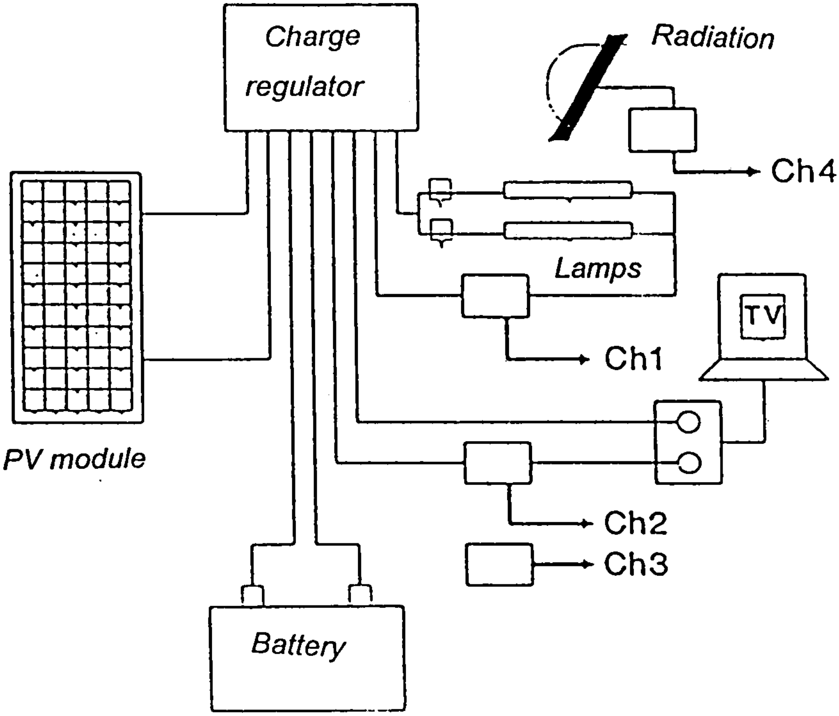


Fig. 9-2 : Connection scheme of the data acquisition system fitted to SHS KEF-42

9.1.3. Solar supply

Solar radiation varies widely in relation to the latitude, season, time of day and the climatic conditions of the specific sites.

For the four SHS monitored, first the average values of the solar radiation on the inclined surface (45°) of the PV module were evaluated. Here are the results for the four seasons:

System number	Spring	Summer	Autumn	Winter	monitored period
-.-	W/m²	W/m²	W/m²	W/m²	months
KEF-42	750	980	800	650	34 months (1990 - 92)
KEF-32	810	970	810	550	37 months (1993 - 96)
KEF-53	830	900	760	600	23 months (1992 - 94)
KEF-07	790	950	780	520	36 months (1992 -95)

Tab. 9-2: SHS monitored by MODAS: average global radiation in W/m² on a surface inclined at 45°(average value per season)

The average radiation, expressed in W per m², is highest in summer. Under the climatic conditions of north-west Tunisia, in spring and autumn it is about 20% lower, and in winter, it is about one third lower compared to the summer period.

In order to illustrate the monthly fluctuation of the global solar radiation on an inclined surface, the case of the system *KEF-53* will be considered. The graph (*Fig. 9-3*) illustrates the reduction of the solar radiation (accumulated daily values in kWh/m² x day) during the winter months. It will be necessary to provide a PV generator, large enough to recharge the battery completely in this season as well. If not, the battery will stay in a state of partial discharge for a long time, thus reducing its potential lifetime (see the result of simulation programmes, chapter 9.4.2.).

Figs. 9-4(a - d) show the average daily data, taken for the system *KEF-07* for four different months, each representing one of the seasons. Solar radiation is relatively homogeneous during the summer days. In spring, autumn and, above all, in winter, there are considerable day-to-day differences due to passing clouds or rain. During these seasons the autonomy of the SHS has to ensure the operation of the electrical equipment.

Finally, the hourly variations underline the high solar radiation in summer *(Fig. 9-5).*

The inclination angle of 45° to 55° of the PV modules was chosen in order to gain a maximum global solar radiation in winter. During summer, when the sun rises higher in the sky, a lower inclination would produce considerably more solar gain. The objective, on which the choice of the fixed angle of inclination was based, was, however, to provide as far as possible a constant quantity of electricity throughout the year, so that the user may adjust his consumption habits to a constant supply of electricity.

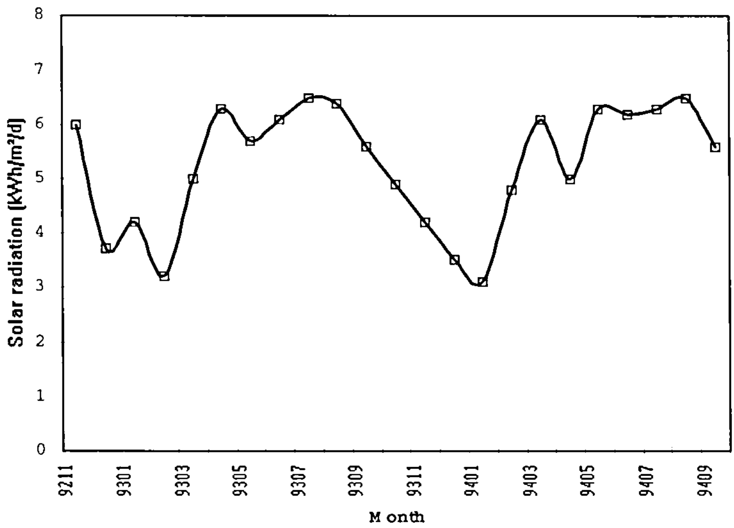


Fig. 9-3: Seasonal variation of global solar radiation on an inclined sur face of 45°. SHS KEF-53, 11/1992 to 09/ 1994

Tab. 9-3 indicates the minimum, maximum and average values of the global radiation on an inclined surface per day for the four monitored SHS.

System number	Spring	Summer	Autumn	Winter
	kWh/m²/d	*kWh/m²/d*	*kWh/m²/d*	*kWh/m²/d*
KEF-42	0.3	4.0	1.6	0.7
KEF-32	1.0	5.5	0.8	0.4
KEF-53	2.0	3.9	0.6	0.6
KEF-07	1.0	5.3	0.5	0.3

Tab. 9-3 a): Daily global solar radiation on an inclined surface of 45°: Minimum values

System number	Spring	Summer	Autumn	Winter
	kWh/m²/d	*kWh/m²/d*	*kWh/m²/d*	*kWh/m²/d*
KEF-42	7.3	7.2	6.9	6.1
KEF-32	8.3	7.8	7.3	7.0
KEF-53	7.1	7.2	7.5	6.5
KEF-07	8.2	7.8	7.5	7.3

Tab. 9-3 b): Daily global solar radiation on an inclined surface of 45°: Maximum values

System number	Spring	Summer	Autumn	Winter
	kWh/m²/d	*kWh/m²/d*	*kWh/m²/d*	*kWh/m²/d*
KEF-42	4.9	6.5	4.6	3.7
KEF-32	5.9	7.1	4.6	3.3
KEF-53	5.5	6.5	4.9	3.1
KEF-07	5.5	7.0	4.2	3.5

Tab. 9-3 c): Daily global solar radiation on an inclined surface of 45°: Average values

The values of the average daily radiation during summer are twice as high as in winter, although the inclination angle chosen favours solar energy gains during the winter months.

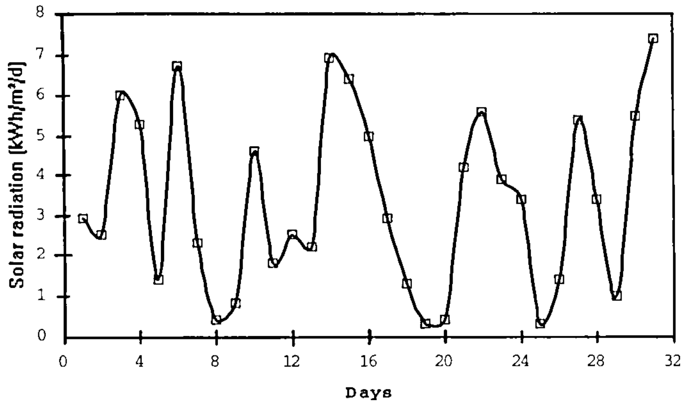


Fig. 9-4a): Daily variation of global solar radiation on inclined surface (SHS KEF-07, January 1994)

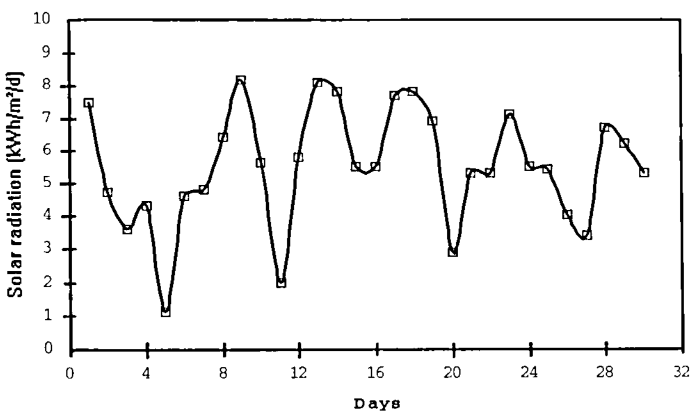


Fig. 9-4b): Daily variation of global solar radiation on inclined surface (SHS KEF-07, April 1994)

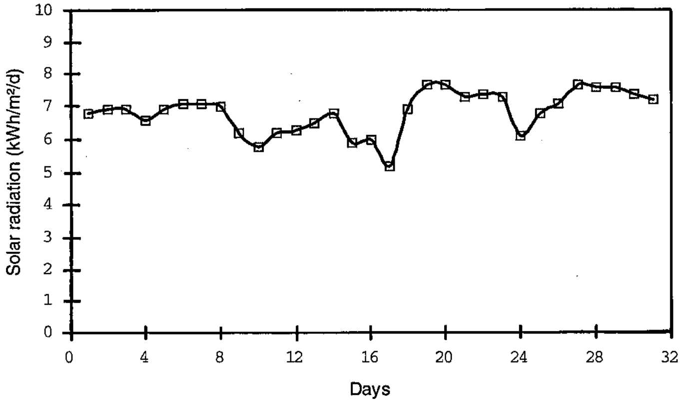


Fig. 9-4c): Daily variation of global solar radiation on inclined surface (SHS KEF-07, August 1994)

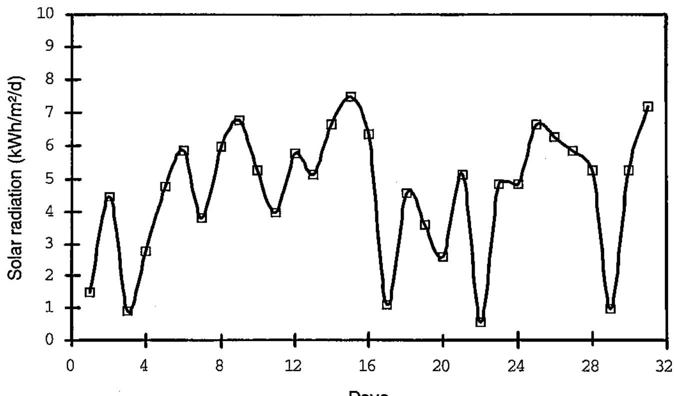


Fig. 9-4d): Daily variation of global solar radiation on inclined surface (SHS KEF-07, October 1994)

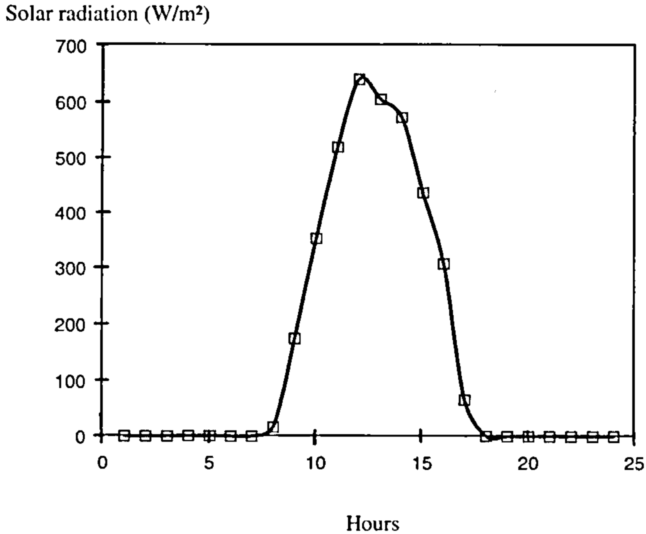


Fig. 9-5a): Hourly variation of global solar radiation on inclined surface (SHS KEF-07, January 1992)

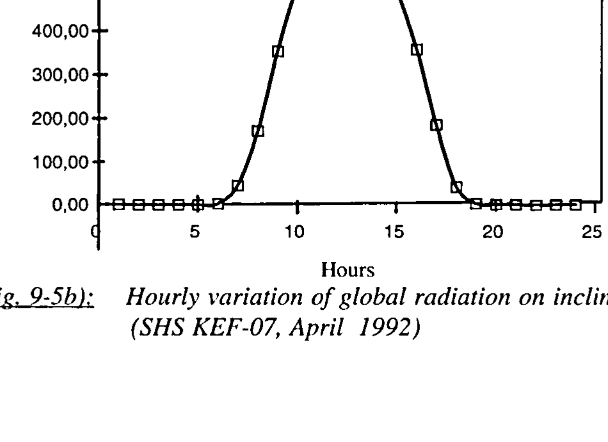


Fig. 9-5b): Hourly variation of global radiation on inclined surface (SHS KEF-07, April 1992)

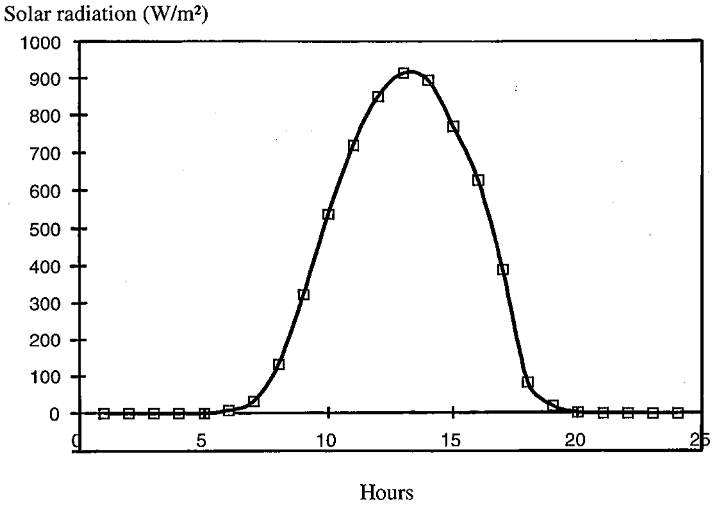


Fig. 9-5c): *Hourly variation of global radiation on inclined surface (SHS KEF-07, August 1992)*

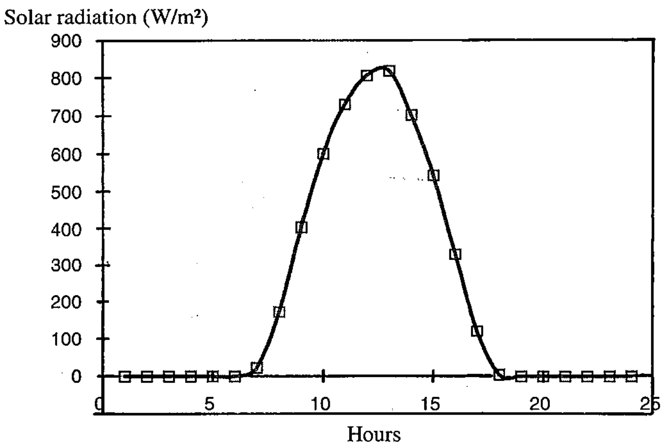


Fig. 9-5d): *Hourly variation of global radiation on inclined surface (SHS KEF-07, October 1992)*

9.1.4. Energy consumption and exploitation of the SHS

In comparing the performances of the four SHS, the effects of the daily electricity consumption and the configuration of the systems were analysed.

Concerning the configurations, there were differences in the power of the PV generators (three systems with one module of 50 Wp, one system of 106 Wp), the capacity of the batteries (between 80 Ah and 180 Ah) and the battery quality (TV battery, starter battery for vans, battery with thick flat plates).

The number of power cuts, effected by the charge regulator to protect the battery from deep discharge, may be an indication of the satisfaction of the user's demand for electrical energy.

The histogram of the cuts of system *KEF-42 (Fig. 9-6)* shows a performance interrupted by frequent cuts.

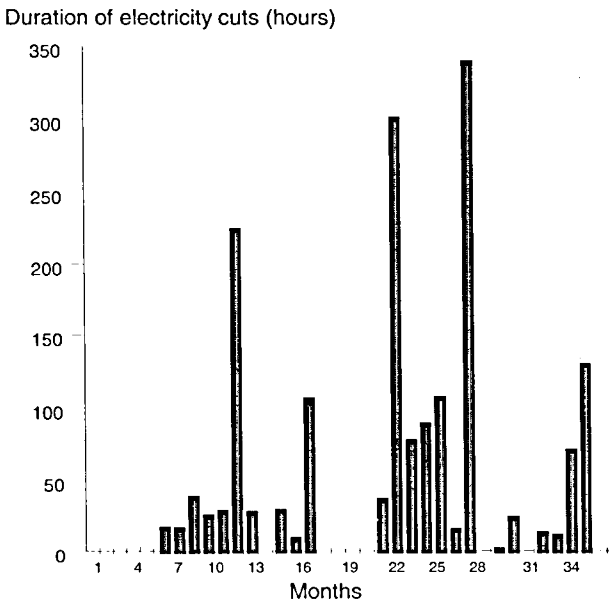
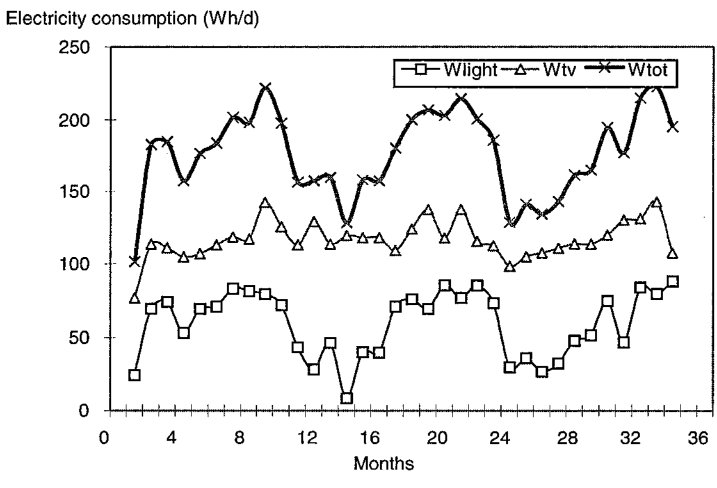


Fig. 9-6: Histogram of electricity cuts (SHS KEF-42, 1990 to 1992)

Electricity cuts started after six months operation of the system. At that time, their length did not exceed one single day.
According to the graph, showing the monthly electricity consumption *(Fig. 9-7)*, these first cuts did not motivate the user household to reduce his electricity consumption during periods of little sunshine.
Evidently, this over-exploitation of the battery caused the anticipated ageing of the battery. The time to discharge the battery became shorter, the cuts became more frequent and longer.

After only 13 months, the user had to change the battery. The following winter, the new battery was emptied again, probably because of a couple of consecutive days without sunshine, although this time the user had reduced his electricity consumption in order to adapt it to the reduced supply of solar energy available.



<u>Fig. 9-7:</u> Seasonal variation of energy, SHS KEF-42 (lamps, radio/TV, total)

After one year of operation, the ageing of the new battery started again, causing frequent and steadily increasing interruptions of electricity consumption, sometimes of more than 15 days. It was therefore necessary to change the battery again.

The normal daily consumption (unaffected by the stand-still of the system) of this household would be about 200 Wh. Evidently, the configuration chosen for this SHS was not capable of delivering this quantity of energy in a satisfactory way. This was later confirmed by computer simulation programmes (chapter 9.4.2.4).

Regarding the consumption priorities, it can be seen that this household favoured television to lighting. The energy consumption of the television set used was relatively high (21 W), and the family watched about five hours television per day. In summer, when the available energy was higher, the daily hours of television increased to seven hours.

So, whereas the television consumption did not show significant changes, it can be seen that the hours of lighting were considerably reduced during periods of low insolation.

The objective of delivering a good lighting quality especially for the school children, allowing them to do their homework in the evening, was not achieved in this household.

The *daily* variations over four months, representing each season *(Fig. 9-8)*, and the *hourly* variations (monthly average data, *Fig. 9-9*), confirm this assumption. After electricity cuts (on the 10th and 28th January 1992) the television consumption immediately reached the same level as in the preceding days, whereas the hours of lighting were reduced considerably.

The lighting consumption starts with a small peak at about six or seven o'clock in the morning, depending of the season, and has its maximum starting at 6 p.m. (in winter) or 7 p.m. (in the other seasons), lasting up to 11 p.m. or even till midnight.
The use of the TV set and lighting are partially complementary. In the evening, when the television is on, the lamps are normally switched off.

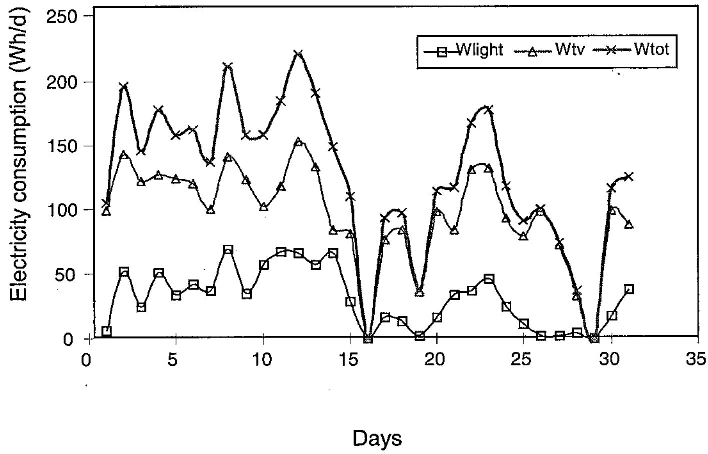


Fig. 9-8a): *Daily variation of electricity consumption (SHS KEF-42, January 1992)*

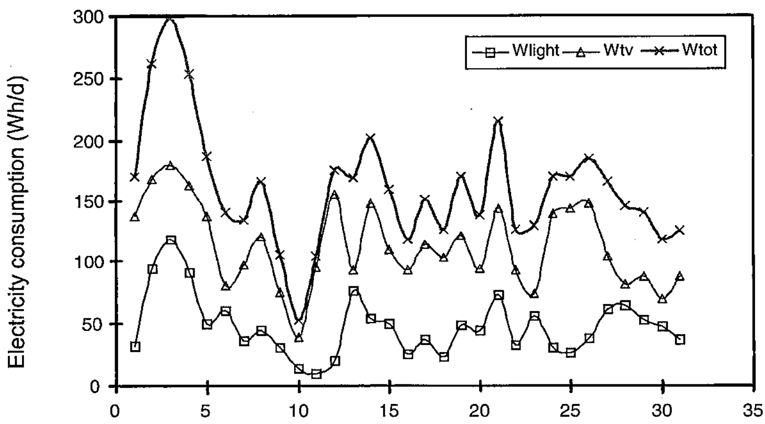


Fig. 9-8b): *Daily variation of electricity consumption (SHS KEF-42, April 1992)*

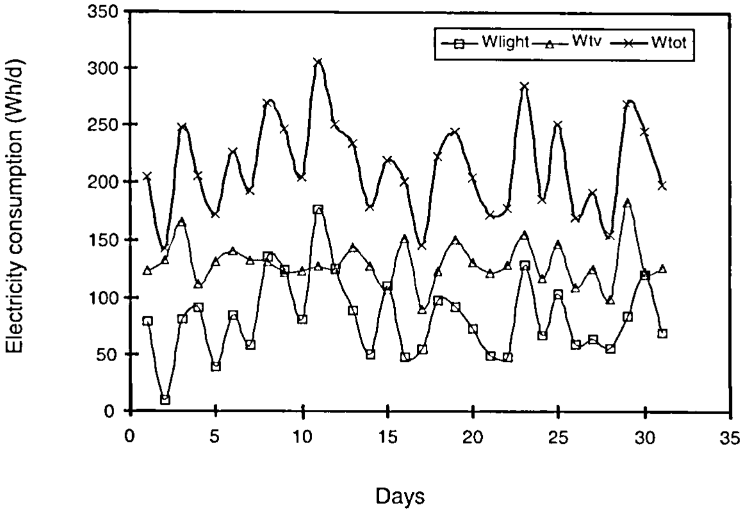


Fig. 9-8c): *Daily variation of electricity consumption (SHS KEF-42, August 1992)*

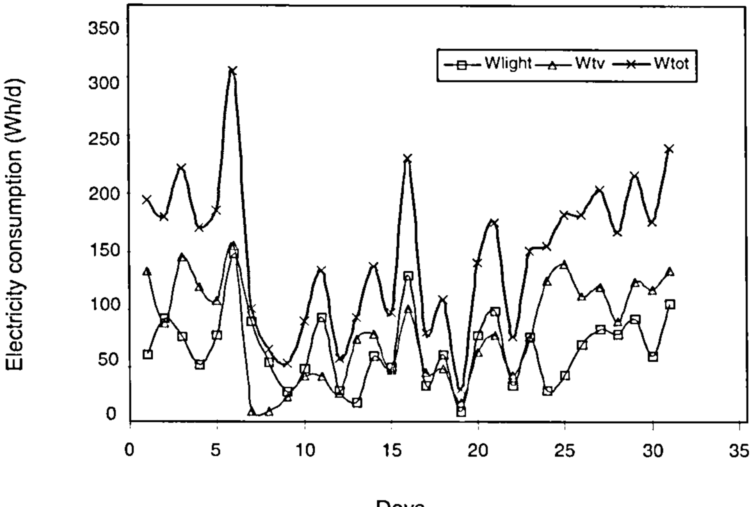


Fig. 9-8d): *Daily variation of electricity consumption (SHS KEF-42, October 1992)*

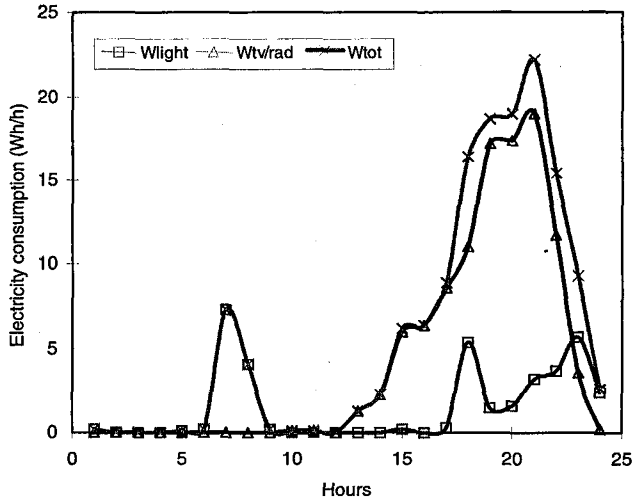


Fig. 9-9a): *Hourly variation of electricity consumption (SHS KEF-42, January 1992)*

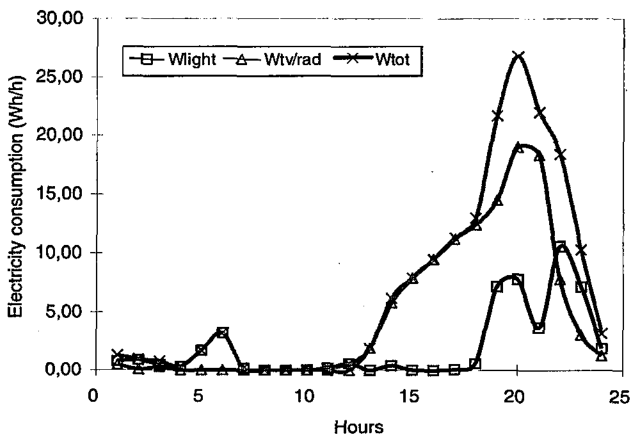


Fig. 9-9b): *Hourly variation of electricity consumption (SHS KEF-42, April 1992)*

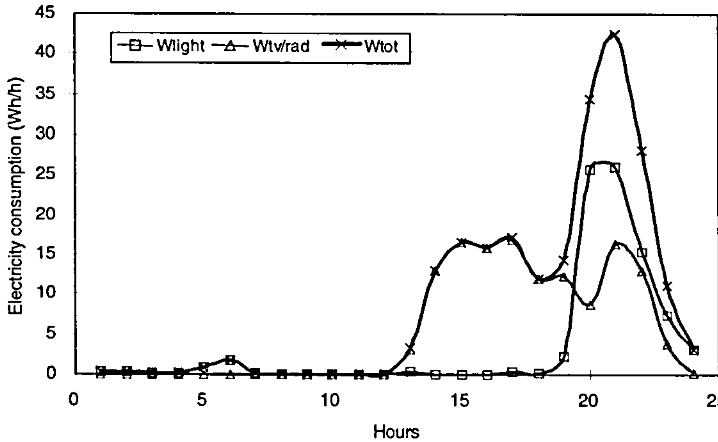


Fig. 9-9c): *Hourly variation of electricity consumption (SHS KEF-42, August 1992)*

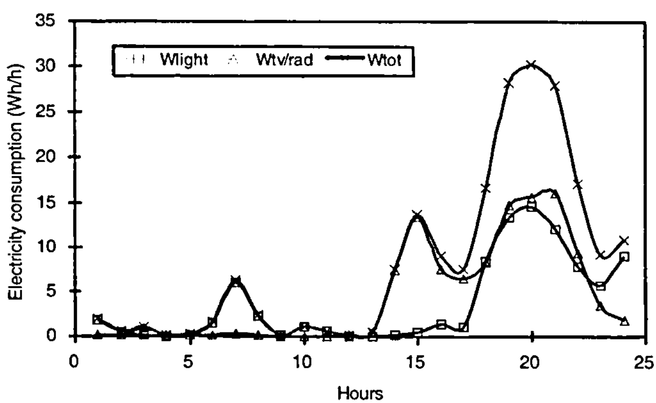
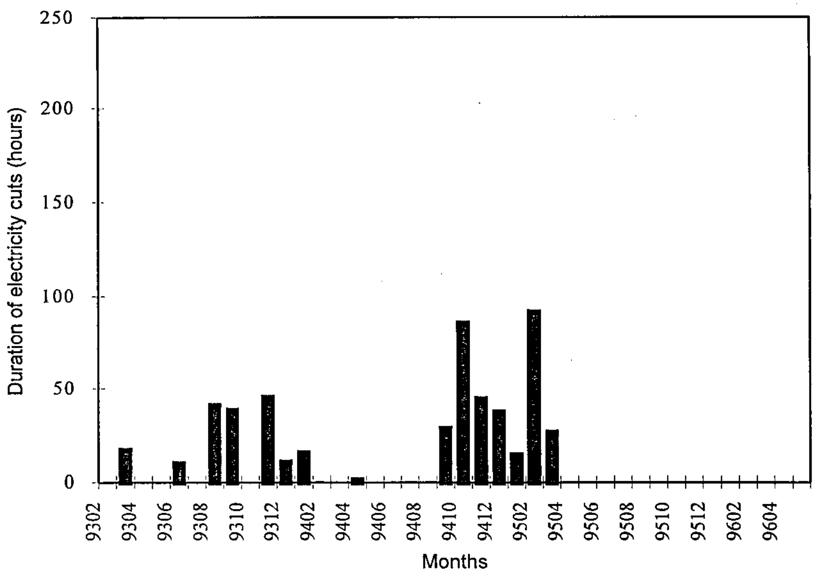


Fig. 9-9d): *Hourly variation of electricity consumption (SHS KEF-42, October 1992)*

The histogram of system <u>*KEF-32*</u> (*Fig. 9-10*) shows a couple of electricity interruptions of one to two days in autumn and winter 1994. The curves of seasonal variation of electricity consumption (Fig. 9-11) prove that the energy consumed by the household during that period of low solar radiation was too high and thus was responsible for the cuts.

Further interruptions could be avoided by the reduction of energy consumption, or by using a higher quantity of electricity which is available during the other periods.

After 18 months of operation, ageing of the battery began, causing more frequent and longer interruptions. After the installation of a new battery, no more interruptions were noted till the end of the monitored period.



<u>*Fig. 9-10:*</u> *Histogram of electricity cuts (SHS KEF-32, 02/1993 to 05/ 1996)*

The daily electricity consumption of this household was considerably lower than that of the preceding one: it did not exceed 150 Wh, and during the period of rational consumption, it was even lowered to only 60 to 80 Wh per day.

This low consumption was mainly due to the low consumption of television in this household. A positive factor was also the very low energy demand of the TV set used (14W instead of 21W for the set used by household KEF-42).

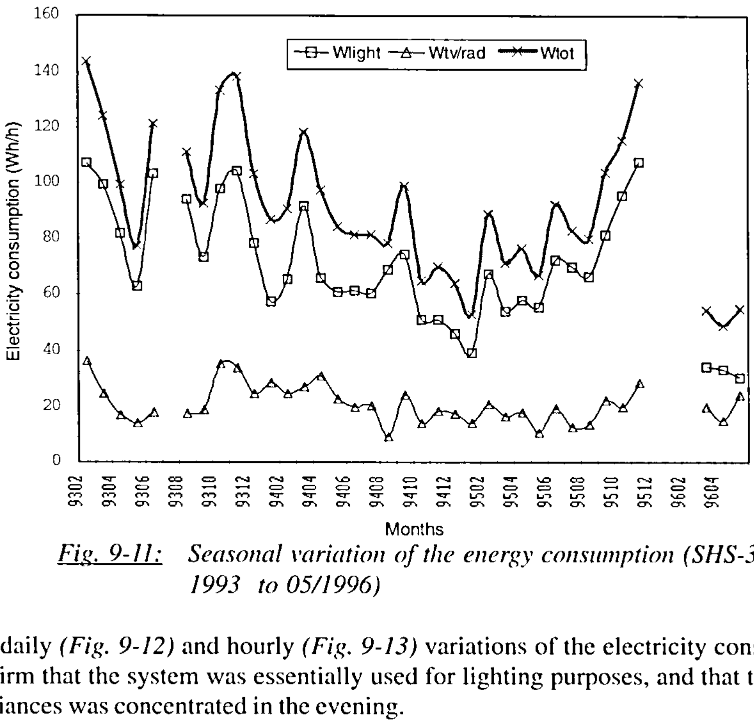


Fig. 9-11: Seasonal variation of the energy consumption (SHS-32, 02/ 1993 to 05/1996)

The daily *(Fig. 9-12)* and hourly *(Fig. 9-13)* variations of the electricity consumption confirm that the system was essentially used for lighting purposes, and that the use of appliances was concentrated in the evening.

It is of particular interest to compare these two SHS with system KEF-53, in order to see the effect of a battery, better adapted to use with a PV system, on the performance. This system was equipped with a battery with thick flat plates (manufacturer: TUDOR Tunisia). Its nominal capacity was 90 Ah, but tests showed that the real capacity was higher (100 to 110 Ah).

Therefore, it is striking to notice that, according to the histogram, only two, but relatively long, interruptions of the electricity supply were noted; both in winter *(Fig. 9-14)*.

A change of battery was not necessary in this SHS during the whole monitoring period.

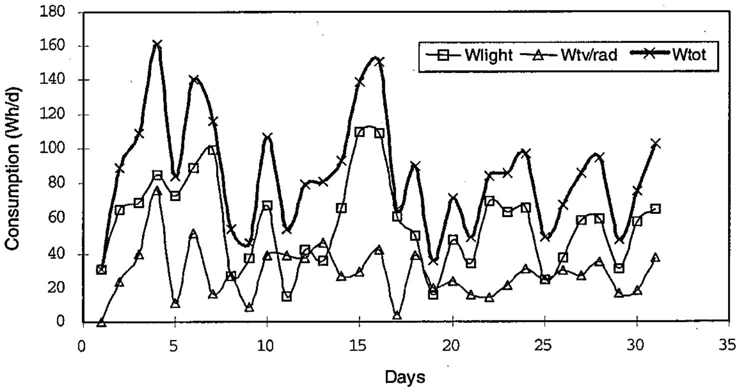


Fig. 9-12a): Daily variation of the electricity consumption (SHS KEF-32, January 1994)

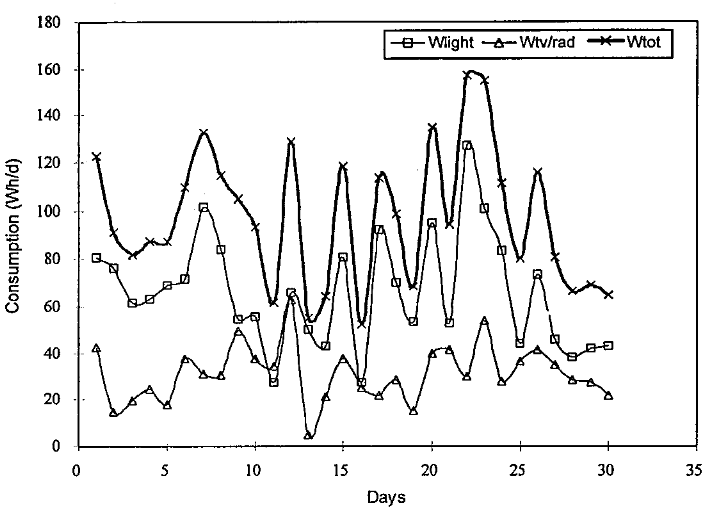


Fig. 9-12b): Daily variation of the electricity consumption (SHS KEF-32, April 1994)

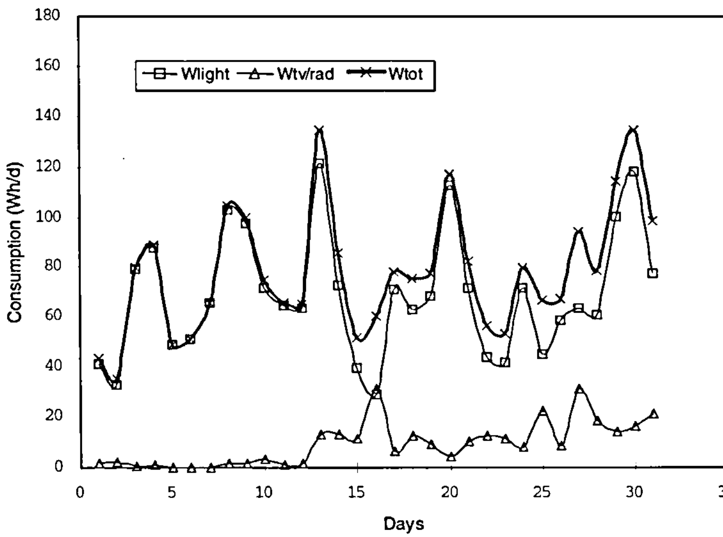


Fig. 9-12c): Daily variation of the electricity consumption (SHS KEF-32, August 1994)

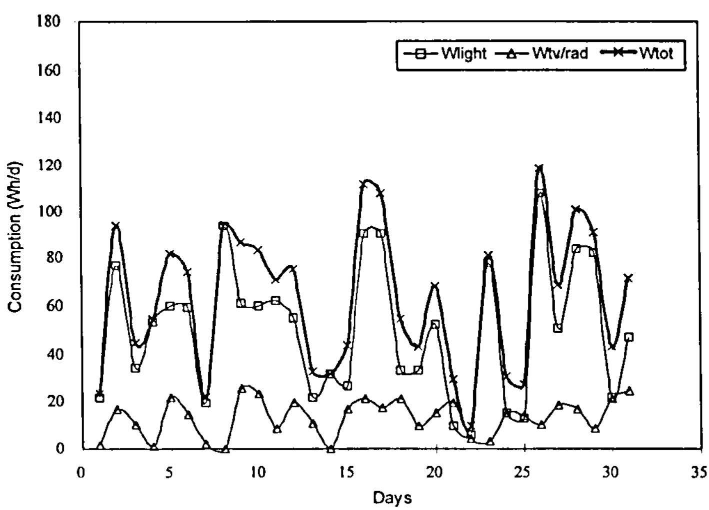


Fig. 9-12d): Daily variation of the electricity consumption (SHS KEF-32, October 1994)

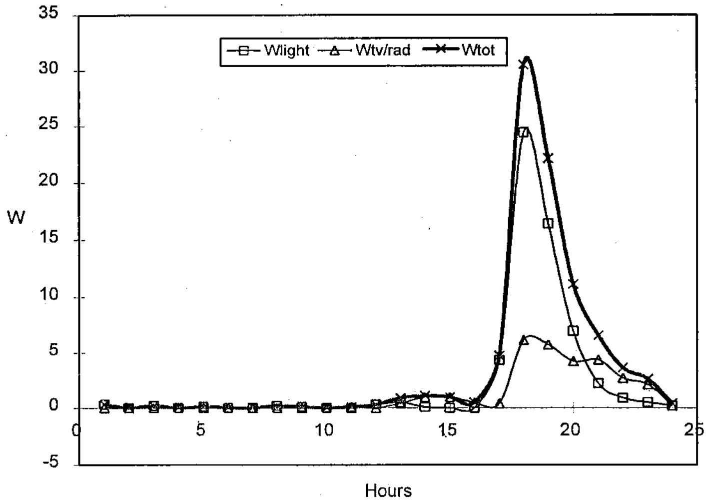


Fig. 9-13a): Hourly variation of the electricity consumption (SHS KEF-32, January 1994)

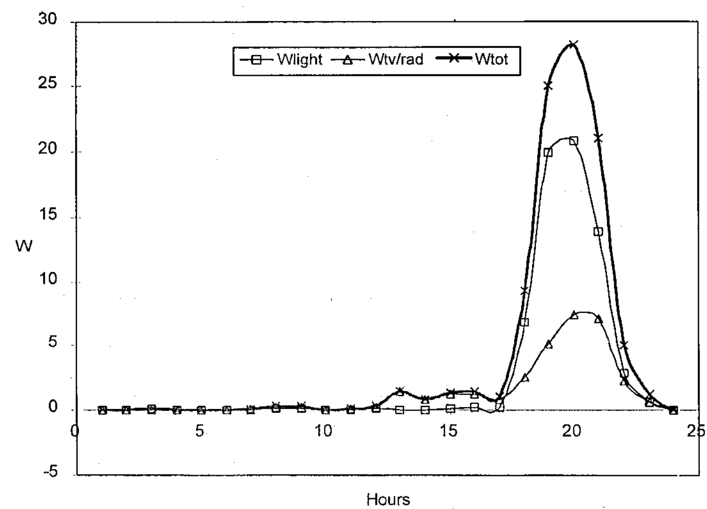


Fig. 9-13b): Hourly variation of the electricity consumption (SHS KEF-32, April 1994)

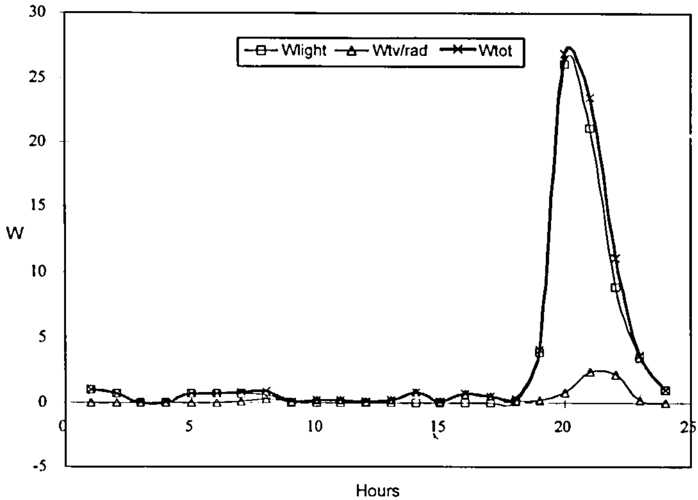


Fig. 9-13c): *Hourly variation of the electricity consumption (SHS KEF-32, August 1994)*

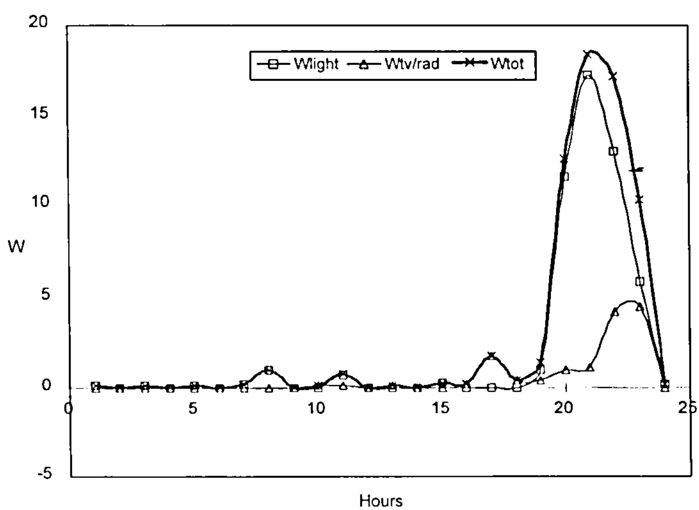


Fig. 9-13d): *Hourly variation of the electricity consumption (SHS KEF-32, October 1994)*

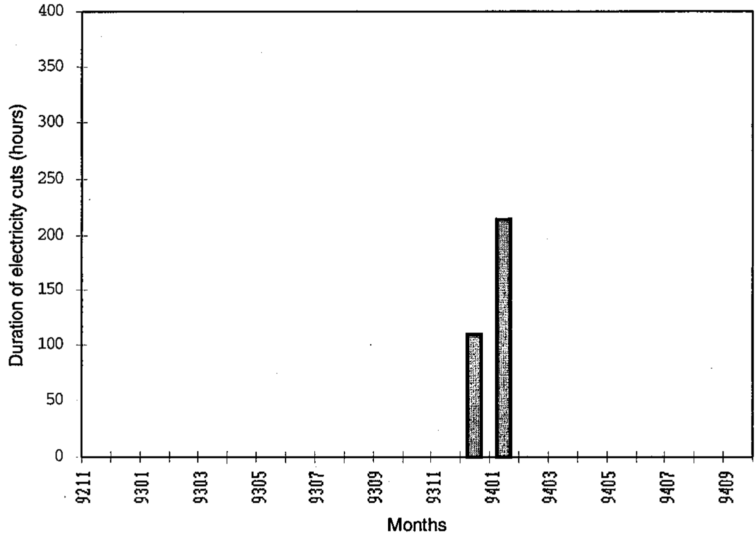


Fig. 9-14: Histogram of electricity cuts (SHS KEF-53, Nov. 1992 to Sept. 1994)

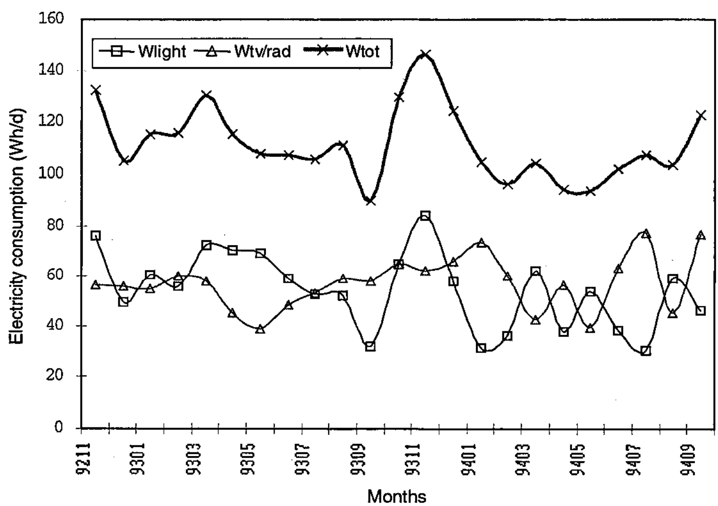


Fig 9-15: Seasonal variation of energy consumption (KEF-53, nov/1992 to sept/ 1994)

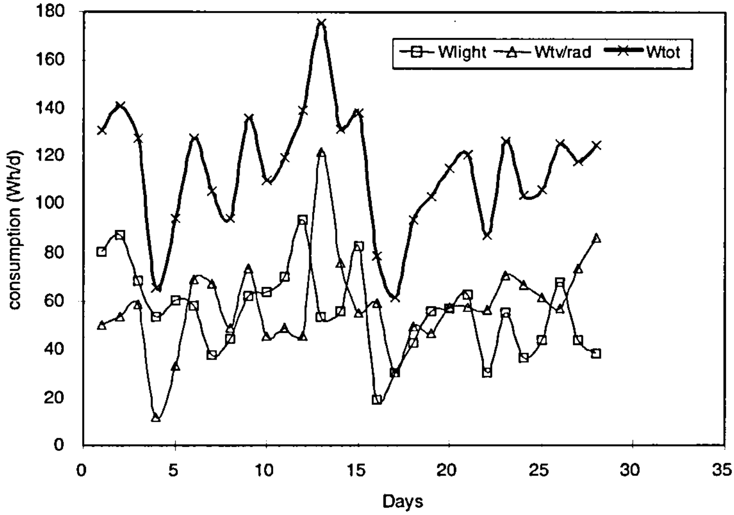


Fig. 9-16a): Daily variation of electricity consumption (SHS KEF-53, February 1993)

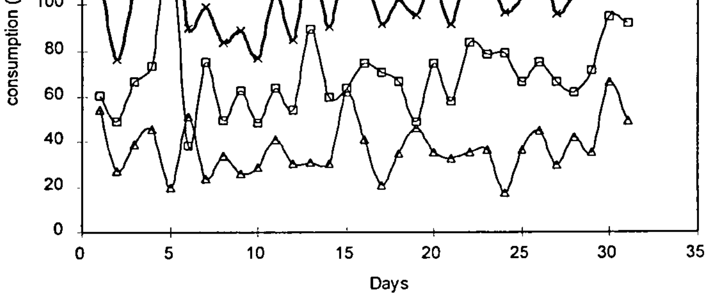


Fig. 9-16b): Daily variation of electricity consumption (SHS KEF-53, May 1993)

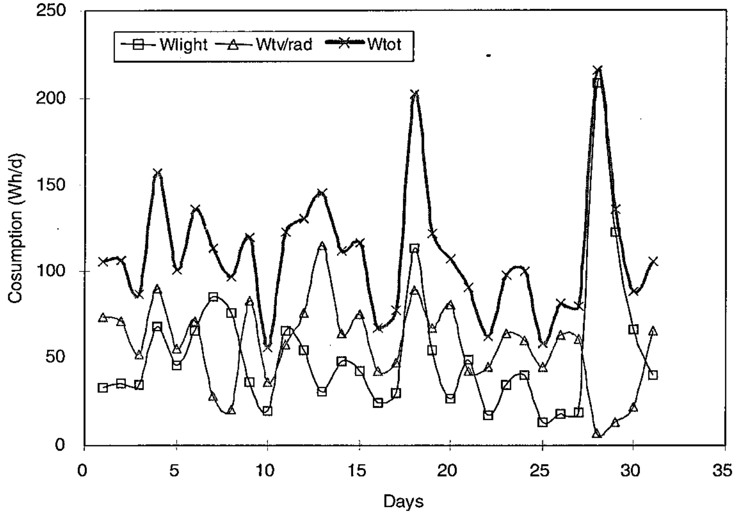


Fig. 9-16c): Daily variation of electricity consumption (SHS KEF-53, August 1993)

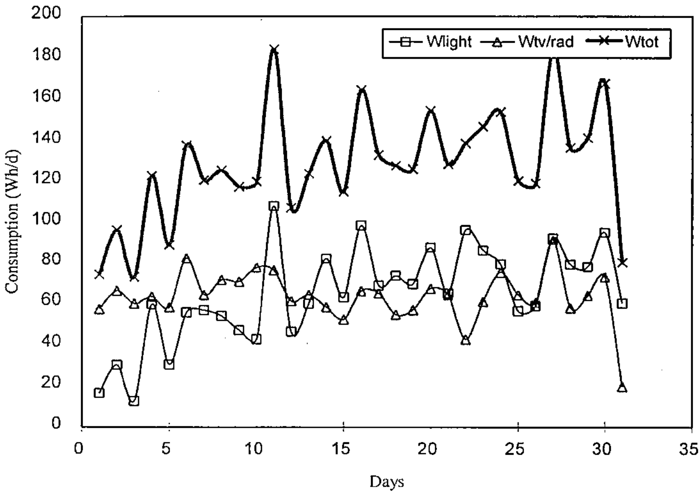


Fig. 9-16d): Daily variation of electricity consumption (SHS KEF-53, October 1993)

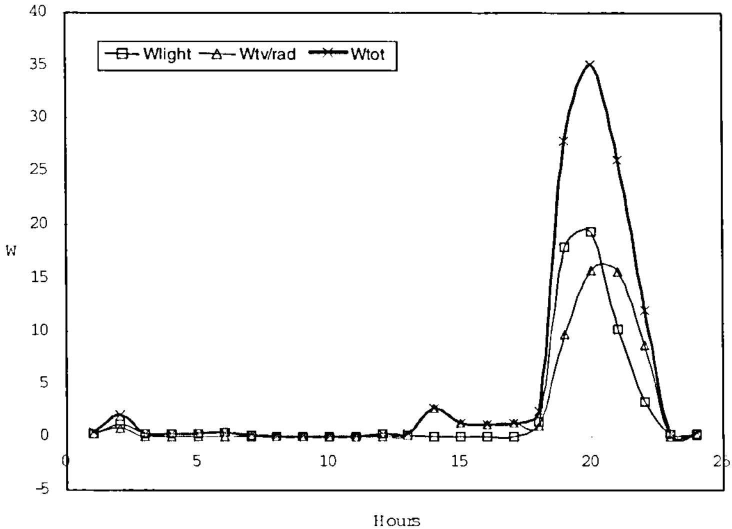


Fig. 9-17a): Hourly variation of electricity consumption (SHS KEF-53, February 1993)

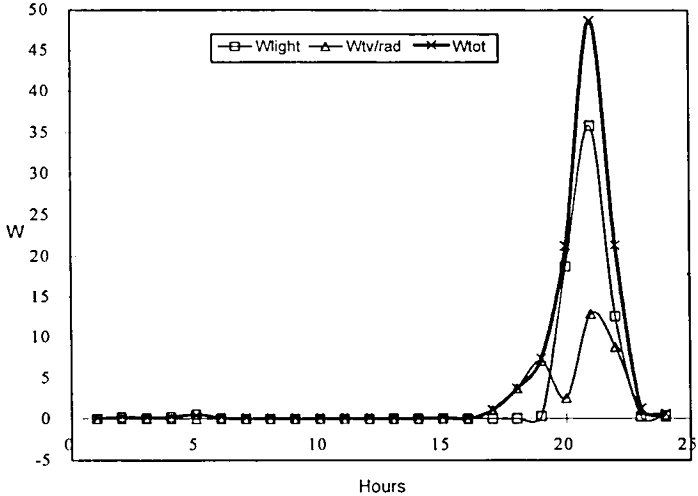


Fig. 9-17b): Hourly variation of electricity consumption (SHS KEF-53, May 1993)

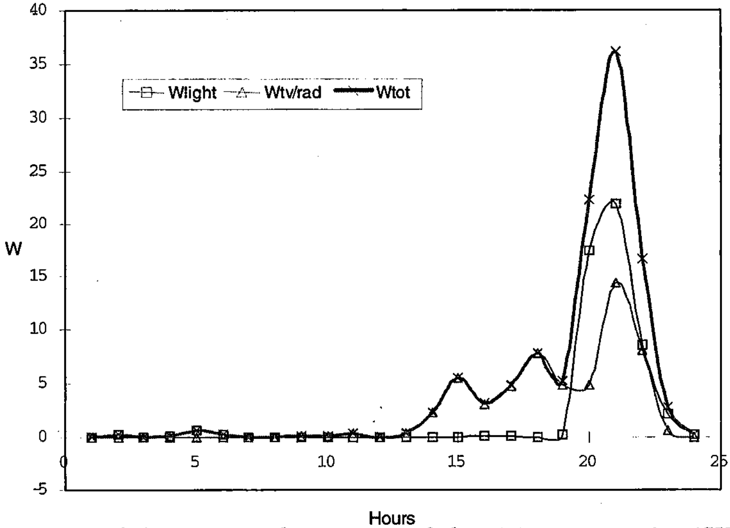


Fig. 9-17c): *Hourly variation of electricity consumption (SHS KEF-53, August 1993)*

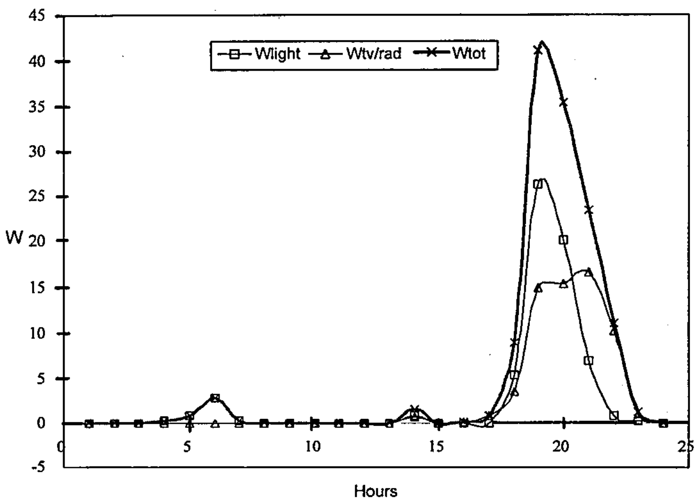


Fig. 9-17d): *Hourly variation of electricity consumption (SHS KEF-53, October 1993)*

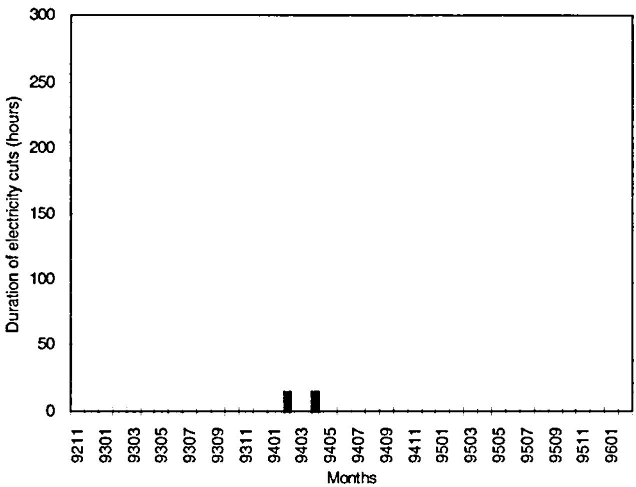
The variation of the daily energy consumption shows a peak during the winter season of 1993, which caused the two interruptions. Afterwards, the users adapted their consumption to the solar offer and thus avoided further cuts *(Fig. 9-15).*

In this household, energy consumption was fairly equally divided between television and lighting. Regarding variations over the month, it can be seen that the months with the highest energy consumption for television were those with the lowest consumption for lighting and vice versa. This indicates that lamps were switched off when the TV was on.

The curves of daily average consumption over four months representing one season *(Fig. 9-16)* and the average hourly consumption *(Fig. 9-17)* show that energy was consumed almost entirely during three to four hours in the evening.

The system <u>*KEF-07*</u> was equipped with two PV modules (total power 106 Wp) and two solar batteries with thick flat plates. A higher electricity consumption compared to the three previous SHS was to be expected, as five (instead of three) lamps were installed.

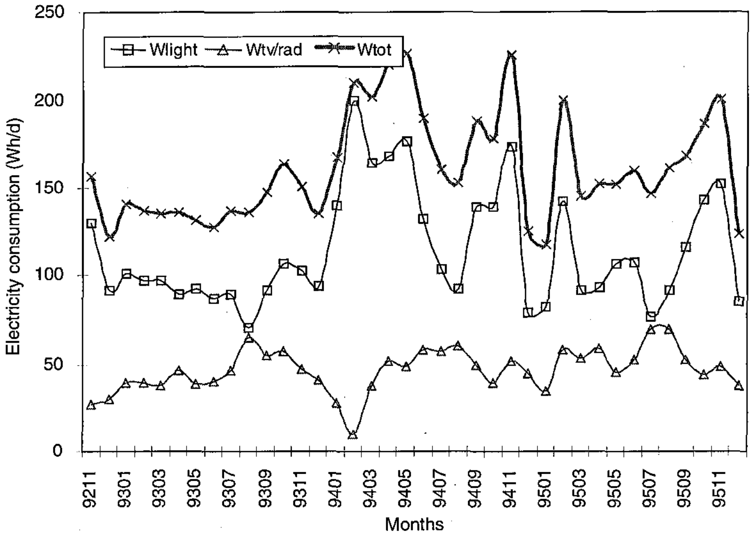
Over the whole monitoring period, the histogram *(Fig. 9-18)* showed just two electricity cuts, in summer and spring 1994. As they were very short (in each case only half a day), they were negligible. A change of battery was not necessary. This positive result is evidently due to the relatively low electricity consumption per lamp (i.e. per room) and the superior quality of the solar batteries (as could already be seen in the preceding case (KEF 53).



<u>*Fig. 9-18:*</u> *Histogram of electricity cuts (SHS KEF-07, Nov. 1992 - Dec. 1995)*

The seasonal variation of the consumption suggests that the user household first limited its consumption to the strict minimum (about 130 Wh per day, which is quite low for the five lamps, the radio and TV set installed). Then consumption was gradually increased up to the moment when the power cut occurred. Afterwards, consumption was adapted to the energy available according to the climatic conditions *(Fig. 9-19).*

The number of hours per day spent watching television kept more or less constant throughout the year, whereas the hours of lighting varied, showing a maximum in spring and winter *(Fig. 9-20).*



<u>Fig. 9-19:</u> *Seasonal variation of electricity consumption (SHS KEF-07, Nov. 1992 to Dec. 1995)*

Compared to the other SHS, the analysis of hourly variations *(Fig. 9-21)* shows a certain amount of electricity consumption for lighting purposes even during the daytime. The reason is probably a lamp installed in the kitchen, a room which is generally dark in rural houses.

In summer, the TV set operated the whole day: a typical phenomenon for rural families with schoolchildren, who like watching television the whole day in the summer holidays. *Tab. 9-4* shows the average consumption values for the four SHS analysed in relation to the seasons:

Number of system	Spring	Summer	Autumn	Winter
	Wh/d	*Wh/d*	*Wh/d*	*Wh/d*
KEF-42	55	76	73	36
KEF-32	65	70	50	60
KEF-53	70	53	65	56
KEF-07	160	100	130	140

Tab. 9-4 a): Average electricity consumption of the four SHS monitored: application: lighting

Number of system	Spring	Summer	Autumn	Winter
	Wh/d	*Wh/d*	*Wh/d*	*Wh/d*
KEF-42	112	124	122	112
KEF-32	31	9	14	30
KEF-53	39	60	65	60
KEF-07	50	60	40	45

Tab. 9-4 b): Average electricity consumption of the four SHS monitored: application: radio/ TV

Number of system	Spring	Summer	Autumn	Winter	Annual average
	Wh/d	*Wh/d*	*Wh/d*	*Wh/d*	*Wh/d*
KEF-42	167	200	195	148	**178**
KEF-32	96	79	64	90	**82**
KEF-53	109	113	174	116	**128**
KEF-07	210	160	170	185	**181**

Tab. 9-4 c): Average electricity consumption of the four SHS monitored: total consumption

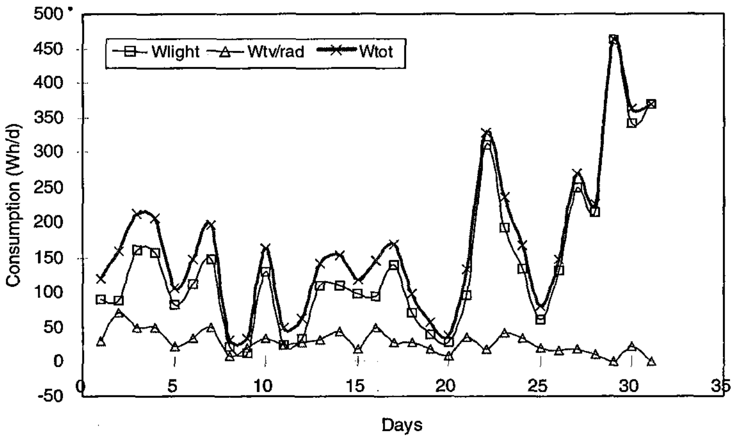


Fig. 9-20a): Daily variation of electricity consumption (SHS KEF-07, January 1994)

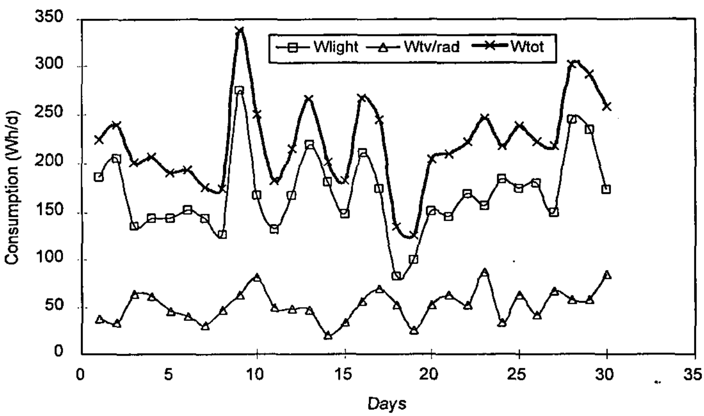


Fig. 9-20b): Daily variation of electricity consumption (SHS KEF-07, April 1994)

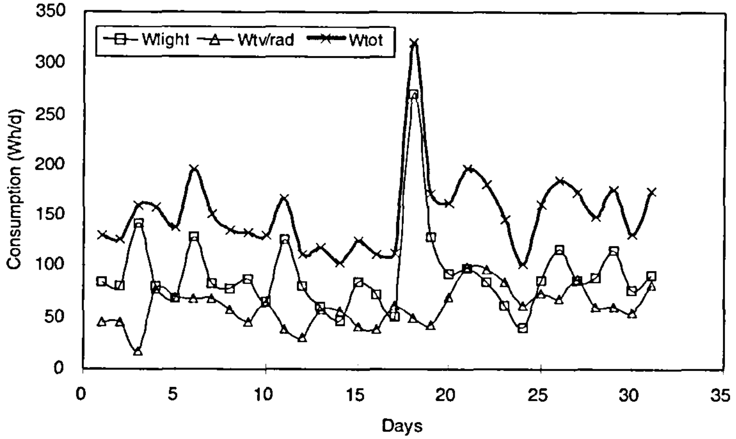


Fig. 9-20c): Daily variation of electricity consumption (SHS KEF-07, August 1994)

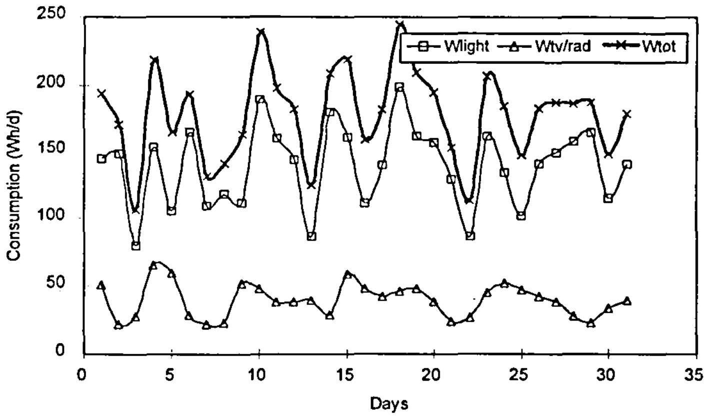


Fig. 9-20d): Daily variation of electricity consumption (SHS KEF-07, October 1994)

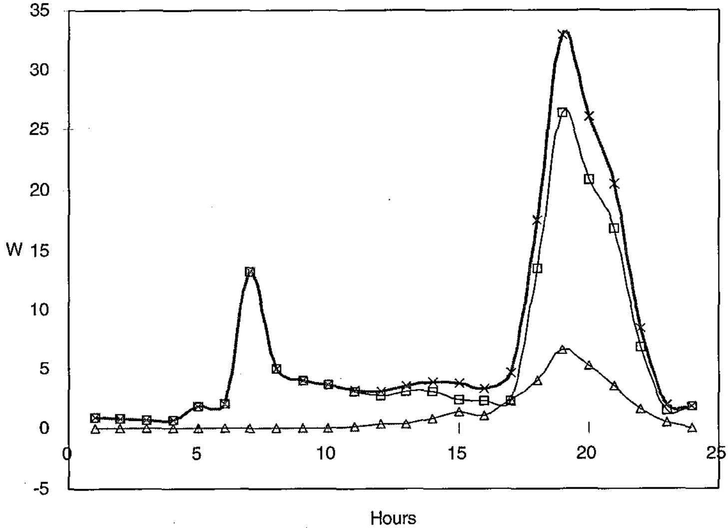


Fig. 9-21a): Hourly variation of electricity consumption (SHS KEF-07, January 1994)

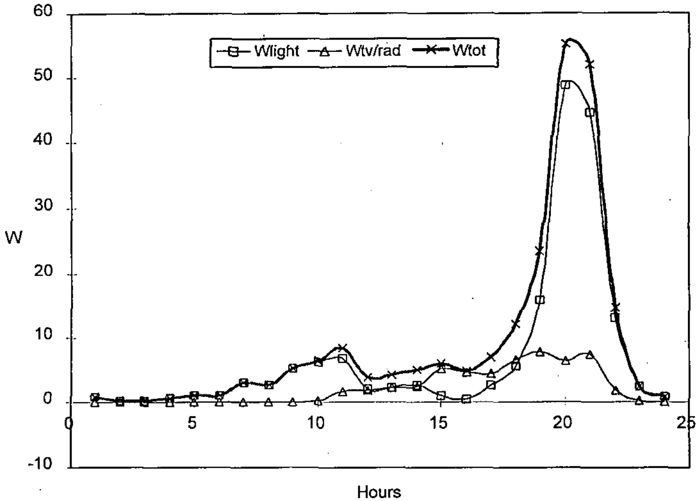


Fig. 9-21b): Hourly variation of electricity consumption (SHS KEF-07, April 1994)

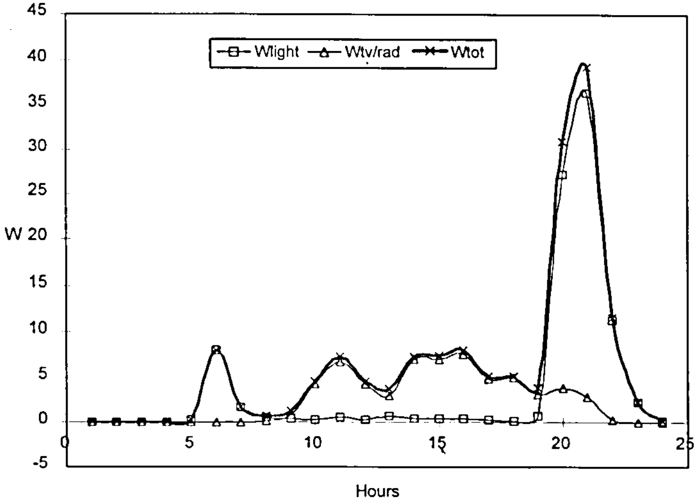


Fig. 9-21c): Hourly variation of electricity consumption (SHS KEF-07, August 1994)

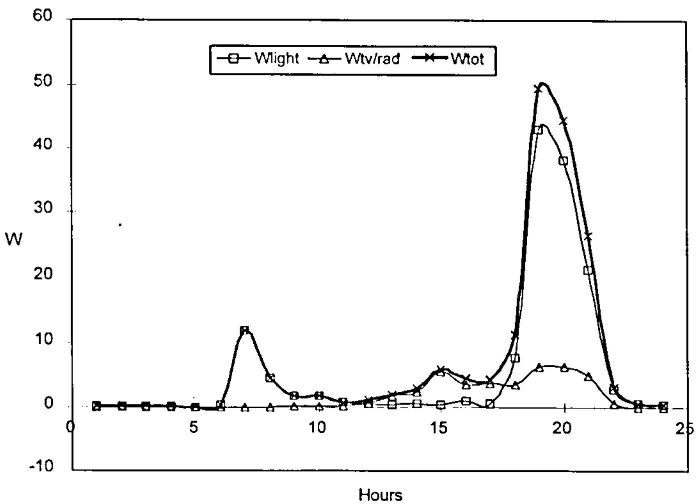


Fig. 9-21d): Hourly variation of electricity consumption (SHS KEF-07, October 1994)

9.1.5. Energy efficiency and the efficiency in ampere-hours

The energy efficiency characterises the ratio of solar energy transformed into electrical energy, which arrived at the "consumers" (radio, TV, lamp).
It is expressed by the following formula:

ηw (%) = (energy received/energy delivered) · 100

with energy received = I · U· (Dt/60) · N
energy delivered = Ø· (Dt/60) · S· N

and

I: total electricity of the electricity consuming appliances (A)
U: voltage of the system (V)
Dt: registration steps of the data (at the data acquisition system) (here: 30 minutes)
N: number of measurementss per day [= (60/ Dt) · 24]
S: surface of the module (m^2)
Ø: global solar radiation on the module surface (W/m^2).

The efficiency in ampere-hours is thus calculated as the product of the particular efficiencies of the charge regulator and the battery. The characteristics of the battery during charge and discharge are different, which makes it difficult to estimate its efficiency correctly. It was therefore calculated according to the following formula:

ηAH (%) = (ampere-hours received / ampere-hours delivered) • 100

with ampere-hours received = I· Dt/60· N
ampere-hours delivered = Ipv· Dt/60· N

and

Ipv: electricity generated by the PV module

The two values calculated for the efficiency vary with the ageing of the battery. There is an optimum when the battery is new, and with operating time there is a decrease of efficiency.

For the system KEF-42, these efficiencies have also been calculated for the different components. The results are presented in the following table.

Component	Energy efficiency (%)	Efficiency in ampere-hours (%)
PV module	12.9%	-.-
Battery	75.4%	75.4%
Regulator (when battery is charged)	94.6%	98.8%
Regulator (when battery is discharged)	97.1%	98.8%
Cabling module-regulator	97.4%	100%
Cabling regulator-battery	98.9%	100%
Cabling regulator -"consdumers"	97.9%	100%

Tab. 9-5: Efficiency of the components (in %)

The efficiency of the complete SHS is thus the product of the efficiency of the components. The formulae are therefore:
$\eta w\ (\%) = \eta$ module $\times\ \eta$ battery $\times\ \eta$ regulator $\times\ \eta$ cables
$\eta AH\ (\%) = \eta$ battery $\times\ \eta$ regulator

With the values of *Tab. 9-5,* the following results have been calculated:

$$\eta\ \mathbf{w} = \mathbf{8.79\ \%}$$
$$\eta\ \mathbf{AH} = \mathbf{74.5\ \%}.$$

9.1.6 Conclusions

An SHS, consisting of one PV module of 53 Wp and a battery of 90 Ah had been designed to cover an average daily electricity consumption of 150 Wp.
The electricity demand of the first household monitored (*KEF-42*) was much higher than the estimated demand for basic needs. The relatively high energy consumption, plus a non-appropriate battery, caused frequent interruptions of electricity supply and an insufficient lifetime of the battery.

The second household (*KEF-32*) used the SHS in a rather restrictive way. In spite of the low consumption (on average less than half of the preceding household) the results were also insufficient. This was due to the choice of battery, which delivered a poor performance when used in an SHS.

In the third household (*KEF-53*), a favourable adaptation of energy consumption to the potential of the available energy was noted. In addition, the good quality solar battery reduced the risks of power cuts to an acceptable level and provided a favourable period of operation. If a tubular battery had been used, the results would certainly have been even better.

The potential of the fourth SHS (*KEF-07*), had evidently been under-exploited by the household. The low number of hours of utilisation would have allowed even more energy-consuming appliances to be connected (e.g. colour TV instead of black and white set) - at least during the summer - without having to fear power cuts. However, the low discharge rate of the battery is a positive factor for extending the lifetime of the battery.

The adaptation of the households to the available energy potential may be illustrated by the following fact: because of the necessity for lighting, the energy demand of the households has a maximum in winter. However, solar radiation and hours of sunshine have a minimum during this season. So, in all of the four households, no peak consumption was noted in winter - neither for lighting, nor for television.

This may be quantified by the "satisfaction ratio" (Ts).
For a defined period it indicates the ratio up to which the SHS had been capable of providing the necessary energy for consumption.

However, the term "satisfaction ratio" may be a misleading. Here it does not in fact indicate whether the household was really satisfied by the quantity of energy delivered, but only whether it had or had not adapted its consumption to the available energy.

A ratio of 100% therefore indicated that the system had been operating without interruptions. But it might easily happen that, in spite of this, the family considers the services of the SHS insufficient, should there be no light in the kitchen or in the courtyard, for example.

The calculation provided the following results:

Number of system	Satisfaction ratio Ts (%)	Monitored period
KEF-42	92.8%	24 months
KEF-32	92.8%	36 months
KEF-53	99.8%	32 months
KEF-07	99%	36 months

Tab. 9-6: Satisfaction ratio of the four SHS monitored

The graphs (*Fig. 9-22*) show the periods during which there was insufficient cover for the demand. These periods correspond to the times when the electricity supply had been interrupted.

The satisfaction ratio of the two systems *KEF-42* and *KEF-32* is too low, that of the two other SHS is very favourable. From these results the importance of the type of battery is demonstrated very clearly. The SHS KEF-53 and KEF-32 were equipped with identical PV modules, only the battery of SHS KEF-53 was more appropriate. Although the average electricity consumption of system KEF-53 was 56% higher than that of KEF-32, the first one provided far more favourable results.

The use of tubular batteries is likely to have increased the satisfaction ratio up to a very high level and for a considerably longer period than in the case of all the other types of batteries installed.

TV batteries and car batteries are no longer used in the framework of the national programme and it is essential to advise the users to buy appropriate batteries in the case of battery replacement, even if the appropriate batteries are more costly.
An important task for the managers of the national programme is therefore to ensure that batteries of good quality are available locally.

Thus the analyses, undertaken using data acquisition systems, provide convenient indications to help understand the mutual relations between the behaviour of the users and the performance of the SHS components. However, considering the low number of SHS monitored, they cannot be regarded as conclusive.

Together with the results of the "survey", they proved that the initial idea of providing "standard SHS" with only 50 Wp of PV generator power was insufficient. Therefore, the power of the PV generator and, consequently, the capacity of battery was raised. Only batteries of an appropriate type were provided in the national programme.

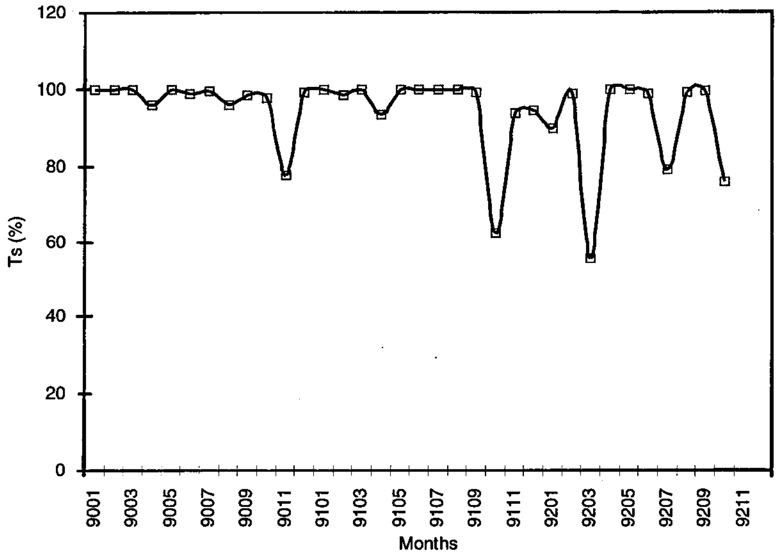


Fig. 9-22a): Monthly satisfaction ratio of SHS KEF-42

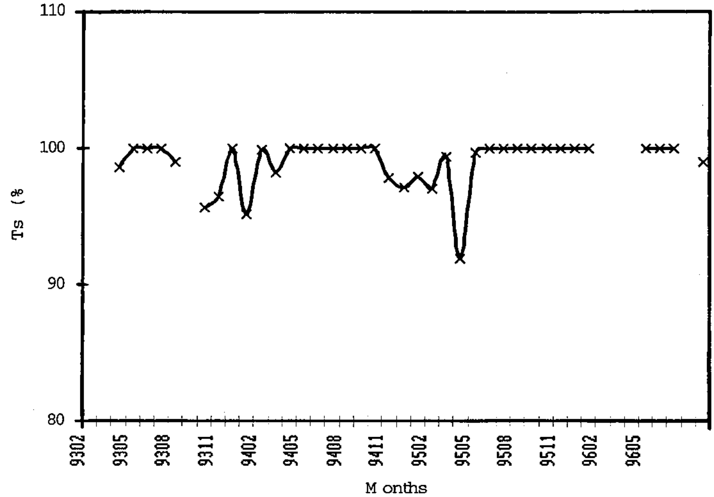


Fig. 9-22b): Monthly satisfaction ratio of SHS KEF-32

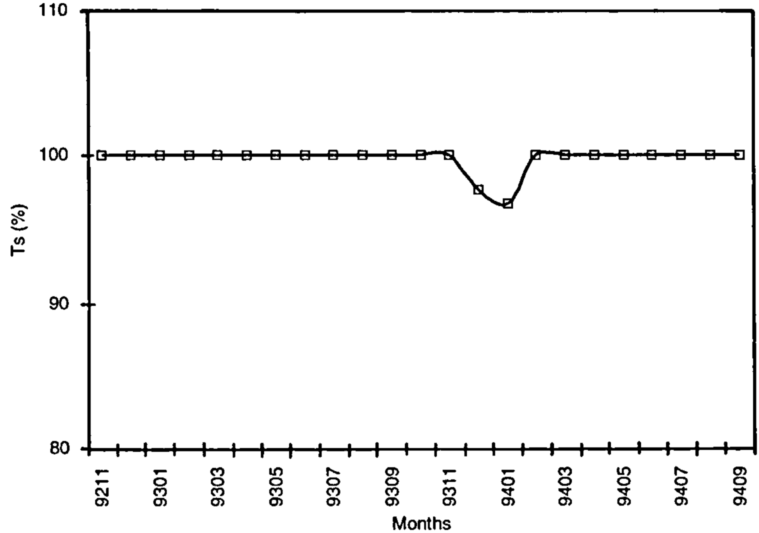


Fig. 9-22c): Monthly satisfaction ratio of SHS KEF-53

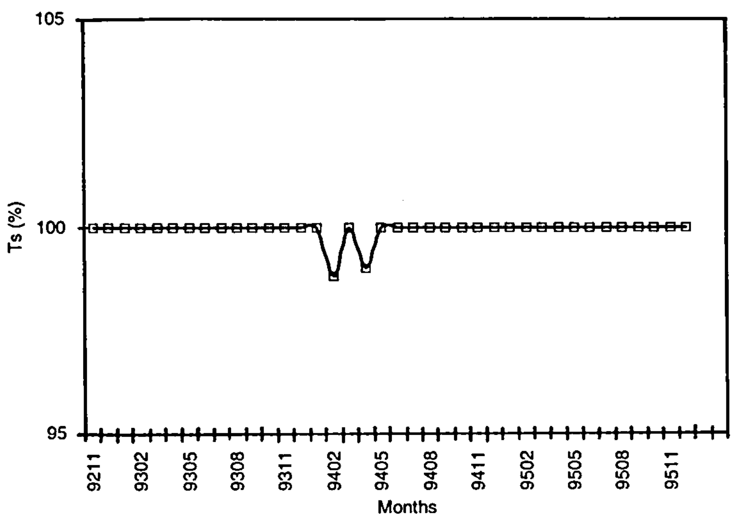


Fig. 9-22d): Monthly satisfaction ratio of SHS KEF-07

9. 2. The user households of the „pilot dissemination phase" (1989) and the „intermediate phase" (1992)

9.2.1. The social and economic position of the households

In the pilot dissemination phase, AME installed 110 SHS in 1989, 90 of these in rural households. 9 SHS were installed in each of the 10 Sectors *(Imadas)* of the Gouvernorat of El Kef, characterised by the lowest rate of electrification via the electrical grid in the long term *(Fig. 9-23).*

There were various reasons for this low rate (not much more than zero), therefore, it is worthwhile looking at them in detail, as they are linked to the general position of the population living in these zones.

The two Sectors *Dyr El Kef* and *Oued Ermal Nord* are in the neighbourhood of the town of El Kef. The geomorphology is the reason for the low electrification rate. The soil is fertile, in spite of being rocky in some places, thus assuring a relatively constant revenue for farmers. Due to the vicinity of the capital of the Gouvernorat, some habitants of these Sectors work in the town, at least on a temporary basis.

The majority of the land belongs to large-scale farmers living in the town of El Kef or even in Tunis. They employ helpers and day-labourers, who often rent small local dwellings. The low wages of these agricultural labourers, who are mostly even paid in harvested goods instead of money, frequently mean that they have to leave after some months or years in order to look for a new job elsewhere.

Because of the altitude (Dyr El Kef means: "the mountain chain of El Kef"), long periods of cloud and fog are quite frequent in these two Sectors. So, the number of sunshine hours is considerably reduced.

The two Sectors *Ain Mezer* and *Farchene* are in the north of the Gouvernorat, adjoining the frontier to Algeria and the Gouvernorat of Jendouba. It's a hilly and mountainous region, covered by forests of Aleppo pines. The loamy soil makes access to the houses impossible during the rainy season even for 4-wheel-drive cars. The population lives either in isolated farm houses or in hamlets (*douars*) in forest clearings. Owing to the isolation and the difficult living conditions, this region is one of the poorest zones of the Republic (together with the area in the south of the Gouvernorat).

In the Sectors *Mzita* and *Sed El Khir*, in the south of the Gouvernorat, the microclimate and vegetation differ widely from those in the north. The climate here is semiarid and the region is almost desert-like. The absence of rainfall even over several consecutive years, which is not unusual, or periods of hail in summer cause great financial difficulties for the rural population, which mostly consists of small farmers and agricultural day-labourers. In addition, the region is mountainous and rocky. The highest mountain, "Jugurtha's Table" borders on the two Sectors. A considerable number of houses can only be reached on foot or by donkey.

Traditionally the region is characterised by a high emigration level and is well-known for its poverty. In spite of being an important part of all regional development and social assistance programmes, it has not been possible to change the fundamental reasons for its development problems. In fact, taking into account the very limited possibilities for agricultural development and the pressure exerted by the population on the natural environment (mainly by grazing sheep and goats and collecting firewood), the region could be considered to be overpopulated.

The other four Sectors (*Banou, Ksour, Hamaima* and *Bouslîâa*) are situated in the centre of the Gouvernorat, in the region of the plains, used for grain cultivation. The farmers live on their own land in farms which are great distances apart. The population is rather wealthy. The distance between the farms makes it extremely costly to connect the houses to the electricity grid.

These 90 systems were the first SHS installed in Tunisia. 65 of the 90 households were equipped with an SHS with only one PV module of 53 Wp, the other larger households were fitted with an array of two modules (in total 106 Wp, see *Fig. 9-24*).

During the first three years of operation of the SHS, the households paid a constant monthly rent for the SHS (2 $ for the systems with one module, and 4 $ for the SHS equipped with two modules), corresponding to the expenditure of a modest, non-grid-connected household on kerosene for lighting. Afterwards, the ownership of the system was transferred to the users, who thus became totally responsible for the equipment. A rent was no longer demanded, but the households were obliged to take care of the maintenance of the systems, the acquisition of spare parts etc. The regular visits from technicians providing advice and assistance were stopped.

In June 1996, 44 households were interviewed (32 of them possessing an SHS with one module, 12 owning a PV system with two modules). Regarding the other 46 SHS, information was collected, but for reasons of time and financial limitations it was not possible to make detailed enquiries at the homes of the users.

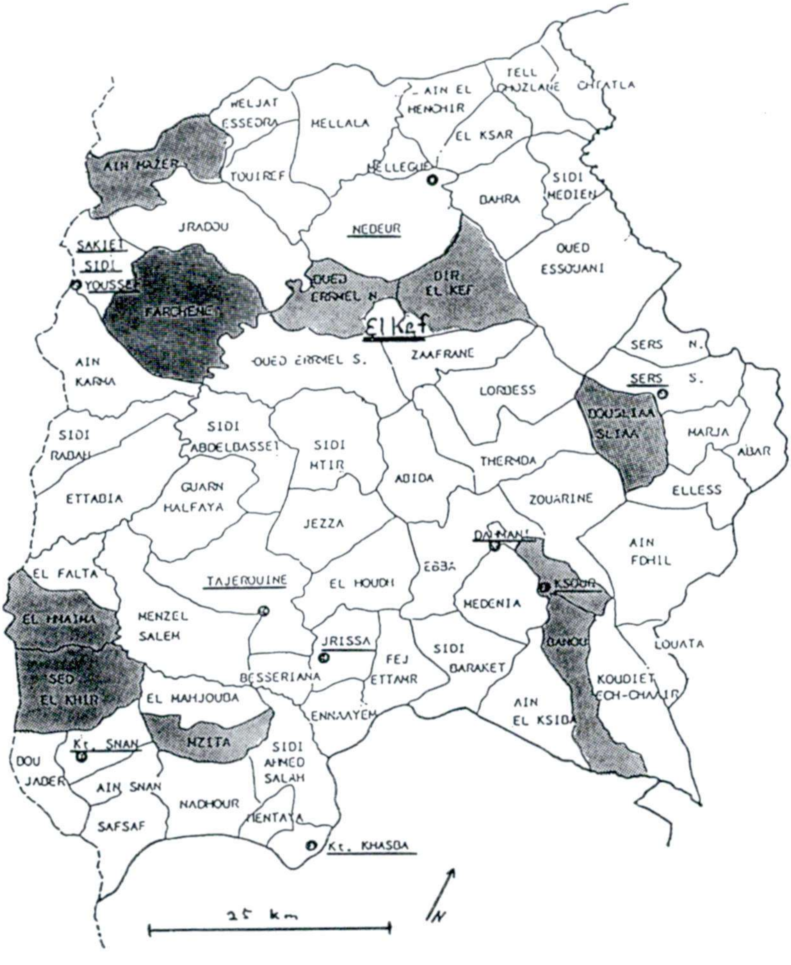


Fig. 9-23): The Sectors of the Gouvernorat of El Kef, selected for the pilot dissemination phase and the intermediate phase

In 1992, another thirty SHS were installed. This was an *intermediate phase* between the pilot dissemination phase and the start of the national programme. The objective was didactic. Firstly, it was used to execute courses of vocational training for technicians and electricians of El Kef and Tunis in order to have a number of qualified installers and repairers of SHS. It was considered essential that these training courses should include a practical component, carried out in the field.

As the theoretical part of these training courses was executed in the town of El Kef, households in the Sectors *Dyr El Kef* and *Nathour* were offered the chance of receiving an SHS (the Sector of Nathour is near Dyr and has similar characteristics). Both Sectors had already been selected for the first stage of the national programme of rural solar electrification. A limited number of interested households could acquire an SHS, simply after payment of 206 $ (200 DT), whereas half this sum was afterwards demanded within the national programme.

The principle objective of the pilot phase was to test acceptability and technical viability of SHS at all social strata in the Gouvernorat. So, a random selection of the whole of the population in dispersed areas of the priority Sectors was chosen. First the names of the households were identified, and then the households were visited and asked whether they wanted to participate in the test, under the favourable conditions offered.

On the other hand, in the intermediate phase, there was a general offer open to all households of the two Sectors. The initiative of acquiring an SHS at that moment was left to the households, who knew that later the conditions of receiving a SHS would be more favourable. 20 of the thirty households of the intermediate phase were interviewed (one household had meanwhile moved).

A comparison was made between the profession of the head of the 44 households of the pilot dissemination phase and the 29 households of the intermediate phase, compared to the respective average values of the Gouvernorat (according to the survey of 1989).

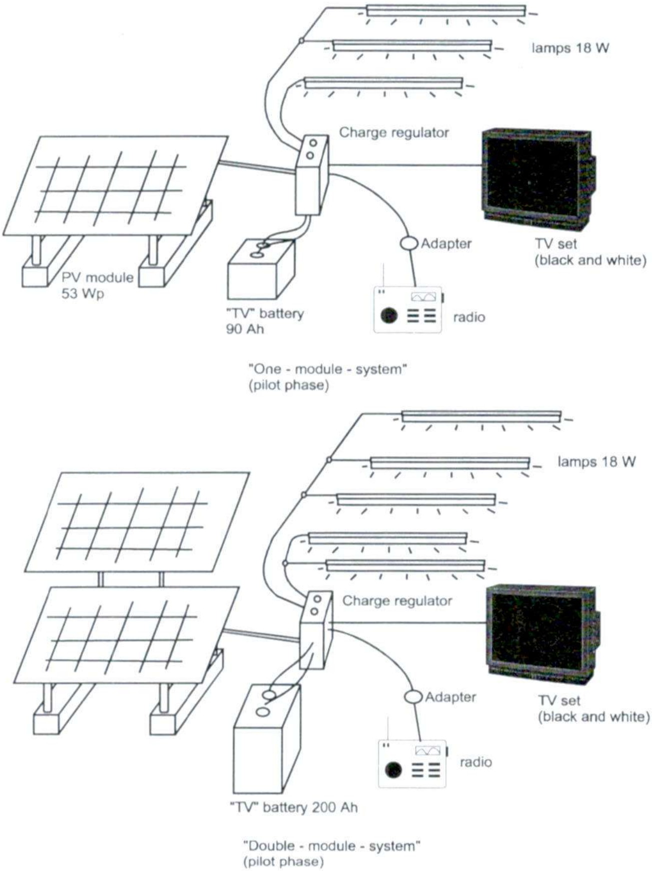


Fig. 9-24: *Configuration of SHS installed in the framework of the pilot dissemination phase (1989)*

Occupation of head of household	Inquiry pilot dissemination phase (1996)		Inquiry intermediate phase (1996)		Survey of the concept (1989)	
	number	%	number	%	number	%
Farmer	18	41%	19	66%	153	59%
Day-labourer	23	52%	7	24%	180	42%
Other occupation (pensioner, civil servant)	3	7%	3	10%	157	37%
Total	***44***	***100%***	***29***	***100%***	***422***	***138%***

Tab. 9-7: Occupations of the heads of households interviewed in El Kef

The total of results from the survey for the "concept" exceeds 100%, as here it was possible to indicate more than one activity (example: "farmer" plus "day labourer").

As day-labourers are the lowest social stratum in rural areas, the majority of the households of the pilot dissemination phase interviewed were below average for the rural population, whereas the majority of households of the intermediate phase were above this level.

There is a certain logic in this. As mentioned earlier, a low electrification rate generally corresponds to zones of low income of the rural population and a random sample of the households was chosen. On the other hand, in the intermediate phase the initiative for acquiring an SHS was left to the household itself. This generally attracted the spirit of "PV pioneers", and so could be assumed to be a selection of dynamic and relatively well-off households.
The results concerning the financial situation of the households were the following:

Social stratum of the household	Inquiry pilot dissemination phase (1996)		Inquiry intermediate phase (1996)		Survey of the concept (1989)	
	number	%	number	%	number	%
Well-off	4	9%	7	24%	49	14%
Average	37	84%	22	76%	212	61%
Poor	3	7%	0	0%	89	25%
Total:	***44***	***100%***	***29***	***100%***	***350***	***100%***

Tab. 9-8: Social stratum of the households interviewed

The results of the enquiries of 1996 cannot be directly compared to those from 1989, when the households were asked to indicate the annual income of the households. So, a household receiving an annual revenue of 520 $ was categorised as "poor", and a household with an income of more than 2.100 $ was considered to be "well-off".

Concerning the inquiries of 1996, only indicators were taken into account for the social classification of the households. A household was considered *poor* when it occupied a one-room dwelling, had only a few acres of land and just three to four sheep or goats. A typical *well-off*-household owned a house with three rooms, a minimum of 10 hectares of land, a flock of 20 sheep or goats etc. Obviously this characterisation cannot reflect the similar standards in an urban environment. An *average* rural family would be considered poor according to urban standards and even very poor compared to conditions in industrialised countries.

The table confirms the difference between the sample of households of the pilot phase and that of the intermediate phase. However, in spite of this, both samples are not very far from the average of the rural population in the Gouvernorat, which is an important factor regarding the generalisation of the results of the inquiries.

9.2.2. SHS and living conditions in rural areas

The stagnation of electricity consumption LT per client had been taken as an indication for a lack of economic growth of households in north-west Tunisia. The results of the enquiries at the households of the pilot phase and those of the intermediate phase show significant differences between improvements of living conditions during recent years, as seen by the householders themselves.

Change of level of the living conditions of the households	Inquiry pilot dissemination phase		Inquiry intermediate phase	
	number	%	number	%
Improvement	14	32%	24	83%
Stagnation or deterioration	30	68%	5	17%
Total	***44***	***100%***	***29***	***100%***

<u>Tab. 9-9:</u> *Change of living conditions of the households since the installation of SHS*

The fact that the majority of households of the "intermediate phase" were farmers living in Sectors which were less affected by the drought, which the Gouvernorat suffered between 1993 and 1995, can only partially explain this result. Evidently these families are more dynamic and better motivated than average in the rural population.

This was confirmed by analysing the major expenditures of the households since the acquisition of SHS.

Major investments since the installation of the SHS	Inquiry pilot dissemination phase		Inquiry intermediate phase	
	number	%	number	%
Additional room	10	23%	1	3%
Room plus vehicle	1	2%	2	7%
2 vehicles	1	2%	0	0%
Room plus other investments (marriage, TV, radio)	3	7%	6	21%
Other investments (marriage, radio, TV)	9	20%	14	48%
No investments	20	46%	6	21%
Total	*44*	*100%*	*29*	*100%*

Tab. 9-10: Major investments by the interviewed households

The priority of the rural families is therefore a completed house, i.e. a house with a minimum of two rooms and a kitchen. Only after this has been achieved, will the family make investments in other equipment.

For poor families an additional room is no luxury, it is a necessity. These families generally have many children, and need at least one room for the girls and another for the boys. An additional room is sometimes needed for a son who brings his wife into his parents' home.

Generally the rooms are built by the families themselves with the help of neighbours. For some work, masons are employed as day-labourers. Governmental assistance programmes offer construction materials (tiles, cement, sand, etc.) by providing soft credits which are paid in kind. Other construction material is taken directly from the building site (stone, clay) or recovered from abandoned buildings. Even stones from roman times are frequently re-used. Financial expenditure of the households is therefore limited.

The households of the "intermediate phase", the majority of which were above the average income level and so already had complete houses, invested to a higher extent in consumer and utility goods.

According to the inquiries, lighting is the most important of the different services provided by SHS. The number of lamps was limited to two (for SHS with one module) or three (for SHS with two modules) in the pilot dissemination phase, in order to limit the services of publicly subsidised PV services to cover basic electricity needs. Each additional lamp, and perhaps also additional PV modules to increase the power of the system, should be bought commercially by the user households.

The number of lighting hours of the households depends on the season, the habits and social status of the household and the number of rooms in the dwelling. In general, the lamps are switched off when the family is watching television. This reduces the number of lighting hours in households with a television set. 23% of the lamps installed in 1989 in the 44 households interviewed in the pilot phase were still operating in 1996. The demand for lighting increased as a result of building additional rooms. But none of the users bought an additional lamp.

This explains the very high number of households dissatisfied by the lighting services offered by SHS. AME was in a dilemma here. It had transferred the responsibility for the PV systems to the users, but it could not recommend buying the lamps and ballast available on the commercial Tunisian market because of technical deficits.

With regard to lighting services, the satisfaction ratio is higher for households of the "intermediate phase". Here, the power of all systems was sufficient to use three lamps, due to the two modules per system. In addition, the lamps were three years younger, so that, at the time of the inquiry, there were fewer technical problems.

Satisfaction for lighting services	**Inquiry of households of the pilot dissemination phase (total: 44)**		**Inquiries of households of the intermediate phase (total: 29)**	
	number	*%*	*number*	*%*
Satisfied	7	16 %	15	52%

Tab. 9-11: Rate of households satisfied with the lighting services offered by SHS

The number of additional lamps demanded by the user households was as on average 1.7 for the households of the pilot phase, and 0.7 for the households of the intermediate phase. There is a high demand for a lamp installed outside the house, which was excluded for the households of the pilot phase. The reason for the demand is that on summer evenings the family stays outside in the courtyard (*haouch*; see *Fig. 8-2* and *Fig. 8-3*).

Lighting is important for schoolchildren for their homework. In the countryside, children go to local primary schools from the age of six. Such schools have been built even in very remote areas. For secondary education, the children have to stay five days a week in boarding hostels near the grammar schools in town.

Primary education takes place in the morning and in the afternoon. As the schools are often at a distance of five an even more kilometres from the children's homes, many children leave their homes very early in the morning and return late in the evening. In order to do their homework well, it is essential that lighting of good quality is available.

From interviews with families from the pilot phase, it was found that the majority of households, who still had children at the local schools, stressed the positive effects of SHS on the schoolwork:

Influence of SHS on the schoolchildren's homework	number	%
Positive effect	20	71%
No effect	5	19%
No answer	3	10%
Total	*28*	*100%*

Tab. 9-12: *Effect of SHS on the children's homework (households of the pilot dissemination phase)*

In spite of the generally difficult situation of the households, the number of families owning a *television set* is increasing year by year. This is mainly due to the availability of small black and white portable TV sets, at a price of about 100 $. Colour TVs, totally absent in rural areas in 1989, are now being introduced.

The main reason for the attractiveness of television in the countryside is the lack of other distractions. Leisure activities are limited to occasional celebrations (marriages and *zerdas*). Above all, television is almost the only form of leisure allowed for girls and young women, who have finished school and are staying with their parents till marriage.

In addition, television is a window to the world, offering isolated households information on politics, culture, sports etc. and is therefore highly appreciated.

According to the survey of the concept in 1989, two thirds of rural households possessed a television set. The proportion of households owning TVs was almost as high for households connected to the grid as for those without access to the grid. The latter used batteries (car batteries or TV batteries, which in fact were slightly modified car batteries) for electricity supply. Every three to four weeks these batteries were taken to the town for charging. However, as this was not always possible, as a result of transportation costs and bad conditions of rural tracks, the batteries sometimes had to stay at home for several weeks in a state of deep discharge. This factor, and the way the batteries were recharged (rapidly and with a strong current), have a negative effect on the potential lifetime of the batteries.

The efforts undertaken by the households and even their readiness to pay a considerable amount (transportation of batteries to and from the town for charging, necessity to buy new batteries once to three times per year) underline the interest of households in access to the media.

The alleviation caused by the availability of SHS, installed in the household, was certainly a motivation for households without a television set to purchase one. However, the stimulation effect for buying TVs was only limited (15%) for households from the pilot phase, but more pronounced (27%) for those in the intermediate phase.

Proportion of households with a television set	**Source**	**Reference year**	**Specification**
66%	"concept" of El Kef	1989	All households of rural areas of the Gouvernorat of El Kef
59%	"concept" of El Kef	1989	Households not connected to the grid (Gvt. of El Kef)
58%	inquiry of households of the "pilot dissemination phase"	1989	44 households in El Kef, not connected to the grid (before installation of an SHS)
73%	inquiry of households of the "pilot dissemination phase"	1996	44 households, having an SHS since 1989 (Gvt. of El Kef)
63% **90%**	inquiry of households of the "intermediate phase" inquiry of households of the "intermediate phase"	1992 1996	29 households in El Kef, not connected to the grid (before installation of an SHS) 29 households in El Kef, having an SHS since 1992
92.4%	survey STEG source: */9-1/*	1994	all grid-connected households in Tunisia
59.5% (only colour TV sets)	survey STEG source: */9-1/*	1994	all grid-connected households in Tunisia

Tab. 9-13: Evolution of television sets (in El Kef and on a national level)

Again, the families of the "intermediate phase" proved to be more dynamic (and financially more capable) than those of the "pilot dissemination phase". They already showed the same rate as STEG-clients with TV sets.

Radios with cassette decks are also widely used in the Tunisian countryside. The households, which are not connected to the grid, operate them with dry batteries, which are rather costly. When an SHS is installed, the radio is plugged permanently into an adapter. The disadvantage of this solution is that the radio can no longer be taken outside the house and used during working hours. In particular, households who do not possess a TV set use the radio very frequently. For them, the radio is an important source of news and information. The other households prefer to use the equipment for listening to cassettes, which are sold at low prices at the local *souks*. The number of hours of operation here is lower.

The proportion of households possessing a radio-cassette player has increased since the acquisition of SHS as well.

Rate of households possessing a radio-cassette player	Source	Reference year	Specification
59.8 %	"concept" of EL Kef	1989	all households in rural areas of El Kef (radios and radios with cassette players)
47.5 %	"concept" of El Kef	1989	households in rural isolated areas of El Kef (radios and radios with cassette players)
66.7 %	"concept" of El Kef	1989	households in rural agglomerations of El Kef (radios and radios with cassette players)
41 %	inquiry of households of the "pilot phase"	1989	44 households equipped with SHS (initial situation)
61 %	inquiry of households of the "pilot phase"	1996	44 households equipped with SHS (actual situation)
53 %	inquiry of households of the "intermediate phase"	1992	29 households equipped with SHS (initial situation)
79 %	inquiry of households of the "intermediate phase"	1996	29 households equipped with SHS (present situation)

Tab. 9-14: Proportion of households possessing radios and cassette-decks

As mentioned earlier, the number of hours that an SHS is used often only reflects the availability of a limited quantity of energy, and not the real demand for energy. An increase in the power of the SHS is likely to result in an increase in the hours of use of the electrical appliances. In the case of radios, which are characterised by a very low electricity consumption, the hours of use are quite similar for households of the pilot dissemination phase (in majority SHS with one module only) and those of the intermediate phase (all systems with two modules).

Service offered by SHS	**Lighting**		**Television**		**Radio-cassette player**	
	households of pilot dissemination phase (44)	households of intermediate phase (29)	households of pilot dissemination phase (44)	households of intermediate phase (29)	households of pilot dissemination phase (44)	households of intermediate phase (29)
average number of hours	**6 hours/d**	**4 hours/d**	**6 hours/d**	**5 hours/d**	**3 hours/d**	**3 hours/d**
Maximum / minimum values	10 hours/d 2 hours/d	10 hours/d 2 hours/d	11 hours/d 2 hours/d	8 hours/d 2 hours/d	*households without TV:* 8 hours/d 3 hours/d *households with TV:* 3 hours/d 1 hour/d	10 hours/d 2 hours/d

Tab. 9-15: Hours of daily utilisation of the "energy services" provided by SHS

9.2.3. Condition of the systems

An analysis of the condition of the 90 SHS installed in the pilot dissemination phase and the 20 SHS of the intermediate phase shows significant differences:

Condition of the SHS (1996)	SHS installed during the pilot dissemination phase (1989); all SHS		SHS installed during the pilot dissemination phase; interviewed households only		Systems installed during the intermediate phase (1992)	
	number	%	number	%	number	%
Operational	42	47%	33	75%	27	90%
Out of order	22	24%	11	25%	2	6%
Household connected to the grid or grid-connection planned	17	19	0	0%	0	0%
Household moved away	6	7%	0	0%	1	3%
System reclaimed by AME (SHS rent not paid)	3	3%	0	0%	0	0%
Total	***90***	***100%***	***44***	***100%***	***30***	***100%***

Tab. 9-16: *Condition of the SHS installed in 1989 and 1992 (all households and interviewed households)*

The SHS characterised as operational also included those, where some parts were not functioning properly (e.g. one lamp not working, reduced autonomy of the system due to ageing of the battery).

Tab. 9-17 shows the situation of the SHS of the pilot dissemination phase in relation to the different sectors.

Sector	Dyr El Kef	Oued Ermal Nord	Ain Mezer	Farchene	Mzita	Sed El Khir	Hmaima	Banou	Ksour	Bousliâa	Total	Total
Status of the SHS	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*number*	*%*
Operational	6	7	3	7	2	4	5	4	1	3	42	47%
Broken	1	2	3	2	4	0	3	1	2	4	22	24%
Household connected to the grid*) or planned for grid-connection	0	0	2	0	1	2	0	4	6	2	17	19%
Household moved away	0	0	1	0	2	3	0	0	0	0	6	7%
Other properties (SHS reclaimed by AME etc.)	2	0	0	0	0	0	1	0	0	0	3	3%
Total	9	9	9	9	9	9	9	9	9	9	90	100%

Tab. 9-17: *Status (June 1996) of the 90 SHS installed in the 10 sectors of the Gouvernorat of El Kef, selected for the pilot dissemination phase.*

The technicians of AME characterised the status of the 44 SHS of the pilot phase as follows:

Condition of the SHS	*number*	*%*
Well-maintained, fully in operation	17	38%
Operational with certain restrictions	16	37%
Out of order	11	25%
Total	*44*	*100%*

Tab. 9-18: *Condition of the SHS of interviewed households of the pilot phase (according to AME technicians)*

The status "operational with certain restrictions" indicates that either the system is not well maintained or cleaned, or that some of the components were not functioning properly.

9.2.4. *Stand-still of SHS: non-technical reasons*

The analysis of user-dependant causes for the breakdown of certain SHS leads to striking conclusions, in spite of the limited number of systems investigated:

- "Stepping up the ladder of comfort" of energy supply by acquiring an SHS is unfortunately a reversible process for the user households. External factors, above all periods without income, or with extremely low income, may mean that a household is unable to take care of the maintenance of the system (e.g. by replacing an out-dated battery). Therefore, it is doubtful whether an effect of "preventing rural exodus" is achievable by dissemination of SHS in the long term, if this measure is not accompanied by other activities offering the households stable sources of income. The economically fragile situation of rural households became evident in the period 1993 to 1995, when most of the Gouvernorat was victim of a serious drought.

- Self-interest of the households, expressed by the initiative of actively contacting the authorities and participating financially in the cost of the SHS is an important factor for the success of a dissemination programme.

- A third factor is the difficulty of some households to contact an experienced technician in the case of technical problems of the system. The regular visits of AME technicians had been abandoned and commercial structures were still not widely established.
  The importance of this factor is evident from the relatively low rate of stand-stills in the two sectors *Dyr El Kef* and *Oued Ermal Nord*, which are close to the town of El

Kef, allowing users to contact the regional representation of AME located there. It is also true for the sector of *Farchène* which has meanwhile become a focus of rural solar electrification as a result of more than 500 SHS installed in this zone.

Since 1989, the extension of the electrical grid in rural areas has been considerably accelerated. The initial planning objectives of STEG have been exceeded and the zones programmed for electrification are now fixed year by year. The favourable conditions of "presidential projects" and FNS-projects allowed the doubling of the acceptable costs for connecting a household to the grid. The availability of these additional funds resulted in a 180% accomplishment of STEG's rural electrification targets as early as 1996, in relation to those foreseen in the VIIIth Five-Year Plan. A clear separation between "grid extension zones" and "photovoltaic zones" was no longer possible. Sometimes, there is an impression that when a zone is programmed for the "solar solution" the supporters of the electrical grid become dynamic in order to achieve the extension of the electrical grid in the same zone.

The high number of non-operational SHS installed during the pilot dissemination phase was disappointing. The families gave the following reasons:

- Poverty: Several years of drought and epidemics among the sheep forced the population to demand public assistance (food, seeds etc.), particularly in the south of the Gouvernorat.. Due to lack of food for animals, the price for animals dropped to half of its initial level. Thus it was impossible for households to provide the necessary budget for spare parts, especially new batteries.

Furthermore, the price of batteries, even car batteries, almost doubled between 1989 and 1996. A battery, which in 1989 cost the equivalent of nine days work for a rural labourer, now costs the equivalent of 14 working days.

An indicator of the limited resources of the households is their capacity to buy a new component in order to replace the broken one:

Financial ability to replace a defective component immediately	**Households of the pilot dissemination phase**		**Households of the intermediate phase**	
	number	%	number	%
Yes	6	14%	25	85%
No	20	45%	4	15%
Possibly	14	32%	0	0%
No answer	4	9%	0	0%
Total	***44***	***100%***	***29***	***100%***

<u>*Tab. 9-19:*</u> *Financial ability of the SHS user households to replace broken components*

The striking difference between the financial situation of the households of the two phases is underlined by the fact that 11 households of the intermediate phase changed their old batteries within one month after the breakdown of the old one.

- <u>*Lack of availability of spare parts:*</u> The only towns, where PV modules, charge regulators and solar batteries can be bought commercially, are Tunis and El Kef, and, to some extent, also the small town of Kalaat Senan. For a farmer, living in a remote area, it is very costly and difficult to go to these towns. Most of the households even ignore the list of addresses of the PV suppliers.

It is surprising that there has never been an initiative from SHS users to form a sort of association in order to acquire spare parts jointly. 61% of the households were unaware of the operating condition of the SHS of the closest neighbour. Only 20% of the interviewed households of the pilot phase had ever thought of creating such an association. These households were living relatively close to one another.

Regarding the availability of lamps, the situation is difficult. Ballast is at present considered by the Agency for Industrial Promotion (API) as a local product. Consequently, imported ballast is charged high taxation and duties. However, for reasons of quality, AME is unable to advise potential clients to buy locally manufactured ballast, or imported ballast, available on the commercial market. An improvement of this situation is expected with the advance of market liberalisation in Tunisia.

- <u>*Expectations of continuous public assistance:*</u> After three years of monitoring, the responsibility for the systems of the pilot dissemination phase was transferred to the user households. Previously, the technicians of AME/GTZ had replaced faulty components free of charge and even carried out the maintenance. Nevertheless, some households continued to count on the further assistance of AME. A number of households offered to contribute towards the costs of maintenance and spare parts, but declared themselves unable to pay the total costs.

The general attitude towards the demand for assistance as expressed by the 44 households interviewed is given in the following table.

Recommendation	households	%
Visit by AME technicians for maintenance and replacement of defective components	27	61%
Better availability of spare parts and after-sales service	5	11%
Additional power of the SHS	2	5%
Advice regarding utilisation and maintenance of the SHS	4	9%
No recommendations	6	14%
Total	*44*	*100%*

Tab. 9-20: *Recommendations of interviewed households of the pilot dissemination phase (inquiry 1996)*

An indicator for the problems of acquiring spare parts is the period between discovering a fault and the day the system is fully operational again.

Average duration of a breakdown	number of households	%
No breakdowns	1	2%
Less than 15 days	9	20%
15 days to one month	10	23%
One to three months	8	18%
Three to six months	2	5%
Six months to one year	4	9%
More than one year	10	23%
Total	*44*	*100%*

Tab. 9-21: *Average duration of technical breakdowns of components of SHS in the households of the pilot dissemination phase (inquiry 1996)*

The general appreciation of SHS can only be expressed in relation to the alternatives offered. In 1989, only a minority of the rural households could dream of being connected to the electrical grid. Therefore, SHS was highly welcomed as alternative to the classic solutions (kerosene lamps, batteries), in spite of offering a less complete service than the grid. Now, households, confronted by the necessity of buying their own spare parts (when available), while seeing the grid advancing rapidly in the countryside (at lower costs for the user households), regard SHS in a more sober light.

The reasons for criticism are therefore:
- a certain under-dimensioning of SHS equipped with only one PV module of 53 Wp (65 of the total of 90 households);
- a limited technical viability of certain components.

So, compared with the first inquiry of 1992, the number of households satisfied with the SHS has decreased considerably:

General satisfaction with SHS	Households of the pilot dissemination phase (inquiry 1992)		Households of the pilot dissemination phase (inquiry 1996)		Households of the intermediate phase (inquiry 1996)	
	number	%	number	%	number	%
Positive	81	90%	24	55%	24	83%
Mainly positive	9	10%	0	0%	1	3%
Mainly negative	0	0%	0	0%	0	0%
Negative	0	0	20	45%	4	17%
Total	***90***	***100%***	***44***	***100%***	***29***	***100%***

Tab. 9-22: *Appreciation of SHS, expressed by the users*

9.2.5. Maintenance of PV systems

Tab. 9-23 shows the condition of components at the time of the inquiry of the 44 SHS installed during the pilot dissemination phase (1989). The striking result is that all components, with the exception of the modules, show results which are not optimum. Via the inquiry, an attempt was made to analyse the influence of maintenance on the continuous operation of SHS.

The necessary maintenance, which has to be executed by the user, is in fact minimal. It concerns:

- cleaning of lamps and modules;
- controlling the acid in the battery; adding, if necessary, distilled water and greasing the poles of the battery, if this has been removed or cleaned.

Component :	Module		Charge regulator		Battery		Lamp / Ballast		Cables	
Status of the component	*number*	%	*number*	%	*number*	%	*number*	%	*number*	%
Clean, operational	36	82%	27	61%	21	48%	16	37%	12	27%
Dirty	2	5%	4	9%	7	16%	10	23%	-.-	-.-
Other properties	2 (broken) 4 (badly fixed)	5% 9%	13 (partly or totally out of order)	30%	5 (missing) 7 (broken) 4 (lack of grease)	11% 16% 9%	7 (tubes with black spots) 9 (one or several broken down) 1 (unspecified problems)	16% 21% 3%	22 (clamps lacking) 10 (bad cabling)	50% 23%
Total	***44***	***100%***	***44***	***100%***	***44***	***100%***	***44***	***100%***	***44***	***100%***

<u>Tab. 9-23:</u> *Actual status of the components of the 44 households interviewed (SHS installed in the pilot dissemination phase, 1989)*

The inquiry gave the following results:

Component:	**Modules**		**Battery**			
Maintenance service:	***Cleaning***		***Greasing poles***		***Adding water***	
Maintenance executed	number	%	number	%	number	%
Regularly	18	41%	10	23%	23 (distilled water) 5 (distilled water or dist. water with acid)	53% 11%
If necessary	23	52%	7	16%	5 (distilled water) 9 (dist. water with acid)	11% 20%
Never	3	7%	27	61%	2	5%
Total households	***44***	***100%***	***44***	***100%***	***44***	***100%***

Tab. 9-24: *Executed maintenance services (inquiry of households of the pilot dissemination phase)*

The table shows that maintenance work is generally carried out appropriately. There is certainly a relation between the operation of the SHS and maintenance. When a component of the SHS breaks down, the general appreciation of the PV system decreases and with it the motivation to take care of maintenance.

The user households had been advised to use only demineralised water for filling up the electrolyte level of the batteries. Unfortunately, the appropriate water is not available everywhere. Some households had to use distilled water containing 4% acid, although this could have a negative effect on the batteries.

Generally a son or the father is in charge of the maintenance services:

Persons responsible for the maintenance of SHS	**number of households**	**in %**
Husband	14	32%
Wife	1	2%
Children	18	41%
All members of the family	11	25%
Total	***44***	***100%***

Tab. 9-25: *Persons in charge of the maintenance of the SHS (inquiry of households of the pilot dissemination phase)*

86% of the interviewed households bought the incidentals needed for maintenance themselves. This mainly only concerned demineralised water for the battery.

Incidentals purchased	Number of households	%
Several items (dist. water, grease, tubes)	17	38%
Distilled water only	21	48%
No purchases	6	14%
Total	***44***	***100%***

Tab. 9-26: *Material bought by the households for maintenance (inquiry households of the pilot dissemination phase)*

It has to be mentioned that the majority of the households did not make provision for possible problems. With the exception of demineralised water, little equipment is kept in reserve in the households. This is also a reason for the sometimes lengthy periods between a breakdown and repair.

Incidentals stored in the households	Number of households	%
Demineralised water plus fuses	1	2%
Demineralised water plus tubes	4	9%
Demineralised water only	29	66%
Nothing stored	10	23%
Total	***44***	***100%***

Tab. 9-27: *Incidentals stored at the households (inquiry of households of the pilot dissemination phase)*

The commercial structures for photovoltaics in the Gouvernorat are still recent. The majority of households of the pilot dissemination phase, above all those in remote areas, have not been informed about them.

As AME installed the SHS, households still tend to rely on it for assistance (preferably free of charge) in the case of problems. The regional office of AME has, however, started to guide the households towards the private structures. Unfortunately, the commercial sector is not always able to satisfy the demand, above all for electronic components, as spare parts of good quality are rare.

Reaction of the household to technical problems	Number	%
Contacts the regional office of AME	33	75%
Contacts a private enterprise or technician	2	5%
Repairs the equipment himself	1	2%
Repairs the equipment himself + contacts the regional office of AME	2	5%
Repairs the equipment himself + contacts private enterprise or technician	3	7%
Does nothing (waits for someone to come)	3	7%
Total	*44*	*100%*

Tab. 9-28: *Reaction to technical problems (inquiry of households of the pilot dissemination phase)*

9.2.6. Breakdown of SHS: technical reasons

9.2.6.1. Initial and present situation

The acquisition of components for SHS of the pilot dissemination phase (1989) was based on the following considerations. The modules, assumed to be a product of high technical viability, were bought from the supplier offering the best financial conditions. Regarding the electronic components (charge regulators and ballast), it was decided to buy the majority of the units from the supplier offering the best services in relation to price and quality. Nevertheless, small quantities of these components were also bought from other suppliers, in order to compare the different products based on field experience.

All the batteries installed were Tunisian products (TV batteries with a capacity of 90 Ah for SHS with one PV module and of 200 Ah for the systems with two modules).

For SHS of the intermediate phase, the material still available in AME's stocks from the pilot phase was used up first. Ballast was also taken from a pilot production series of a Tunisian manufacturer (MIFAX, Sfax). Either local flat-plate batteries, or starter batteries for lorries with a capacity of 180 Ah, imported from Morocco were used.

65 of the 90 SHS of the pilot dissemination phase were equipped with one module and one to two lamps. The others had two modules and three lamps. For all households of the intermediate phase, two PV modules were installed, and there were three lamps, whereby either all three lamps were inside the house, or two inside and one outside to light the courtyard.

Tab. 9-29 shows the initial and the present condition of components installed in 44 of the households of the pilot phase, and 29 households of the intermediate phase, who were interviewed.

Equipment	*Manufacturer*	**Interviewed households of the pilot dissemination phase (44)**				**Interviewed households of the intermediate phase**			
		initial situation		*present situation*		*initial situation*		*present situation*	
		no. of units	%	no. of units	%	no. of units	%	no. of units	%
Modules	Siemens 53 Wp	56	100%	54	97%	20	34%	20	34%
	Kyocera 51 Wp	0	0%	0	0%	38	66%	38	66%
	out of operation	-.-	-.-	2	3%	-.-	-.-	-.-	-.-
	Total	***56***	***100%***	***56***	***100%***	***58***	***100%***	***58***	***100%***

Equipment	Manufacturer	**Interviewed households of the pilot dissemination phase (44)**				**Interviewed households of the intermediate phase (29)**			
		Initial situation		*Present situation*		*Initial situation*		*Present situation*	
		no. of units	*%*	*no. of units*	*%*	*no. of units*	*%*	*no. of units*	*%*
Charge regulators	Helios	33	75%	35 (fully operational) 3 (problem of fuse-holder) 3 (defective)	79% 7% 7%	29	100%	23 (fully operational) 3 (problem of fuse-holder) 3 (defective)	80% 10% 10%
	SVE	6	14%	0	0%	29	100%	0	0%
	Siemens	5	11%	2	5%	0	0%	0	0%
	IBC	0	0%	1	2%	0	0%	0	0%
	Total	***44***	***100%***	***44***	***100%***	***29***	***100%***	***29***	***100%***
Ballast	Helios	9	8%	5	5%	31	35%	26	30%
	SVE	84	76%	82	75%	4	5%	2	2%
	SET	2	2%	0	0%	23	26%	18	22%
	Eckerle	15	14%	4	4%	-.-	-.-	-.-	-.-
	MIFAX	0	0%	3	0%	28	32%	25	29%
	not specifed	-.-	-.-	-.-	-.-	2	2%	2	2%
	defective	-.-	-.-	16	16%	-.-	-.-	13	15%
	Total	***110***	***100%***	***110***	***100%***	***88***	***100%***	***88***	***100%***

Equipment	Manufacturer	Interviewed households of the pilot dissemination phase (44)				Interviewed households of the intermediate phase (29)			
		Initial situation		*Present situation*		*Initial situation*		*Present situation*	
		no. of units	*%*	*no. of units*	*%*	*no. of units*	*%*	*no. of units*	*%*
Batteries	ASSAD TV 90 Ah	32	73%	not specified	-.-	-.-	-.-	-.-	-.-
	ASSAD 200 Ah	12	27%	-.-	-.-	-.-	-.-	-.-	-.-
	TUDOR MOROCCO 90 Ah	-.-	-.-	-.-	-.-	11x2=22	38%	1x2 = 2	4%
	ASSAD 90 Ah *)	-.-	-.-	-.-	-.-	9x2=18	31%	9x2 =18 + 2x2=4**)	47%
	NOUR 90 Ah	-.-	-.-	-.-	-.-	5x2=10	17%	2x2= 4	9%
	TUDOR TUNISIA 90 Ah*)	-.-	-.-	-.-	-.-	4x2= 8	14%	2x4= 8	17%
	Batteries from various manufacturers	-.-	-.-	33	75%	-.-	-.-	11x1=11 (car batteries NOUR and ASSAD)	23%
	defective or missing	-.-	-.-	11	25%	-.-	-.-	-.-	-.-
	Total	***44***	***100%***	***44***	***100%***	***2x29=58+)***	***100%***	***47***	***100%***

+) Two batteries of 90 Ah each were installed in all households of the intermediate phase

*) solar batteries with flat thick plates

**) The 18 batteries initially installed plus two new battery sets (replacing TUDOR MOROCCO batteries)

<u>*Tab. 9-29:*</u> *Initially installed and present components (SHS of the pilot dissemination and intermediate phase)*

9.2.6.2. Initial and present condition of the components

The modules proved to be products of high quality and technical viability. Two modules (from a total of 114) were broken, possibly by a stone or heavy hail. No infiltration of dust or other effect, which might potentially reduce the power of the cells, (browning or whitening effects) were noted. Therefore, it may be said that the modules of the two producers <u>*Siemens*</u> and <u>*Kyocera*</u> were the best components of the photovoltaic systems installed in 1989 and 1992.

The producers of the electronic equipment (*charge regulators and ballast*) claimed that the equipment, installed within the two phases, is no longer available on the market and that the new equipment has been improved considerably. There is, however, no guarantee that the more modern equipment will be of a higher technical viability.

For the systems with one PV module, the service provided by the charge regulator *Helios* was satisfactory. As the current exceeded 8 Amperes in the systems equipped with two modules, the fuse-holders melted. After consultation with the manufacturer, the fuse-holders were changed; and the electricity permitted was now 10 Amperes.

Unfortunately, it was not possible to change all the fuse-holders at the same time. Therefore, on the occasion of the inquiry, *Helios* regulators were found in six households, where the fuse-holders had melted but the regulator was still in operation, whereas in six other households the regulator was out of order.

The charge regulators from *Siemens* and *SVE* were not protected against inversion of the polarity. So, if the poles of the battery were by chance reversed, the current passed the charge regulator with the wrong polarity and could damage the electrical appliances, if these were not protected by additional fuses.

In addition, in the *SVE* regulator, the cables were not well connected to the case.

In 1991, because of these problems, all the *SVE* regulators and some of the *Siemens* regulators were replaced by *Helios* regulators. The only charge regulator from *IBC*, installed for test reasons, proved to be technically viable.

The technical deficits mentioned were also confirmed on the occasion of the inquiry.

Technical problems and breakdowns of charge regulators	**Interviewed households of the pilot dissemination phase**		**Interviewed households of the intermediate phase**	
	Number of households	%	Number of households	%
No breakdowns	24	55%	22	76%
One breakdown	14	32%	7	24%
Two breakdowns	1	2%	0	0%
Fuse melted (due to manipulation by the user)	5	11%	0	0%
Total	***44***	***100%***	***29***	***100%***

Tab. 9-30: *Number of technical problems and breakdowns of charge regulators*

Ballast from the manufacturers *Eckerle* and *SET* showed some technical deficits rather early. The lifetime of the Eckerle ballast was insufficient, and it was impossible to listen to the radio or watch television, due to interference, when the *SET* ballast was operating. As few spares were available, these regulators were then replaced by *SVE* ballast.

According to the producer Eckerle, the equipment delivered was part of a pilot series and therefore could not be considered as the final product. The favourable characteristics (luminosity and lifetime) made SVE ballast preferable, in spite of the growing number of breakdowns after four to five years of operation. Unfortunately, according to the producer, the type of ballast delivered is no longer available on the market, because of its rather high price.

Two types of ballast from the manufacturer *Helios* were installed: The type *Helios B1* turned out to be the more viable one and could be recommended for large-scale dissemination.

MIFAX ballast was part of a pilot series of a Tunisian manufacturer. However, this producer has meanwhile stopped his involvement in the development of electronic components for SHS, as he was disappointed by the low number of units he could sell. This decision is regrettable as MIFAX ballast gave a satisfactory performance. Only one ballast of the 28 MIFAX installed had a defect.

The result of the interviews reflects the technical problems of the various ballast.

Technical problems and breakdowns of *ballast*	**Interviewed households of pilot dissemination phase**		**Interviewed households of intermediate phase**	
	Number of households	*%*	*Number of households*	*%*
No problem: only melted fuse	22	50%	22	76%
One or two defective	22	50%	7	24%
Total	***44***	***100%***	***29***	***100%***

Tab. 9-31: *Number of technical problems and breakdowns of ballast*

The choice of *battery* was based on the experience from a GTZ-project in Peru, later confirmed by the experience in a project in Chile /9-2/. For SHS, it was proposed using Tunisian TV batteries, for which a lifetime of about three years was expected. These TV batteries are slightly modified car batteries, used by off-grid rural households for the electricity supply of their TV sets. In Chile, it had been found that even local car batteries performed well in SHS for more than four years.

The lifetime of the batteries depends of the number of cycles (charge and discharge) and of the rate of discharge (see *Fig. 9-1*).

It turned out that the electricity consumption of a rural Tunisian household is considerably higher than that of a Latin American SHS user household. In Chile, SHS are almost exclusively used for the purpose of lighting. The daily estimated discharge rate of the battery is only 10%, whereas in Tunisia the SHS equipped with one module are discharged daily by about 30% and stay in a state of partial discharge throughout the winter season.

In addition, the ambient temperature in Tunisia varies considerably with the seasons. In summer, it may exceed 40°C even inside the houses, and in winter, it may drop to five to six degrees indoors. In the Andes regions of Latin America, the ambient temperature is more or less constant (about 15°C) throughout the year. So, for Tunisian conditions, normal batteries (TV batteries and car batteries) cannot be recommended for use with SHS.

Therefore, it was very fortunate that solar lead batteries with flat plates, developed by two Tunisian manufacturers (ASSAD and TUDOR TUNISIA) turned out to be products of high quality. These are still doing well even after four years of operation (of course with a certain reduction of the autonomy).

Evidently, the discharge rate is less pronounced for the SHS equipped with two PV modules and two batteries of 90 Ah each, providing a certain protection of the batteries.

When it was necessary to replace batteries, the households usually bought car batteries. The reasons were the non-availability of the appropriate batteries in the region, as they are only available in the town of El Kef, and the high cost of the solar batteries. The breakdown of batteries remains the main reason for the end of operation of SHS.

During the first years of operation of SHS, when the households of the pilot dissemination phase paid a monthly rent for their use, AME changed the out-dated batteries free of charge. Afterwards the responsibility was transferred to the user households.
The households of the intermediate phase were totally responsible for the SHS after expiration of the two-year guarantee period.

The efforts undertaken by the households to acquire new batteries are nevertheless considerable.

Battery replaced after installation of the SHS	Interviewed households of the pilot dissemination phase		Interviewed households of the intermediate phase	
	Number	*%*	*Number*	*%*
Never	0	0%	26	62%
Once	22	50%	13	38%
Twice	9	20%	0	0%
Three times	13	30%	0	0%
Total	**44**	**100%**	**29**	**100%**

Tab. 9-32 : Replacement of batteries

Due to the lack of availability and funds, the households bought a large variety of different batteries to replace the original ones. The capacity ranged from 66 to 120 Ah. Only two households, possessing SHS since the intermediate phase, were financially in the position to buy a rack of two solar batteries.

As for SHS, there is a relation between the power of the PV generator and the capacity of the battery. Evidently the more powerful SHS, disposing of two PV modules, are no longer used in an optimal way, once the initial two batteries are replaced by just one new one.

The *cabling* of the SHS is usually fixed by clamps to the walls. The diameter of the cables has to be appropriate for an application in 12V dc systems. All outdoor cables have to be resistant to ultra-violet radiation. It is often difficult to provide a stable fixing of the clamps if the wall consists of clay or natural stones. In SHS installed during the pilot phase, a deterioration of the cabling was often noted:

Condition of cabling of the SHS	**interviewed households of the pilot dissemination phase**	**%**
Favourable	12	27%
Acceptable	22	50%
Poor	10	23%
Total	***44***	***100%***

Tab. 9-33: Condition of cabling of the SHS (interviewed households of the pilot dissemination phase)

9.2.7. Conclusions:

- An SHS does not represent an appropriate solution for all social strata of the rural population. The very poor are not capable of providing the necessary funds for spare parts, above all batteries. Their situation is very insecure. We estimate this stratum to be about 20% of the rural households. In the case of several successive years of drought, this rate may increase considerably(on a regional level). If the Tunisian government wants to include these households in the national programme, funds necessary for permanent assistance have to be provided.

- In the case of difficulty obtaining spare parts, SHS will stay (totally or partly) out of operation for long periods. If, after the first partial breakdown, another component becomes defective, the budget necessary to replace the parts may exceed the financial capabilities of the household and result in the complete SHS being abandoned. The majority of households is not able to save small amounts of money regularly for repairs or acquisition of spare parts. The users do not make provision for possible technical problems (stock of spare parts). In addition, there are no actions taken by the community; each user tries to solve technical problems by himself.

- From the viewpoint of the user households, SHS are still closely linked to services, which in their opinion have to be provided by the government. In particular, even if the financial contribution of the households is marginal, they still count on public institutions for repairs and spare parts.

- Taking into account the meteorological conditions of the north-west Tunisia, SHS equipped with one PV module of about 50 Wp are insufficient to cover the basic electricity demands of rural households. The performance is characterised by a high number of electricity cuts and a shortened lifetime of the battery. On the other hand, an SHS of 100 Wp (for three lamps, TV and radio) raises financial problems, when the appropriate batteries have to be purchased by the households themselves.

- The availability of spare parts of good quality and an autonomous commercial structure for repair and after-sales services are not yet assured on a local level. Therefore, the presence of AME in the pilot region is still necessary. Throughout the years, a climate of mutual understanding and confidence has been created between the representatives of AME and the rural households.

- The planning of the extension of the electrical grid seems to be done rather spontaneously, from one year to the next, and not according to strategic long-term programmes. A clear separation between the priority zone for grid and for solar electrification has thus become impossible. Due to its less favourable financial conditions and services, solar electrification risks being considered as a temporary or second choice solution. This would be very negative for its image, and might even cause negligence and non-replacement of defective components.

From the experience of the pilot dissemination phase and the intermediate phase, the following lessons should be learnt and implemented in the national programme:

- Households should contribute a lump sum to the acquisition of SHS. The amount, fixed at 104 $ (100 DT) should be paid in two instalments before installation. A financing system, based on renting, was not effective. Other financing schemes, combining payments in small instalments with low management costs to the programme, are still in a research or demonstration stage (electricity meters operating with coins or solar cards).

- The standard system for the national programme should be designed as follows, in accordance with the results of the calculations, see chapter 9.4:
  - PV generator between 70 to 100 Wp;
  - three lamps (either three lamps in the interior of the dwelling or two lamps inside and one outside the house), plus the option to connect a radio-cassette-deck and a TV set;
  - battery of a capacity between 90 and 100 Ah.

- The permanent presence of the supplier and installer of the SHS in the region (or at least in the capital of the region) is essential.
  Solar batteries should be integrated in the existing regional sales structures of the Tunisian manufacturers, so that they are available in the small towns as well.

- The organisations concerned (AME, Gouvernorat, STEG, FNS) should agree on a long-term plan, defining the zones to be electrified via the grid, and those to be preferably equipped with SHS.

- The quality of the components to be installed should be assured (specifications to be fixed in the tender documents).

- AME should be present with a sufficient number of skilled personnel and logistics in the Gouvernorats targeted by the programme. This presence, including field work and advice to users, may be reduced but only when commercial structures are operational and provide the necessary services for the user households.

9.3. Economic aspects

9.3.1. Formulation of the questions

Based on the field experience (pilot dissemination phase and intermediate phase) and taking into account the ongoing activities of the national programme for rural solar electrification, the following questions were examined:

- How did the costs of SHS (complete systems and components) develop within the different programmes and projects?
- What is the economically most favourable option for the batteries: car batteries, solar lead batteries with thick flat plates, or tubular batteries?
- What are the total costs to be expected after twenty years of operation for alternative configurations of SHS, from the minimum solution (power 70 Wp) to the almost complete solution of 200 Wp power? Depending on the different financing schemes, what share of these costs would have to be borne by the users and which costs would be charged to the government? Are these costs acceptable?
- Finally, which SHS configurations and which financing schemes would be most profitable for the government, compared to the cost of extending the electrical grid?

9.3.2. Comparison of the costs of the SHS

The first five calls for tenders for SHS in Tunisia had the following result.

N°	Responsible for call for tenders (A) and for execution (B)	Financing	Site	Number of SHS installed	Date	Nominal power	No. of lamps per SHS	Battery
1	(A): AME (B): SES, Tunisia	GTZ / national	Gvt. of El Kef	1 000 systems	Dec. 1993	1 x 70 / 75 Wp	3	thick flat plates 90 Ah/ tubular 100 Ah
2	(A): AME (B): APEX, France	credit World Bank / national	Gvts. Siliana, Kasserine	1 250 systems	May 1994	2 x 50 = 100 Wp	2	thick flat plates 90 Ah
3	(A): AME (B): ANIT, Italy	credit World Bank / national	Gvts. Siliana, Kasserine	1 000 systems	June 1995	2 x 50 = 100 Wp	3	thick flat plates 130 Ah
4	(A): FNS (B): SES, Tunisia	national	Gvt. of El Kef	180 systems	June 1995	2 x 50 = 100 / 2 x 53 =106 Wp	3	tubular 190 Ah/ tubular 180 Ah/ tubular 2 100 Ah
5	(A): FNS (B): SES, Tunisia	national	Gvt. of El Kef	114 systems	Aug. 1995	2 x 53 = 160 Wp	3	tubular 190 Ah/ tubular 180 Ah

Tab. 9-34: *Results of the first five calls for tenders for solar electrification of rural households in Tunisia*

The costs of the SHS installed in the framework of these calls for tenders have risen constantly.

The reasons for this are:

- the 51% increase of the power of the standard system (from 70/75 Wp - call for tenders N° 1 - to 106 Wp - call for tenders N° 5);
- the resulting increase of the capacity of the batteries, combined with the decision to opt for tubular batteries instead of batteries with thick flat plates.

Some producers of PV modules intended executing reference projects in order to develop the new Tunisian market and therefore submitted very favourable offers. The conditions of consecutive offers from the same producers were less favourable.

Call for tenders N°	Cost per SHS (all inclusive)	Cost (all inclusive) per Wp installed
1a (flat plate solar batteries)	**814 $**	11.6 $
1b (tubular batteries)	865 $	12.3 $
2	961 $	9.6 $
3	842 $	**8.4 $**
4	***1 534*** $	***15.3 $*** *)
5	1 416 $	13.5 $ **)

*) version with ELSI charge regulator and BP Solar modules

**) version with ELSI charge regulator and SIEMENS Solar modules

Tab. 9-35: *Comparison of the SHS costs (all inclusive and per Wp installed), resulting from calls for tenders*

Regarding the cost of the SHS, *Tab. 9-35* shows significant differences (up to 77%). These differences are somewhat less (up to 55%), if the costs per Wp are compared.

Call for tenders N°	1a		1b		2		3		4		5	
	US $	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*
Equipment	616 $	76%	667 $	77%	676 $	70%	692 $	82%	1274 $	83%	1218 $	86%
Installation, cabling, supports etc.	198 $	24%	198 $	23%	285 $	30%	150 $	18%	260 $	17%	198 $	14%
Total	814 $	100%	865 $	100%	961 $	100%	842 $	100%	1534 $	100%	1416 $	100%

Tab. 9-36: *Results of calls for tenders: cost of PV equipment and installation cost (incidentals included)*

The average cost of installation (transportation on site, labour, cabling and supports) is thus 208 US $.

The average cost of the modules (per Wp) is 5.48 US $ (*Tab. 9-37*). The equipment of the same producer was offered at a different price in two cases.

Call for tenders N°	1	2	3	4a	4b	4c	5a	5b
Producer	BP Solar	Photowatt	ANIT	BP Solar	Photowatt	Solarex	Solarex	Siemens Solar
Country of origin	Spain	France	Italy	Spain	France	United States	United States	United States/ Germany
Cost per Wp	**5.4 $**	**5.3 $**	**4.3 $**	**6.3$**	**5.8 $**	**5.7 $**	**5.7 $**	**5.4 $**

Tab. 9-37: *Results of call for tenders: cost of the PV modules (per Wp)*

The cost of the charge regulators amounted to about 80 to 90 US $ (*Tab. 9-38*).
At the time of the calls for tenders 1 and 2, foreign charge regulators could be imported free of taxes and duties. Afterwards, this was no longer possible, causing a considerable rise in the cost of imported regulators. Tunisian manufacturers produce charge regulators only by order. The electronic elements and cases are costly, as they are only bought in small quantities and, to some extent, they have to be imported as well. Therefore, local production did not have any effect on cost reduction.

Call for tenders N°	1	2	3	4a	4b	4c	5a	5b
Producer charge regulator	BP Solar	APEX	ELSI	ELSI	BP Solar	Le Rayon solaire	ELSI	Le of Rayon solaire
Type	BPRM1	APZ-512	STM 16/12	STM 16-12	BPRM1	RS-RA 12	STM 16-12	RS-RA 12
Country of origin	Spain	France	Tunisia	Tunisia	Spain	Tunisia	Tunisia	Tunisia
Cost (in US $)	**76 $**	**58 $**	**69 $**	**94 $**	**166 $**	**78 $**	**90 $**	**78 $**
Import taxes and duties	free	free	-.-	-.-	included	-.-	-.-	-.-

Tab. 9-38: *Results of call for tenders: cost of charge regulators*

Field experience and laboratory tests showed that regulators and ballast with only very simple electronics are not capable of meeting the requirements stipulated by the tender documents. This concerns safety aspects (regulators) and the lifetime of the tubes (ballast).

Products offered at low prices are mainly designed for leisure applications (camping, holiday homes) and are not adapted to the sometimes extreme conditions of remote dwellings in the Tunisian countryside.

A high price, however, does not automatically mean a product of high quality. The necessity of replacing and repairing electronic components within the warranty period gives rise to dissatisfaction of the user households and financial losses for the suppliers.

Call for tenders N°	1	2	3	4a	4b	4c	5a	5b	5c
Manu-facturer of lamp	Solen-ersa *)	Solen-ersa *)	Labcraft *)	Labcraft *)	Inver-tec	Le Rayon solaire	Le Rayon solaire	Labcraft *)	SVE
Type	-.-	-.-	BL 18	BL 18	-.-	-.-	-.-	BL 18	-.-
Country of origin	Spain	Spain	United King-dom	United King-dom	United King-dom	Tunisia	Tunisia	United King-dom	Germany (China?)
Cost in US $	29 $	33 $	34 $	47 $	74 $	40 $	50 $	71 $	45 $
Import taxes and duties	free	free	free	free	free	-.-	-.-	included	included

*) equipment has meanwhile been modified

Tab. 9-39: *Results of calls for tenders: cost of lamps*

The battery racks installed in the framework of the different calls for tenders show the highest variations among all components of SHS. Whereas the power of the PV generators varied between 70 and 106 Wp, i.e. 51%, the capacity of the batteries varied between 90 Ah and 190 Ah, thus 211%!

Instead of the batteries with flat plates, tubular batteries are actually preferred because of their longer lifetime. Regarding the initial investmet, they are, however, by far the most expensive solution.

Call for tenders N°	1a	1b	2	3	4a	4b	4c	5a	5b
Battery manufac-turer	Assad	Fulmen	Assad	Assad	Tudor Tunisia	Assad	Fulmen	Tudor Tunisia	Assad
Country of origin	Tunisia	Spain	Tunisia	Tunisia	Tunisia	Tunisia	Spain	Tunisia	Tunisia
Type	SL110	6 IRF 4	SL 110	SL 130	180 PLT	6 ADL 7	6 IRF 4	180 PLT	6 ADL 7
Techno-logy	thick flat plates	tubular	thick flat plates	thick flat plates	tubular	tubular	tubular	tubular	tubular
Capacity of the battery rack	1 x 90 Ah in C20	1 x 100 Ah in C10	1 x 90 Ah in C20	1 x 130 Ah in C20	1 x 190 Ah in C20	1 x 180 Ah in C20	2 x 100 Ah in C10	1 x 190 Ah in C20	1 x 180 Ah in C20
Cost of the battery rack	**74 $**	**130 $**	**68 $**	**93 $**	**362 $**	**333 $**	**460 $**	**362 $**	**348 $**
Import-ation taxes and duties	-.-	free	-.-	-.-	-.-	-.-	included	-.-	-.-

<u>Tab. 9-40 :</u> Results of calls of tenders: cost of the battery rack

Let us now regard the relative importance of the components in respect of the total costs of SHS. The PV generator (module(s)) in general represent between 50 and 70% of the net costs of an SHS (excluding installation, cabling and incidentals). The regulator and the lamps each contribute 10 to 15%, whereas the contribution of the battery rack varies between 15 and 35% (*Tab. 9-41*).

Compared to the costs of SHS in commercial or publicly supported programmes of other countries, the results obtained from the Tunisian calls for tenders are among the most favourable (*Fig. 9-25*).

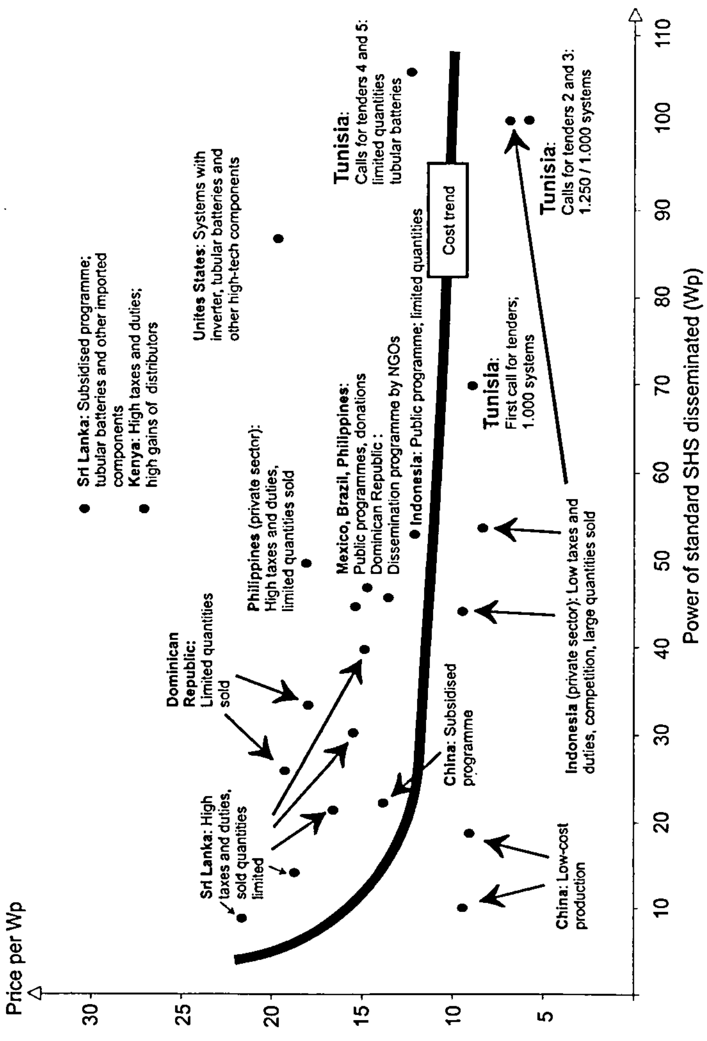


Fig. 9-25: ***Results of the Tunisian calls for tenders for SHS in relation to other results on international level-Source :/9-3/(completed)***

Call for tender N°	1a		1b		2		3	
	US $	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*
module(s)	**378 $**	61%	378 $	56%	530 $	73%	430 $	62%
charge regulator	76 $	12%	76 $	11%	**58 $**	8%	69 $	10%
lamps	87 $	14%	87 $	13%	**66 $**	9%	102 $	15%
battery rack	**74 $**	13%	130 $	20%	68 $	10%	93 $	13%
Total	***615 $***	***100%***	***671 $***	***100%***	***722 $***	***100%***	***694 $***	***100%***

Call for tender N°	4a		4b		4c		5a		5b		5c	
	US $	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*	*US $*	*%*
module(s)	580 $	49%	604 $	46%	**620 $**	53%	604 $	50%	572 $	47%	572 $	50%
charge regulator	**94 $**	8%	166 $	13%	78 $	7%	90 $	7%	78 $	6%	78 $	7%
lamps	141 $	12%	222 $	17%	120 $	10%	150 $	12%	**217 $**	12%	135 $	12%
battery rack	362 $	31%	333 $	34%	**460 $**	30%	362 $	32%	348 $	35%	348 $	31%
Total	***1 177 $***	***100%***	***1 325 $***	***100%***	***1 170 $***	***100%***	***1 206 $***	***100%***	***1 215 $***	***100%***	***1 133 $***	***100%***

Tab. 9-41: *Results of calls for tenders: Comparison of the costs of the components*

9.3.3. Results of computer simulation programmes

9.3.3.1. The methodology applied

An investment is assumed to be profitable, when the economic gains exceed the initial expenses and the cost of operation within a given period.

Apart from this absolute economy, there is also a relative economy. In this case, the costs and/ or gains of several economic measures or decisions are compared. The most favourable option will be the one which delivers - under specified framework conditions - the most favourable values for a defined indicator.

For our simulation calculations, this indicator is represented by global costs, relative to prices today. This means it is the amount (in cash) which would have to be available at present in order to be able to finance the acquisition and the operation of a component or a complete SHS for a specified period of time.

Thus, not only the costs of the equipment are taken into consideration, but also the inflation rate and the interest on the capital to be invested.
The most favourable result from the economic point of view is therefore the solution with the lowest relative global costs.

The framework conditions are assumed to remain stable during the period to be analysed and are as follows:

Factor	**Inflation rate**	**Increase in electricity prices (grid)**	**Interest rate on invested capital**	**Analysed period**
Value	4.9% per year	5.35% per year	8% per year	20 years
Justification	average of the period 1990 to 1994 in Tunisia	average of the period 1990 to 1994 in Tunisia	fixed in relation to the inflation rate	estimated lifetime of the PV modules

Tab. 9-42: General factors for the economic simulation calculations

9.3.3.2. Economic comparison of three battery types

Several types of batteries may be used for the SHS. They differ widely in relation to price and lifetime.

In order to compare the alternatives, we have taken the case of a 12V-SHS with a nominal power of 100 Wp and a capacity of the battery rack of 180 Ah.

Three types of batteries of a Tunisian manufacturer are at present on the market:

Type of battery	**Car battery**	**Solar battery with thick flat plates**	**Tubular battery**
Manufacturer	Assad 11 H6G cap	Assad SL 100	Assad 6 ADL 7
Capacity in C20	2 x 90 Ah	2 x 90 Ah	1 x 180 Ah
Price of battery rack	175 $	259 $	366 $

Tab. 9-43 : Economic comparison: types of batteries

The *car battery* is manufactured in mass production and is therefore available at a favourable price. Unfortunately, this type of battery, designed to deliver a strong current during a short period, is not adapted to the characteristics of an SHS, the battery of which is discharged every evening for five to seven hours and recharged the following day (see chapter 11.2.6.). When such a battery is installed as component of an SHS, its lifetime will be limited.

Tubular batteries, developed as industrial (stationary) batteries, are much more suitable to the cycling conditions of an SHS. Unfortunately, such batteries are only manufactured in small series and are therefore costly. In addition, some components have to be imported. The limited sales do not justify producing these components locally.

The *solar battery, having thick flat plates* constitutes a sort of compromise between the two preceding types. Its characteristics resemble those of a tubular battery, but its price is considerably lower.

The results of simulation calculations for a period of twenty years are the following:

Type of battery	**Car battery**		**Solar battery with thick flat plates**		**Tubular battery**	
Estimated lifetime	minimum: 0.75 years	maximum: 1 year	minimum: 2 years	maximum: 3.5 years	minimum: 4.5 years	maximum: 6 years
Relative global costs	3.609 $	2 692 $	2 021 $	1 222.8 $	1 430 $	**1 147 $**

Tab. 9-44 : Comparison of batteries: relative global costs

Fig. 9-26 a) shows the costs of the different alternatives, whereas *Fig. 9-26 b)* and *c)* indicate the dates of the break-even-points in the case of the minima and the maxima of expected lifetimes of the batteries.

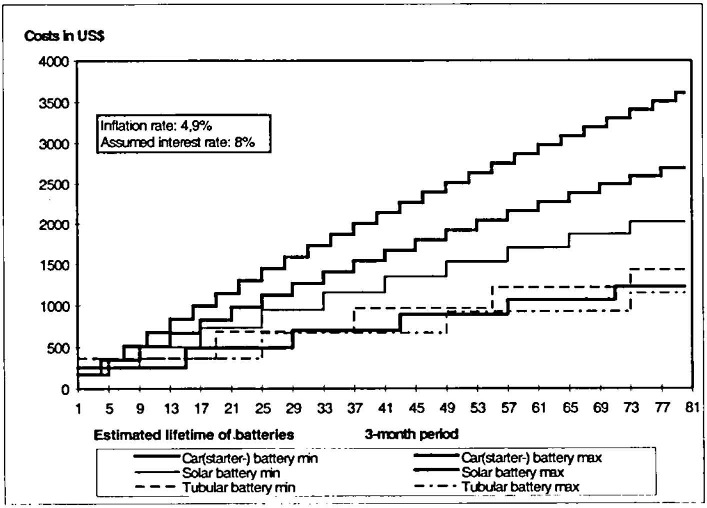


Fig. 9-26a): Economic comparison of several types of batteries (Step diagram)

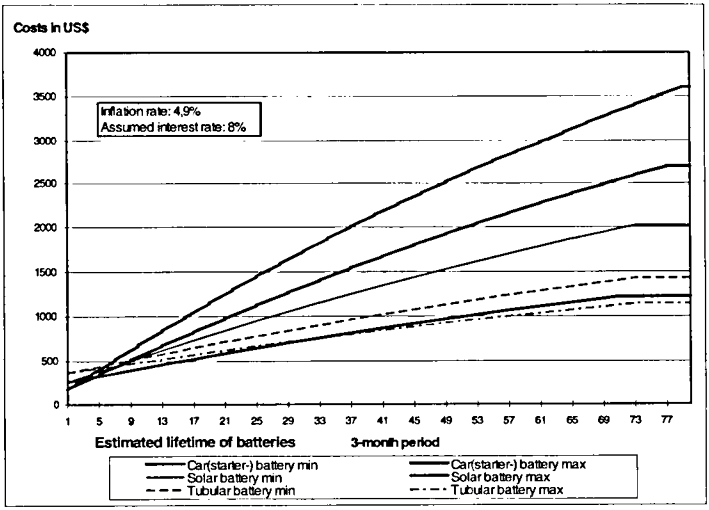


Fig. 9-26b): Economic comparison of several types of batteries (presented linearly)

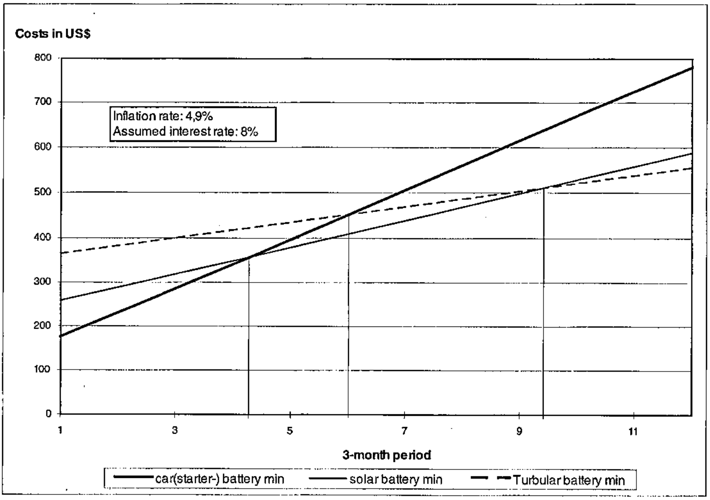


Fig. 9-26 c): Economic comparison of several types of batteries: minimum estimated lifetime, showing break-even points (presented linearly)

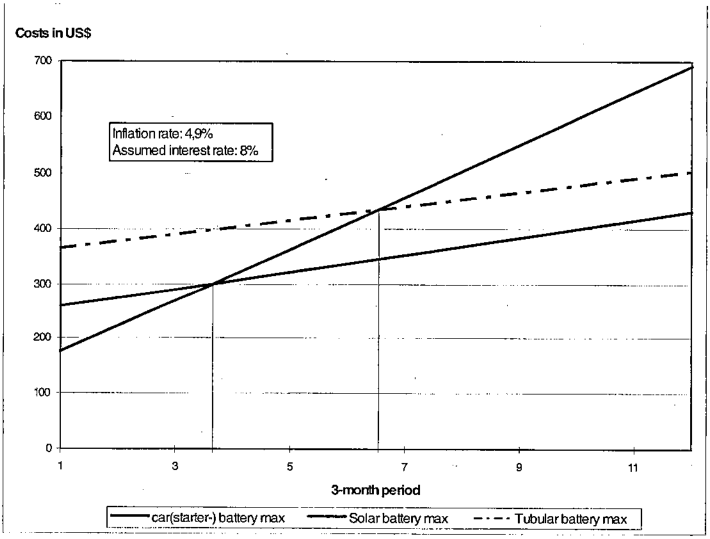


Fig. 9-26 d): Economic comparison of different types of batteries: maximum estimated lifetime: break-even points (presented linearly)

Discussion of the results

Although its price is low, the car battery is not a solution to be recommended for use with an SHS, at least not under Tunisian conditions. After three to four months of operation, the solar battery with thick flat plates becomes the economically more favourable option. In the long term, the tubular battery offers the most economically favourable conditions. However, these advantages are not striking. Under certain conditions (favourable lifetime of the solar battery and unfavourable lifetime of the tubular battery) the battery with thick flat plates is competitive to the tubular battery and may even become the more favourable solution from an economic point of view.

At present, the price of a tubular battery corresponds to three months' income of the head of an average rural household.

Because of this very high price, the vast majority of the households will never be able to buy a new tubular battery without public financial assistance.Therefore, the solar battery with thick flat plates should be the solution recommended as standard both for SHS disseminated in the framework of national programmes as well as for commercialisation.
Due to the fact that, within the national programme, the government only provides financial assistance for the initial cost of the SHS, the selection of batteries with thick flat plates would considerably reduce the costs of the systems and improve the chances of solar electrification as alternative to the extension of the electrical grid.

9.3.3.3. Economic comparison of different configurations of SHS

The SHS installed in the framework of different projects and calls for tenders of the national programme differ with respect to the power of PV generators, the type and capacity of batteries, the types and number of lamps and types of charge regulators.
For an economic comparison, the configuration of the SHS of the pilot dissemination phase (*one module of 53 Wp, one battery of 90 Ah and two lamps*) may be ignored. Owing to climatic conditions and the energy demand of households, this configuration is insufficient to cover the basic needs of electrical energy (see chapter 9.1.4. and chapter 9.4.2.).

The configuration having only *two lamps* (national programme: second call for tenders) may also be neglected as the reactions of the user households at this stage of the programme showed that three lamps have to be considered as a minimum standard for an SHS (see chapter 9.2.2.).

The three selected systems (Systems A, B, C), compared economically, are therefore those of the first call for tenders (bilateral co-operation with Germany - *Tab. 9-34, 9-35*: configuration 1a), of the third call for tenders (financed by World Bank credit - *Tab. 9-*

34: configuration 3) and that of the FNS project in El Kef (national financing - *Tab. 9-34, 9-37*: configuration 4a).

The fourth configuration (System "D") chosen for this analysis is that of a PV system of 200 Wp, operating at 230 V and equipped with an ac/dc inverter. According to /9-1/, AME may in future favour this solution, which corresponds to the systems installed in rural solar electrification programmes in Spain, in its programmes of rural solar electrification. This allows a colour TV and perhaps even a small refrigerator to be connected (see also chapter 9.4.2.6).

It has to be noted that the energy services offered by the four systems of this economic comparison are not identical. They vary from the strictly minimum, system A, to an option, which is almost capable of offering the same comfort as the electrical grid, system D.

Although the study elaborated by INESTENE/WB/AME */9-1/* includes economic calculations, we consider it useful to consider this subject here as well, taking into account the real costs of installed SHS, the technical experiences with the components, and analysing more in detail the costs of planning, management and follow-up of the programme.

The characteristics of the four PV systems compared are as follows:

System	**A**	**B**	**C**	**D**
Power of the PV generator	1 x 70 Wp	2 x 50 Wp = 100 Wp	2 x 50 Wp = 100 Wp	4 x 50 Wp = 200 Wp
Voltage	12 V	12 V	12 V	12 V / 220 V
Number of lamps (tubes 18 W)	3	3	3	6
Type and capacity of the battery	thick flat plates, 90 Ah	thick flat plates, 130 Ah	tubular 180 Ah	tubular 2 x 180 = 360 Ah
Costs of equipment	616 $	692 $	1 274 $	2 728 $
Cost of installation, cabling and incidentals	198 $	150 $	260 $	281 $
Total costs of the installed PV system	***814 $***	***842 $***	***1 534 $***	***3 009 $***

Tab. 9-45 : Economic comparison: configuration and costs of the four PV systems

The estimated lifetime of the different components is as follows:

Component	**PV module**	**Charge regulator**	**Inverter**	**Lamp**	**Solar battery with thick flat plates**	**Tubular battery**
Estimated lifetime:	20 years	6 years	5 years	4 years	3.5 years	6 years

Tab. 9-46 : Economic comparison: estimated lifetime of the components

This estimation is based on the following assumptions:

PV projects which have been the subject of monitoring for a period of more than 20 years cannot be found in any conference proceedings or documentation. Regarding the *modules*, a certain reduction of power cannot be excluded after several years of operation, because of degradation of the PV cells, infiltration of dust etc. In addition, in economic calculations for technical products an estimated lifetime of twenty years is already exceptional. A calculation, based on a lifetime of thirty years, applied in */9-1/*, is therefore most unusual.

The estimation of the lifetime of the *charge regulators* is based on experience with the best products installed during the pilot dissemination phase. The charge regulators installed in the systems A, B and C all showed technical weaknesses even after only short periods of operation and therefore had to be repaired or replaced. The field experience with these regulators does not in fact exceed two years.

For the *inverter* (system D only) the lifetime has been assumed to be slightly worse than that of the charge regulator, as series production is still limited and no wide-scale field experience is available.

Regarding the *lamps*, the estimation of the lifetime is based on the experience of the pilot dissemination phase with the best products installed. The lamps installed within the systems A and B, offered at a favourable price, had to be replaced by other products in the framework of the warranty offered by the supplier.

A national programme for rural solar electrification, requires a permanent structure both in the capital as well as at the regional level (see chapter 11.2.1). The costs of such organisational structures are often underestimated, if not completely ignored in comparative economic calculations (see */9-3/*).

Organisational unit	Position	Costs per year (assumed)	Costs per position and year	Total costs per year
Regional service	3 engineers	3 x 780 $/ month x 12	28 080 $	
	5 technicians	5 x 468 $/ month x 12	28 080 $	
	1 secretary	1 x 364 $/ month x 12	4 368 $	
	4 cars (four-wheel drive)	4 x 20 800 $ / 7 years	11 886 $	
	rent of office and workshop	520 $ x 12	6 240 $	
	fuel	20.8 $ x 300 days	6 240 $	
	overhead costs	520 $ x 12	6 240 $	
	telephone	260 $ x 12	3 120 $	
	Total regional			***94 254 $***
Central administration (Tunis)	2 engineers	2 x 780 $ x 12	18 720 $	
	1 secretary	1 x 364 $ x 12	4 368 $	
	1 technician	1 x 468 $ x12	5 616 $	
	overhead costs	0.4 x (18 720 +	11 482 $	
	(40%)	4 368 + 5 616)		
	Total central			***40 186 $***
Total				**134 440 $**

Tab. 9-47: *Annual costs of planning, management and follow-up of a dissemination programme of 3 000 SHS*

Taking into account that this organisational structure is capable of managing a dissemination programme of up to 3 000 SHS, and that a period of three years after installation would be necessary for the follow-up, the annual costs of 44.8 US $ would amount to a total of *134 US $* per system.

These costs have been added to the costs of the systems A to D.

The relative global costs of each of the four SHS have been calculated for a period of twenty years based on these data (*Tab. 9-48* and *Fig. 9-27*).

Component	System A				System B				System C				System D			
	Costs of initial investment	*%*	*Relative global cost (20 years)*	*%*	*Costs of initial investment*	*%*	*Relative global cost (20 years)*	*%*	*Costs of initial investment*	*%*	*Relative global cost (20 years)*	*%*	*Costs of initial investment*	*%*	*Relative global cost (20 years)*	*%*
PV module(s)	379 $	40%	379 $	17%	427 $	44%	427 $	18 %	625 $	37%	625 $	16%	1 083 $	34 %	1 083 $	14%
Battery(s)	74 $	8%	344 $	15%	93 $	9%	420 $	17 %	333 $	20%	1 045 $	27%	666 $	21 %	2 091 $	28%
Charge regulator	76 $	8%	238 $	10%	69 $	7%	216 $	9%	94 $	6%	294 $	8%	104 $	3 %	327 $	4%
Inverter	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	-.-	750 $	24 %	2 443 $	33%
Lamps	87 $	9%	351 $	15%	103 $	11%	414 $	17 %	222 $	13%	890 $	23 %	125 $	4 %	502 $	7%
Installation	83 $	9%	83 $	4%	104 $	11%	104 $	4%	99 $	6%	99 $	3%	125 $	4 %	125 $	2%
Cabling, supports and incidentals)	115 $	12%	115 $	5%	46 $	5%	46 $	2%	161 $	10%	161 $	4%	156 $	5 %	156 $	2%
Planning and management of the programme	134 $	14%	134 $	6%	134 $	14%	134 $	6%	134 $	8%	134 $	3%	134 $	4 %	134 $	2%
Maintenance and repairs	-.-	-.-	649 $	28 %	-.-	-.-	649 $	27%	-.-	-.-	649 $	16%	-.-	-.-	649 $	8%
Total	**949 $**	**100%**	**2 293 $**	**100%**	**976 $**	**100%**	**2 410 $**	**100%**	**1 668 $**	**100%**	**3 898 $**	**100%**	**3 144 $**	**100%**	**7 509 $**	**100%**

Tab. 9-48: *Economic comparison: costs of the components of the four SHS configurations (initial investment and relative global costs for 20 years)*

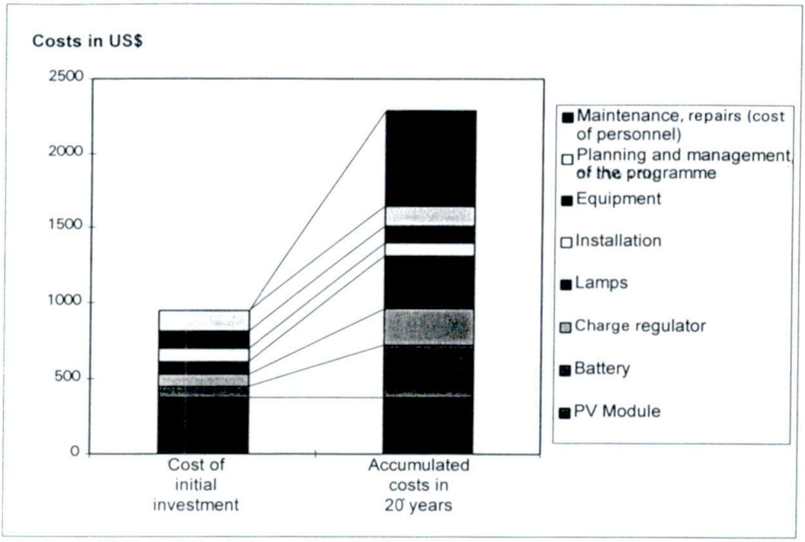


Fig. 9-27 a): Economic comparison of SHS components, System A (initial investment and relative global costs for 20 years of operation)

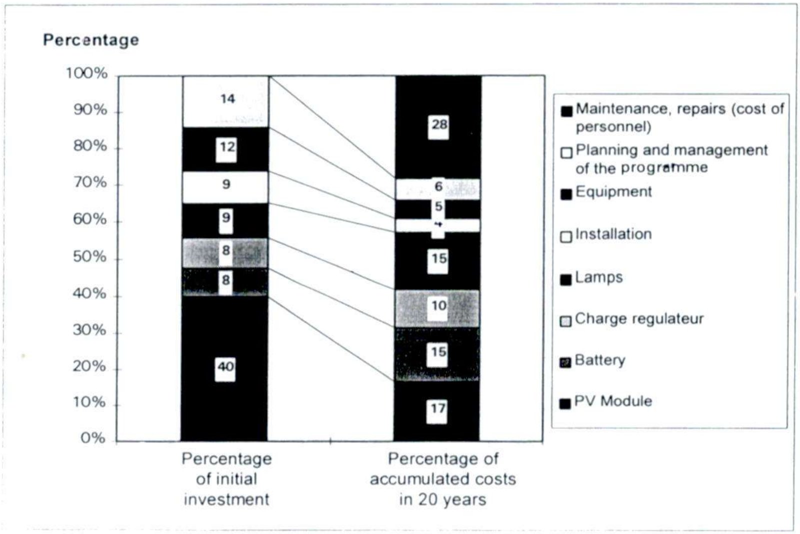


Fig. 9-27 b): Economic comparison of SHS components, System A (initial investment and relative global costs for 20 years of operation) as percentage of the total costs

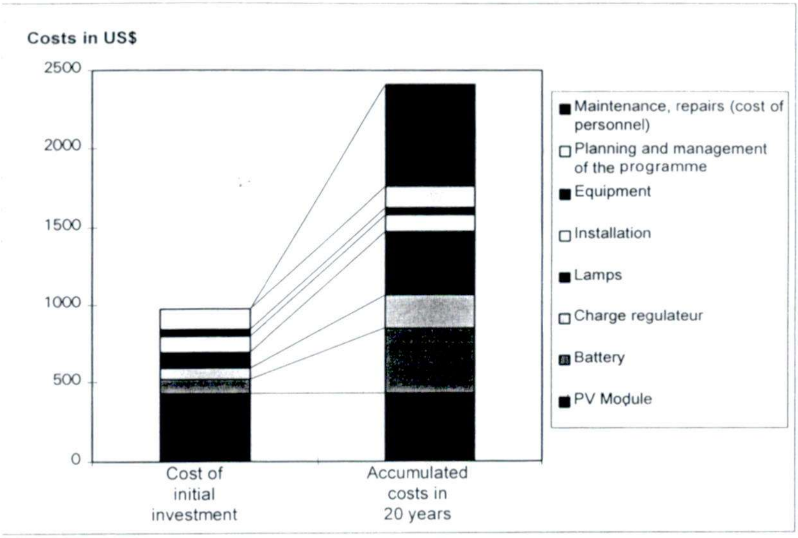


Fig. 9-27 c): *Economic comparison of SHS components, System B (initial investment and relative global costs for 20 years of operation;*

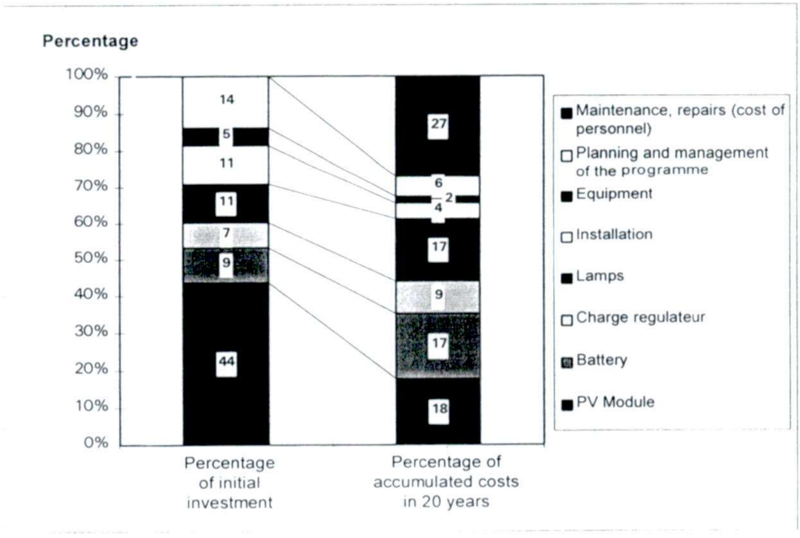


Fig. 9-27 d): *Economic comparison of SHS components, System B (initial investment and relative global costs for 20 years of operation) as percentage of the total costs*

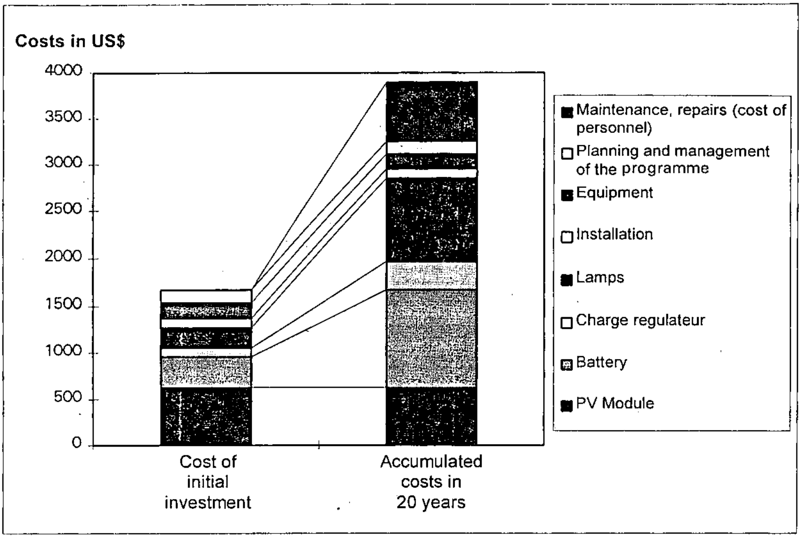


Fig. 9-27 e): Economic comparison of SHS components, System C (initial investment and relative global costs for 20 years of operation)

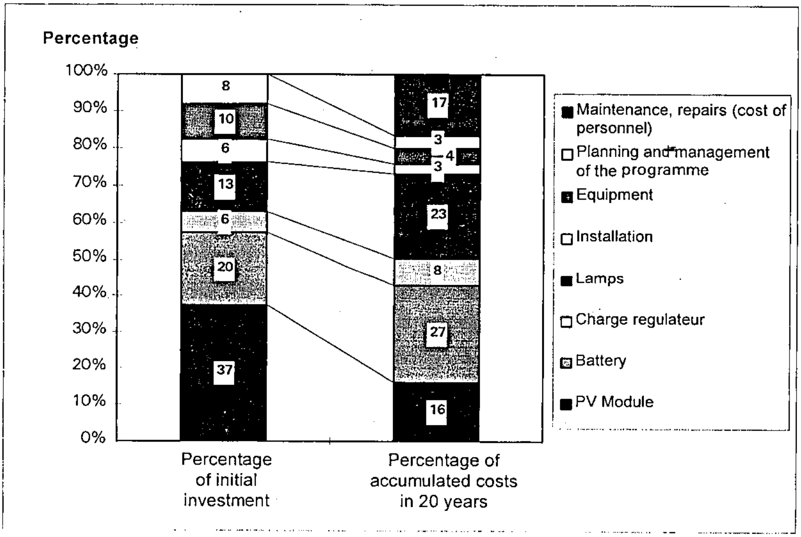


Fig. 9-27 f): Economic comparison of SHS components, System C (initial investment and relative global costs for 20 years of operation) as percentage of the total costs

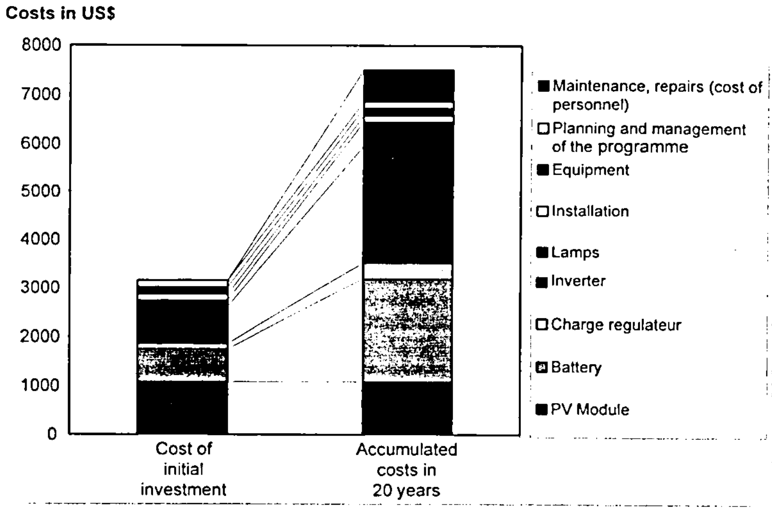


Fig. 9-27 g): Economic comparison of SHS components, System D (initial investment and relative global costs for 20 years of operation)

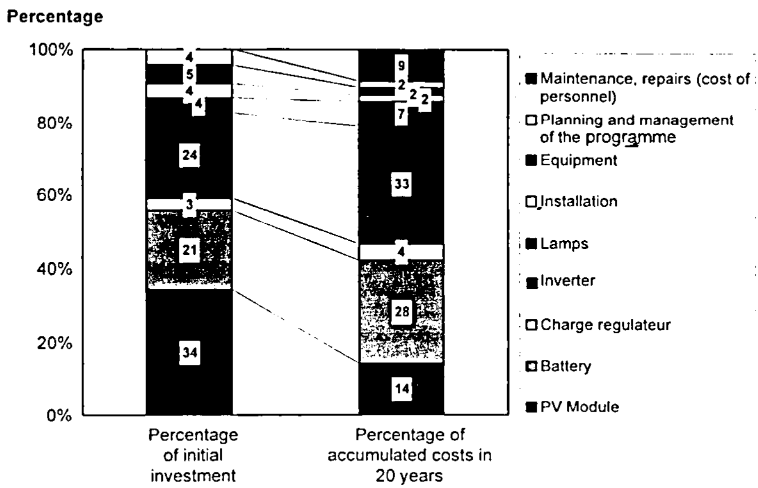


Fig. 9-27 h): Economic comparison of SHS components, System D (initial investment and relative global costs for 20 years of operation) as percentage of the total costs

Discussion of the results

The PV generator (the *module(s)*) is the most significant cost factor in all of the four systems analysed regarding initial investment costs. However, its contribution is below half of the total cost, varying between 34 and 44%.

In twenty years its contribution to the relative global costs is considerably less important (14% to 18%), due to its long lifetime.

On the other hand, the contribution of the *battery* to the initial investment costs is rather low (between 8% - in the case of a battery with thick flat plates - to 21% for two tubular batteries) but, with respect to the relative global costs, it becomes the most important component (contribution between 15% and 27%).

If the user installs inappropriate batteries (car batteries), their contribution to the relative global costs may easily exceed 50%.

The costs of personnel for *repair and maintenance* are of the same order of magnitude as those for the battery in the analysis of the relative global costs.

This underlines once more that the expected cost reduction of PV cells (which actually contribute to about half of the costs of the modules) will not lead to any significant decrease in the costs of the SHS.

Even now the *BOS* (*Balance of the System* - components of the SHS apart from the module) make up the majority of the costs of decentralised PV systems of low power. Improvements of quality and viability of these components are therefore more important and effective for cost reduction than a reduction in the price of the cells.

Batteries still offer a potential for cost reduction. Unfortunately, their price depends on the international price of lead. Owing to the sharp rise in the price of lead in recent years, the Tunisian battery manufacturers almost doubled battery prices between 1989 and 1996.

For system D, operating at 230 V ac, the economic influence of the *inverter* has to be underlined, as it contributes to about one third of the relative global costs of the system for twenty years of operation.

Therefore, although solar energy is free, the costs of its exploitation and conversion into electricity are by no means negligible.

In order to ensure operation of the SHS for twenty years, it will be necessary to invest between 1.5 and 2 times the amount spent on the initial acquisition.

9.3.3.4. Comparison between costs for SHS and those for connection to the electrical grid

In order to calculate the cost per kWh of electricity from photovoltaics, it is assumed that a PV module of 50 Wp allows a consumption of 150 Wh per day.

System	A	B	C	D
Production per year	77 kWh	110 kWh	110 kWh	219 kWh
Production in 20 years	1 533 kWh	2 190 kWh	2 190 kWh	4 380 kWh
Cost per kWh	*1.49 $*	*1.10 $*	*1.78 $*	*1.71 $*

Tab. 9-49: *Cost per kWh of solar electricity produced by the four SHS configurations*

In the national programme, the costs of SHS are shared between the user households and the Tunisian government.

In our calculations, we consider three alternatives:

- *Case1:*
  The user household pays a lump sum of 104 US $. The rest of the initial investment is taken over by the public authorities.
  In addition, the government provides and finances the national and regional structures, necessary for planning and management of the programme, the control and acceptance of the installations, provision of advice to the users etc. During the warranty period of two years, this structure also protects the rights of the users in claims against the supplier and installer of the systems. Afterwards, the public structure will still be available to give advice to the users (estimated time: one year), but will no longer provide financial help for repairs or the acquisition and distribution of spare parts. Such costs will be borne entirely by the user households.

- *Case 2:*
  The user household pays a lump sum of 104 US $. The rest of the initial investment costs plus the total costs linked to the operation of the systems (permanent public structure, replacement of defective components, repairs and maintenance) will be taken over by the public authorities.

The main arguments in favour of this approach are:

- The services provided by SHS are inferior to those of the grid. This justifies charging the SHS user households less than those connected to the grid.
- It is feared that a considerable number of user households will not be able to pay for the necessary spare parts, mainly batteries. Hundreds, if not thousands of frustrated households will complain to the regional and national authorities and advertise the insufficient services of SHS. This will bring a bad image to solar rural electrification.
- The government has a moral responsibility for SHS, which it acquired and entrusted to the user households. This responsibility, which should continue beyond the warranty period, includes, if necessary, the replacement of faulty components and other services necessary to ensure the continuous operation of the PV systems.

- <u>Case 3:</u>
  Identical conditions to case 2, but here the user household contributes to the cost of operation of the SHS by a constant yearly amount of 34 US $. In the comparative calculations, expenditures incurred in collecting this financial contribution are not taken into account.

Case 1 corresponds to that recommended in the "Energy Supply Concept" for rural areas of the Gouvernorat of El Kef. This approach has so far been applied as a standard in the framework of the national programme for solar rural electrification.

The two other approaches are at present being discussed in Tunisia. They are part of the negotiations between AME, STEG and regional authorities for the preparation of the IXth Five-Year Plan.

For each of the three approaches and each of the four configurations the costs to be charged to the user household and to pubic authorities have been calculated on the basis of the relative global costs for a period of twenty years.

Let us now regard the "grid" alternative.
The costs of the connection of the household to the electrical grid are shared between the user and the public authorities (budgets of the Gouvernorat and of STEG) as follows: the user pays a fixed amount (208 US $, in some cases even less) in instalments together with his bimonthly bill, over a period of two years. The rest is taken over by public authorities.

The majority of the STEG clients in rural areas benefits from the special tariff for "small LT consumers", which is 0.069 US $ per kWh (0.065 US $ plus 6% VAT plus 0.02 US

$ tax). It is limited to clients with a monthly electricity consumption of less than 50 kWh.

This tariff is heavily subsidised. Based on STEG figures, the real costs are estimated as shown in the following table.

Cost position	**Grid maintenance**	**Billing and collecting money**	**Management**	**Production**
Amount	13.2 $ per client and year	5.3 $ per client and year	7.9 $ per client and year	0.107 $/ kWh

Tab. 9-50: Cost of electricity supply via the electrical grid LT of STEG

Based on these unit prices and an estimated yearly consumption of 400 kWh per client in rural areas of north-west and central Tunisia, the relative global costs for a period of twenty years have been calculated. We have taken into account four different costs, depending on the distance of the dwelling from the existing grid, to express the costs of the grid connection.

The relatively low electricity consumption estimated is justified as follows:

- the electricity consumption per client LT in the Gouvernorats of north-west and central Tunisia has been stagnant for at least ten years. There are no indications that this will change in future (see chapter 3.3.).
- In the countryside, the average consumption per client is about two thirds of the average consumption of all LT clients of the Gouvernorat.

We have estimated the yearly growth rate of the electricity prices to be 5.35%

Cost of grid connection(in US $)	***1 562 $***	***2 083 $***	***2 603 $***	***3 124 $***
in DT	1 500 DT	2 000 DT	2 500 DT	3 000 DT
Relative global costs (20 years)	***2 653 $***	***3 174 $***	***3 694 $***	***4 216 $***
Cost per kWh	***0.33 $***	***0.40 $***	***0.46 $***	***0.53 $***

Tab. 9-51: Relative global costs for a period of 20 years for households, connected to the electrical grid; and costs per kWh

Tab. 9-52 shows the sharing of the costs between the user and public authorities.
The user (client of STEG) contributes to the grid connection costs (208 US $) and pays for his yearly electricity consumption of 400 kWh, which in twenty years amounts to a total of 440 US $. The rest is taken over by public funds.

Cost of grid connection(in US $)	***1 562 $***	***2 083 $***	***2 603 $***	***3 124 $***
Relative global costs: contribution from public funds	**2 005 $**	**2 526 $**	**3 046 $**	**3 568 $**
as %	76 %	80 %	82 %	85 %
Contribution of the household (client of STEG)	**648 $**	**648 $**	**648 $**	**648 $**
as %	24 %	20 %	18 %	15 %

Tab. 9-52: *Relative global costs of a grid-connected household: sharing of costs between public authorities and the user*

Conclusions:

The motivation for introducing the solar option into the rural electrification programmes in Tunisia was:
- to reduce the permanent burden of the government in respect to the existing grid-based programme by offering a less costly alternative, and
- to complete the electrification programme in regions where, due to a dispersed habitat or a difficult geomorphology, the grid would never have a chance of reaching.

The inconvenience, that the services offered by the solar solution were less complete, as a result of the limited quantity of energy generated, was accepted. These services are nevertheless more favourable than the classic solutions (kerosene lamps, batteries). Because of the superiority of the services of the grid solution, the national and regional authorities favour the solar solution only in the case when it offers clear economic advantages.

Compared to the cost of connecting a household to the grid at 1 562 $ (1 500.- DT), only an SHS configuration, operating at 12 V and having a PV generator of up to 100Wp plus a flat plate battery will provide an interesting alternative.

A configuration consisting of a PV generator of 100 Wp and a tubular battery would also be competitive, under the condition that the cost of operation was charged entirely to the user. However, taking into account the high prices of these batteries, it is unrealistic to assume that users would buy such batteries as spare parts.

For system D (200 Wp, tubular batteries) the operational costs are excessively high and only a small wealthy elite of the rural households are capable of paying them. Therefore, it is preferable to connect households to the grid even when connecting costs exceed 3 000 US $, instead of providing this configuration as a standard PV system.

If the government decides to cover the operational cost of SHS, the photovoltaic alternative rapidly loses any economic advantage compared to the electrical grid. Subsidies would rise to a level of 95% to 99%, which would certainly not be in line with support for "self-help initiatives".

A financial contribution of 34 $ per year and user household is nowhere near enough to cover the operational cost of SHS (repairs, maintenance), even when the cost of collecting this money is not taken into account.

For the consequences of the different approaches and configurations on the potential of photovoltaics in Tunisia, see chapter 12.

A view on the costs per kWh generated by photovoltaics shows that the solar alternative is still a costly one. The costs per solar kWh are at least four times as high as those of the classic grid solution. Consequently, this expensive energy should not be wasted, and lamps, radios and TV sets should be optimised for low electrical consumption.

Case	1						2						3					
Initial invest-ment	User: 104 $ Public authority: the rest						Identical to case 1						Identical to case 1					
Repairs mainten-ance etc.	User: all (after warranty) Public authority: Structure for advice to users and follow-up						User: nothing Public authority: all						User: 34 $ per year Public authority: the rest					
Sharing of the relative global costs (20 years)	contri-bution of user	%	**public contri-bution**	%	Cost of kWh for the user	Cost of kWh for the author-ities	contri-bution of user	%	**public contri-bution**	%	Cost of kWh for the user	Cost of kWh for the author-ities	contri-bution of user	%	**public contri-bution**	%	Cost of kWh for the user	Cost of kWh for the author-ities
System A	1 448 $	63%	**845 $**	37%	0.94 $	0.55 $	104 $	5%	**2 189 $**	95%	0.07$	1.42 $	602 $	26%	**1 691$**	74%	0.39 $	0.80 $
System B	1 538 $	64%	**872 $**	36%	0.70 $	0.40 $	104 $	4%	**2 306 $**	96%	0.05 $	1.05 $	602 $	25%	**1 808$**	75%	0.27 $	0.83 $
System C	2 334 $	60%	**1 564 $**	40%	1.07 $	0.71 $	104 $	3%	**3 898 $**	97%	0.05$	1.73 $	602 $	15%	**3 400 $**	85%	0.27 $	1.51 $
System D	4 469 $	60%	**3 040 $**	40%	1.02 $	0.69 $	104 $	1%	**7 509 $**	99%	0.02 $	1.69 $	602 $	15%	**7 011 $**	85%	0.08 $	1.63 $

<u>*Tab. 9-53:*</u> *Economic comparison: sharing of the relative global costs (20 years) between the users and the public authorities according to three different approaches*

9.4. The design of the standard system

9.4.1. The design of the components according to formulas

9.4.1.1. Application of the formulas of Siemens

9.4.1.1.1. The power of the PV generator

The formulas of *Siemens Solar /9-4/* allow an SHS to be designed approximately. They are applied here for the case of Tunisia.

The power of the PV generator is calculated as follows:

Estimated daily electricity consumption (Wh)	200
+ Supplement of 30% for compensation of the losses of the battery and the other components (Wh)	+ 60
= Average daily electricity demand to be covered	= 260
divided by:	
Nominal power of a PV module (Wp)	50
x Regional factor for the climatic zone of Tunisia	x 4
Product (50 x 4) =	= 200

Number of modules: 260 / 200 = 1.3

Taking into account the power of the reference module (50 Wp), the necessary **nominal power of the PV generator** thus amounts to:

50 x 1.3 = **65 Wp**

9.4.1.1.2. The capacity of the battery

According to /9-4/, the capacity of the battery may be estimated as follows:

Average daily electricity demand (Wh)	260
x Autonomy of the system (days)	x 3
260 x 3 =	= 780
+ Increase to protect the battery against deep discharge (30%): 780 x 0.3 =	+ 234
= Necessary capacity in Wh	= 1 014
Divided for transformation in Ah for a PV system operating at 12 V	./. 12
= Necessary capacity (Ah)	= 84.5

Thus, the necessary capacity is 84.5 Ah.
The *appropriate capacity* for a battery thus becomes **90 Ah.**

9.4.1.2. The design based on the results from data acquisition systems

9.4.1.2.1. The power of the PV generator

In applying the evaluated data of the four *MODAS* (see chapter 9.1.) a more precise design of SHS components is possible.

The calculation is based on the simple fact that the consumed energy must correspond to the generated solar energy.

Taking into account the average daily consumption of 200 Wh, the yearly average consumption is:
200 x 360 = 72 000 Wh/ year, or 72 kWh / year.

The quantity of solar electricity to be delivered can thus be estimated as:

Average solar radiation on an inclined surface of 45° (case of El Kef, see chapter. 9-3 c) kWh/ [(m^2 x d)]	5.05
to be transformed in hourly radiation	x 0.1
x Number of sunshine hours per year (*Fig. 9-28 /9-5/;* case for the west of the Gouvernorat of El Kef)	5.05
x Efficiency of the system (see chapter 9.1.5)	x 0.0879
x Compensation factor for sunshine hours, which cannot be used (case of the already fully charged battery)	x 1.15
x Surface of the module to "catch" the solar radiation (m^2)	x F

Thus,
72 kWh/a = 5.05 x 0.1 x 2 700 x 0.0879 x 1.15 x F

the result for F becomes:
F = 72 / 137.83 = 0.522 m^2

According to */9-4/* the surface of a 50 Wp module is: 1.293 x 0.329 = 0.425 m^2
So, the necessary surface for 1 Wp is:
0.425 / 50 = 0.0085 m^2
and the necessary power of the PV generator becomes:

0.522/ 0.0085 = **61 Wp**

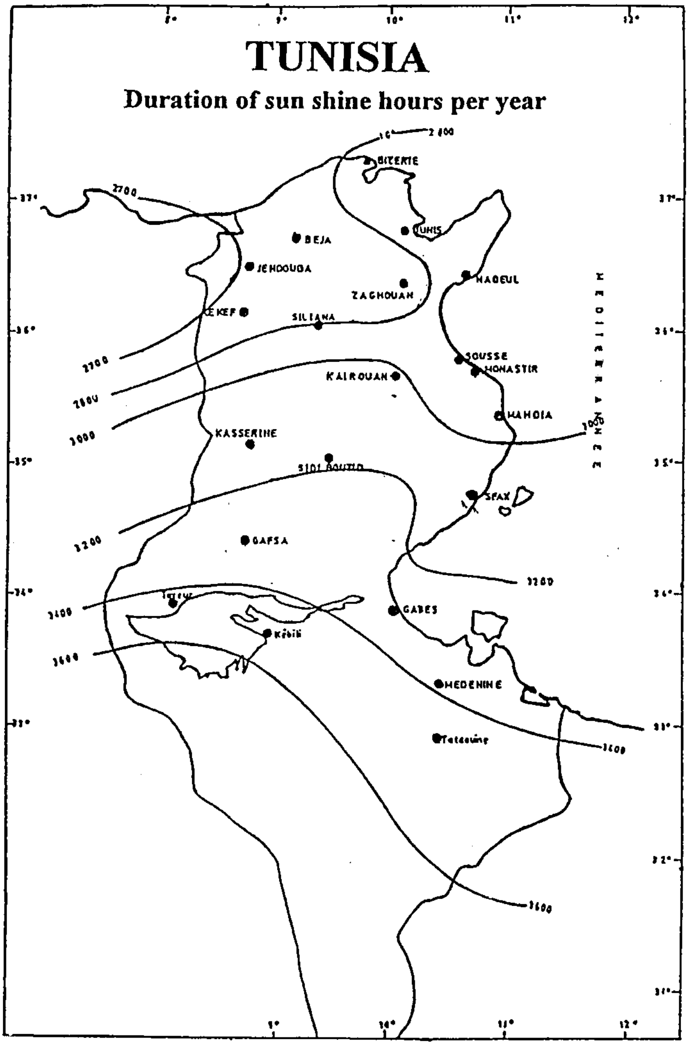
9.4.1.2.2. The estimation of the necessary capacity of the battery

Average daily consumption (Wh/ day)	200
x Autonomy (days)	x 3
x Factor for taking into account tthe fact that the battery will be discharged to a maximum of 60%: 1/0.6 =	x 1.67
x Factor for compensating the losses of the system (see chapter 9.1.5): 1/ 0.745	x 1.34
./. Voltage of the PV system (12 V)	./. 12

The necessary capacity is thus calculated as: (200 x 3 x 1.67 x 1.34) / 12 = **112 Ah**

For the photovoltaic generator, the results of the two calculations are rather close. A *module of 70 Wp*, such as selected for the first stage of the national programme, should therefore be sufficient to cover a daily average consumption of electrical energy of 200 Wh.

In respect of the battery, the results differ more widely. Taking into account the estimates and simplifications inherent in the calculations, the selection of a solar battery with thick flat plates of a nominal capacity of *100 Ah* may be considered as appropriate.



<u>Fig. 9-28:</u> *Annual sunshine hours in Tunisia Source:/9-5/*

9.4.2. Design based on computer simulation programmes

9.4.2.1. Programmes applied and the framework conditions

The simulation programmes allow an energy balance to be worked out, taking into account the variation of the meteorological data and the consumption as well as the characteristics of the components of the SHS. The programme indicates the level of charge of the battery, and in consequence the number of cuts in electricity supply, which have to be expected.

In order to avoid repeated cuts and to ensure a maximum lifetime of the battery, the power of the PV generator has to be sufficient to charge the battery completely, even in winter. In *Fig. 9-1* and chapter 11.1.4. it can be seen that a battery cycled in a state of partial discharge will suffer from premature "ageing" resulting in a shortened lifetime.

Most of the calculations have been carried out with the INSEL computer programme /9-6/. These calculations were based on a constant daily consumption profile and used the characteristic curves of a new battery. However, we found that ageing effects appeared after only six months of operation, in the case of TV batteries, and this significantly influenced the "consumable" quantity of electricity. The results of the data acquisition instruments in El Kef have shown, in addition, that the daily consumption of electricity of the households varies seasonally (*Fig. 9-3* to *9-21*).

Improvements to the *INSEL* programme, made by *Jraidi* (ENIT) allowed daily or seasonal variations of the electricity consumption of the households plus the ageing effects of the batteries to be taken into account */9-7/*.

This computer programme was applied to calculations based on the real consumption of a household (SHS KEF-42). The ageing effect was taken into account in respect of the TV batteries with a nominal capacity of 90 Ah.

The meteorological data registered by the data acquisition system for the year 1992 were applied over half hour intervals. Unfortunately during 10 consecutive days at the end of March, no radiation was registered (probably because something had been laid on the measuring sensors). As the autonomy of the system foreseen was just three days, in all graphs during this period an electricity cut has been marked, which is hardly realistic.

In the simulations, electricity cuts were programmed to occur at the moment that the discharge fell to a level of 20% of the nominal capacity of the battery.

All calculations started with a battery assumed to be new and fully charged. The maximum voltage of the battery at the state of charging was fixed at 14.2 V

9.4.2.2. The spectrum of the calculations

The configurations taken into account (*Tab. 9-53*) are those of the pilot dissemination phase (system with one module, corresponding to the SHS KEF-42, see Tab. *9-1*), and the first (configuration with solar flat plate battery and tubular battery), second and third stage of the national programme, plus a configuration applied in the framework of an FNS project (see also *Tab. 9-34* to *9-40*).

Configuration N°	Project, programme	PV module(s)	Nr. of lamps	Nr. of TV sets*)	Battery
1	Pilot dissemination phase	Siemens, 53 Wp	2	1	Assad TV, 90 Ah in C20
2	First stage of national programme (variation a)	BP Solar, 75 Wp	3	1	Assad SL 110, thick flat plates 90 Ah in C20
3	First stage of national programme (variation b)	BP Solar, 75 Wp	3	1	Fulmen, tubular, 100 Ah in C10
4	Second stage of national programme	Photowatt, 2 x 50 Wp=100 Wp	2	1	Assad SL 110 thick flat plates 90 Ah in C20
5	Third stage of national programme	ANIT, 2 x 50 Wp=100 Wp	3	1	Assad SL 110 thick flat plates 90 Ah in C20
6	FNS	Photowatt, 2 x 50 Wp=100 Wp	3	1	Tudor Tunisia, tubular, 130 Ah in C20

*) assumed: black and white TV set, consumption: 21 W in dc (identical to SHS *KEF-42*, see *Tab. 9-1*)

Tab. 9-54: Configurations of the SHS treated in the simulations

In applying the above-mentioned framework conditions (chapter 9.4.2.1.) and these six configurations, the effects of a daily constant electricity consumption of 150, 180, 250 and 350 Wh were examined.

In addition, calculations were performed applying a realistic consumption profile of a user household (that of the SHS KEF-42, a system with one module and two lamps, see chapter 9.1.4.). In order to adapt this profile to the configurations with three lamps (configurations 2, 3, 4, and 6), the consumption profile was modified, simulating the use of an additional lamp. The effect of the use of a colour TV, characterised by a higher electricity consumption, was considered as well.

We therefore have six calculations, applied to the six SHS configurations. We will present only a selection of the multitude of results obtained.

9.4.2.3. Simulations with constant hourly consumption profile

For the *configuration 1 (one PV module of 53 Wp, TV battery)*, a daily consumption of 150 Wh *(Fig. 9-29)* causes a drop in the state of charge of the battery, resulting in cuts in the electricity supply. The battery, assumed to be fully charged at the beginning of the year, does not reach this condition again until the month of April. In autumn and winter, the level of charge drops again. Consequently, the battery arrives at a state of complete charge only during six months per year. This long period of cycling at a level of partial discharge provokes a premature ageing of the battery and a reduction of its optimum lifetime.

Logically, if the average daily electricity consumption is raised, the situation for the battery becomes even worse *(Fig. 9-30)*.

Therefore, this configuration is not appropriate to cover the basic electricity needs of a rural household.

For the *configuration 2 (one module of 75 Wp, battery with thick flat plates)*, the case of a daily electricity consumption of 180 Wh was analysed first. Just one electricity cut is seen in March, and the periods of cycling the battery in a state of partial discharge do not exceed one month *(Fig. 9-31)*.The configuration thus proves to be appropriate for this level of consumption.

For an average daily consumption of 250 Wh this is no longer the case (Fig. 9-32). The periods of battery cycling without reaching the level of complete recharge become long, and the electricity cuts become frequent. In summer, however, this configuration does allow a relatively high electricity consumption.

If the battery with thick flat plates were replaced by a tubular battery with a slightly higher nominal capacity *(configuration 3)*, this would not result in a significant change in the performance described.

The increase of the power of the PV generator to 100 Wp (*configurations 4 and 5, batteries with thick flat plates*) shows a surplus of "non consumable" energy of 26.6% at a daily average consumption of 180 Wh (*Fig. 9-33*). Electricity cuts are therefore not expected. Even in the case of a rise to an average daily consumption of 250 Wh *(Fig. 9-34),* this configuration would still be satisfactory.

The installation of a battery of superior capacity *(configuration 6, PV generator of 100 Wp, tubular battery of 130 Ah)* has no significant effect on the state of charge of the battery. The results are almost identical to those of the configurations 4 and 5 (see *Fig. 9-35*, showing the performance of a daily consumption of 250 Wh). However, for a daily average consumption of 350 Wh, this configuration turns out to be insufficient as well (*Fig. 9-36*).

Tab. 9-55 summarises the results of the calculations.

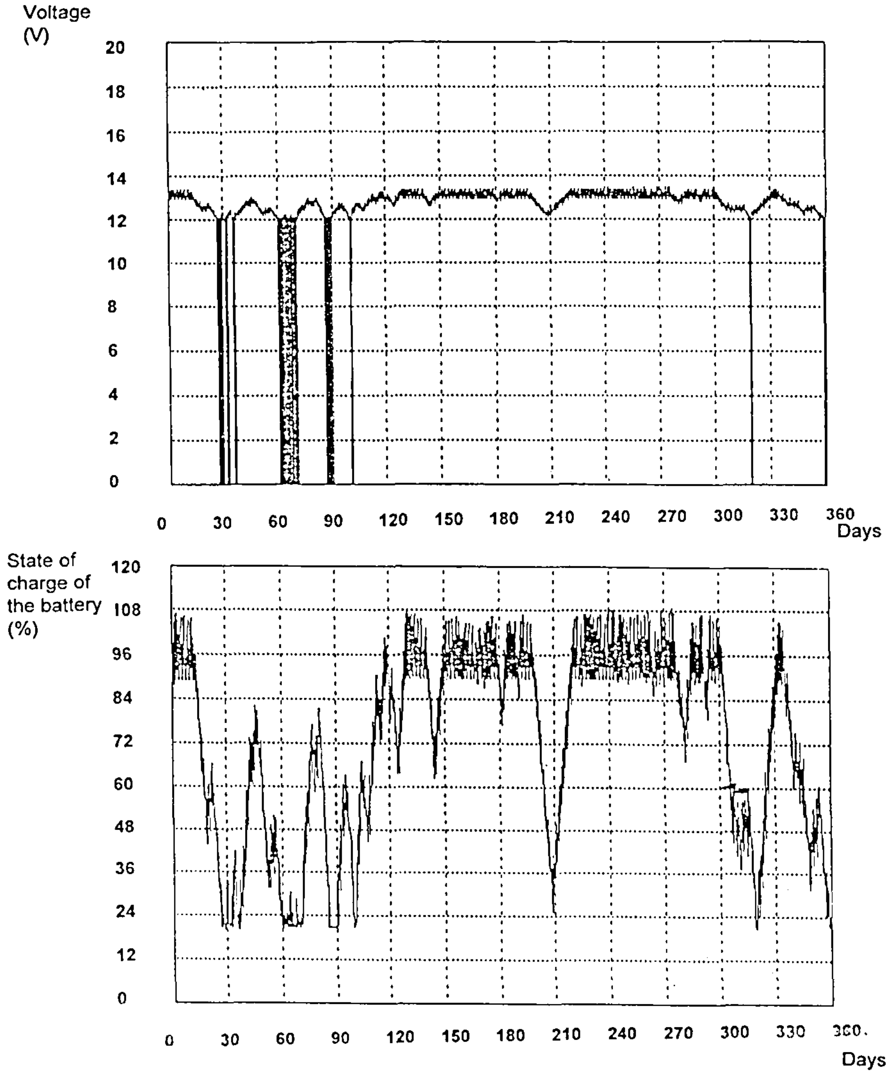


Fig. 9-29: Results of simulations
Configuration 1 *(module 53 Wp, TV battery, capacity 90 Ah),*
daily constant consumption of ***150 Wh****.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Remark: the electricity cut around the 90th day is not realistic; it is the consequence of a lack of registration of radiation data of 10 days

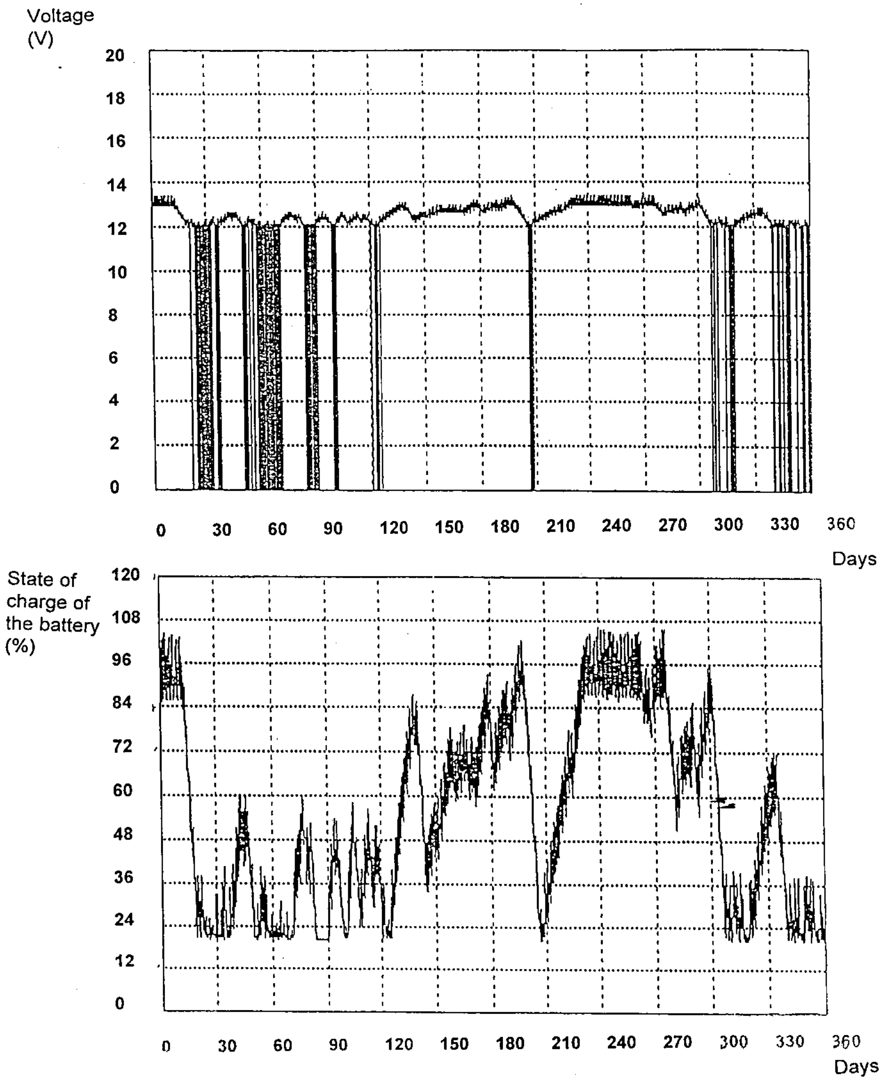


Fig. 9-30: Results of simulations
Configuration 1 *(module 53 Wp, TV battery, capacity 90 Ah),*
daily constant consumption of ***180 Wh****.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

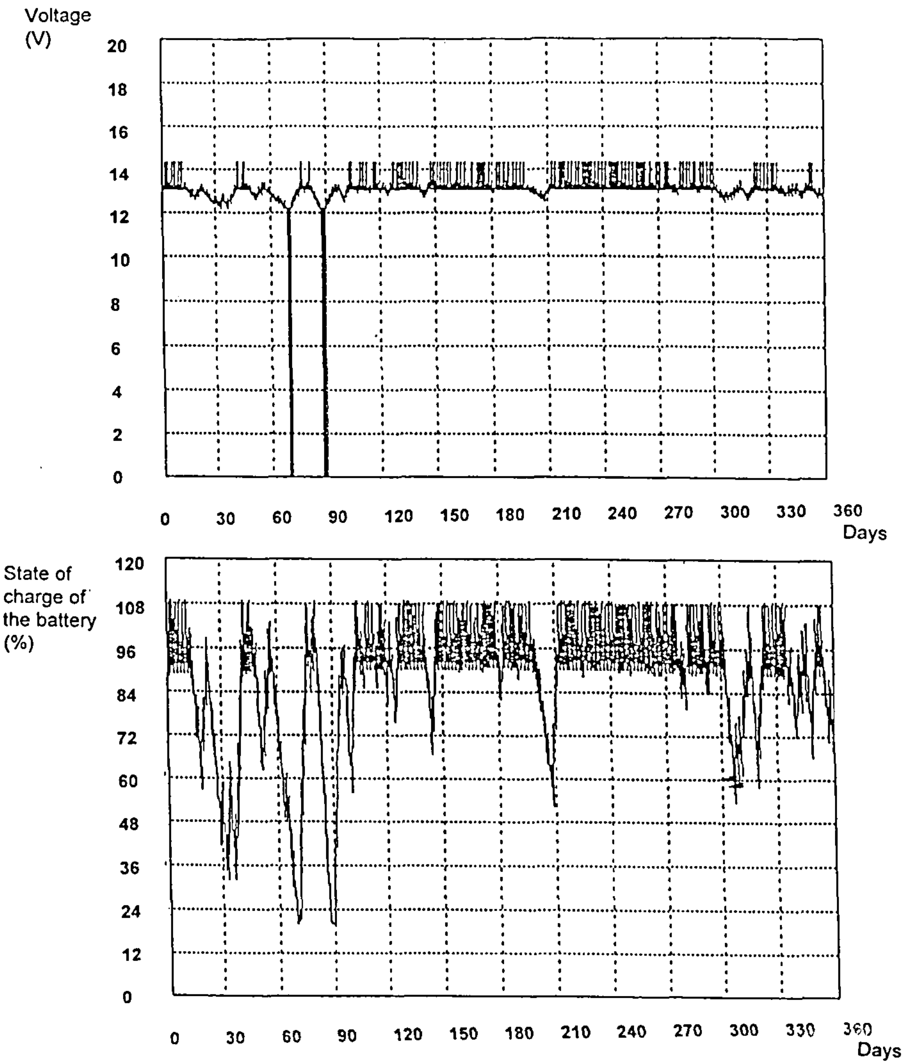


Fig. 9-31: Results of simulations
***Configuration 2** (module 75 Wp, "solar" battery with thick flat plates, capacity 90 Ah), daily constant consumption of **180 Wh**.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

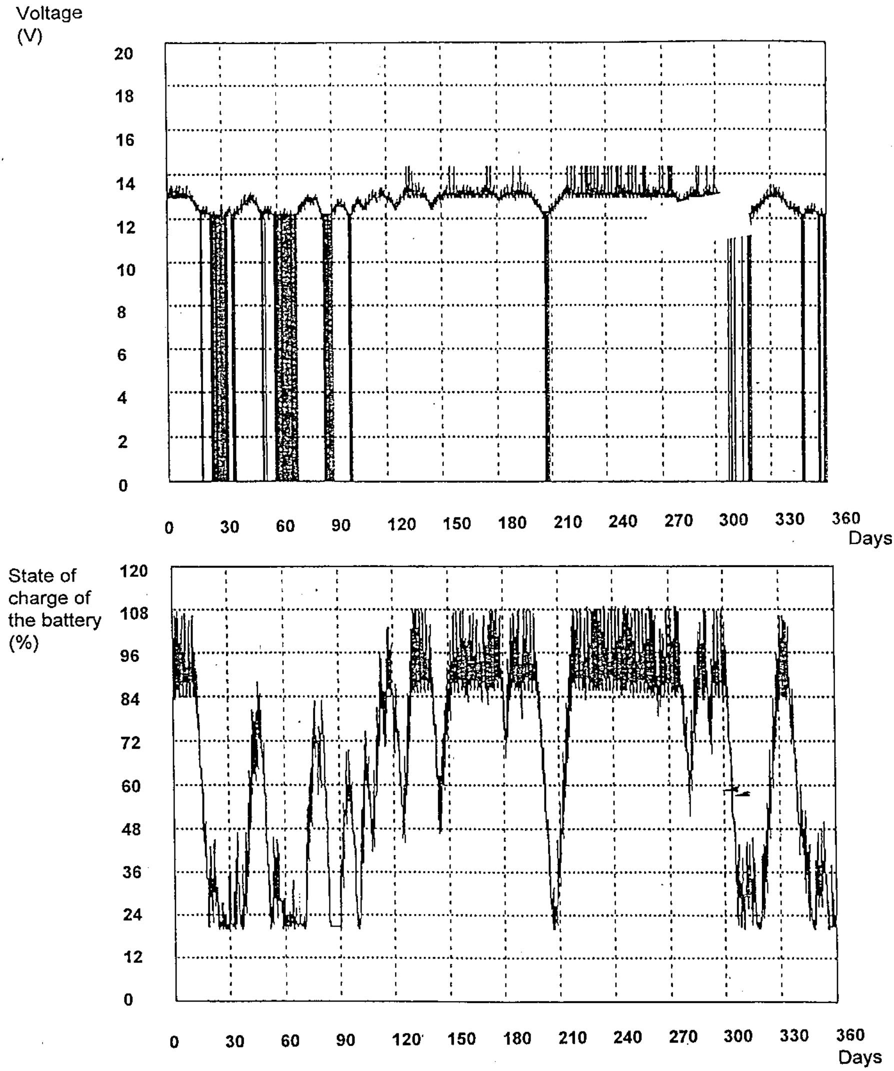
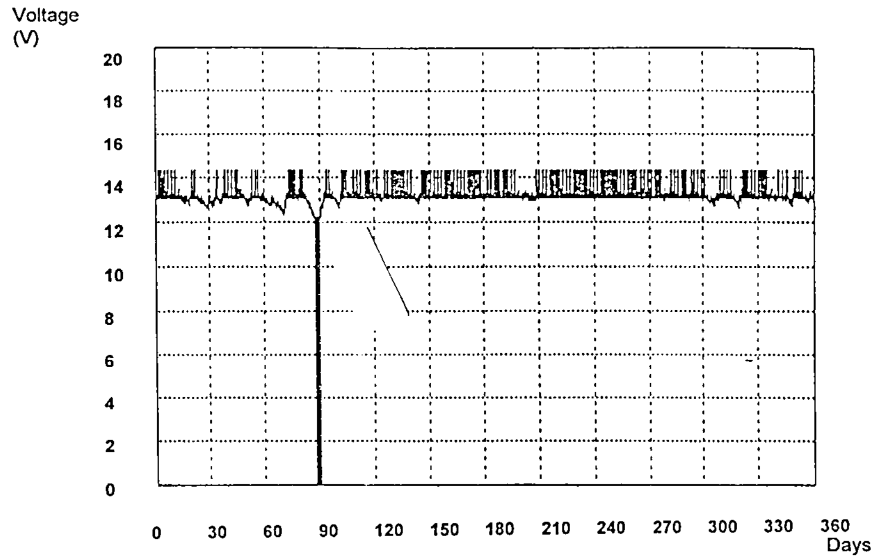
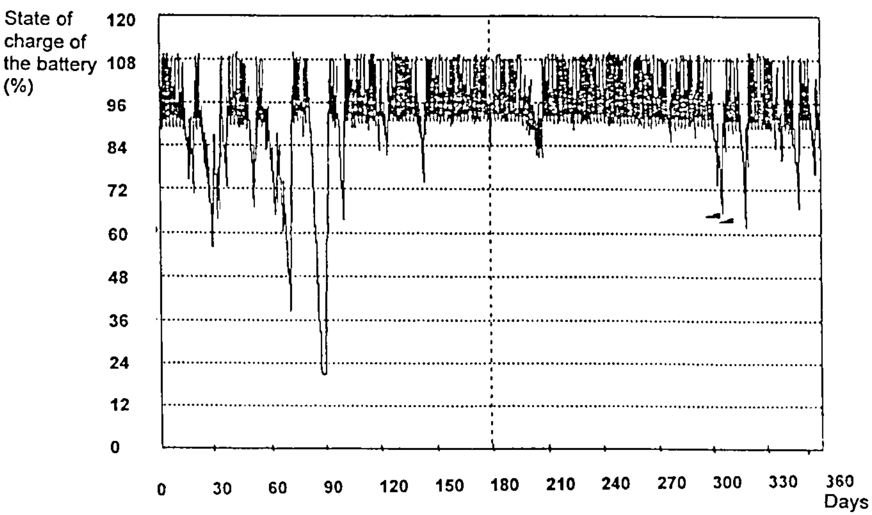


Fig. 9-32: Results of simulations
Configuration 2 *(module 75 Wp, "solar" battery with thick flat plates, capacity 90 Ah), daily constant consumption of* ***250 Wh****.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)





<u>Fig. 9-33</u>: Results of simulations
<u>Configuration 4,5</u> *(PV panel 100 Wp, "solar" battery with thick flat plates, capacity 90 Ah), daily constant consumption of* ***<u>180 Wh</u>.***
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

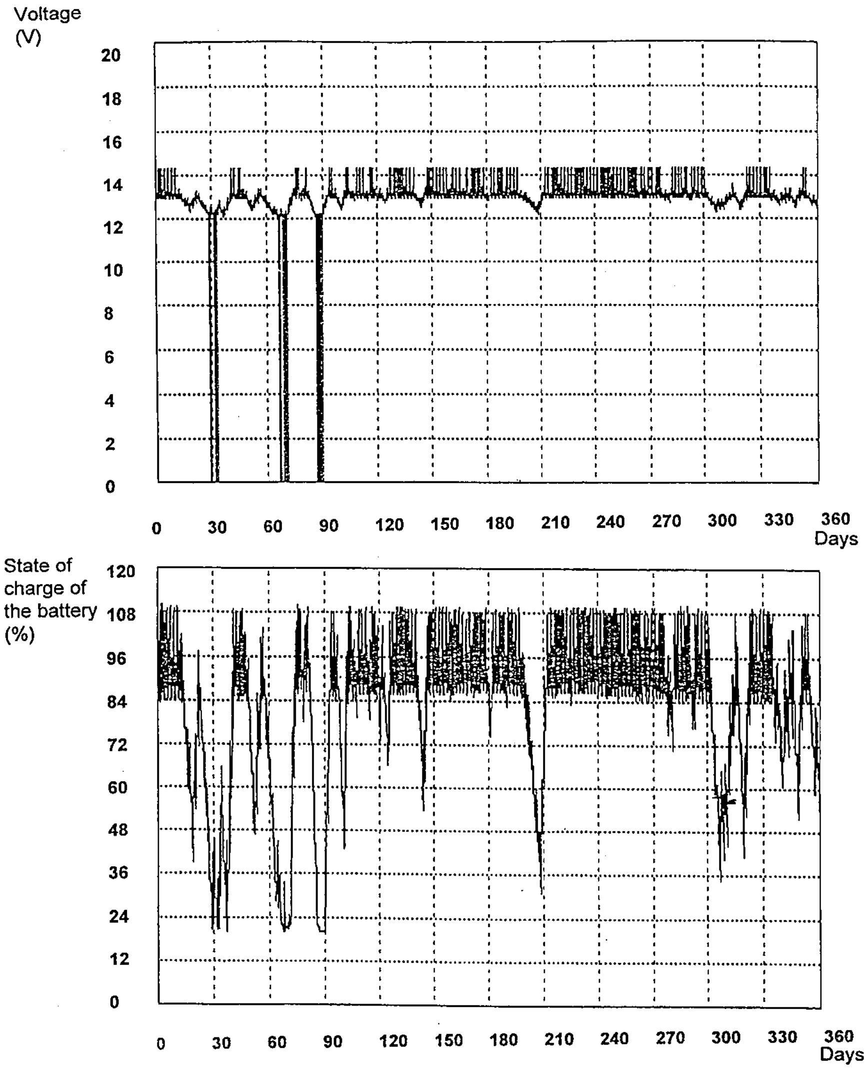
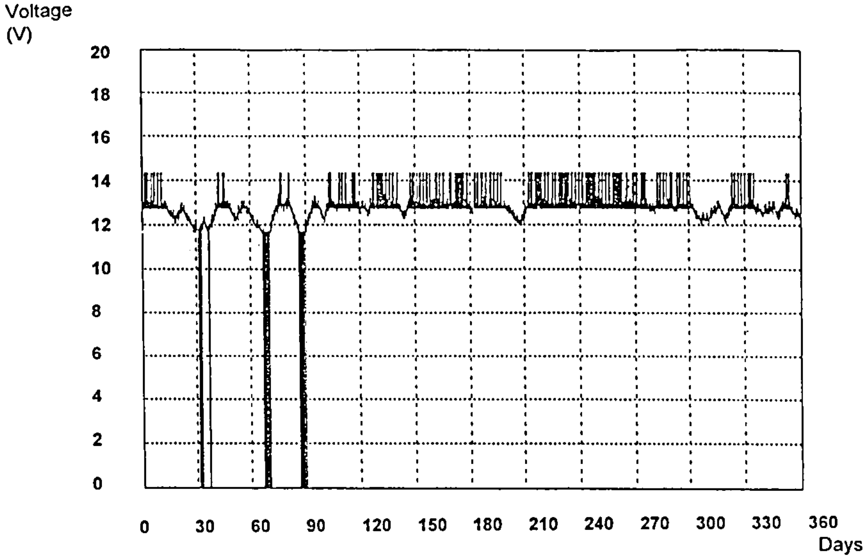
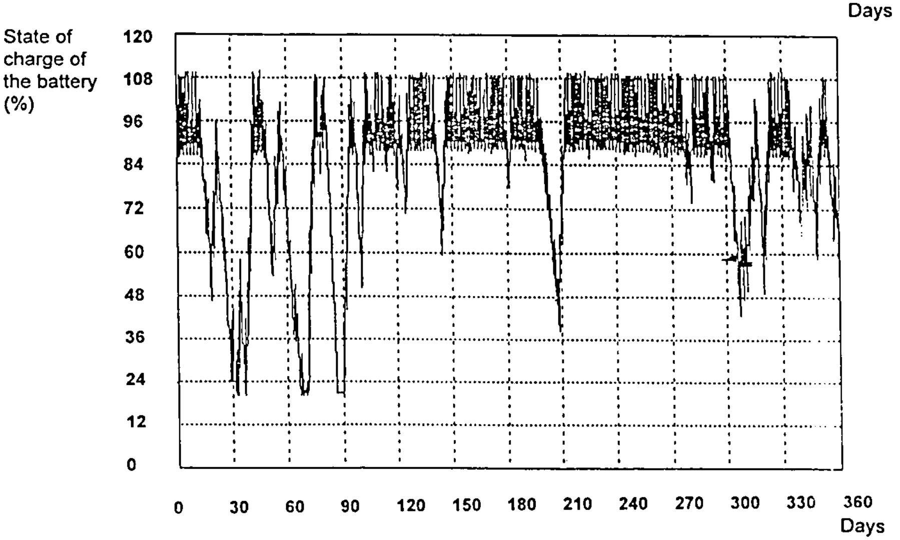
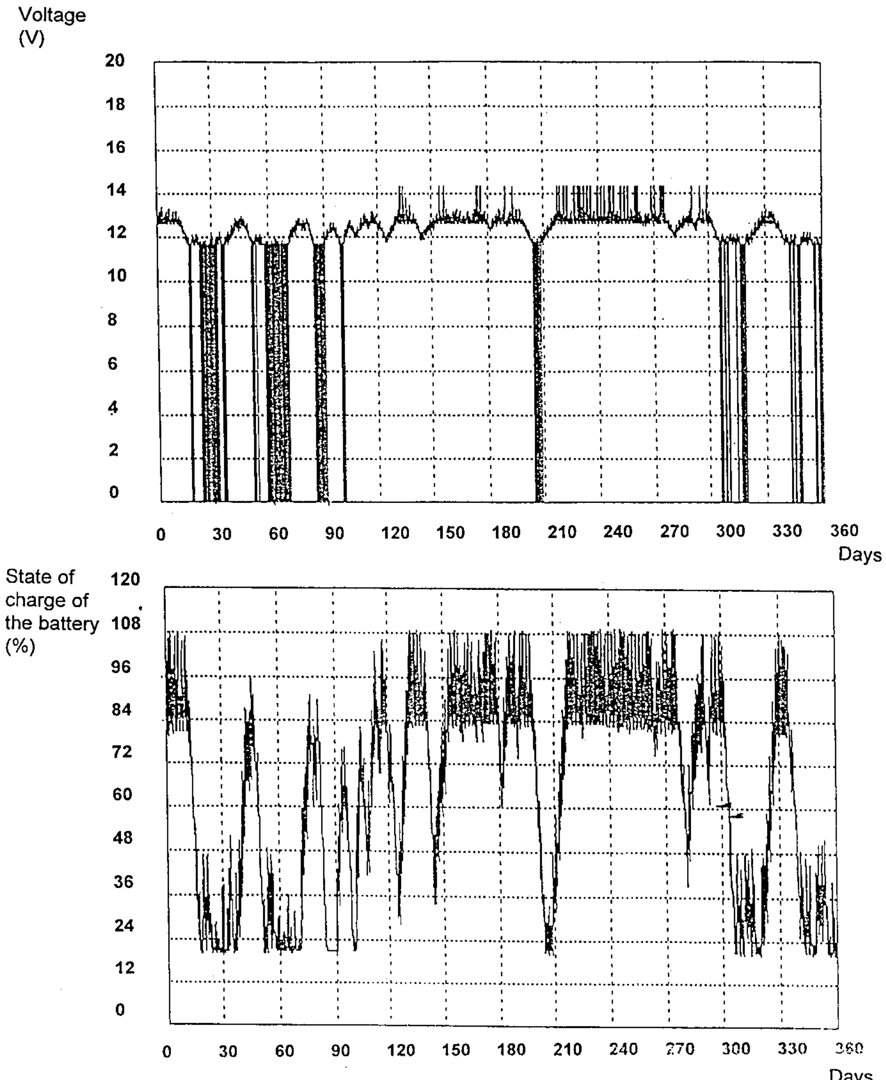


Fig. 9-34: Results of simulations
Configuration 4,5 *(PV panel 100 Wp, "solar" battery with thick flat plates, capacity 90 Ah), daily constant consumption of* ***250 Wh****.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)





<u>Fig. 9-35</u>: Results of simulations
<u>Configuration 6</u> *(PV panel 100 Wp, tubular battery, capacity 130 Ah), daily constant consumption of* ***<u>250 Wh</u>****.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)



<u>Fig. 9-36</u>: Results of simulations
<u>Configuration 6</u> *(PV panel 100 Wp, tubular battery, capacity 130 Ah), daily constant consumption of* ***<u>350 Wh</u>***.
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

Configu-ration	Daily average electricity consumption 150 Wh				Daily average electricity consumption 180 Wh			
	Annual number of electricity cuts	*Rate of charge of the battery*)*	*Energy deficit*)*	*Surplus energy*)*	*Annual number of electricity cuts*	*Rate of charge of the battery*)*	*Energy deficit*)*	*Surplus energy*)*
1	about 10	in winter 45%, in summer 95%; yearly average 71.2%	2.5%	none	significant; about 20	in winter 30%, in summer 60%, annual average 53.9%	6.2%	none
2		90.2%	none	16.5%	1	85.5%	0.5%	8.6%
3	none	91.2%	none	5.3 %	1	86.1%	0.3%	1.2%
4, 5	none	93.6%	none	46.6%	none	91.2%	none	31.8%
6	none	94.5%	none	40.1 %	none	92.2%	none	26.6%

Configu-ration	Daily average electricity consumption 250 Wh				Daily average electricity consumption 350 Wh			
	Annual number of electricity cuts	*Rate of charge of the battery*)*	*Energy deficit*)*	*Surplus energy*)*	*Annual number of electricity cuts*	*Rate of charge of the battery*)*	*Energy deficit*)*	*Surplus energy*)*
1	very significant, unaccept-able	26.1%	17.8%	none	very significant,u naccept-able	24.8%	26.9%	none
2	significant; about 25	65.9%	4.4%	0.6%	very significant, unaccept-able	28.6%	14.2%	none
3	significant; about 25	64.2%	4.4%	none	very significant, unaccept-able	27.2%	14.8%	none
4, 5	5	81.1%	1.1%	12.3%	significant; more than 30	64.6%	5.3%	1.6%
6	4	82.5%	1%	9.4%	significant; about 30	63.9%	5.3%	0.6%

*) annual average

Tab. 9-55: *Results of simulations carried out with several PV configurations for constant daily consumption profiles of 150, 180, 250 and 350 Wh*

9.4.2.4. Simulations using a realistic electricity consumption profile

The application of realistic consumption data gives a better impression of the potential for SHS to cover the electricity needs of a household, than the application of a constant daily consumption profile. The variable profile takes into account seasonal variations in consumption and the adaptation of consumption to the changing climatic conditions. As a reference, we took the case of the SHS *KEF-42*, a system equipped with one module of 53 Wp (*Fig. 9-37*).

It has to be admitted that, owing to the considerable number of power cuts (see histogram, Fig. 9-6), the demand for energy of the household was higher than the energy offered by theSHS, the configuration of which corresponds to system 1.
Regarding the configuration with three lamps, the consumption of SHS KEF-42 for lighting was raised correspondingly (system KEF-42 has only two lamps at its disposal).

In addition, the hypothetical effect of the installation of a colour TV (estimated power: 40 W) instead of the usual black and white TV was also treated here.

Regarding *configuration 1 (module of 53 Wp, TV battery, 2 lamps)* in addition the ageing effect (accelerated discharge) of the battery was taken into account. Comparing the calculated results with the measured data (chapter 9.1.4, *Fig. 9-6 to 9-9),* the calculation corresponds, grosso modo, to a validation of the computer simulation programme. However, the results cannot be identical, as the calculations were carried out on the basis of a battery, which at the beginning of the observed period (1.1.92) was new and fully charged, whereas in reality this was not the case. Nevertheless, the results are very close.

The key result is that the battery remains permanently in a state of partial discharge, resulting in frequent power cuts and an insufficient overall performance (*Fig. 9-38*).

The difference between the first configuration and *configuration 2 (module of 75 Wp, battery with thick flat plates, three lamps)* is significant. This system is well adapted to the consumption profile, if not "oversized", taking into account the energy surplus rate of 50.9% (*Fig. 9-39*). In summer, this system could accept the replacement of the black and white TV set by a small colour TV without any problems. In winter, the colour TV would cause a number of power cuts (although still acceptable). The installation of tubular batteries with an increase of about 10% in capacity (*configuration 3*) would change the results in performance only marginally.

In fact, the *configurations 4 (with two lamps) and 5 (with three lamps)*, characterised by a nominal power of 100 Wp and batteries with flat thick plates, are over-dimensioned with respect to the realistic consumption profile. The use of a colour TV would be possible throughout the year, with only a minimum number of power cuts. (*Fig. 9-41*).

An SHS with a tubular battery of even higher nominal capacity (*configuration 6*) does not provide any advantages regarding its performance, compared with the preceding ones.

The detailed results are shown in *Tab. 9-56.*

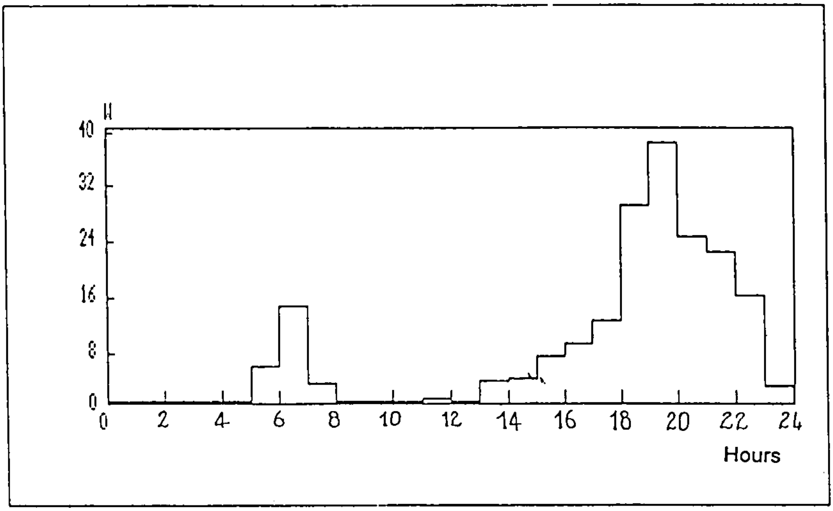


Fig. 9-37: *Mean annual profile of daily consumption, using intervals of 30 minutes, SHS KEF-42, 1992. The simulation takes into account the authentic daily profile. For the configurations 2.3.5. and 6, the "lighting" part of the profile was raised in order to simulate the use of a third lamp.*

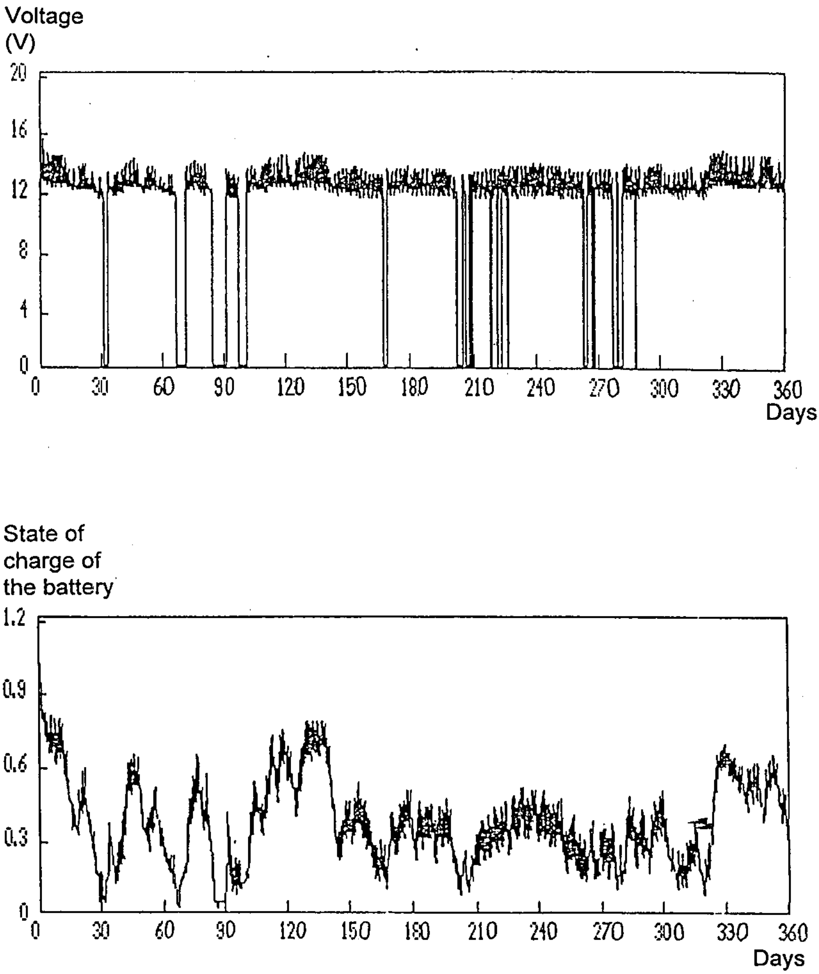
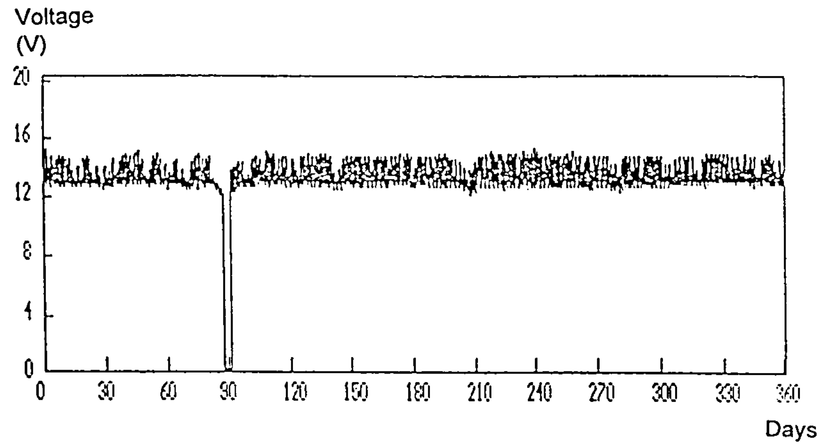


Fig. 9-38: Results of simulations
Configuration 1 *(module 53 Wp, TV battery, capacity 90 Ah),*
authentic consumption profile of SHS Kef-42.
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)



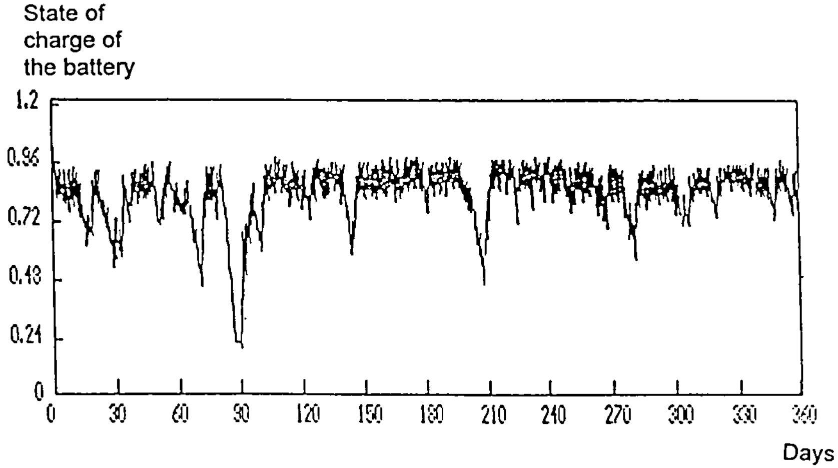
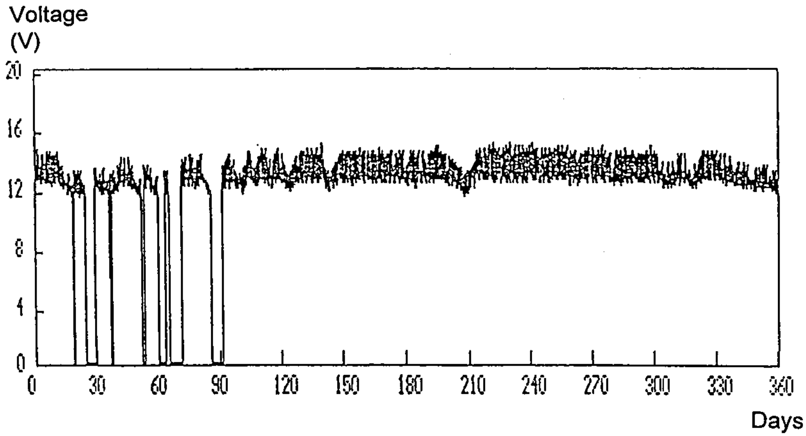


Fig. 9-39: Results of simulations
Configuration 2 *(module 75 Wp, "solar" battery with flat plates, capacity 90 Ah), consumption profile as Fig 9-39, consumption for lighting raised in order to simulate the use of a 3rd lamp.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)



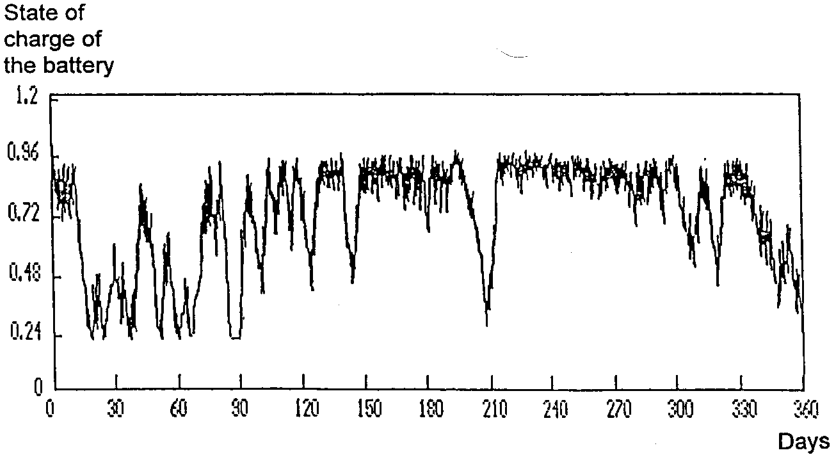
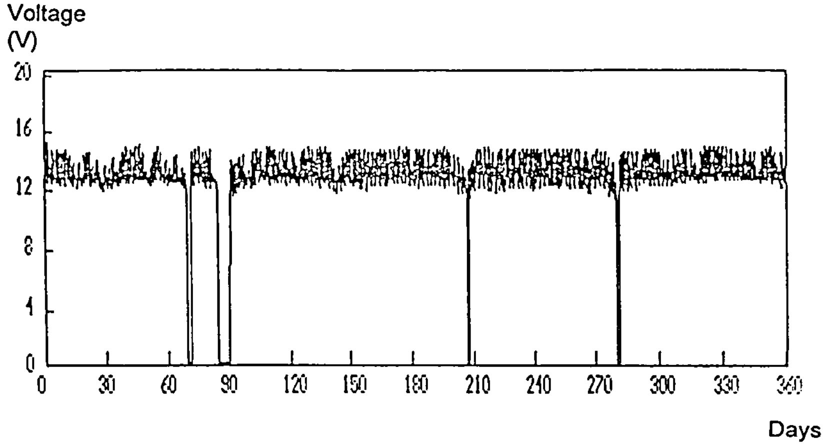


Fig. 9-40: Results of simulations
Configuration 2 *(module 75 Wp, "solar" battery with flat plates, capacity 90 Ah), consumption profile as Fig 9-39, TV-consumption raised in order to simulate the use of a colour TV set.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)



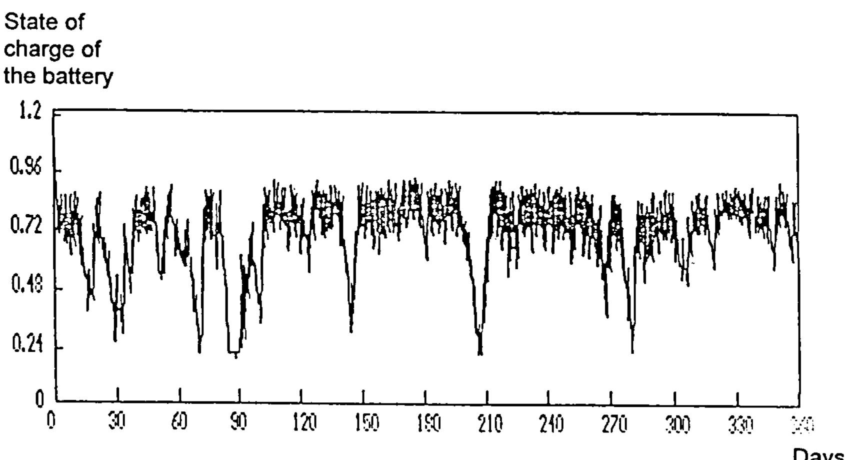


Fig. 9-41: Results of simulations
Configuration 4 *(module 75 Wp, "solar" battery with flat plates, capacity 90 Ah), consumption profile as Fig 9-37, TV-consumption raised in order to simulate the use of a colour TV set.*
Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)
a) Variation of the battery voltage
b) Variation of the state of charge of the battery
Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

Config-uration	Electricity consumption (Profile of household KEF-42)				Electricity consumption (Profile of household KEF-42, colour TV instead of black and white TV)			
	Annual number of electricity cuts	*Rate of charge of the battery *)*	*Energy deficit*)*	*Surplus energy*)*	*Annual number of electricity cuts*	*Rate of charge of the battery*)*	*Energy deficit*)*	*Surplus energy*)*
1	significant, about 15	35.0%	7.4%	3.9%	very significant, unaccepta-ble	25.5%	42.2%	negligible
2**)	none	80.5%	none	50.9%	6	69.5%	6.3%	34.7%
3**)	none	76.0%	none	47.8%	7	65.3%	6.7%	31.9%
4	none	81.7%	none	130.1%	3	67.5%	2.1%	33.3%
5**)	none	80%	none	110.7%	1	74.5%	2.4%	83%
6**)	none	89.7%	none	109.1%	1	85.1%	2.2%	78.8%

*) annual average

**) consumption for lighting increased in order to take into consideration the third lamp installed

Tab. 9-56: Results of simulations with a realistic consumption profile (household of SHS KEF-42); plus profile, assuming the use of a colour TV

9.4.2.5. Conclusions

According to calculations, the performance to be expected by a standard SHS with one module of about 50 Wp is insufficient under the climatic conditions of north-west Tunisia. The field results are thus confirmed by the simulations.

There is a significant impact on the performance of SHS if solar batteries with thick flat plates are installed instead of TV batteries. However, the differences in quality between batteries with thick flat plates and tubular batteries are not reflected in a higher charge rate of the batteries. This is at least partially due to the fact that the respective calculations were carried out with the initial version of the computer programme, which neglected the "ageing effect" of the battery. Nevertheless, the calculations confirmed that batteries with thick flat plates are an appropriate choice for SHS.

The increase of the nominal capacity of the batteries from 90 Ah in C20 to 100 Ah and even 130 Ah showed little impact on the services delivered by the SHS. An optimum solution is offered by a PV generator of 70 to 100 Wp and a solar battery with a capacity of about 90 Ah. A further increase of the capacity would only lead to considerable additional costs (see *Tab. 9-40*), without providing any corresponding increase in the autonomy of the system.

For a daily average electricity consumption of a household of about 180 to 200 Wh (comparable to that of SHS KEF-42), a PV generator of 70 to 75 Wp would be sufficient, under the condition that a solar battery of 90 Ah is installed. This configuration offers sufficient reserves of energy to allow a small portable colour TV set or an additional lamp to be used.

For an average daily electricity consumption between 180 to 200 Wh, a PV generator of 100 Wp would be oversized. A considerable amount of electricity generated would not serve to charge the battery, but would be "destroyed" by the charge regulator.
Certainly, a power of 100 Wp of the PV generator offers more "buffers": during the summer months as it allows an increased daily consumption of up to 350 Wh, but this is hardly an appropriate requirement of a PV system designed to cover the basic electricity needs of the rural population.

The configuration selected for the first stage of the national programme (module of 70 Wp, battery with thick flat plates with a capacity of 90 Ah) can therefore be recommended as a standard system for the national programme, considering the aspects of covering the basic demand and needs for electrical energy as well as the economic aspects.

The detailed simulations and the simplified calculations have produced results which are quite close to each other. Evidently, the application of simple formulae is sufficient for the design of SHS. But the formulae do not take into consideration the different types of batteries. In a general way, SHS users are advised to buy solar batteries with thick flat plates, when "aged" batteries have to be replaced.

9.4.2.6. Design of an SHS configuration, which allows the connection of a refrigerator

Households and political decision makers often ask whether an SHS could accept the additional load of a refrigerator.

Technically, this is possible and even proven, mainly for rural health stations (cooling of vaccines and medicine). In a co-operation project with France, AME is testing a number of PV-powered refrigerators in rural households. A favourable factor is the coincidence of the peak energy demand for cooling with the peak offer of solar energy in summer.

The configuration of a PV system, capable of providing a "full service", would thus be composed of three lamps (of 18 W each), a colour TV (40 W), and a small refrigerator of 140 litres (average daily electricity consumption 300 Wh). Such a configuration would exceed even the services offered by the "solution D", analysed in the framework of the economic simulations (see chapter 9.3.3.3.).

For the simulations, two computer programmes were applied: *INSEL* and *PVDIMENS* (developed by the company *ITW*, 1991), and they delivered identical results.

In the calculations, the case of a system operating at 12 V dc was analysed, and in addition a system with inverter, operating at 230 V.

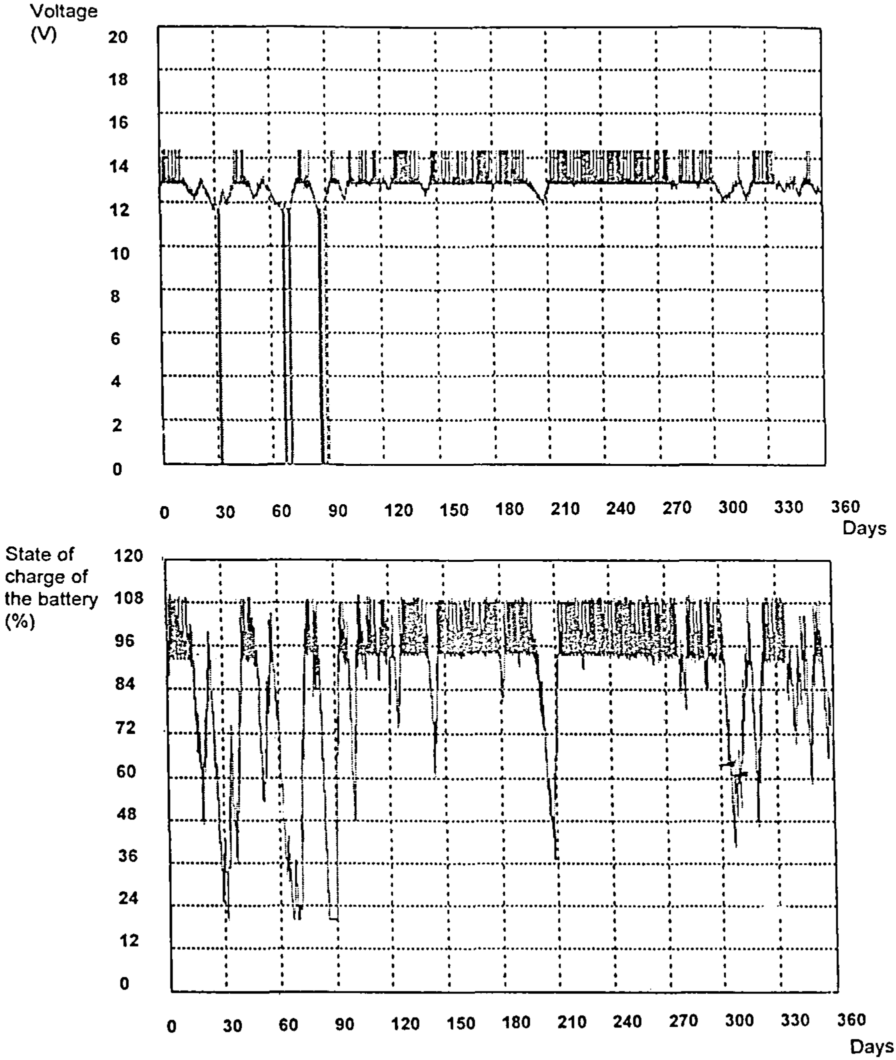
The results of the calculations were based on the following configurations.
For operation in dc, an array consisting of five PV modules of 50 Wp each, plus two tubular batteries of a nominal capacity of 130 Ah each for energy storage was chosen. However, even in the case of the selection of such a system a small number of electricity cuts have to be accepted in winter (*Fig. 9-42*).

For a system operating at 230 V, the installation of a supplementary module was recommended, for compensation of the additional energy losses caused by the inverter. For the two configurations, the programme *INSEL* delivered the following results.

Configuration	**Annual number of electricity cuts**	**Rate of charge of battery *)**	**Energy deficit *)**	**Surplus of energy *)**
PV generator: 5 x 50 = 250 Wp; batteries: 2 x 130 = 260 Ah (tubular)	3 (only in winter)	85.5%	1.3%	3%
PV generator: 6 x 50 = 300 Wp; batteries: 2 x 130 = 260 Ah (tubular)	none	92.5%	0.4%	17.8%

*) annual average

<u>Tab. 9-57:</u> *Design of PV system, allowing the connection of a refrigerator, dc*



<u>Fig. 9-42</u>: Results of simulations

<u>Configuration:</u> *PV panel 250 Wp, tubular batteries 2 x 130 Ah, allowing the use of 3 lamps, a colour TV set, a refrigerator.*

Meteorological data of El Kef (MODAS of SHS KEF-42, 1.1.92 to 31.12.92)

a) Variation of the battery voltage

b) Variation of the state of charge of the battery

Concerning the electricity cut around the 90th day, see Fig. 9-29 (remark)

Configuration	Annual number of electricity cuts	Rate of charge of battery *)	Energy deficit *)	Surplus of energy *)
PV generator: 6 x 50 = 300 Wp; inverter; batteries: 2 x 130 = 260 Ah (tubular)	4	87.4%	1.2%	19.5%
PV generator: 7 x 50 = 350 Wp; inverter; batteries: 2 x 130 = 260 Ah (tubular)	none	93.3%	0.4%	23.6%

*) annual average

Tab. 9-58: Design of a PV system, allowing the connection of a refrigerator, ac

The costs of such a PV system, operating either with ac or dc, are so considerable that dissemination in the framework of a publicly supported programme is excluded.

10. Preparatory Programmes and Projects of the National Programme (outside SEP)

The projects, which preceded and prepared for the national programme for rural electrification were the *Special Energy Programme* (SEP, end of 1987 to the end of 1995), with its long-term commitment, followed by the projects *Ouled Nouaouia* (1990/92) and *Dhokkara* (1993).

The latter were two projects carried out on a local level, executed in the framework of the Tunisian co-operation with Spain and France. Their main objective was the demonstration of a certain SHS configuration. Foreign participation was limited to the delivery of the equipment and to the installation.

Based on the first positive experience of SEP, in 1991 the Tunisian government started the national solar electrification *programme for 200 rural primary schools.*

10.1. Two small scale demonstration projects

10.1.1. The project of Ouled Nouaouia

The hamlet of *Ouled Nouaouia* is situated in a plain, at a distance of 23 km from *Kairouan*, the capital of the *Gouvernorat*. The dwellings are isolated; the families live on or close to their land. Fruit (almonds and olives) are the main source of income. Cereals are cultivated between the trees. In addition, each family owns a small flock of sheep or goats.

There are important differences between the households regarding their social standing. Whereas some well-off farming families own tractors, harvesting machines and pick-up trucks, the families of small farmers and occasional or day labourers live in very simple houses of just one room.

At the time of the installation of the SHS, the electrical grid was more than eight kilometres away and connection to the *douar* was out of the question due to the high costs.

The project was supported by the Spanish co-operation, the responsible partner being the company *BP Solar Spain*. 47 SHS, each consisting of one module of 50 Wp, one to three lamps (12 V/18 W) and one tubular battery of 125 Ah, were installed in households, and two local schools were also equipped with SHS.

Six other households received PV kits consisting of one module of 34 Wp, lamps of low electricity consumption and a charge regulator with simple electronics fixed on the back of the module.

The initial appreciation of the SHS resulted in an additional demand from other households living close to the hamlet. Therefore, in 1992 AME agreed to install another ten SHS.

Among the *positive experiences* in this project, the low number of electricity cuts during winter, in spite of the rather restrictive power of the modules (50 Wp), should be mentioned. The households rapidly adapted their consumption to the seasonal variations in electricity supply. The majority of the households preferred to limit the use of the television set in winter in favour of lighting, so that the school children could do their homework better.

It has to be noted that, in the *Gouvernorat* of Kairouan, the annual number of hours of sunshine is at least 10% higher than the average of the *Gouvernorat* of El Kef (see *Fig. 9-28*).

The tubular batteries proved to be viable products with a long lifetime. 95% of the batteries were still in operation after four years, and about 25% were operational even after six years, although there was no regular control and maintenance, and in spite of long periods of partial discharge because of the low power of the PV generator.
The *inconveniences* were seen on the technical level mainly with respect to the lighting kit systems. After four years of operation, three of the six charge regulators were defective.
In spite of the small sample, and taking into account information from other countries, such as Morocco, this seems to be an indication of technical problems to be expected with kits.

The most severe problems, however, were on the non-technical level.
The financing system applied was to charge a monthly rent of 5.2 US $ (5 DT) for the SHS.
In theory, this amount was sufficient to cover the operational costs (maintenance, repairs, spare parts).
So, first of all, AME concluded a contract limited to a period of one year with the company *Khadamet* (with its main office in Tunis - Ezzarah, which had an office in Kairouan) to ensure the maintenance of the PV systems.

In practice, the approach, adopted by AME, was confronted with similar problems as those encountered with the households of the pilot-phase in El Kef.

In the beginning, AME sent its accountant once a month from Tunis to the *douar* in order to collect the monthly rent. This was a costly and difficult procedure. When the rent was due, some of the heads of the households were absent, others did not have the money available at the day of collection, others declared themselves unable to pay because of financial problems (bad harvest, illnesses). Afterwards, AME entrusted an inhabitant of the *douar* with collecting the rent, but the results were still unsatisfactory.

Besides the reasons mentioned above, the user households argued that
- the installed equipment was a gift. They did not want to pay for a product that Tunisia had received free of charge;
- the first breakdowns of components (above all tubes and ballast) were experienced without AME being able to intervene to replace the faulty components at once. In fact, the number of spare parts delivered by the supplier in the framework of the project was insufficient. The households refused to pay for SHS which were to some extent not operational.

The general impression was a mixture of justified complaints and pretexts to escape from paying the monthly rent. The consequence, however, was a total stop of payments.

Therefore, AME was no longer in a position to extend the maintenance contract. The user households refused to give the SHS back to AME. It was impossible for AME to take them back by force. The recuperation of equipment, fixed to a house, requires the prior juridical mandate and also an active participation of the regional and local authorities.
In the case of *Ouled Nouaouia,* the Head of Sector, himself an SHS user, also refused to pay the monthly rent to AME. In this situation, AME saw no other solution than a complete withdrawal from the project, which it put into effect in 1994.

During a visit to the area in July 1996, it was noted that the *douar* had been selected as a project of FNS. Works were going on to construct an asphalt road to the *douar*, and, in spite of the installed SHS (at least a quarter of which was still operational to some extent), the FNS also financed the extension of the electrical grid and the connection of all households.

The households, which had formerly declared themselves incapable of paying a monthly rent of 5.2 US $ for an SHS, were now evidently ready to pay the financial contribution of 208 US $ (according to the conditions of STEG) in order to be connected to the grid.

The Head of the Sector explained that the main motivation for demanding "the grid", was "to have the possibility of using a refrigerator". This position is comprehensive for the well-off households, but not for the poorer families, who are in the majority and do not have the necessary financial means to buy a refrigerator.

Evidently the minority, the richer households, had influence over the majority of the *douar* to demand a solution, which was not appropriate taking into account the SHS already installed) and which was, in addition, costly for the public authorities.

10.1.2. The Dhokkara project

Dhokkara is a small hamlet of isolated dwellings in the *Gouvernorat* of *Bizerte*. From the *douar*, situated at an altitude of about 200 metres in a hilly and rocky zone, there is a picturesque view of the Mediterranean Sea. The vegetation consists of degraded forests (maquis). The only possible form of agriculture is the breeding of sheep and goats. The income of the households is low.

The project was executed in the framework of co-operation with France. The principal objective was to test and demonstrate SHS components, produced in France. The main interest was to gain experience with lamps of low consumption (13 W instead of normal 18 W tubes).

The project consisted of the solar electrification of 45 households, a primary school with three classrooms and two houses for the director and teachers. The configuration of the SHS was the following: two modules of 47 Wp each (*Photowatt*, polycrystalline), three lamps, one fixed outside the house (*Labcraft* 12 V/13 W) and a solar battery with thick flat plates (*Steco*, 105 Ah).

Following a call for tenders among French enterprises, AME awarded a contract to the company *Vergnet* S.A. for delivery of the equipment. The Tunisian enterprise *SEN* took over the installation.

Before the installation of the PV systems, each household had to pay a lump sum of 104 US $ (100 DT) to AME. In this way, the financing scheme proposed for the national programme was already being applied.
The households were very interested in acquiring SHS; therefore the collection of the demanded financial contributions did not take much time.

During the warranty period of two years, a regular monitoring was organised.

In June 1996, a visit of representatives of AME to the *douar* were given a rather pessimistic impression. Half of the charge regulators were broken down, fuses in the regulators had melted and had been replaced by a piece of aluminium foil or a wire. Some users had connected the modules directly to the batteries (reason: defective regulator due to lack of appropriate fuses), tubes had blackened prematurely or had broken down.

The quality of the ballast was clearly insufficient, and spare tubes of 13 W and appropriate ballast could not be found in the region. The batteries imported from France were no longer operating and only some of them had been replaced by the user households.

It is therefore understandable that the users unanimously expressed their dissatisfaction at the technology installed.
On this occasion, the staff of AME repaired the systems as far as possible.

10.1.3 Conclusions

The disappointing story of the projects *Ouled Nouaouia* and *Dhokkara* leads to the following conclusions:

Every project, which is not integrated into a large-scale context (concentration of at least 500, but if possible even a thousand SHS in the same region) will inevitably fail, as the number of installations is not sufficient to interest a private enterprise in maintenance and repair. It was impossible for AME to ensure regular maintenance of the SHS, due to the high travel costs for technicians from the capitals of the *Gouvernorats* concerned to the sites of these small-scale projects.

A number of makes of electronic components were not technically viable, or were not appropriate for operation under the conditions of rural isolated regions in Tunisia. Besides, the quantity of spare parts, delivered by the co-operation partner, was insufficient.

A financing system based on renting SHS to the users has once more proved to be ineffective (as earlier in the framework of SEP).

Initiatives of the users to organise by themselves a sustainable operating of SHS were negligible. No association was created and there was no joint action to contact reliable technicians for repairs or a supplier in the capital in the search for effective spare parts.
Instead of this, either the users did a poor job themselves, while awaiting the arrival of a representative from AME to solve the problems or they claimed to be connected to the grid.

The example of *AIC (Associations of Common Interest)* created by the rural population, which is a precondition demanded by the government before sinking new wells or deep drills for drinking water supply, shows that the formation of self-help organisations is in principle possible. But such an initiative cannot be started to order, it would have to come from the inhabitants themselves. For sensitising the population and providing advice, the assistance of a non-governmental organisation (NGO) would be necessary, at least for a first period. However, for small isolated projects, such an effort cannot be justified financially.

It is amazing that even the teachers and directors of the schools in the *douars*, when confronted with technical problems, did not themselves take measures to ensure the operation of the SHS - neither for the systems installed in the school, nor for those of the other users.

Another problem linked to all small-scale projects is the arbitrary selection of the sites. Why just these two *douars*, why not others from the thousands of isolated *douars* in the Tunisian countryside? Neutral criteria of sampling cannot be applied for these small projects.

Therefore, these two projects have to be considered as "poisoned gifts", both for the donators (negative reference) as well as for AME (loss of time and money, negative reputation of photovoltaics).

10.2. The national programme for solar electrification of rural schools

10.2.1. Justification for the programme

Basic education of boys and girls is traditionally one of the priorities of the Tunisian government. This includes the rural isolated areas, where primary schools are to be found even at sites very far away from asphalt roads and the electricity grid.

Primary school buildings are constructed according to a standard plan. The schools consist of a main building with three classrooms. The latrines are built beside it. The director of the school lives with his family in a small building of three rooms just some metres from the main building. The teachers (bachelors) live in another small separate building, two men (or women) living in one small room.
The director and the teachers change school after a period of one to three years. For their first period of employment, the young ones are usually sent to the most remote and isolated sites.

Cleaning and maintenance of the school buildings is carried out by the warden, who is from the region, living with his family not far from the school in his own dwelling. In the countryside, these wardens do not have full-time jobs, they work as farmers as well.

The pupils attend these co-educational schools in the morning and in the afternoon, with a break between noon and 3 p.m.

The quality of education varies widely between schools and from one year to the other, depending on the commitment of the teachers, and is also influenced by the frequent movement of teachers from one school to the next. An indicator is the success rate of pupils passing the examination for secondary education. Generally, the national average success ratio is about 50%. This ratio is considerably lower in rural isolated areas (about 20%), although it might exceed 90% in some schools, where directors and teachers are dedicated to the education of the rural youth (example: the primary school at *Mahjouba*, Delegation of *Kalaat Senan*).

The reasons for the modest results of pupils in rural areas are well-known. They are mainly the result of difficult social and general living conditions (leaving home very early in the morning, often walking more than five kilometres to school, arriving home late in the evening, lack of a quiet place at home for homework, necessity to help their parents at home and in the field instead of working for the examinations). In addition, there are the poor conditions at school (bad quality of lighting, no heating in winter) and a lack of motivation on the part of the teachers, who find themselves - after years of studies in the towns - in an environment, which they consider hostile (isolated sites, difficult access and sometimes even cut off completely during the rainy season in winter, difficult living conditions without running water, electricity for television, radio and lighting. It is therefore not surprising that the rate of absence is high among the teachers in rural isolated zones.

The programme of solar electrification of rural schools was therefore not only justified by the better quality of lighting in the classrooms, but also, and this even a priority, by the improvement of living conditions for the school staff.
Other arguments *in favour* or this programme were:

- Education is a basic need, and a contribution to its improvement helps to even out social disparities;
- Not only minorities benefit from this programme, but all families having children at school;
- Finally, the solar electrification of a school is an excellent tool to sensitise and even familiarise the households living around the school with the new technology of photovoltaics.

In spite of these advantages, there were also grounds for *criticism*:

- The exploitation of the SHS for the classrooms is low. Lighting is only necessary in winter, maximum for one hour in the morning and one hour in the evening. During week-ends and holidays, there is no electricity consumption at all. As a result of low consumption, the cost per kWh is very high */10-1/*.
- The organisation for maintenance and possible repairs may cause problems. It was hoped to be able to solve them by concentrating on schools in a limited number of

Gouvernorats, integrating local technicians into the installation crew, and by training teachers, wardens and even teachers from technical high schools in maintenance and the theory of photovoltaics.

- The budget of the Ministry of Education, designated to cover the operational costs of the primary schools is very low, and the administrative procedures are sometimes bureaucratic and lengthy. Often, there were complaints from directors of rural primary schools that urgent repairs were not carried out in time. In some cases, the directors were obliged to ask the parents of the pupils to finance the costs of minor repairs, such as the replacement of a broken window. Therefore, it was feared that the regional structures of the Ministry of Education would not be capable of ensuring the operation of PV systems in the long term.

10.2.2. Execution and experience

The *execution* of the programme was concentrated on the eight *Gouvernorats* of the north-west (*Jendouba:* 27 schools, *Béja:* 8 schools, *Siliana:* 30 schools, *El Kef:* 30 schools) and the central Tunisia (30 schools in each of the *Gouvernorats* of *Kasserine*, *Sidi Bouzid* et *Kairouan*). In this way, the regions defined as priority for the rural solar electrification by CGDR (see chapter 7) were covered.

The budget of the programme was provided by the Ministry of Education (45%), the *Gouvernorats* (16% - in the framework of their programmes for regional development) and AME (39%).

For the *Gouvernorat* of El Kef, the costs were shared equally between AME and the German technical co-operation (GTZ-SEP).

In 1990, AME, as the organisation responsible for the implementation of the programme, signed the agreements with the *Gouvernorats*. Its responsibility was limited to the management of the programme and operation during the warranty period of two years. After this period, it was the turn of the *Gouvernorats* to ensure adequate measures for the sustainable operation of the systems.

Taking into account its limited capacities of infrastructure and staff, AME entrusted the company *SEN* as general contractor with the execution of the programme in seven *Gouvernorats*, reserving for its own staff the task of identifying the buildings where the PV systems should be installed, signing of contracts for delivery of equipment and commissioning of installed systems. In addition, the engineers of AME participated actively in the provisional acceptance of the components (control at the factory).

In detail, AME delegated to *SEN* the following tasks:
- consultation regarding selection of the suppliers of components and allocation of the contracts;
- quantitative and qualitative acceptance of the equipment;
- storage of the delivered parts;
- installation and maintenance of the systems during the warranty period;
- organisation of after-sales-services.

After consultation with the international market, *SEN* concluded a delivery contract with the French enterprise *Total Energy*, at that time producer of the photovoltaic equipment *Photowatt*.

Most of the 15 technicians of *SEN* were contracted only for the period of the installation programme and came from the *Gouvernorats* where the programme was to be carried out. Subsequently, AME trained them at the centre for professional education (*CNMA*) in El Kef. This group of technicians was subdivided into five crews, working in parallel in the different *Gouvernorats*. A sixth crew was charged with the co-ordination and control of the work.

Almost two years, from the beginning of 1991 to the end of 1992, passed between the start of the installation works and the receipt of the PV systems at the last school.

In the *Gouvernorat* of El Kef, the management of the solar school electrification was modified. Here, the equipment was acquired via a call for tenders executed by GTZ (head office) in Germany, in agreement with AME. Installation and follow-up during the warranty period was entrusted to the AME/SEP-team in El Kef, which applied itself to the vocational training of private technicians.

For the *Gouvernorats* outside El Kef, each school was typically equipped with three independent SHS. The first system, consisting of a PV generator of 98 Wp (two modules) and a TV battery of 200 Ah delivered the energy for lighting the three classrooms (3 lamps of 18 W per classroom). The two other systems (each of a PV power of 98 Wp and 3 lamps of 18 W) were to ensure the supply of supplementary buildings (houses of the director, the male and the female teachers). In these houses the possibility of connecting a TV set was provided, but for economic reasons, no radio adapters were foreseen.

The configuration was modified for the *Gouvernorat* of El Kef as follows:

Whenever possible, an attempt was made to combine SHS, which were installed for lighting of the classrooms, with those of the neighbouring house of the director. This solution of a "mini-centre" offered the advantage of a better exploitation of the energy generated. It was, however, only possible when the distance between the two buildings was a maximum of ten metres. In these cases, *Siemens* charge regulators were used as, at the time, these were the only regulators capable of connecting four PV modules and a significant number of electricity consumers (lamps, radios, etc.).

As the three lamps of 18 W could not provide good quality of lighting for the classrooms, it was decided to install tubes of 36 W and these required the installation of special ballast.

As a result of the teachers' request for radios, all systems in El Kef were equipped with radio adapters. Their interest, however, did not only concern radios, but also the use of cassette-decks for educational purposes in the classrooms.

Finally, it was also considered necessary to integrate the wardens of the schools in the programme. This was seen as a means of sensitising them to the maintenance of the systems. If the wardens were neglected, there was a risk that batteries would be removed at week-ends and holidays to be used in their private houses.

Therefore, in El Kef, besides the school programme, a mini programme was established for the 30 wardens. On payment of a lump sum of 208 US $ (200 DT), each warden's household received an SHS with one module of 50 Wp and three lamps.
At a meeting attended by representatives from AME, directors of the rural schools and the regional representative of the Ministry of Education, the training of the following personnel was decided:

- wardens (for the regular maintenance works);
- teachers;
- a teacher from the Technical High School of El Kef, who was to visit the schools regularly and change and possibly even repair faulty components.

In the first years of operation, the general appreciation of the PV systems was very positive.

The analysis of some cases of *breakdown or incorrect operation* during the warranty period revealed three rather trivial technical defects:

- The connection boxes on the back of the modules were not waterproof. Humidity could enter the box and cause short-cuts. The boxes were therefore sealed with silicone.

- The cables (copper wires) had not been connected properly to the modules, so the current passed only through some of the wires and was therefore low. This was repaired.

- Especially in the classroom buildings, the cables were too long for the selected diameter of 4 mm², resulting in a drop in the system voltage. After consulting experts, this problem was solved by changing the cables.

The problems became more severe after the expiration of the warranty, as by then, the systems were no longer the responsibility of AME. Nevertheless, AME continued to assist the other partners (Ministry of Education, *Gouvernorats*) in the analysis and the solution of the problems. For this purpose, in 1995, four years after installation, the company *SES* was contracted with a diagnosis of the state of the systems (outside the *Gouvernorat* of El Kef). 148 of the 155 primary school were analysed in this study.

In the schools visited, there were in total 455 SHS, and 350 (77%) of them were in a state of complete standstill. The remaining systems were only partially in operation (some broken-down components, frequent electricity cuts, etc.).

Regarding the components, the analysis gave the following results:

Component	Modules	Charge regulators	Ballast	Tubes	Batteries
Percentage of broken-down components	18 % (broken)	18.2 %	28.1 %	90 %	89.7 %

Tab. 10-1 : *Programme for solar electrification of rural schools: state of components of the PV systems in 1996*

There were technical as well as organisational reasons for this disappointing state of affairs.

It was confirmed that three lamps of 18 W were insufficient to assure good quality lighting in the classrooms. In addition, the ballast could not ensure the operation of the tubes for their normal lifetime, a rapid blackening of the tubes and their subsequent breakdown was seen.

The potential lifetime of the batteries had initially been over-estimated (a lifetime of three instead of two years had been expected). An autopsy of some broken-down batteries provided hints for an additional reason for their weak performance: During the holiday season (three months in summer in the season of highest solar radiation) there was no electrical consumption at all. In spite of the presence of a charge regulator, an overcharging of the batteries at this period could not be excluded.

Unfortunately the available measuring instruments did not allow AME to execute detailed research and analysis on this subject.

The rapid ageing of the batteries, sometimes seen even after only a few months of operation, produced a sharp reduction in the autonomy of the systems (an autonomy of three days had been considered to be necessary).

The charge regulator (*Solelec RS 200*) was not appropriate for the nine lamps in the three classrooms. The current could rise up to 15 A, whereas the charge regulator had been designed for operation up to 10 A only.
The rate of broken modules (18%) was significant, especially in comparison to the SHS installed in households, where it was close to zero.
The reaction of the pupils by throwing stones at the modules was an expression of their attitude after PV systems had ceased to operate.

In El Kef, it was apparent that many teachers took the special plugs for radios and TV sets with them when they left the schools. So, every year, it was necessary to reinstall and adapt this equipment.

Finally, the absence of maintenance and availability of spare parts was noted.
Unfortunately, it is always difficult to ensure the necessary means for preventive activities.
The regional authorities, already faced with chronic budgetary problems while trying to cover the running costs of the schools, had not foreseen the funds necessary for spare parts of SHS, above all for the batteries.

The frequent change of directors and teachers made it more difficult to select and train responsible personnel for maintenance and small repairs at each school. The new staff, arriving at a school equipped with PV systems, did not know how to contact a competent person in the case of technical problems.

Due to the lack of a vehicle, it was impossible to obtain a teacher from the technical high school to be responsible for repairs and maintenance.

Regarding the wardens, they could only be entrusted with simple regular maintenance activities, such as adding demineralised water to the batteries; although in some cases they were interested in more important activities.

The problems seen in this schools' programme are therefore complex. A quick replacement of tubes and batteries could not solve the basic problems.

AME contacted the French co-operation regarding a joint repair and restoration of the systems, since the installed equipment, although financed by Tunisian authorities, had been imported from France.
Until now AME has not received a positive reaction from the French side.

In 1996, in El Kef, the *Gouvernorat* replaced the first thirty batteries at its own cost and planned to continue this action to the same extent in the coming years. It has also been noted that teachers bought batteries themselves in order to profit from the installed PV equipment.

The solution of the problems of the school-programme demands the elaboration of a complete and long-term strategy for the restoration of the PV systems, and afterwards the creation of a structure allowing swift actions regarding maintenance and repair.
A growing number of schools has been connected to the electrical grid or has already been programmed for grid-connection.

Hopefully, the Tunisian authorities will find the international support needed to avoid the loss of the important investment they have made.

11. Implementation of the National Programme

11.1. The components of SHS: requirements and reality

11.1.1. Charge regulators

A charge regulator has three principle tasks:
- the protection of the whole SHS against technical faults and manipulation;
- the protection of the battery against overcharge and deep discharge;
- the management of the battery, and thus the optimal exploitation of its storage capacity.

In order to understand the operation of the charge regulator as the *manager and protector of the battery*, it is necessary to be aware of some characteristics (see also chapter 9.1.1.1.).

The level of charge of a battery is generally characterised by its voltage.
If this exceeds a certain level (under normal conditions about 14.8 V), the water of the electrolyte begins to separate into hydrogen and oxygen, and is gassed. A gassing therefore signalises an overcharge of the battery. This is damaging for the battery as gas bubbles cause a loss of particles from the active plates. These sediments fall to the bottom of the battery and may cause a short-cut between the plates, resulting in a sudden standstill of the operation of the battery */11-1/.* If the battery is placed in an inhabited room, as is the case for SHS in Tunisia, the gas emission may even be toxic for the persons living there.

Therefore the charge process is generally stopped at a certain voltage (14.4 V), before gassing starts.

The first generation of charge regulators allowed batteries to be charged up to this voltage, the *top level of charging*. When this level was reached, the regulator stopped the charging process. It took up charging again at a lower voltage, called the *level of restarting charging*. Consequently, the charging process could only start after a period of electricity consumption. This management of the battery is therefore called "regulation at two levels", and the difference between the two levels is called the *hysteresis of restarting.*

This regulation is not optimum. If, for example, the battery is discharged during the day and the voltage has not yet gone down to the level of restarting the charge, the battery will not be charged, although there is sufficient solar radiation. The solar potential is therefore insufficiently exploited.

A deep discharge of the battery causes a sulphatation of the lead plates, and thus a reduction in the capacity and potential lifetime of the battery. The process of discharge must therefore be stopped before a harmful voltage level is reached. This level corresponds to a certain *low level of discharge*.

This level is generally fixed at a voltage between 10.5 and 11.5 V. The specifications of the calls for tenders of the national programme fixed this level at 11.4 V, which corresponds to a rate of discharge of the battery of about 60%. Some manufacturers of batteries considered this level as too low and proposed cutting electricity consumption at 50 % of the nominal capacity of the battery, i.e. at an even higher voltage.

After an electricity cut, the battery must recover, meaning it must be recharged up to a relatively high voltage before it can be accepted for further operation. In this way, cycling the battery at a low voltage level, causing repeated new electricity cuts, is avoided.
In the specifications of the call for tenders of the national programme, the voltage *level of restarting operation* of the battery after an electricity cut was fixed at 12.9 V.

So there are at least four voltage levels, which should be programmed in a charge regulator.
But this is still not sufficient for a favourable management of an SHS. By measuring the density of the electrolyte, it can be shown that the battery is not yet completely charged, when the voltage arrives at the upper charge level.
If the charge regulator stops the charge process of the battery when this voltage is reached, the battery will always stay in a state of partial discharge.

There are several options for solving this problem.
Either, the hysteresis of restarting is reduced, a pulsed charge of the battery is provided, or the top charge level is allowed to increase at regular intervals.
In the latter case, a light gassing of the electrolyte is accepted from time to time in order to avoid a stratification of acid at different densities.

The electronics of certain charge regulators allow this circulation of the electrolyte either automatically (by increasing regularly the upper charge level of the voltage) or, on request, by pressing a *forced charge* button. Such a forced charge should not be confused with an accelerated charge with a strong current, observed with battery chargers operating at 230 V.

When high cases are used for industrial batteries, the negative influence of stratification is not negligible. However, it is much less for batteries with compact cases, as used for SHS. Systematic studies have still not been undertaken in this field.

Moreover, the voltage levels of the charge regulator vary with the ambient temperature. Taking into account the annual temperature differences in rural Tunisian dwellings (about 10°C in winter, and up to 40°C in summer), the influence of the temperature might cause a change of the levels of up to 0.8 V */11-2/*. It might even cause a deregulation of the levels, which were fixed previously by the manufacturer.

When ageing of the battery starts, it is discharged more rapidly, so that electricity cuts become more frequent. During this final period of its operation, it would be appropriate to discharge it to a deeper level in order to take most benefit of the capacity, still available. It would therefore be advantageous for the charge regulator to register the state of the battery and modify the levels accordingly.

So, whereas the first generation of charge regulators was restricted to managing the operation of the battery exclusively in relation to its voltage based on fixed voltage levels, the more recent generation measures the current, the ambient temperature and manages the operation of the battery in a flexible way by means of intelligent electronics according to the discharge rate, the temperature and the age of the battery */11-2/*.
Therefore a manufacturer of charge regulators considered the fixed levels, stipulated by the tender documents for the national programme, to be inappropriate.

Beside the management of the battery, the charge regulator has a protective function for all components of the SHS and for the user.

This mainly includes the following topics:

Protection in the case of a reversal of the poles of the battery
Against all advise, the users sometimes remove the batteries, for example to lend them to neighbours for weddings.
When the battery is connected to the system again, it might happen that the user connects the positive pole of the battery to the negative cable and vice versa. In such cases, the electrical current passes inversely and may damage the charge regulator or the consumers (e.g. lamps, television set). Therefore, the regulator itself and the consumers must be protected by appropriate electronics.

Some manufacturers are of the opinion that it would be sufficient for the charge regulator not to be damaged in the case of a change of polarity, because the ballast of the tubes and the TV sets are protected by additional fuses.
It has been shown, however, that this is true for all appliances. In addition, after repair of a television set or a radio electricians often forget to replace the fuse.

The number of breakdowns caused by inversion of the polarity might be reduced by installing battery poles, which would - due to their form - avoid any confusion. Technically, this is possible, but according to a battery manufacturer (ASSAD), the quantity of solar batteries sold does not justify such a special provision at the moment.

Stop of operation of the SHS, when the battery is disconnected
If the battery is removed, some charge regulators pass the electrical current directly from the module to the consumers, thus causing an interrupted operation, which may damage the consumers. In addition, in some regulators of the series type a relay is rapidly switched on and off continuously, which risks a deterioration of the charge regulator.

High efficiency and low electricity consumption
It is clear that a component within a system, which only provides a limited amount of energy, must be optimised in respect to its efficiency and electricity consumption. This is also valid in the case of electricity cuts: a charge regulator which continues to consume electricity in the event of an electricity cut, thus emptying the battery which it should be protecting against deep discharge, cannot be considered as appropriate.

Option for a future extension of the SHS
An advantage of the photovoltaic systems is their modular character. The user may enlarge or complete his system by adding one or several modules and consumers (lamps etc.) according to his wishes. It is desirable that this enlargement of the system will not require the installation of an additional charge regulator. Therefore, the regulator must allow consumers of up to 15 A and four PV modules of different power to be connected.

In addition, there must be a sufficient number of points to connect the cables, and a connecting strip with enough space between the connecting points so that cables of the necessary diameter can be fixed without problems.

Adaptation of the electronics to the Tunisian climate
As the ambient temperature in the rural dwellings easily reaches 40°C in summer, the electronic elements must be selected to ensure operation even under these temperatures. On the electronic circuit board the distance between the elements must be sufficient to avoid overheating; and any cooling vanes must be properly designed.

Adaptation to the conditions of rural environment in Tunisia
This includes a number of technical provisions:
- a case, which protects the electronics against the infiltration of dust and humidity, and against insects;
- traction relief in order to ensure a permanent connection of the cables to the regulator case;
- protection against interference of radio and television (taking into account the frequencies of radio and TV stations in Tunisia and neighbouring countries);
- a high-quality soldering of the electronic circuit board to ensure long-term operation without corrosion or other problems;

- detailed, careful and repeated control during the manufacturing process in order to minimise costly touching-up activities after installation;
- the matching of all electronic elements and components of the whole delivery with the sample submitted for testing with the tender.

The *fuses* are a matter of particular importance. It has been under discussion for a long time, whether it would be better to place the fuses inside the case of the regulator (which would mean that an electrician would be needed to change them) or outside the case (offering an easy access, but also the risk that the user might replace them by a piece of aluminium foil or wire when the fuse melted).

In SHS installed within the pilot dissemination phase of SEP, and in the projects *Ouled Nouaouia* and *Dhokkara*, it was seen that, after the warranty period, users changed the fuses themselves or manipulated them, when there was a technical problem, and even opened the case of the charge regulator by force. Very often, an appropriate fuse was not available, causing the user to replace it by any other fuse he found or by a by-pass.

Some manufacturers therefore tried to avoid fuses altogether by replacing them with a reconnectable overload protection (which failed) or a micro-processor, built into the regulator (installed in the first stage of the national programme) or sophisticated, intelligent electronics.

The *indicators* (LED display) must be clear to provide essential information on the state of the SHS for the user. Should the system cease operation, the LED must indicate whether the reason was an *electricity cut* or a *breakdown*. In the first case, the user only has to wait - the system will restart again automatically when the battery is sufficiently recharged. In the latter case, the user must call a technician to analyse the reason for the breakdown and to repair or replace the broken component. Therefore, two LED displays ("cut" and "breakdown") are necessary and sufficient.

It is advantageous to integrate the radio *adapter* into the case of the charge regulator. The adapter must be able to operate at the different voltages of the common cassette-radio players on the Tunisian market.

Tab. 11-1 shows the experience made with the different types of charge regulators. It proves that so far all models installed have given reasons for dissatisfaction - at least for a certain period.

Due to the problems found, it is considered useful to introduce a clause in the delivery contracts, obliging the supplier to change all the equipment installed, if the number of breakdowns exceeds a certain percentage (2 to 5%) within the warranty period.

Besides the types of charge regulators shown in *Tab. 11-1*, AME has also carried out short-term tests with a considerable number of other models. These charge regulators were either provided by the manufacturers, or had been sent to AME by partner projects in other countries. In this way, regulators from Senegal, Spain, Germany, Morocco and Tunisia were tested. Some of these regulators were also successfully installed in households (for example the regulators *IBC* from Germany, *MIFAX* and *Le Rayon Solaire* from Tunisia) but, either because of the small sample or the short period of utilisation, a final judgement of the quality of the equipment was not possible.

Since the Tunisian authorities declared charge regulators to be a product available from national production, all foreign regulators have been subjected to high importation taxes. The imported equipment, which is no longer financially competitive with local products, has now disappeared from the commercial Tunisian market.

11.1.2. Ballast and tubes

The task of the ballast is to transform the electrical current arriving from the battery into a form appropriate for the operation of a fluorescent tube.

Ballast operating at 230 V is a mass-produced article, manufactured at very low prices, and consisting of simple electronics.

It has been shown that the use of ballast in SHS demands optimised and sophisticated electronics. Otherwise, after only a few months, black spots will appear at the ends of the tube. These spots become rapidly larger, reduce the luminosity of the tube and finally cause its premature breakdown. In some products, some minutes after the breakdown of the tube the ballast is destroyed as well.

Long-term tests (long-term cycling tests and long-term test with switched-on tube) are therefore an essential proof of the quality of a ballast. At least 15,000 cycles of switching the lamp on and off plus 5,000 hours with the lamp switched-on should be guaranteed. However, these tests demand long periods of time for their execution and thus cannot be part of the quick comparative tests carried out by AME in the framework of the evaluation of calls for tenders.

The *characteristic curve* of the ballast gives a first impression of its quality. Ideally, it is a sinus-curve on the oscilloscope. Rectangular curves or curves with pronounced peaks indicate that the lifetime of the tube will be shortened.

The ballast has to be designed for *operation at 18 W*, as this was selected as a standard by AME. The 18-W-tubes are available even in the small regional towns and their high luminosity is appreciated by the users.

Product, Country of origin, Year of installation	Number of installed units, Type/ Nominal voltage/ Maximum PV current	Technical problems	Improvements carried out after installation	Favourable aspects	Remarks
Helios HLR 12-2 Germany 1989-92	250 units shunt 12 V 6.3 A	• interference (radio) when battery charge is stopped to protect against overcharge • maximum current too low, if two modules are connected	• installation of two additional capacitors • fuse holder and calibre of fuse changed (8 A)	• three fuses: if one fuse melts, the rest of the SHS is still operational • two LED, clear indicators	• very low number of breakdowns after technical improvements • has not been offered for the national programme, probably because of its high price
SVE SLRT 10/15 Germany 1989	11 units shunt 12 V not indicated	• interference during charge of the battery • if polarity of the battery is changed, the radio adapter is damaged • description only in German language • bad fixing of cables			• according to the producer part of a pilot series • no longer available on the market
Siemens Germany 1989-91	13 units shunt 12 V 14 A	• interference (radio) during charge of the battery • oscillation of the relay, if battery is removed • if polarity is changed, the current passes the regulator inversely • LED display insufficient		allows to connect up to four PV modules	• mainly installed as "mini-central" in schools • no longer available on the market

Tab. 11-1 a): Charge regulators installed during the pilot dissemination phase or the intermediate phase

Product, Country of origin, Year of installation	Number of installed units, Type/ Nominal voltage/ Maximum PV current	Technical problems	Improvements carried out after installation	Favourable aspects	Remarks
BP Solar BPRD Spain 1990	50 units series 12 V 10 A	• oscillation of the relay, if battery is removed • if polarity is changed, the current passes inversely • description of LED display in Spanish only • fuse holder may easily be broken when fuse is changed • no traction relief of cables, only porcelain insulators			• installed in the project *Ouled Nouaouia* • no longer available in the market
Solelec France 1991	480 units series 12 V 10 A	• without traction relief for cables • 3 fuses of a type, not available in Tunisia • LED display too small, description only in French • Maximum current insufficient to connect two modules (regulator becomes hot)			installed in the "school electrification programme" in seven Gouvernorats
BP Solar BPRM 1 Spain 1994-95	1,000 units series 12 V 13 A	interference with television sets due to voltage drops	"Repaired" by removing a diode. Protection against change of polarity not assured	In the case of a short-cut the micro-processor blocks the system: no fuses to be changed!	After modification of electronics rate of breakdowns below 5%

Tab. 11-1b): *Charge regulators: Project Ouled Nouaouia, school electrification programme, national programme (first stage)*

Product, Country of origin, Year of installation	Number of installed units, Type/ Nominal voltage/ Maximum PV current	Technical problems	Improvements carried out after installation	Favourable aspects	Remarks
APEX APZ 500 France 1994-95	1,250 units series 12 V 13 A	• fuse holder broken after fuses changed by the users • type of fuse of the radio adapter not available in Tunisia • several MOSFET damaged, relays blocked, board for fixing the cables broken			
ELSI Tunisia 1993-96	about 1,500 units series, time-controlled 12 V 15 A	In several cases: • prefixed voltage levels changed • relay blocked or damaged • when one or two lamps or television set are switched in succession, electricity supply to consumers is cut • radio adapter non-appropriate for some makes of radio			• number of breakdowns considered to be unacceptable • repairs and technical improvements ongoing

Tab. 11-1c): Charge regulators: national programme, second and fourth stage, FNS projects

The ballast must be able to endure *idle operation*. When the tube is broken or has been removed and the lamp is still switched on, the ballast risks becoming overheated. A good quality ballast endures this idle operation even for two to three weeks without the electronics being damaged.

The rapid and reliable *ignition* of the lamp is important as well, but not assured for all models available on the market.

Characteristics, which are important both for charge regulators as well as for ballast, concern the *adaptation to the conditions of rural environment* in Tunisia, such as protection against interference (radio/TV), against the infiltration of humidity, dust and insects (which is even more important for ballast than for charge regulators, as the lamps are often fixed under the ceiling and therefore more difficult to protect and clean than a charge regulator, which is fixed on the wall), and must be resistant to ambient temperatures. This is an essential point particularly for ballast installed in sealed lamp-cases, which behave like a "passive solar collector" (especially when they are fixed on the outer walls).

Ballast, delivered as samples for test as part of the tender, must be identical to the equipment which is delivered afterwards. Homogeneity is not always assured, as some manufacturers reserve the right to modify or "improve" their products without prior notice.

Tab. 11-2 shows that in thousands of cases, ballast, offered and afterwards installed in the framework of the different stages of the national programme, did not fully correspond to the demands of the tender documents and thus caused significant financial losses to the manufacturers and suppliers, severe delays in the execution of the national programme, and a scepticism from the side of the political decision-makers in Tunisia regarding the viability of photovoltaic technology as a whole.

As in the case of charge regulators, ballast of foreign production is now victim of high importation taxes and duties and has therefore disappeared from the commercial Tunisian market. This, too, raises the problem of availability of spare parts of superior quality.

Product, Country of origin	Number of installed units/ Period of operation since installation	Projects and programmes	Technical problems	Improvements carried out after installation	Favourable aspects	Remarks
SVE Germany	310 2 to 6 years	• School electrification programme (Gouvernorat of El Kef) • SEP, pilot dissemination phase	some breakdowns because of infiltration of dust and humidity (problem of the lamp case, not of the ballast)	use of water-protected lamp cases	ballast considered as viable	• assembling of ballast, tube and lamp case at El Kef • after 6 years, 55% of the ballast were still operational • according to the supplier no longer available on the market (price too high)
Helios/ Helios B1 Germany	240 2 to 6 years	• School electrification programme (Gouvernorat of El Kef) • SEP, pilot dissemination phase and intermediate phase	Helios (initial version): • ballast without case; electronic board too large for standard lamp cases of 18 W tubes in Tunisia • better protection against humidity and dust desirable • some breakdowns of the transformer	Helios B1 (new version): no more technical problems	ballast type B1 considered as viable	
SET Germany	35 2 years	SEP, intermediate phase	• protection against idle operation insufficient • causes interference with the radio			not used for the dissemination programme
Eckerle Germany	38 2 years	SEP pilot dissemination phase	blackening of tubes after only two to three months of operation			• not used for the dissemination programme • according to the manufacturer, the equipment was part of a pilot series and is not identical to commercial product

Tab. 11-2a): Technical experience with several types of ballast (nominal voltage 12 V; for tubes of 18 W)

Product, Country of origin	Number of installed units/ Period of operation	Projects and programmes	Technical problems	Improvements carried out after installation	Favourable aspects	Remarks
Eckerle (for 36 W tubes)	200 5 years	school programme (Gvt. of El Kef)				special ballast for lamps in classrooms
Labcraft UK	2,825 1 to 5 years	• school programme (7 Gouvernorats) • nat. programme, 3rd stage • programme of FNS (south Tunisia)	national programme: • blackening of tubes after 2 to 3 months of operation • ballast damaged after blackening of tubes		equipment of FNS programme: acceptable rate of breakdowns	problems with ballast of national programme probably due to • non-appropriate assembling (by producer of ballast) • tube not adapted • electronics modified
Solelec Spain	5,600 1 to 2 years	• project Ouled Nouaouia • nat. programme, first stage • nat. programme 3rd stage	*Ouled Nouaouia*: acceptable rate of breakdowns *national programme*: • blackening of tubes after 2 to 3 months of operation • some breakdowns of ballast after blackening of tube • ballast damaged due to short cut: charge regulator stops operation of the entire SHS			• elements (transformer, diode, transistor) vary from one project to the other • more than 30% of breakdowns during warranty period (2 years) • all ballast replaced by a different product
Invertec UK	3,000 1 year	national programme first stage			rate of breakdowns after one year below 2%	short-term experience (installation in 1995)
MIFAX Tunisia	30 4 years	SEP, pilot diss. phase and intermediate phase				pilot series; production meanwhile stopped
ELSI Tunisia	160 1 year	FNS, project at Zaghouan	technical problems (eliminated within the warranty)			

<u>Tab. 11-2 b):</u> Technical experience with several types of ballast (12 V/18 W; Eckerle: 12 V/36 W)

11.1.3. The photovoltaic modules

The nominal power of the photovoltaic generator is expressed in Wp (= Watt peak). These standard conditions (solar radiation of 1000 W/ m², ambient temperature 25°C) do not correspond to the normal climatic conditions in Tunisia.
It is stipulated that modules are operational for a period of twenty or even thirty years. Although today producers of modules with amorphous silicon cells offer a guarantee period of ten years (identical to those of mono- or polycrystalline cells), AME was conservative in its calls for tenders and accepted exclusively *mono- or polycrystalline PV cell material* in the offers.

Generally, the producers propose modules with *variation of the peak power* of 10% (sometimes 5%) and guarantee a *maximum reduction of this power* of up to 10% after ten years of operation. So, a module with a measured power of 80% of its nominal power would still be considered as acceptable for the client after ten years of operation. In the first stage of the national programme, when the nominal power of the PV generator had been fixed to 70 Wp, a potential reduction of 20% would have resulted in a power of only 56 Wp, a value considered to be too low. Therefore, for this call for tenders a minimal power (65 Wp) was fixed and had to be guaranteed by the suppliers for the new modules.

To be able to charge the battery, the voltage relating to the electrical current produced by the PV module has to be superior to the voltage, defined as the *top charge level* of the battery, at all ambient temperatures. If this is not the case, the PV generator will not charge the battery completely and the client will pay for imaginary watts. Modules with such characteristics are not appropriate for SHS, but they can be used without problems for other purposes, such as water pumping.

For SHS, the efficiency of the photovoltaic cells is not a priority. Of course, if the surfaces of two modules are necessary instead of one to deliver a certain power, the costs per Wp will increase considerably (due to the additional frame, glass, support, etc.). Space, however, is not a problem if the modules are fixed on the roofs. It is, however, essential that the installation is made according to the state-of-the-art. This means that the inclination of the module(s) is between 45 and 55°, the supports are conveniently fixed so that they are storm and rain resistant, all steel supports are corrosion protected by galvanising or two layers of anti-rust paint, the module(s) are directed towards the south and shadows are avoided.

Slight infiltration of dust through the silicone sealing of the frame, as sometimes noticed in modules installed in Tunisia at the beginning of the eighties (but seemingly without any reduction of power) has not been observed with the modules installed within the pilot dissemination phase, the national programme or the FNS projects. Also, there has been no change of colour of the cells (browning or whitening) which might lead to a reduction of the power.

So, the experience with all types and makes so far installed is very positive (*Tab. 11-3*). The rare problems that occurred are of a more ordinary nature for they concerned connection boxes and diodes.

The rate of modules being damaged by vandalism was high in the national programme for the electrification of rural schools - but it seems that the children only started throwing stones at the modules after the systems had stopped operating correctly, so that the pupils no longer benefited from the technology. The cases of modules found broken at SHS installed in programmes and projects for the electrification of individual households are negligible.

The number of modules broken as a result of hail was also negligible, although in some regions of north-west Tunisia there are severe hailstorms every year.

The modules are fragile and relatively heavy so that there is a risk of damage during transportation and storage. Because of non-appropriate storage at Tunis airport, a number of connection boxes of modules delivered for the pilot dissemination phase were broken. The boxes were thicker than the frames of the modules so that the whole weight of the stored modules lay on these boxes. The boxes were replaced locally.

There was only one case of a module being broken during installation, A hole was drilled through the frame of the module and the drill came in contact with the glass, which broke immediately. Taking into account the difficult local conditions (transportation to isolated sites via tracks and even on foot, difficult mounting of the modules on roofs), this low ratio of losses proves that the technicians worked very carefully.

In principle, the assembling of modules (glassing, framing) is also possible in Tunisia, especially after a regional market in the Maghreb has started to develop. But before investing in a partial local production, foreign investors demand that the Tunisian government should guarantee purchasing a certain quantity of modules per year. Due to the strong competition between international PV manufacturers, resulting in favourable prices of the modules offered, Tunisian decision makers should not rely on only one manufacturer.

11.1.4. The batteries

The principal characteristics of different types of batteries were analysed in relation to the management of the battery by the charge regulator and the experience with several types of batteries in rural households (chapter 9.1.1.1.).

The case of a lead battery contains several groups of positive and negative plates. Each group (called an element) of 2 V is placed in a separate compartment. A battery of 12 V is thus composed of six elements, which are connected by a piece of metal, the connecting bridge. In order to avoid shortcuts, sheets of plastic foil, rubber or glass fibre are placed between the plates. These are called the *separators*.

Shortcuts, caused by metal particles which have detached themselves from the plates and fallen to the bottom of the battery case, should be excluded as well. Batteries of superior quality therefore have separators which form an *envelope* around each single plate.

Product, Country of origin, Nominal power per module (Wp)	Number of installed units, period of operation	Total installed power (kWp)	Projects	Technical problems within the responsibility of the manufacturer	Problems within the responsibility of Third parties	Improvements carried out	Remarks
Siemens Solar Germany / United States 53 Wp	300 2 to 6 years	16 kWp	• SEP, pilot phase • FNS, *Béja*	some connection boxes broken (non-appropriate storage)	two modules broken due to vandalism (stones)	connection boxes repaired locally (warranty)	favourable operation, negligible rate of problems
Photowatt France 50 Wp	3,419 up to 4 years	171 kWp	• School electrification programme • national programme 2d stage	*schools:* • some infiltration of water into the connection boxes • some diodes badly fixed	relatively high rate of modules broken due to vandalism (stones; School programme)	boxes: water protection improved by silicone sealing; diodes fixed (warranty)	after solving problem of non-waterproof connection boxes, favourable operation
BP Solar Spain BP 270 70 Wp	1,000 2 years	70 kWp	National programme first stage	• one module broken by hail • one box torn away by storm	two modules broken due to vandalism (stones)	one box repaired locally	favourable operation, negligible rate of problems
BP Solar Spain BP 250 50 Wp	540 2 to 5 years	24 kWp	• FNS (*Gantas, Zouarine, Kef*) • Project *Ouled Nouaouia*	• one connection box melted • anti-parallel diodes of one module damaged		one box and diodes repaired	favourable operation, negligible rate of problems

Tab. 11-3 a): Technical experience with photovoltaic modules from different producers

Product, Country of origin, Nominal power per module (Wp)	Number of installed units, period of operation	Total installed power (kWp)	Projects	Technical problems within the responsibility of the manufacturer	Problems within the responsibility of Third parties	Improvements carried out	Remarks
Kyocera Japan 50 Wp	500 2 to 6 years	33.5 kWp	• school programme (Gvt of *El Kef*) • SEP, intermediate phase • FNS (*Médnine, Ayaicha Djebel)*	-.-	one module broken during work on the roof	-.-	favourable operation
ANIT Italy 50 Wp	828 up to two years	41.4 kWp	• national programme 3rd stage • FNS (*Souasia, Sidi Amer)*	breakdown of diodes in 2 SHS			favourable operation, rate of problems negligible
Solarex United States 50 Wp	1 year	15.1 kWp	• FNS *(Zaghouan)*				favourable operation

Tab. 11-3 b): Technical experience with photovoltaic modules from different producers

The battery, which is first charged "dry" at the workshop, is then brought to the site and is filled with electrolyte (acid). The plates must always be covered with electrolyte. Gases, which are occasionally produced due to a light overcharge of the battery, are emitted through the plugs of the battery lid. Gassing must be very low in order not to affect the health of the user family as the battery is installed in the living room. Negative effects arising from gassing on the health of the users have not be reported in Tunisian projects and programmes.

The batteries installed in SHS of the national programme are batteries of *low maintenance*. According to the producers, it is sufficient to add demineralised water at intervals of nine or twelve months, or even more.

A *large case* is preferable, as it allows a good circulation of the electrolyte. If it is more compact, the stratification effect (separation of electrolyte into strata of different acid concentrations) will not occur in a pronounced form, and so a regular cycling of the electrolyte will not be necessary.
The case is preferably made from *transparent* plastic material. This allows the electrolyte level to be controlled by viewing without opening the plugs. For tubular batteries a stronger material is essential for the case, as their dimension and weight are more significant. Cases for these batteries are therefore made from ebonite, a black opaque material.

In batteries with an ebonite case, the metal connecting bridge of the elements is situated on the outside, on the lid. This is not an optimal solution because, if a piece of metal falls on the bridge, it may cause a shortcut. The only accident, which occurred with a battery, and which might have had severe consequences, was caused by a screw driver which fell on the connecting bridge, causing an explosion of the battery. Therefore, it is recommended that these metal connection bridges are covered with rubber protection.

Transportation of the heavy batteries on foot to the dwellings of the user households is very hard work, even for two people. It is self-evident that for transportation *appropriate handles* on two sides of the case are necessary.

For SHS installed in the pilot dissemination phase (1989) only local batteries of a capacity of 90 and 200 Ah (TV batteries) were installed. In the majority of cases, their exploitable lifetime was between a year and a half and two years, thus insufficient (see chapter 9.1.1.2.).
These negative experiences led AME to execute some systematic research on the subject of batteries /11-1/. Furthermore, AME had to find procedures for relatively quick tests in order to judge the quality of batteries, proposed in tenders for the national programme.

In January 1993, Tunisian producers of batteries and charge regulators, as well as scientists, representatives of institutions of material testing and standardisation met in Tunis, at the invitation of AME, for round-table discussions. Due to the negative experience with TV batteries, the battery manufacturers agreed to start development of batteries, which would be more appropriate for solar applications. In fact, the initial technical problems with batteries may now be considered to be solved. Both on an international as well as on a national level, batteries are available which assure a convenient operation of SHS for three to five years or even more. Present problems concern more commercialisation and the price of these special solar batteries *(Tab. 11-4).*

At the round-table meeting, an agreement was achieved for carrying out two types of battery tests: one to determine the capacity of the new battery, the other for estimating the long-term endurance in cycles. The procedure for the capacity test was adapted to the one stipulated in the standards for industrial and starter batteries.

The standards for stationary batteries state that the test procedures described for cycling endurance should also be valid for batteries, installed in photovoltaic systems. Unfortunately, the cycles of charge and discharge prescribed in this standard are very long, so that the tests would take much time. These tests were therefore not appropriate for testing batteries of SHS.

On the other hand, tests with solar batteries, applying too short cycling periods of charge and discharge would not be significant. Short cycles are more characteristic of car (starter) batteries.

As a compromise, it was agreed to use cycles with a constant charge current of *2 x I20* (that means. for a battery of 90 Ah a current of 9 A) till the battery is completely charged. Then, the battery is discharged for one hour with a current of 18 A. Every 100 cycles, the capacity of the battery is measured, when it is completely recharged.

The test finishes at the moment when the capacity has decreased to half its nominal capacity in C20. Experience has shown that a battery at this level of capacity loss cannot be used any more in SHS and must be replaced.

A Tunis-based institute, specialised in material testing (the *CETIME)* was contracted with the execution of the tests /11-3/.
In parallel, capacity tests were executed with other batteries at the workshop of SEP in El Kef. Although the equipment here was much less sophisticated, the results of the laboratory tests at *CETIME* were confirmed by the tests at the workshop.

Producer	Make	Type	Country of origin	Nominal capacity	Number of installed units (approx.)	Principal projects and programmes	Lifetime
ASSAD	SL 90 P/ SL 200 P	TV battery	Tunisia	90 Ah / 200 Ah	1,000	• SEP, pilot dissemination phase • school electrification programme	1 to 2 years (estimated average)
ASSAD	SL 110 (SL 90 RP)/ SL 130	battery with thick flat plates	Tunisia	90 Ah/ 130 Ah	2,000	• SEP, intermediate phase • national programme phases 1,2,3	2 to 3 years (estimated average)
ASSAD	6 ADL 7	tubular battery	Tunisia	190 Ah	200	FNS projects	operational for two years (estimated lifetime: 4 to 6 years)
TUDOR Tunisia	M 12 SH	battery with thick flat plates	Tunisia	90 Ah	100	• SEP, intermediate phase • FNS projects	2 to 3 years (estimated average)
TUDOR	190 PLT	tubular battery	Tunisia	180 Ah	200	FNS projects	operational for two years (estimated lifetime: 4 to 6 years)
STECO	3000	battery with thick flat plates	France	105 Ah	50	*Dhokkara* project	3 to 4 years (estimated average)
FULMEN	6 IRF 4	tubular battery	Spain	100 Ah	600	• national programme first stage • FNS projects	operational for two years (estimated lifetime: 4 to 6 years)
TUDOR Spain		tubular battery	Spain	100 Ah	50	*Ouled Nouaioua* project	5 years (estimated average)

Tab. 11-4: *Types and lifetime of batteries installed in SHS in Tunisia*

The capacity tests of two new TV batteries showed that the capacity of one of them was (in C20) almost 30% below the nominal capacity indicated by the manufacturer, whereas for the second battery the nominal capacity was confirmed.

The characteristic curves of the test procedure indicated that the voltage, corresponding to the low discharge level, was reached after 14, or 20 hours.
This would correspond to an autonomy of 3, 4, or 5 days. The first result would probably not ensure a satisfactory operation of the SHS in the long term, especially as the cycling of the battery during a period without solar insolation often starts when the battery is not completely charged.

The solar battery (battery with thick flat plates) of one manufacturer also had a capacity inferior to the nominal capacity indicated.
The capacity, which was measured for two other types of solar batteries from the same producer and of three types of another manufacturer, exceeded the nominal capacity, sometimes even considerably.

In the endurance tests, a TV battery was cycled 420 times before the capacity dropped to half of its nominal capacity. This would correspond to 14 months of operation; a result which is quite close to reality for batteries of this type installed in households (*Fig. 11-1*).

Fig. 11-2 shows the result of capacity tests, executed with a new battery, and which were repeated after ten and eleven months of operation in a rural household. The ageing effect of the battery is seen clearly. In relation to the cycles performed, the battery is discharged more rapidly, thus causing a significant loss of autonomy of the PV system. This ageing is much less accentuated for solar batteries with thick flat plates. *Fig. 11-3* shows the results of endurance tests with three different solar batteries of Tunisian production (two batteries with thick flat plates, one battery of the TV-type, but equipped with *envelope* separators of improved quality). Two batteries possessed more than 50% of their nominal capacity after 900 cycles of charge and discharge. This favourable result confirmed the field experience regarding batteries of this type. It was quite surprising to see that the influence of a simple measure, such as the improvement of the separators, could have a striking positive effect on the performance of a battery. Unfortunately, the battery with *envelope* separators has never been commercialised, so that the laboratory test result could not be confirmed by a representative sample of such batteries installed in SHS.

The results of the endurance cycling tests were excellent for tubular batteries of Tunisian production. The tests had to be stopped after more than a thousand cycles, when the capacity of the batteries was still well above the level of 50% of the nominal capacity.

The programme of measurements at the CETIME laboratory and at the SEP-workshop was completed by measurements on batteries, which had been installed some months or even years in SHS user households. First the nominal capacity of the new battery was measured by tracing the "characteristic curve". After some months of operation, the actual capacity of the battery was measured again in the state that it was found at the household. After a complete recharge at the workshop, the capacity was measured once more. The procedure was repeated after some months.

The test programme produced the following results:

The reduction of the capacity of the batteries in relation to the time of operation was evident (see *Fig. 11-2, 11-3*), but no significant correlation could be found *(Fig. 11-5)*.

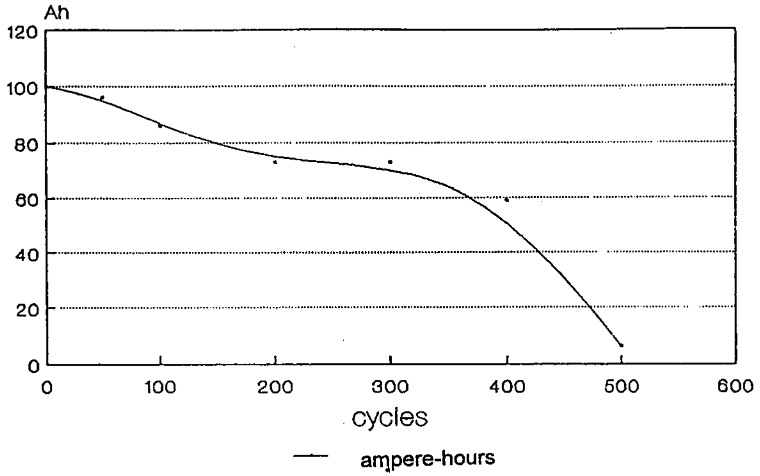


Fig. 11-1: *Long-term cycling test of a TV-battery: after 420 cycles the capacity is reduced to about half of the initial capacity. Source: CETIME (test report for AME-GTZ)*

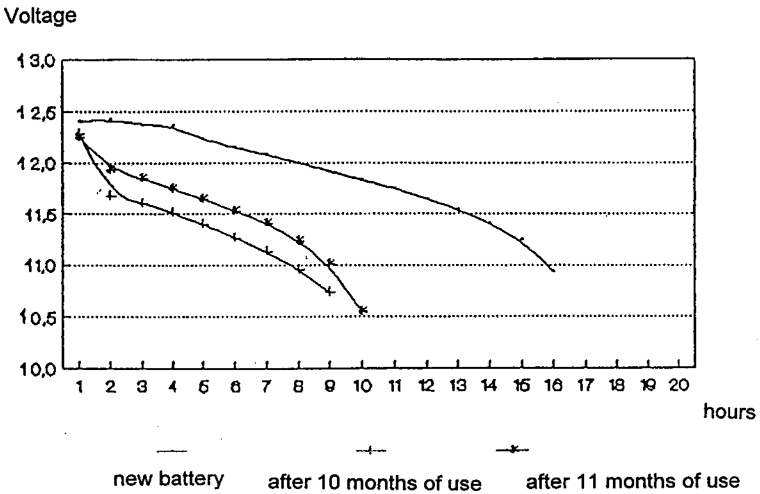


Fig. 11-2: *The premature ageing of TV-batteries was confirmed by tests of batteries installed at user housebolds. After 10 to 11 months of utilisation, the battery is rapidly discharged, and thus the autonomy of the system considerably reduced*
Source: AME (tests at workshop in El Kef)

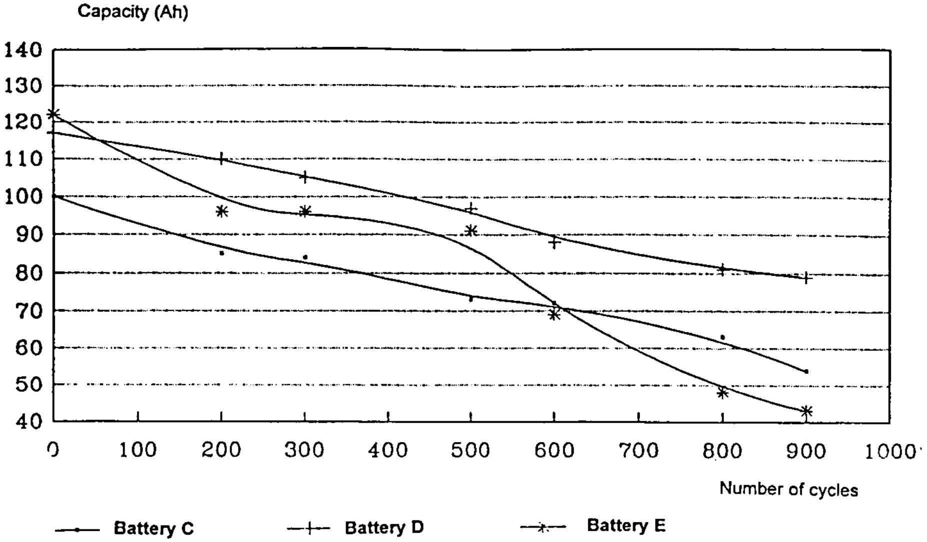


Fig. 11-3: *Capacity variation of three batteries of Tunisian production (two solar batteries with thick flat plates, one TV-battery with improved separators), in relation to the number of cycle of charge and discharge*
The improvement in relation to the test results with a TV-battery is evident
Source; Test report CETIME for AME-GTZ

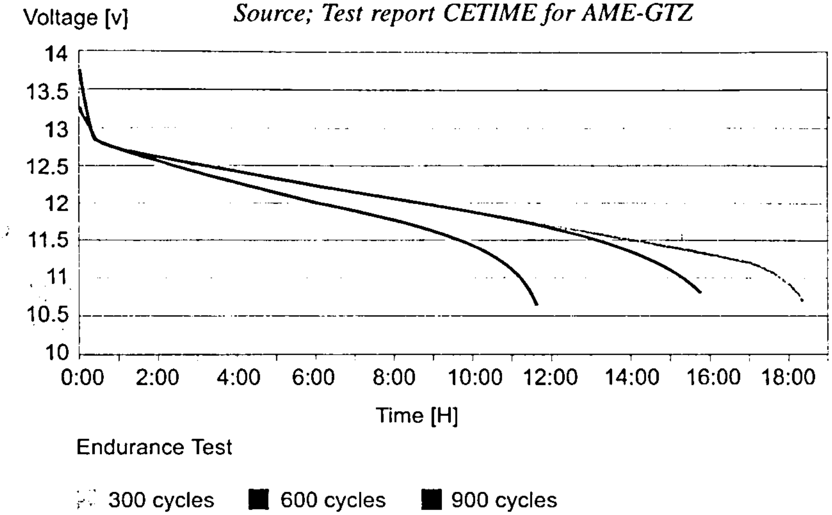


Fig. 11-4: *Ageing of solar battery with thick flat plates, produced in Tunisia (results of tests at CETIME)*

As several factors (variation of the initial capacity of the batteries, differences in the energy consumption of the individual households) play a role, the scatter band of the ageing effect is rather large.

This is confirmed by the data registered by the four MODAS systems installed at different households (see chapter 9.1.). However, the significant decrease in capacity, found for some TV batteries even after only a few months of operation, was striking. SEP, which supported the test and measuring activities, was unfortunately not able to extend this programme, as its main objective was technology dissemination and not research.

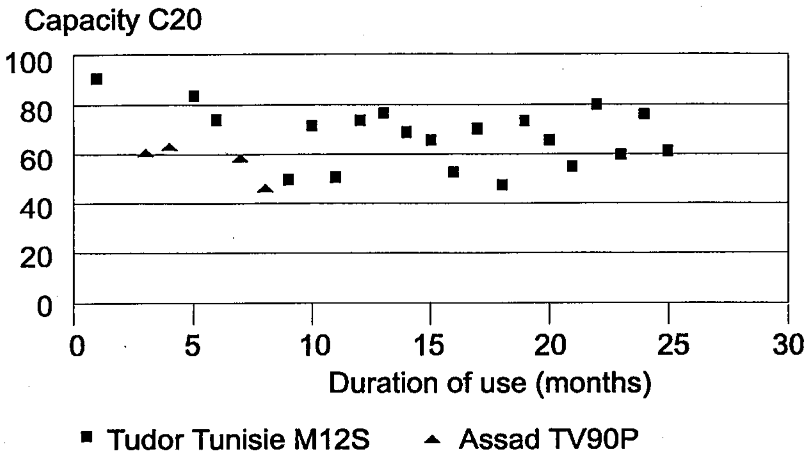


Fig. 11-5: *Capacity losses (in Ah) of TV batteries installed in SHS in relation to their time of operation*

The decision on the standard battery to be installed in the national programme is rather difficult. Regarding other components, the option has always been made in favour of the product offering the best quality. Taking into account the limited financial means of the Tunisian government, a decision would have to be taken between
a product of favourable quality, acceptable price, and with a lifetime of between twoand
- three years (perhaps even more, depending on its use), thus a solar battery with thick flat plates; and
- an alternative offering the same services, but for twice the lifetime and for almost three times the price: the tubular battery.

Economic calculations showed that the tubular battery has an advantage only after a considerable period of operation, thus not until the responsibility for the SHS has passed to the user household. In addition, these advantages are not striking and under certain conditions, the battery with thick flat plates might even be the better solution in the long term from the economic point of view (see chapter 9.3). Moreover, the majority of households would not be able to afford a new tubular battery, once the initial one is no longer operational. So, why favour a technology which will not remain the normal equipment for SHS in the long term?

11.2. Structural and organisational aspects of the national programme

11.2.1. Determination of the responsible organisation

11.2.1.1. The concept

In the framework of the VIIIth Five-Year Plan (1991 - 1996), the national programme for rural solar electrification was initiated, providing for the installation of 10,000 SHS. The programme was defined in such a way that the extent of its execution depended on the available budget. So, the number of households to be electrified by photovoltaics was more a general objective than an obligation.

The evaluation mission for the second phase of SEP (1993) considered the designation of a responsible organisation for the national programme to be a key question which had to be solved as quickly as possible. After consultations with AME and STEG, the relevant Tunisian Ministry proposed that AME should take over this function.

Accepting responsibility for the execution of a national programme was a task new to AME and not fully in line with its principle objectives. The agency had seen its role as an initiator, catalyst and promoter of new ideas, technologies and strategies in the field of renewable energy and rational use of energy. For the execution of the programme, it had motivated well-established, interested partners, such as offices, companies, research institutions, consultants, etc. Logically, AME had seen its main field to be feasibility studies, demonstration projects and pilot dissemination phases. Its structure, consisting of technical units of teams of young specialised engineers, was adapted to this philosophy.

STEG also had reservations against becoming responsible for the photovoltaic electrification programme. At first, this is difficult to understand, taking into account the enormous involvement of STEG in the rural electrification programmes via the electric grid which had been going on for more then twenty years. The main reasons for the restrictive position of STEG were:

- Its entire structure is linked to the grid. The respective technology, methodology, costs, accounting systems were all well known and established. Photovoltaics did not fit easily into this system. Considerable organisational and administrative efforts would be needed.

- STEG estimated the potential of rural solar electrification to be marginal. Its impact would be limited to the rural environment with isolated dwellings, which, according to STEG at the time, were going to disappear anyway. There was considerable doubt about the necessity for a new electrification programme, complementary to the classic one.

- STEG had twice been involved in solar "adventures". The first experience was *Hammam Biadha*, a PV power station for a village. After some years of successful operation, it fell a victim to technical problems, causing costly repairs. The second case was the manufacture of solar water heaters by a subsidiary of STEG, *SIAME*. Production was stopped after some years as a result of a growing number of claims and complaints from customers.

- Finally, national policy was targeted at a privatisation of STEG. The separation of the sectors electricity (making losses) and gas (profitable) was being discussed. In this situation, STEG could not accept additional responsibility for a new sector, which would depend on public assistance in the long term.

However, discussions with STEG, with its regional structure of districts equivalent to the regional political and administrative structure (*Gouvernorats*) and representations (antennas) in all small Tunisian towns, continued and are still going on. Even if STEG has refused the role of being the organisation responsible for the programme, would it accept responsibility for the implementation of the programme in the field, under the general authority of AME? Under which conditions would STEG be ready to collaborate with AME?
For AME, it was clear from the very beginning that, in spite of all reservations of STEG, a programme of rural solar electrification could never succeed without the prior agreement, co-operation and active participation of STEG. In addition, it had decided to make use of the private sector and of the existing regional administrative structures to a maximum extent.

Convinced of the importance of photovoltaics for Tunisia, AME then accepted the task to act as organisation responsible for the programme, under the following conditions:

- the programme was to concentrate on the seven *Gouvernorats* in the north-west (*Siliana, Jendouba, El Kef* and *Kasserine*) and of the Centre (*Kairouan, Sidi Bouzid* and *Mahdia*);
- AME's role was to be limited for the time being to the first two stages of the programme;

- there was to be a close co-operation with STEG and the regional authorities.

The adopted concept envisaged the management of the national programme by the head office of AME at Tunis and two regional representations, one for the *Gouvernorats* of the north-west (already existing in the form of a nucleus in El Kef), the other for the central *Gouvernorats* was still to be established.

The *Gouvernorat* of El Kef was selected for the implementation of the first stage of the national programme, supported by the bilateral technical co-operation with Germany (GTZ). STEG became involved by strengthening the regional office of AME in El Kef by a crew composed of one engineer and two skilled technicians. Following an initiative of the *Gouvernorat*'s administration, the head of the regional office of AME and the head of the planning department of the El Kef district of STEG visited the whole of the *Gouvernorat* and fixed the border line between the priority zones for the grid and those for the solar alternative, *Sector* by *Sector*, *douar* by *douar*. If the estimated amount for connecting a rural household to the grid exceeded 1 563 US $ (1 500 DT), the photovoltaic solution was considered to be preferable and the household became part of the potential solar electrification. This systematic work allowed the potential rural PV electrification to be worked out in detail.

When the next stages of the programme were due to be planned, representatives of AME contacted the Governors and the Head of the District of STEG in *Jendouba*, *Siliana* and *Kasserine*, in order to identify the potential rural solar electrification there as well, and to clarify the priority zones for the grid and for photovoltaics.

A factor, helpful to enlarge the number of SHS installed but harmful to the national solar programme, was the number of Presidential Projects, followed by the activities of FNS. The two programmes intervene in favour of the development of infrastructure and the creation of jobs in the countryside. The costs, which are accepted for the construction of tracks, supply of water and electricity etc., considerably exceed the maximum unit costs fixed in the Five-Year Plan for such tasks.

The large number of FNS projects (more than one thousand all over the Republic) and their small size (one project for up to fifty households) makes the establishment of permanent regional follow-up structures extremely difficult.

As a positive aspect, FNS considers photovoltaics to be a normal solution for the electrification of some isolated sites. However, the scattering of the projects and the high costs, which are accepted for connecting households to the electrical grid, are negative.

The success of the public PV dissemination programme complemented by a simultaneous development of a commercial market depends on a clear and long-term programming. As the FNS programme offers the chance of receiving a subsidised SHS to potentially every household far from the grid, the approaches of the national programme and the FNS programme are not compatible.

Therefore, AME expressed some reservations concerning the FNS concept and refused to manage the solar rural electrification sector of this programme. But, owing to the importance of the FNS programme, it accepted assisting FNS and the corresponding administration in the *Gouvernorats* in the preparation and evaluation of calls for tenders and in the acceptance of the equipment installed. Inevitably, AME will always be involved in this programme in the case of problems, as the national competence in this field is concentrated in this agency.

The problems with FNS installations regarding the breakdown of components will certainly become more severe in the future. In order to survive, these small-scale projects demand repeated and costly interventions. Otherwise, as has been shown in the cases of *Ouled Nouaouia* and *Dhokkara*, they deteriorate rapidly and finally fail.

11.2.1.2. Regional representation of AME in El Kef

AME's decision in 1994 to leave the place, temporarily put at its disposal by the centre for professional education in El Kef, and to rent a new area with offices and workshops, underlines its desire to be present in the long term in the north-west of Tunisia.

Under the responsibility of the head of the regional service, two sections were created, the firewood section (objective: large-scale dissemination of improved traditional stoves in order to reduce firewood consumption) and rural solar electrification section with one crew each from AME and STEG, both composed of an engineer and two technicians, plus two secretaries.

For its regional office, the head office of AME applies a modern, decentralised management. The initiative and the responsibility for the activities in the region, its management and the budget related to overheads (fuel, office equipment, fax, telephone) have widely been transferred to the service in El Kef. The administrative procedures (accounting etc.) are well established and efficient.

Even under normal conditions, the work load of the engineers and technicians, working in the field of photovoltaics, is very high. It includes the designation of the zones to be selected, negotiations and agreements with local and regional authorities, participation in the identification or at least verification of the lists of interested households, advice to the households before the installation of SHS, evaluation of offers and the contractual negotiations, test and receipt of equipment (at the factory and at the storeroom) and provisional and final acceptance of the installations on site.

The technical problems of the charge regulators and the lamps, noted in thousands of cases, have aggravated the work load of the directorate at the head office and at the regional service centre. The analysis of technical problems, negotiation of acceptable solutions, verification of agreed rectification occupied the responsible persons of AME up to the limits, obliging them to work to the point of exhaustion doing overtime in the evenings, holidays and week-ends.

It is clear that these urgent activities did not leave enough time for the execution of other important tasks. This may have negative consequences in the future for, when the number of new installations is multiplying, hundreds, if not thousands of old SHS will stop operating as a result of the end of the lifetime of the batteries; a fact which is foreseeable and normal after a period of two to three years of operation.
Systematic advice to users, professional education and training of local technicians, support for the establishment of regional commercial structures, regional and local availability of spare components (batteries, ballast, charge regulators) - all this important work could not be done systematically, for a lack of available personnel from AME.

The success of a programme depends to a great extent on the motivation and commitment of individual personalities. In order to understand the administrative structures, to know the sites and rural tracks etc., to gain professional all-round experience, and to win the confidence of the rural population, experience of several years is necessary.

Therefore it must be mentioned that, in spite of the very motivated and skilled staff (both at head quarters as well as in the regional service in El Kef), the regional structures are still weak (as in the case of the *Gouvernorat* of El Kef), or are only rudimentary (in the case of the other *Gouvernorats* affected by the programme).

11.2.2. Identification of the potential user households

The approach, initially proposed, had foreseen

- defining a ranking of the *Sectors* according to the criterion of a low long-term electrification rate via the electrical grid in the selected priority *Gouvernorats*;
- starting the programme in the *Sectors* with the lowest electrification rate, and
- offering all households living in these *Sectors* an equal chance to acquire an SHS.

The list of the *Sectors* and the rankings were to be published, allowing every household

living in these *Gouvernorats* to estimate, if or when it would have a chance of receiving a subsidised SHS. Those excluded from the national programme for the next five to seven years would be guided to the commercial sector, should they be interested in acquiring an SHS. In this way it was thought that the public programme and the commercial market could develop side by side.
During the implementation of the *first stage* of the national programme in the *Gouvernorat* of El Kef, it was already seen that this concept could not be applied in its original form; it had to be adapted.

The problems were as follows:

The extension of the grid had not followed the long term plan, as fixed in the documents of the CGDR. Even during identification of the households for the pilot dissemination phase (1989/90), many households were found to be connected to the grid, although, according to information of CGDR, it would not have been possible to connect them to the grid even in the long term. The list, defining the ranking of the priority *Sectors*, was already outdated.

The decentralisation policy had transferred the responsibility for the decision on zones to be electrified from the national to the regional authorities (in fact to the Governor), in agreement with the Head of the STEG district and in the framework of budgets fixed year by year. The extension of the grid no longer followed the one criterion of lowest costs, but could now reflect other criteria and demands, such as giving priority to zones near the border, or preferring zones with high economic potential.

So, it was not possible to impose a programme with selection criteria on the *Gouvernorat*, without tolerating its participation.

Furthermore, due to the hopes of the population, and the relatively long period between the formulation of the concept and the start of the installations of the national programme, some promises had been made by regional authorities to the inhabitants of *douars*, who were excluded from access to the grid and were demanding the solar alternative.

There were other difficulties with this strategy:

The priority *Sectors* were situated in several Delegations. A commercial structure for maintenance and repair would require a certain number of near-by installations in order to be profitable for an electrician. The number of households in just one *Sector* would not be sufficient. It was not possible to predict when the neighbouring *Sectors* would benefit from the programme as well, because the velocity of the progress was dependent on co-financing of international financing institutions. These additional funds had to be assured for each stage of the programme, so that the drafting of a binding plan *Sector* by *Sector* for the next few years was not possible.

The majority of *Sectors* with a low electrification rate was characterised by extremely difficult access and where the majority of the inhabitants was poor. So, the programme was started under local conditions, considered among the most difficult for the whole of Tunisia.

Taking into account these inconveniences, while still convinced of the spirit of the strategy proposed (transparency, simplicity, neutrality) and regarding the number of SHS available for the first stage of the programme (800, later increased to 1 000), four zones were fixed instead of a larger number of *Sectors*. These zones consisted of one or two neighbouring *Sectors* and were subsequently enlarged to include further adjoining *Sectors* based on the number of SHS available. The *Sectors* of these selected zones were among the fifteen priority *Sectors* according to the initial ranking of the *Sectors*.

Most of these selected *Sectors* were identical to those identified before within the pilot dissemination phase. The population was thus aware of the advantages and restrictions of the photovoltaic technology. The minimum number of SHS per zone was fixed to about 150. It had been thought that this number would be sufficient to motivate a private electrician to start a small business for repair and maintenance of the SHS. Later it was found that this number was highly insufficient.

Much effort was given to providing *information* and *identification* of the households. In agreement with the Heads of the *Sectors*, a mixed team (a female inquirer and a technician) visited every household in the zones, talked to the housewife, the husband and the children and explained the details and conditions of the national programme. The interested households (about 90% in the priority zones), put their names on the list, at this time still without having to pay the first instalment of their financial contribution (52 US $).

The households, who refused the SHS gave the following reasons:

- lack of money (the argument mainly of elderly persons, living alone);
- fear of having too many visitors (neighbours, relatives) to watch television;
- fear of being excluded from access to the electrical grid, once the household had opted in favour of SHS.

Six to eight months later, during the evaluation of the offers, the households were visited again, this time in order to collect the first instalment.

The rate of households, still interested and ready to pay in order to receive an SHS was high (about 80%) in the *Sectors* close to the capital of the *Gouvernorat* and those in the plains. The majority of the population in these two zones does not belong to the lowest social classes of the *Gouvernorat* (see chapter 9.2). The rate was less in the mountainous zone of the extreme north-west (about 70% in the Delegation of *Sakiet Sidi Youssef*), and low in the south of the *Gouvernorat* (*Kalaat Senan*, a Delegation with a population which is generally poor).

In the *Sector* of *Mzita* (Delegation of *Kalaat Senan*), the whole of the population wanted to receive SHS, but completely refused to contribute financially. The region had suffered from drought for several years. Illnesses had, in addition, killed many sheep and goats. Having no income, the farmers were obliged to eat seeds. A small farmer told us: "I prefer to go hungry in order to be able to feed my animals". STEG was unpopular in this *Sector* for the same reason. In the framework of a Presidential Project, it had constructed an LT line in one part of the *Sector*, but all households refused to pay the first instalment for grid connection. However, for STEG, this situation was not at all new. As it was permanently present in the *Gouvernorat*, it could wait several years until the majority of the households had paid its first instalment, before starting with the grid connection of the households. However, SEP, which supported the start of the national PV programme, was forced to act rapidly so that it did not fall behind schedule. So, instead of the households in *Mzita*, households demanding solar electrification and living in the adjacent *Sectors* were considered (*Tab. 11-5, Fig. 11-6*).

The conditions of the solar programme had been established in a way which should allow access to electricity to at least the same percentage of the rural population as the STEG-programme in the same regions. In spite of the refusal of the population at *Mzita*, it can be concluded that this objective was reached.

Zone N°	Delegation	Programmed Sectors according to call for tenders	Sectors chosen after identification and collection of first instalment from the households	Installed SHS per zone
1	Sakiet Sidi Youssef	Ain Mazer	Ain Mazer, Jradou, Farchène	318
2	Kef East	Nathour, Dyr El Kef	Nathour, Dyr El Kef, Sarkouna, Oued Ermal N.	251
3	Ksour (Sers)	Ain Fdhil	Ain Fthil, Zitouna, Bousliâa	205
4	Kalaat Senan	Mzita, Ain Snan	Ain Snan, Bou Jaber, Safsaf, Mahjouba, Sed El Khir, Kalaat Senan	230

<u>Tab. 11-5</u> : *First stage of the national programme (Gouvernorat of El Kef): selected Sectors*

Fig. 11-6: *Sectors of the Gouvernorat of El Kef, where the first stage of the National Programme was implemented*

In the implementation of the *second stage* of the programme, the involvement of AME in the identification of the user households was limited to fixing the priority *Delegations*, in agreement with the *Gouvernorats* concerned. The process of identification of individual households and collecting the financial contribution was left to the regional and local authorities. The agency waited to receive the lists of the potential households officially from the administration of the *Gouvernorat* in order to forward them to the companies contracted with the installation. The intention was to reduce the work load for the staff of AME. In addition, the agency did not want to be involved in potential discussions with households interested in receiving SHS, but eventually considered by the regional authorities as unworthy or incapable of managing the expensive, publicly-subsidised SHS correctly. Of course, such an approach was against the principle of strict neutrality proposed in the initial strategy.

However, practice showed the necessity of the involvement of AME in the process of identification of the households. The lists of households produced by the administration of the *Gouvernorats* were incomplete or mentioned households, which could favourably be connected to the grid, being close to an LT line. So, corresponding to the principles of the initial strategy, and even for reasons of pragmatism, in the *third stage* of the programme AME again took over responsibility for selecting the households. The installation works of this stage were stopped temporarily due to technical problems with electronic components. The installations are scheduled to be taken up again in 1997 (*Fig. 11-7*).

Fig. II-7: *Delegations, where the first three stages of the National Programme were implemented*

Gouvernorat	Delegation	Sectors	Number of SHS installed
Kasserine	Laâyoun Jedlien	Tiwicha Ain Om Jdour, Fej Tarbah, Mehrza, Ain Hmadna	120 75
	Haidra	Lajred-Tabaga, Haidra, Mkimen	83
	Thala	Dachra, Lahmed, Barmajna, Chafi, Zalfen, Oued Archah, Sray, Ain Jdaida, Oueljet Edhal, Bni Med, Ejoua	175
Siliana	Bourouis	Bourouis Sud, Krib-Gare	56
	Makthar	Bez, Soualem, Sind Hadded, Bni Hazem, Garâa	100
	Krib	Krib-North, Krib-Sud, Dokkania, Messaoudi-Sud	174
	Gâafour	Lakouet, Lahouez	57
	Bargou	Ahouez Bargou	1
Jendouba	Gardimaou	Forgsan, Rakaa, Ain Soltan, El Marasen, Fej Hcine, Sray, Wichtata, Galâa	336
Total			***1 177***

Tab. 11-6: *Second stage of the national programme: selected Sectors*

Gouvernorat	Delegation	Number of installed SHS
Siliana	Bargou	59
	Bouarada	50
	Gâafour	30
	Kesra	50
	Krib	40
	Siliana North	50
	Siliana South	61
Total		***340***

Tab. 11-7: *Third stage of the national programme: in 1996 Delegations and installations (state of work; another 620 SHS will be installed in the Gouvernorats of Jendouba and Kasserine)*

All zones had therefore been selected according to reasonable criteria, either that of a low long term electrification rate (national programme, first stage), or that of closeness to the AME subsidiary office in El Kef, combined with that of a present low electrification rate (second and third stage). All households in the priority zones of the solar rural electrification programme could thus acquire an SHS, under the condition that the financial instalment had been paid.

However, owing to the dependency of the progress of the programme on the availability of funds and taking into account the delays because of technical problems, it was in fact impossible for a rural household to know, if or when it could benefit from the national programme.

In El Kef, in a limited number of cases, the representatives of the *Gouvernorat* had promised households in some isolated hamlets that they would receive SHS. These promises were made before a common agreement on a nation-wide strategy was found. It was difficult for the *Gouvernorat* not to keep its promises.

So, after written confirmation of the *Gouvernorat*, which in this way took the political responsibility for the decision, AME agreed to supply SHS to these households. However, their number did not exceed five per cent of this first stage of the programme. These user households also paid the obligatory financial contribution.

It was seen earlier that the programme of the *National Solidarity Fund* had been following a different dissemination strategy compared to that of the national programme. Because of the massive financial interventions and the small size of the projects, every household far from the electrical grid could now hope to be connected to the grid or to benefit from receiving a subsidised SHS. As the photovoltaic system offered less services at costs which, in the long term, were higher than those for the grid, the solar solution was now considered as a second choice.

Gouvernorat	Delegation	Sector /Douar	Number of systems	Date of installation
Gafsa	Ben Khir	Ayaicha, Djebal	29	August 1994
Kebili	Douz	Ksar Guilène	48	November 1996
El Kef	Sakiet Sidi Youssef, Kalaat Senan	Jradou, Farchène, Ettabia, Mzita	180	February 1995
Jendouba	Jendouba South	Guantass	26	
Ben Arous		Ezzouaouine	37	May 1996
Béja		Henchir Mansour	56	February 1996
Zaghouan	El Fahs	Sidi Amer Esseassif, Drahmia, Ouled Graguis	53 124	July 1995 July 1995
Médenine			239	December 1994
Sidi Bouzid		Tallet Essouissia	21	July 1995
Tataouine			65	October 1995
Total			***878***	

Tab. 11-8: *SHS installed in the framework of the FNS programme*

We visited some households, which had first refused photovoltaics (case of *Sidi Amer*), or which had, in spite of the SHS already installed, successfully demanded to be connected to the electrical grid (case of *Ouled Nouaouia*).

Although the programme of the National Solidarity Fund was mainly created for the most disadvantaged households of the Republic, at these sites there were also some families of a higher social level (well-off farmers, retailers of agricultural goods, teachers). These people acted as promoters, so that their *douar* could benefit from the programme, and they influenced and articulated the demands of the other households (see the two interviews).
The refusal of SHS, on the grounds that they "do not allow the use of a colour TV and refrigerator", as expressed in *Zaghouan* and *Kairouan*, only reflects the position of these well-off promoters, as up to now only a minority of the rural households possess such electrical appliances in Tunisia. An important increase in the power of the SHS, discussed in the planning of the IXth Five-Year Plan, cannot be justified economically and would only correspond to the interest of a small minority of the rural households. It is exactly this rich elite, which would be financially capable of acquiring an SHS commercially.

STEG has made enormous progress with its rural grid extension programme. According to the official figures of STEG, in the *Gouvernorat* of El Kef, which is among the least electrified *Gouvernorats*, the rate has increased from 2.4% in 1975 to 65% in 1996 *(Fig. 11-8)*. During the VIIIth Five-Year Plan, STEG fulfilled the initial objective (connection of 3 300 households and installation of 50 electric pumps) with 180% (6 400 households connected). It must be mentioned that STEG considers a cluster of households as electrified, when the grid arrives at the *douar* and the possibility of a connection exists for the households. It neglects traditional dwellings (considered as temporary or rudimentary). The realistic electrification rate in the countryside, even with these restrictions, should exceed the level of 50% of the households.

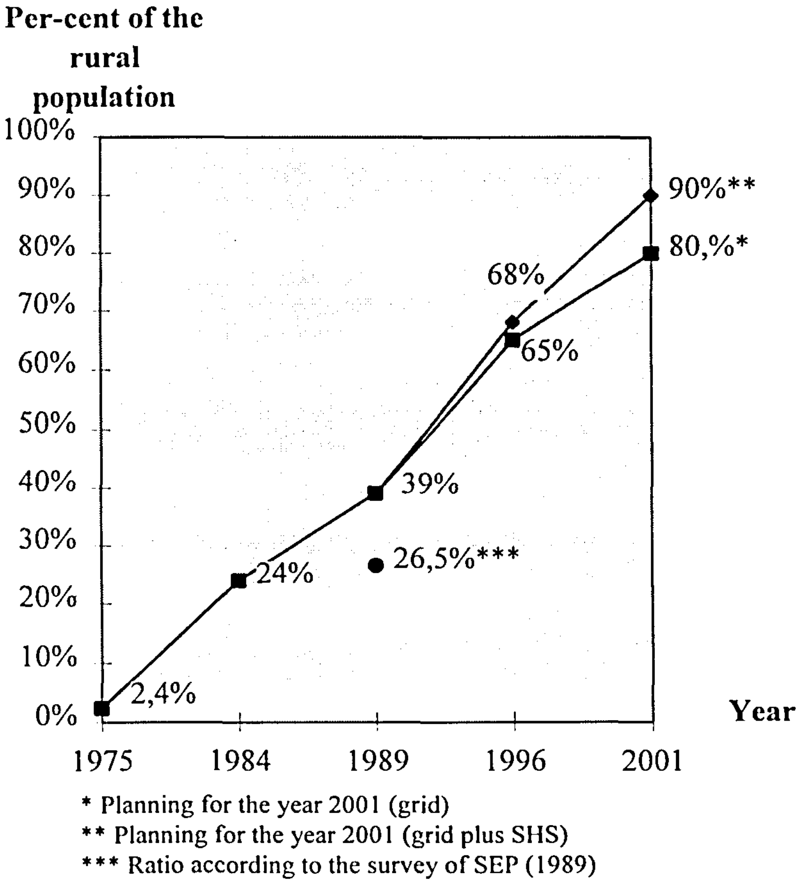


Fig. 11-8: *Electrification rate via the electrical grid in rural areas of the Gouvernorat of El Kef Sources: /11-4/, information STEG (1996)*

In the framework of the preparation of the IXth Five-Year Plan, STEG is at present negotiating in order to increase considerably, even double, the maximum cost per grid connection of a household, in order to arrive at a rate of rural electrification of 90%.

Such an enormous effort is certainly favourable for the households concerned. It is a political decision of the government to accept the high cost related to it.
For solar electrification, the consequence of this decision would be a reduction of the potential to a minimum and a decrease in the number of installations to zones of very small size. It would not be possible to establish private structures for repair and maintenance under these conditions, and the continuation of the solar programme would be at risk.

11.2.3. Contracts with the user households

For the national programme, the Tunisian government has opted for a financing scheme, which demands a financial participation of the users in the form of a lump sum. The rest is taken over by the public authorities (see chapter 7). As the large majority of rural households only have a low income, their financial contribution had to be small, forcing the government to foresee high subsidies. Low subsidies would certainly allow more SHS to be installed with the limited public budget available, but in this case there would have been criticism for aggravating existing social disparities by excluding the low-income households.

Although photovoltaics is a technology which cannot be compared to the grid, the services delivered to the households are in principle identical. But whereas the grid allows an inexhaustible supply of energy, the services of SHS are limited. In addition, in the case of the grid, the operational costs are almost totally covered by the public authorities, but, according to the proposed strategy, they would have to be borne completely by the consumer in the case of photovoltaics (see chapter 9.3.).

So, AME fixed the users' contribution, following the experience of the financing schemes of the pilot projects and programmes, to an amount of 104 US $ (100 DT) per household. The whole sum had to be paid before installation.

The financial contribution demanded by STEG for the grid connection is 208.- US $ per household, but the instalment to be paid in advance is limited to 52 US $, and the rest is paid afterwards over two years together with the bimonthly bills. A payment by instalments was excluded for solar electrification, due to the problems of money collection from the households on site, once the SHS had been installed (see the case of the project *Ouled Nouaouia,* chapter 10).

Because of the relatively long period (six months to one year) between the identification of the households and installation of the SHS, the potential users were able to save some money in order to ensure their financial contribution. The amount of this participation corresponded to 13% of the cost of an SHS at the first stage of the national programme. This would be the equivalent of the solar battery and one lamp. The finan-

cial participation was thus a measure to ensure that the household would later be able to pay for the essential spare parts on the commercial market at its own expense.
Due to the significant increase in the cost of SHS in the subsequent stages and especially in the FNS projects, the user's contribution has become an almost symbolic participation in the cost of the PV systems. In fact, this participation is not even sufficient to pay one third of the cost of the batteries of superior quality installed!

National programme, First stage	Second stage	Third stage	National Solidarity Fund (FNS) project El Kef (1)	FNS, project El Kef (2)
13 %	11 %	12 %	7 %	7 %

Tab. 11-9: *Percentage of the user's participation (104 US $) to the cost of the SHS installed*

The purpose of the contract concluded between AME and the user household was to define clearly the responsibility of the user for the maintenance of the SHS and the acquisition of spare parts after the warranty period of two years. He was forbidden to sell the subsidised SHS for a period of ten years.
For some components, the warranty period, fixed in the contracts between AME and the suppliers, could exceed a period of two years. The power of the modules was guaranteed for ten years (maximum acceptable reduction in the nominal power between 5 and 10%); and in the case of tubular batteries a warranty of four years (two years complete, and two years digressive) was accepted by the manufacturer.

The contents of the one-page contract with AME were explained in detail to the user households before signing. During these visits to the households, they were made conscious of their rights and obligations.

11.2.4 Financing the programme

The first projects of rural solar electrification were executed in the framework of bilateral co-operation. The foreign contribution in the form of donations, included equipment plus installation for the projects *Ouled Nouaouia* and *Dhokkara*.

Regarding the first stage (1 000 SHS), there were five partners who collaborated and jointly financed the national programme (in currency or by financing in kind):

- AME (personnel for management, regional structure in El Kef);
- the *Gouvernorat* of El Kef (financial contribution via its Programme for Regional Development, participation in the programme management);

- STEG (by putting at its disposal a technical crew and one 4-wheel-drive car);
- the users (lump sum payment of 104 US $);
- the German technical co-operation (GTZ; financing the experts, some of the technical staff, participation in the cost of infrastructure - cars, office equipment - participation in the cost of SHS equipment).

According to the agreement fixed in the plan of operation, the Tunisian side took over the local costs (Tunisian staff, rent, fuel and the SHS components available on the Tunisian market: batteries, cables, supports etc., plus the management and installation). In total this was about one third of the cost, whereas the German side paid for the foreign costs (experts and imported components).

Beside the contribution of the users, the second and the third stage of the national programme were financed by a credit of the BIRD programme of the World Bank, whereas the national programme of solar electrification of rural primary schools and the FNS projects are completely financed by the national budget.

It must be mentioned that the extension of STEG's rural grid is financed by credit (from the *African Development Bank*), plus the regional development programme of the *Gouvernorats* and, in addition, by a contribution of the users.

For several years AME has undertaken initiatives in order to ensure a secure, long-term *financial basis* for its PV dissemination programme.

In 1992, on the occasion of a rise in the tariffs for LT electrical consumption, it was foreseen that STEG should transfer part of the additional income ("solar Millime") to AME in order to ensure the financing of the solar programme. This *cross-financing* was supposed to be an act of solidarity by the clients of STEG in favour of the households living far from the grid. Unfortunately, this action never materialised, as the financial situation of STEG was at that time difficult in the electricity sector, forcing it to use the total of the tariff increase for its own purposes.

A new initiative has been made to create a fund (*FONAME*), to be put at the disposal of AME by the Tunisian government and financed by a tax on hydrocarbons.

The financing of the national PV programme by loans should remain an exception. Rural electrification is a measure to improve living conditions, thus it is mainly humanitarian and difficult to justify by criteria of profitability.

The influence of the programmes of rural electrification (be it classic or solar) on the reduction of rural exodus, and thus minimising the related social cost, cannot be proven quantitatively. There is moreover the impression that rural electrification, as an isolated measure (similar to other public assistance activities, such as soft credits for the construction of houses), will not have a stabilising effect on the households, if it is not combined with income-generating (productive) activities for the small farmers. In isolation, its effect will be to treat the symptoms of poverty without attacking its roots.

In fact, the problems threatening the success of the national photovoltaic programme are not mainly on the financial level, but are of a technical nature (electronic components) and organisational weaknesses (lack of commercial structures close to the users).

It would be justifiable for industrialised countries, having a strong interest in the survival of the photovoltaic industry, to assist AME in its efforts to put its programme on a stable and sustainable basis. Hopefully, the international community, which is profiting from programmes like those in Tunisia by gaining experience, will join the efforts of the Tunisian authorities in order to continue the promotion of the programme in an even better way.

11.2.5. Configuration of the systems

A view on the configuration of the systems, which were installed in the different stages of the programme, shows a wide variety of types, powers and capacities. It is striking to see that the power of the modules increased considerably (from 70 Wp in the first stage of the programme to 100/106 Wp in the following stages), and, still more important, that the capacity of the batteries has doubled (from 90 Ah to 180 Ah). The type of battery, too, has changed (from solar batteries with thick flat plates to tubular batteries as a standard), so that the price of the batteries has even tripled.

Certainly an SHS can hardly be oversized. By installing a more powerful PV generator and a stronger battery, the discharge rate of the battery will decrease (if the consumption is stable), and thus the lifetime of be battery will be extended. On the other hand, SHS in El Kef, equipped with a module of 70 Wp operate in a satisfactory way, with a minimum of electricity cuts in winter. Experience, confirmed by the computer simulation programmes, shows that this power is sufficient to cover the normal electricity consumption of rural isolated households (between 150 and 200 Ah per day). Taking this experience into account, the decision to demand a power of 100 or 106 Wp as a standard in the tender documents, might therefore be reconsidered in the future.

As there is a relation between the power of the PV generator and the optimal capacity of the battery, in this case a reduction of the capacity of the batteries from 180 Ah (present standard) to about 110 Ah would be possible (see also chapter 9.4.).

Three lamps, one of which - at the request of the user - is to be fixed on the outer wall of the house, have become standard. In spite of the demands of a number of users to receive additional lamps, these three lamps are considered to be enough in order to cover the basic needs in lighting for the majority of the rural households. Users interested in installing additional lamps should buy them at their own expense. Unfortunately the PV lamps actually offered on the Tunisian market do not seem to correspond to the quality specifications stipulated by AME and thus could not be recommended. This is linked to the fact that imported components of satisfactory performance are not available on the commercial market, as they are subject to high importation taxes and duties. AME should undertake further efforts to create the conditions to make quality electronic components commercially available close to the clients.

All electronic components (ballast and charge regulators) operate at the same voltage of 12 V. For the lamps, fluorescent tubes of 18 W have become standard. So, charge regulators and lamps supplied by various manufacturers in the framework of the different calls for tenders might be used as spare parts in case of technical problems. The electronic boards of these components are in general protected in order not to be copied. This makes repair impossible (except for simple ones, like changing a fuse or fuseholder), and it forces the user to renew the electronic board or even the complete component in the case of a breakdown.

11.2.6. Certification of components

Taking into account experiences from the pilot dissemination phase, results of component tests carried out at the workshop of AME in El Kef, at the laboratory of CETIME at Ksar Said (Tunis), at the laboratory of industrial technologies at the National Technical University of Tunis (ENIT), AME was able to prepare tender documents for the first stage of the national programme, which were also used - with some modifications and adaptations - for the following stages of the national programme and the projects of FNS as well.

The quality of two of the four components of an SHS (module, battery, charge regulator, ballast) was relatively easy to estimate: the modules and the batteries worked in a satisfactory manner in the installations of the national programme.

Samples of *modules* have been tested and certified by internationally proven laboratories, such as the European Research Centre of *Ispra* (Italy). In addition, short term measurements are carried out on every module after production in the factory. This allows modules of a power below the demanded level to be eliminated at an early state.

Regarding the *batteries*, AME developed test procedures for the nominal capacity and endurance cycling tests, which were applied to a number of batteries of local and foreign production. They confirmed the field results obtained with identical types of batteries (see chapter 11.1.). As the types (thick flat plates and tubular) and manufacturers (two local and one foreign manufacturer) of the batteries offered in the calls for tenders were limited, regarding the evaluation of the offers for the national programme, reference could be made to the tests executed at the laboratory of CETIME, the workshop in El Kef, and the field experience.

The permanent control of the quality of solar batteries in Tunisia is assured, as the most important producer is certified according to the standard ISO 9001. The few batteries of the two Tunisian manufacturers, which were found to be faulty during the warranty period, were changed without problem at the factory.

The electronic components are the weak points of the SHS as far as the technology is concerned. Unfortunately, up to now there are no standards nor standardised test procedures for these components. The requirements included the technical part of the tender documents of AME, the minimum characteristics stipulated by GTZ and by the *Fraunhofer Institute for Solar Thermal Systems (ISE)* in Freiburg plus the specifications of the *Junta Andalusía* in Spain are all similar, but no not have the character of internationally recognised standards.

The only comparative tests published are those of *ISE*, carried out for ballast (financially supported by the European Commission, 1993 */11-5/11-6/*) and for charge regulators (financed by GTZ, 1994). However, since the producers constantly change their products and often sell products from other manufacturers under their label, the equipment offered by the same supplier may vary considerably from one call for tenders to the next. Even the results of tests of components are often out of date as soon as they are published, as the tested model has already been replaced by the producer or supplier.

In the framework of the evaluation of calls for tenders, AME sometimes had to judge the quality of more than twenty different models of ballast and charge regulators, which, according to the suppliers, all corresponded to the specifications stipulated in the tender documents.

Because of the very short time (maximum three to four weeks) allowed to accept or refuse a component, and owing to the relatively simple and non-scientific measuring instruments available at AME's workshop, the engineers and technicians were only able to perform some basic tests on the samples delivered. For the execution of more sophisticated tests (for example, to test the imperviousness of the cases and the luminosity of the lamps), the necessary instrumentation was not available and, for the execution of long-term endurance tests, the time was too short.

Nevertheless, the basic, quick tests already proved that a considerable number of the components offered did not correspond to the specifications of the tender documents, or that the suppliers had interpreted these specifications in a rather strange way.

Some examples:

- A supplier claimed that his ballast, in spite of causing interference that made it impossible to listen to the radio when a lamp was switched on, should nevertheless be protected against interference, as the normal radio frequencies in his home country were not affected. These frequencies were, however, not identical with those of the radio stations received in north-west Tunisia.

- A manufacturer declared that his charge regulator was protected against inversion of the polarity. In reality, the regulator itself would not be damaged in such a case, but the consumers (lamps, radio, TV set) were not protected!

- A ballast, faulty after only a few minutes of operation without tube due to overheating, was characterised by a supplier as protected against idle operation, as a minimum delay of operation without tube or a maximum temperature were not indicated in the tender documents.

- A producer refused to change his charge regulator, which had shown some problems during the warranty period, with the argument that AME had certified the equipment. In reality, the simple tests executed by the engineers and technicians of the agency could not reveal the hidden problems only found afterwards when the SHS were installed in the households. An official certificate had never been granted.

The list of excuses and pretexts for not changing faulty and inappropriate equipment was long.
The analysis of this situation leads to the following conclusions, which are not very complimentary to the suppliers:

- Evidently, tenders are generally prepared by the marketing and sales departments.

The documents were essentially based on the information to be found in their catalogues. The specifications of the tender documents had evidently not been studied in detail.

- No supplier manufactures all components of the SHS himself. The producers of PV modules or the assemblers of components often integrate components from other manufacturers in their offers, without previously testing the quality of these products, for which they will later be held responsible in the framework of the warranty.

- Because of strong competition, the favourable offers have generally been calculated with an extremely low margin for profit and unforeseen difficulties. In the case of quality problems with a component, which might first be seen after the installation of hundreds of SHS, the financial losses due to the warranty become enormous. This might easily threaten a small or medium-sized enterprise with bankruptcy. In order to avoid this, some suppliers try hard to refuse all claims for warranty and deny responsibility. Thus negotiations between AME and the supplier might easily take one month or even more - a period during which the SHS stay out of operation and the installation programme is stopped. The households, which paid their financial contribution a long time ago and are waiting impatiently for the arrival of the SHS, justifiably start to complain. Even if AME is right in demanding the complete substitution of some components, its position is weak, as it must be avoided that hundreds, if not thousands of SHS stay in a broken-down state, leading to a rapid decline of the PV equipment already installed (see the case of the rural schools).

The history of the breakdowns and problems is as follows:

First stage of the programme (1 000 systems):
Considerable drop of voltage at the charge regulator. The ballast of the lamps is heated and subsequently destroyed. The problems continue after substituting the ballast for another model.
Solution (or, more precisely, compromise): reduction in the drop of voltage by eliminating a protection function in all charge regulators installed, gradual substitution of all ballast.

Second stage (1 250 systems):
Blackening and premature breakdown of the tubes
Solution: first, change the tubes. Afterwards, change the ballast

Third stage (1 000 systems):
Technical problems with the electronics of the charge regulator causing breakdowns of the SHS; necessity to stop the installation programme for some months.
Solution: repair the charge regulators, change the ballast.

Similar problems have been seen in several projects of FNS. These small-scale projects have often been used for testing new components in the field, particularly components developed by Tunisian enterprises. The limited number of installations per project of FNS is in fact a chance for testing new equipment. However, as a result of the technical risks involved, such projects should be defined from the start as demonstration projects. Otherwise, the staff responsible at AME might be accused of having recommended non-viable equipment. Problems in FNS projects are reported directly to high-level political decision makers, and in these projects a failure is not allowed. The usual problems of demonstration projects with novel technological developments might thus influence the image of photovoltaics in a very negative way.

For the criterion, certification of equipment, here is a summary of the experience:

All kinds of *PV modules*, installed in the framework of the national programme and the preceding projects, have proved to be equipment corresponding to the specifications and thus certified.

The same is true for the *solar batteries* with thick flat plates, as produced by the two Tunisian manufacturers (capacity: 90 to 110 Ah), and also for the *tubular* batteries of Tunisian and Spanish production.
Even the best models of the *charge regulators* installed do not represent more than a compromise, and of the whole range of *ballast* installed just one or two models gave satisfactory results.

The inconveniences of the charge regulators (interference with radio and television, considerable electricity consumption, fuse problems, breakdowns etc.) and those of ballast and lamps (blackening and subsequent breakdown of tubes, low luminosity) have affected the progress of the programme enormously. They have taken up the time and commitment of the staff of AME and they have even put doubt on the image of photovoltaics in Tunisia.

However, there is an impression that due to a growing demand, more efficient, larger companies, with more specialised staff, high-tech equipment and reliable production control mechanisms have started to be interested in the technology of electronic components for SHS. The Tunisian experience thus represents a transitional phase, in which these components had more the character of prototypes and products still being developed than finished products.

For the future, it is essential that standards for the electronic components should be elaborated and published as soon as possible, so that manufacturers, eager to participate with their products in calls for tenders, could present as part of their offer a test certificate from an internationally recognised test laboratory.

Although considerable costs for such certification would have to be borne by the manufacturers, these costs would certainly be less than those for the replacement of large quantities of broken down components after installation at thousands of isolated sites in the countryside. In this way, the client as well as the producer would be protected.

11.2.7. Certification of the installers

The strategy of the national programme had foreseen:

- involving the private sector as much as possible, by limiting the activities of public administration to certain essential management tasks (programming of priority zones, identification of the households, execution of calls for tenders, control and acceptance of installations);
- by defining clearly the priority regions for the national programme, allowing simultaneously the development of a commercial market for SHS.

In addition, a distinction was made between

- assemblers and wholesalers with offices exclusively in the capital;
- electricians and other specialised craftsmen, owning small workshops in the small regional towns; plus
- companies, interested in the local production of components.

During the preparation of the national programme, AME had already started organising vocational training courses in a centre for professional education (CNMA) in El Kef. For this purpose, the engineers of AME had elaborated a relevant manual together with Tunisian experts, researchers of ENIT and the trainers of the centre */11-7/*.

Ten working places at the workshop were equipped with didactic material (small PV modules, measuring instruments, tools). The training programme consisted of two weeks of theory, with practical tests in the laboratory and, in the third week, participation in realistic installations and maintenance work. The courses were given in Arabic in the form of an open presentation and discussion between the participants and the lecturers and trainers.

The results of the final tests, necessary for the award of a certificate as installer of SHS were very positive, in spite of the considerable difference in the level of education of the participants. This ranged from craftsmen with only on the job training and experience to engineers with university degrees). In total, about 60 people were trained in this way. So, the basis was prepared for personnel skilled in the principles of operation of PV systems, who knew the main elements of installation and maintenance of SHS.

Unfortunately an initiative, to integrate the sector of photovoltaics into the normal training programmes of the centre, failed due to a change in the professional training priorities of this institution.

In order to stimulate the Tunisian commercial structures in the field of photovoltaics, the first stage of the national programme was implemented by a tender only open to *national* bidders. In addition, the enterprises had the choice of offering the equipment plus installation or to be limited exclusively to installation (for all zones or for just one). AME, supported by the *Gouvernorat*, therefore contacted companies and craftsmen living in these zones in order to inform them about the tender and to encourage them to participate at least in the installation sector.

Some barriers very quickly became apparent:
With the exception of only one, the companies, certified by STEG in the *Gouvernorat* for the execution of grid extension works, proved to be disinterested in photovoltaic electrification. They were more specialised in civil works (foundations, installation of the masts, laying cables), and their work usually ended with the installation of the electricity meter on the outer wall of the building. Electrical installations inside the houses were not considered as their field of interest.

Local electricians do not generally have vehicles and bank accounts, and not even an official authorisation for the execution of their work. It was impossible for them to provide the necessary bank guarantees to be accepted for participation in calls for tenders, published by a public organisation. Therefore, the staff of SEP went to a great deal of effort to allow at least some craftsmen and technicians (among them two former employees of the project) to participate in the call for tenders.

In the framework of the evaluation of the offers and the contractual negotiations, AME preferred to entrust the whole scope of works to one general contractor (the company *SES* with office in Tunis), in order to avoid possible problems later with a split responsibility in case of claims of warranty and to facilitate the management of the programme. The chosen bidder offered to open an office in the town of El Kef, to integrate local technicians as subcontractors and to supply them with four-wheel-drive cars in order to ensure the transportation to the dwellings of the user households.

From today's point of view, this was a wise decision, because of the unforeseen technical problems with some electronic components, which demanded the change of thousands of ballast and charge regulators after installation. However, in the long term the number of SHS installed in the zones (between 150 and 500) was still considered to be insufficient to allow a local electrician to earn his living, even if he is ready to accept additional work, such as electrical installations in buildings and the repair of radios and TV sets.

After a period of two years, only one of the local craftsmen was still commercially involved in SHS maintenance (at *Kalaat Senan*), a second completely stopped his involvement in this business, a third became an employee of the general contractor at his office in El Kef, whereas the fourth one was re-integrated in the Regional Service of AME, also in the town of El Kef. Evidently, even a potential of several thousand SHS in one region (*Gouvernorat* of El Kef plus the neighbouring *Gouvernorats*) does not seem to be interesting for SHS retailers to create regional commercial structures and offices. There have been no initiatives for the sales of spare parts to the user households in the field. The employees and technicians of the only company represented in the region wait for clients at their workshop and offices or are occupied with new installations in the framework of the national programme.

In the case of problems or demands for spare parts, the users are often not even informed about the address of the company in El Kef, and continue to contact the staff of AME, who, when the warranty period is expired, guide them to the private companies.

The efforts to arouse the interest of private businesses in other *Gouvernorats* involved in the national programme (*Jendouba, Siliana, Kasserine*) unfortunately failed completely. As they did not see a rapid and easy market development, they withdrew from this field just some months after they had made the installations.

The general manager of the company, which executed the majority of the installations (the company SES), as well as the engineers of AME, share the opinion that a significant concentration of SHS in one zone of one or two neighbouring Delegations is absolutely necessary to arouse permanent interest of local private enterprises in photovoltaics. The minimum number of SHS in such a zone should be one thousand.

There are about ten Tunisian companies who started to be involved as assemblers of photovoltaic systems in a more or less intensive way. Three of them (*SES, SEN* and "*Le Rayon Solaire*") share about 90% of the market.

The number of installations at private clients is very limited (less than ten per company). These include large and sophisticated systems, operating at 230 V, and even a hybrid system (PV plus wind turbine as battery charger at *Rafraf, Gouvernorat* of *Bizerte*).

Three Tunisian companies started development and production of charge regulators and ballast. Two samples of charge regulators (one from a manufacturer, who has meanwhile stopped production) were included in a comparative test at the *Fraunhofer Institute in Freiburg* (*ISE*), financed by GTZ. The result of the test was that none of the twenty models corresponded fully to the specifications set, and all models produced in developing countries were low in the ranking. The reason for this disappointing result in the case of one of the Tunisian charge regulators was the high electrical consumption of the electronics. This disadvantage might have been corrected easily by changing just one of the electronic elements.

As all imported ballast and charge regulators undergo high importation duties and taxes, only products manufactured locally are available on the commercial market. Regarding the charge regulators, the limited Tunisian market does not allow the development of sophisticated models, equipped with micro-processors or intelligent algorithms. A solution might be a future collaboration between European and Tunisian enterprises in this field (common development, adaptation, assembling, joint venture).

12. The Potential for Rural Solar Electrification in Tunisia

In 1989, the "energy supply concept for rural areas of the *Gouvernorat* of El Kef" had identified the potential number of SHS users to be up to 40% of the rural population and had also predicted a net increase of this potential for the future.

It has to be remembered that this prognosis was based on the following assumptions:

- the extension of the electrical grid would be limited to agglomerations of settlements;
- within the selected zones, the conditions for access to SHS would allow the same rate of households to be electrified as the grid solution (at least 80%);
- the number of households in rural areas with isolated dwellings would increase considerably after a slight reduction over a few years. Although the rural exodus would continue, the number of isolated rural households would increase, due to the reduction of the number of persons per household. Consequently the potential for solar electrification would increase too.

The situation in 1996 and 1997 can be described as follows:

- rural electrification by connection to the grid has increased enormously. Additional budgets allowed grids to be extended into regions with isolated settlements;
- the number of households in rural isolated environment has stayed more or less constant (increase of two per cent between 1989 and 1995 in the *Gouvernorat* of El Kef, see chapter 3.3.) */12-1/.*

So, taking into account the number of rural households on a national level (615 000 in 1993) and a realistic rural electrification rate of 70% up to the year 2001, there is a potential of about 185 000 households nation-wide for solar electrification.

In 1995, STEG carried out a detailed census of all rural villages in Tunisia not yet connected to the grid (in fact, the large majority of these were not villages, but isolated hamlets). This involved a total of about 100 000 households. At first sight, this number seems to be too low. STEG neglected the following in its statistics:

- traditional dwellings, which are not built of solid construction material. STEG considers these to be temporary, rudimentary, or sheds for occasional use and so refuses to connect them to the grid;

- isolated houses, where the costs of grid connection are extremely high. Such houses may even be found near a Low Tension or Medium Tension line of STEG, or even close to a cluster of electrified houses.

If these isolated households and some of the households living in traditional dwellings were included, the estimated potential of 185 000 SHS for Tunisia would possibly be confirmed.

Regarding the figures per *Gouvernorat*, they show that *Kasserine*, *Kairouan, Bizerte, Jendouba*, and - surprisingly enough *Sfax* - offer the most important potential for solar rural electrification.

This, of course, is a theoretical potential. Its exploitation depends on the availability of public funds, the financing scheme (sharing of costs between the user and public authorities) and the configuration of the selected standard SHS.

Cost of grid connection Number of households per Gouvernorat	*< 1 562 $*	*< 1 875 $*	*< 2 083 $*	*< 2 291$*	*< 2 603 $*	*< 3 124 $*	*Total per Gouvernorat*
Ariana	85	98	127	151	331	600	***1 287***
Ben Arous	222	238	257	257	358	395	***477***
Bizerte	4 864	6 507	7 423	8 523	9 319	9 789	***9 979***
Zaghouan	122	243	347	602	980	1 726	***2 526***
Nabeul	461	1 045	1 507	1 591	1 898	2 250	***2 401***
Béja	559	1 074	1 259	1 368	1 788	2 330	***2 661***
Jendouba	4 769	5 138	5 624	5 864	6 032	6 067	***6 184***
El Kef	96	106	394	574	1 200	2 724	***3 281***
Siliana	413	1 188	1 667	1 990	3 055	3 491	***4 400***
Sousse	539	864	1 106	1 157	1 511	1 993	***2 460***
Monastir	172	312	424	431	545	640	***1 124***
Mahdia	520	952	1 175	1 350	1 912	2 753	***3 613***
Kairouan	7 689	11 409	12 966	13 951	15 133	16 421	***17 113***
Kasserine	5 280	9 134	11 477	13 266	14 760	16 320	***17 640***
Sidi Bouzid	1 889	4 148	5 108	5 590	5 997	6 690	***6 820***
Gafsa	154	557	770	1 124	1 619	2 581	***4 390***
Sfax	609	1 275	2 255	3 038	4 099	4 725	***5 742***
Gabès	218	433	514	573	760	1 498	***3 482***
Kébili	0	0	61	61	61	61	***187***
Médenine	145	289	374	810	1 233	2 071	***3 258***
Tataouine	8	61	61	61	224	396	***1 333***
Total	***28 814***	***45 071***	***54 896***	***62 332***	***72 815***	***85 521***	***100 358***

Tab. 12-1: *Number of non-electrified households per Gouvernorat in relation to the cost of grid connection (1995). Source: STEG*

For the group of 28 814 households, where the cost of grid-connection is below 1 562 US $ (1 500 DT) per household, STEG estimated the average connection cost to be 1 245 US $.
These average costs rise to 4 341 US $ for the 14 837 households, where the costs of grid-connection exceed the amount of 3 124 US $ (3 000 DT).

This ranking of all households, so far not electrified, according to the cost of grid connection, shows that the most important group (29%) could still be connected at costs below the maximum amount fixed for the VIII Five-Year Plan (1 562 US $ - 1 500 DT).

Cost of grid connection in US $	**< 1 562**	**1 562 - 1875**	**1 875 - 2 082**	**2 082 - 2 291**	**2 291 - 2 603**	**2 603 - 3 124**	**> 3 124**	**Total**
Percentage number of households not connected to the grid	29 %	16 %	10 %	7 %	10 %	13 %	15 %	100 %

Tab. 12-2: *Percentage of non-electrified households in relation to the costs of grid-connection (100 358 households = 100 %)*
Source: STEG, 1995 (modified)

In order to determine the solution which is macro-economically favourable (solar or grid), the up-dated global cost for a period of twenty years should be compared for each of the two alternatives (see chapter 9.3.3.4.).

Regarding the photovoltaic solution, we considered several alternative financing models (cost sharing between the user household and public funding: case 1 to 3), combined with different configurations of equipment (systems A to D). For the grid solution, the up-dated costs vary only in relation to the grid connection costs (*Fig. 12-1, Tab. 12-3*).

Potential favourable for the solar solution (in per cent of the households not yet electrified)	Approach / configuration of SHS
100 %	Approach: Case 1 Configurations: Systems A, B, C Approach: Case 3 Configurations: Systems A, B
71 %	Approach: Case 2 Configuration: System A
55 %	Approach: Case 2 Configuration: System B
38 %	Approach: Case 1 Configuration: System D
28 %	Approach: Case 3 Configuration: System C
15 %	Approach: Case 2 Configuration: System C

Note:

Approaches:

Case 1: initial investment: the user contributes with 104 $, the rest is taken over by public funding.

Operational costs: to be fully covered by the user

Case 2: initial investment: see Case 1

Operational costs: to be covered by public funding

Case 3: initial investment: see Case 1

Operational costs: the user contributes 34 $ per year, the rest is covered by public funding

Configurations:

System A: PV module: 70 Wp, 3 lamps, battery 90 Ah (thick flat plates)

System B: PV modules: 100 Wp, 3 lamps, battery 130 Ah (thick flat plates)

System C: PV modules: 100 Wp, 3 lamps, battery 180 Ah (tubular)

System D: PV modules: 200 Wp, 6 lamps (220 V), batteries 360 Ah (tubular)

Tab. 12-3: *Percentage of households, favourable for electrification by the solar solution (basis: potential of non-electrified households according to the figures of STEG -1995-)*

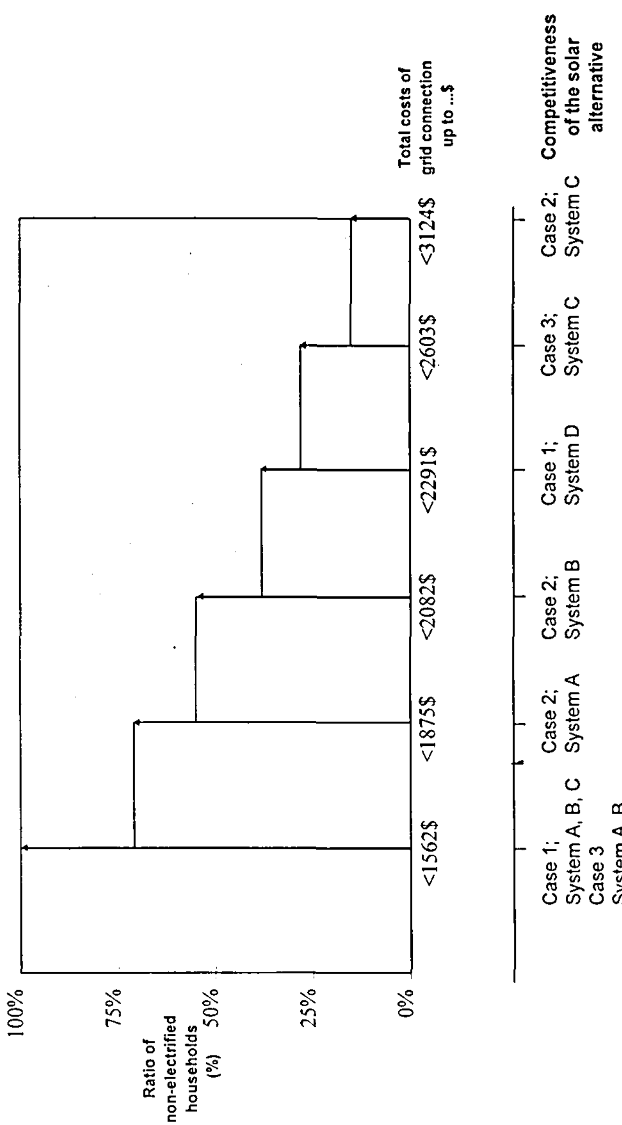


Fig. 12-1: *Exploitable potential for solar electrification (in per-cent of non-electrified households)*

The result of this analysis confirms the earlier economic conclusions: for a national photovoltaic programme, only an approach which reduces the burden on public funds from the operational cost (spare parts, repairs), plus a configuration, restricted to covering basic needs, will be an economically favourable alternative to the grid solution. The other options, above all that of a PV systems of 200 Wp with inverter, will reduce the potential of the solar solution to a marginal level.

For the user household, the grid alternative will be less costly than the PV electrification, if the operational costs are borne by the user himself.

Even if a solar programme offers clear advantages to the users, compared to the classic alternatives (kerosene lamps, batteries) in respect to the costs (mainly because of the extension of the lifetime of the battery used for the TV set), users will try to charge as much as possible of the operational costs of the SHS to public funding.
The strict application of the principles (neutrality, transparency) will thus be an essential condition for the success of the solar programme. Users must be conscious of their rights and obligations. Otherwise, the photovoltaic programme will rapidly be reduced to a programme of free change of batteries for the SHS user households.
It will therefore be necessary to continue information and advice to the users. In respect of spare parts, users must be guided to suppliers offering the appropriate equipment.

If public funding authorities are not in a position to apply this policy strictly, it would be better *"to pay a thousand Dinars (1 040 US $) more for connecting a household to the grid, and thus avoid all sorts of problems"* (citation of the General Secretary of a *Gouvernorat*)

The limitation of solar electrification to the zones, where the connection of a household to the grid exceeds 3 124 US $ (3 000 DT), would have severe consequences for the photovoltaic programme:

- there would be a multitude of scattered, small-scale projects, the survival of which (maintenance, spare parts) would depend on permanent government-financed structures. This would be an extremely costly measure and difficult to justify due to the limited availability of public funds;
- no margin would be left for any commercial dissemination of SHS.

Anyhow, the commercial market potential for SHS in Tunisia is limited. Due to low purchasing power, the percentage of households capable of buying a SHS by paying cash is estimated to be about 2 to 3% of the non-electrified rural households (see *Fig. 6-7*), corresponding to 3 700 to 5 500 households. These potential clients are distributed all over the Republic. Access to these households, information, advertising, after-sales-service etc. are therefore difficult and organisation of such services will be costly.

In *Indonesia*, the commercial success of SHS dissemination is limited to densely populated settlements close to the office of the supplier. The situation is thus quite different from that of Tunisia with a high percentage of households already connected to the electrical grid in the more densely populated regions.

The marginal sales of SHS to private clients confirm that even in the future the Tunisian photovoltaic market will be dominated by public programmes.

What could be transferred as a model from the Tunisian approach and the Tunisian experience to other countries?

It has already been mentioned that the boundary conditions vary from one country to another, so that a mere copy of the Tunisian approach could not be recommended. Nevertheless, its basic principles would merit becoming part of energy supply programmes in other countries.

These are mainly (see chapter 6.1.3):

- to set the priority of activities in favour of regions, which are at a disadvantage, i.e. rural populations living in isolated dwellings. This implies giving at least the same attention to the domestic source of energy (wood) as to photovoltaics and the extension of the electrical grid;
- to concentrate on technical solutions offering a potential for improving the living conditions of the majority of the rural population;
- to strictly apply the criteria of neutrality, clarity and transparency in respect to the selection of the households, which benefit from the programme;
- to provide support for the establishment of competent and sustainable structures, both on a regional as well as on the national level.

Technical problems, which considerably upset the first stages of the national programme, are likely to be solved within the next calls for tenders, taking into account the results of recent technological developments.

The structural aspects, mainly consisting of a service centre close to the client, and the availability of spare parts of favourable quality in the small regional towns, will become more important in future. They could be solved by concentrating a considerable number of SHS per zone, by continuous and repeated information to the user households and by motivating, encouraging and training businessmen, craftsmen and technicians both in the capital as well as in the priority regions of the programme.

The approach of the national programme for rural solar electrification should be harmonised with that of the FNS (in order to avoid scattering the installations), and with that of STEG (which otherwise would leave only a marginal role for photovoltaics).

The position of STEG is not unusual for an entity seeing its monopoly endangered and trying to defend its position. The positive experience of the *co-operation* between AME and STEG in the *Gouvernorat* of El Kef in the framework of the first stage of the national programme has nevertheless shown that a harmonisation and a complementarity of the different approaches are possible.

13. Interviews

An element characterising the dynamics of the national programme and the SEP is the continuous adoption of acquired experience in the planning of future activities.
The dialogue, be it in the framework of round table meetings with representatives of public organisations, research institutions and private enterprises, be it via the daily contacts with SHS user households, has always been open and constructive.

In order to allow a flashback on the sometimes diverging positions of the different participants and actors, we asked a number of people to grant us an interview. In all cases, this was accepted at once.

Among the SHS users interviewed, three households lived in the *Gouvernorat* of El Kef. One household had received its SHS within the pilot dissemination phase (1989), the second on the occasion of the "solar school electrification programme" (1991), whereas the third household lived in a zone selected for the first stage of the national programme (1994).

In the *Gouvernorat* of *Zaghouan*, two households, living in a hamlet where the population had initially refused solar electrification as part of an FNS project, were visited and we discussed with them the reasons for their initial refusal.

A businessman, who participated successfully in public calls for tenders and who also made efforts towards the commercial dissemination of photovoltaics, presented his position in respect to dissemination barriers and gave advice for the future.

The first interview underlines the importance of the activities of AME and of the Tunisian-German co-operation in the field of renewable energy sources for the pilot region, the *Gouvernorat* of El Kef.

"A positive balance..."

13.1. Interview with Mr. Abdelwouheb NASRI, Director of the Regional Development Programmes

at the administration of the Gouvernorat of El Kef.

Question: Mr. Nasri, for seven years the *Gouvernorat* of El Kef has been playing the role of pioneer in the dissemination of renewable energy technologies in Tunisia.

Mr. Nasri: When AME and the German co-operation proposed that El Kef should become the pilot region for renewable energy technologies, we accepted it.
Now we note, with some pride, that the experience of El Kef serves as a model for other *Gouvernorats* of the north-west and central Tunisia.

Let's take the case of photovoltaics: the positive balance is clearly documented by the rise in the electrification rate in rural areas. The new technology suddenly offered a solution for households, which previously had no access to modern lighting and communications; in other words: to progress.

Q.: Will there be follow-up activities to the programme of 1 000 PV systems in El Kef?

Mr. Nasri: The thousand systems were financed jointly by the German co-operation, the *Gouvernorat* of El Kef, AME and by the users themselves. There was already a follow-up: more than 350 additional households have been equipped with PV systems in our *Gouvernorat* via projects of the National Solidarity Fund.
In addition, we have informed AME that this year we have foreseen a special budget to ensure the continuation of the rural solar electrification programme. There are many new demands.

Q.: What is the procedure for the acquisition of equipment and for installation?

Mr. Nasri: We are inviting companies, active in this field in Tunisia to participate in calls for tenders. Fortunately, there are already some such enterprises. This is our normal procedure, which we apply for all our projects for regional development.

Concerning the technical specifications, the evaluation of the technical part of the offers, the provisional and final acceptance, we are counting on the competence and assistance of the National Energy Agency (AME), which has a regional service here in the town of El Kef. This support by AME is absolutely necessary.

Q.: How do you ensure maintenance and after-sales service?

Mr. Nasri: We are paying much attention to these points. Even in the installation phase we insist that enterprises and craftsmen from our region are involved. With the growing number of installations, a commercial structure has begun to be established in our *Gouvernorat*.
But we still want to go further. We foresee, within the framework of the "2626" programme, credits between 2 000 and 3 000 Dinars, allowing technicians or craftsmen to create local micro-enterprises for maintenance, basic repair works of PV systems and the sales of spare components.
Installations in these zones are quite recent; so that the establishment of relevant craft and trade in this field will follow.

Q.: The planning of the IXth Plan foresees connecting households even at costs between 2 500 to 3 000 Dinars to the electric grid. This will considerably reduce the potential of photovoltaics.
In addition, the agreement between AME and STEG of El Kef, defining the priority regions for the grid and for photovoltaics, will no longer be valid.

Mr. Nasri: In fact, the electrification rate in rural areas of our *Gouvernorat* - be it by PV, be it by the grid - is 65%. This still leaves sufficient margin for both technical options in the years to come.
The planning of the zones to be electrified starts at the level of the Delegations. Then, it is discussed between the administration of the *Gouvernorat* and STEG, passes the Regional Council of the *Gouvernorat* before being finally approved. This procedure avoids an overlapping between the priority zones for STEG and for PV.

In some rare cases in the past the grid arrived after the households had received PV systems. Then, the PV systems were returned to the workshop of AME, to be given to other households.

Q.: We have seen enormous efforts for improving infrastructure and living conditions in the countryside of the *Gouvernorat* of El Kef. Nevertheless, some SHS user households have meanwhile abandoned their houses in order to move to the towns.

Mr. Nasri: The national policy intends to stabilise the rural population on their land, even in areas with isolated dwellings. For this purpose, we continuously invest considerable funds, not only for the supply of electricity and potable water, but also for the construction of rural tracks, schools, health stations etc.

The programme includes job-creating incentives. I've already mentioned craft and trade. In spite of all these efforts, we cannot exclude a number of cases of rural exodus, above all after several years of drought, as occurred in our region in recent years.

"Risky participation in public calls for tenders, minimal commercial market..."

13.2. Interview with Mr. Ali KANZARI, General Manager of the company *Solar Energy Systems* (SES), Tunis

Question: What was your motivation for establishing a new enterprise in the field of renewable energy technologies?

Mr. Kanzari: Before the creation of my company, I acquired several years of experience in the field of renewable energy sources and rational use of energy.
My professional experience allowed me to have a clear picture of the Tunisian market and to assess the chances of success.

The principal objective of SES, which I created in 1992, is to develop and disseminate solar thermal and photovoltaic systems in Tunisia.

In spite of public support, dissemination of solar thermal systems has been slowed down by the temporary monopoly of the partly state-owned company *Société des Energies Nouvelles, SEN.* We hope that the GEF programme will introduce new dynamics in the market of solar water heaters.

With respect to photovoltaics, the starting point was the Special Energy Programme (SEP), financed by GTZ of the German co-operation, which revealed quite interesting perspectives for this sector.

Q.: How many employees are working in your company?

Mr. Kanzari: We are in fact 14 persons. In Tunis, at the head office, I have four collaborators, three of them are engineers. The others (one engineer, one secretary and seven technicians) are at our office in El Kef. The choice of the town of El Kef to be the technical centre of our activities was not chance. As the Tunisian north-west, and above all the *Gouvernorat* of El Kef, is in fact at the centre of the rural electrification programmes, we are situated right in the middle.

Q.: Are you linked to just one photovoltaic producer, for example by licence or co-operation agreement?

Mr. Kanzari: The Tunisian market in the field of photovoltaics depends widely on calls for tenders published by the government. These are both national and international calls. Unfortunately, because of the strong competition, the price is generally the decisive element.

In these calls, the profit margin for the participants is often minimal; the offers are very close to each other as far as the prices are concerned. So, sometimes, it's the exchange rate between the currencies and also the fact that most of the imported components are charged high duties and taxes, which become the decisive elements.

Therefore, we are in close contact with several well-known PV producers (mainly from Spain, Italy, Germany), but without being permanently linked to just one producer.

As a general contractor or as a company solely responsible for the installation works, we have installed to-date 2 500 PV systems, which represents the majority of SHS installed in Tunisia.

Q.: What options do you see for the commercial dissemination of PV in Tunisia?

Mr. Kanzari: In principle, we would have preferred a mainly commercial market, functioning according to the law of offer and demand.

A market, which only develops in the rhythm of public calls for tenders, forces us to submit offers at very tight prices. As the State additionally demands a wide range of guarantees, these offers are risky for new private companies such as ours. In addition, the public authority is a slow payer, and we have to finance the equipment to be installed in advance.
Therefore, it should be understood that, for most of the projects, our balance of payments has been negative.

The number of commercial sales of PV systems stays at a minimum. There are some well-off people, with holiday villas or isolated farms, who prefer photovoltaics to diesel generators (in order to avoid noise, dirt and technical problems). Some also work in public administration or are businessmen living in town, who want to improve the living conditions of their relatives living at isolated rural sites.

In Tunisia, it is generally known that the government supports photovoltaics financially and that the user only has to pay a symbolic sum of a hundred Dinars. It's these public subsidies which limit commercial dissemination.

Q.: And regarding PV pumping, the secondary market of spare parts and SHS components?

Mr. Kanzari: At present, the photovoltaic pump is a costly solution, when compared to a diesel pump, in particular in Tunisia, where fuel is available nearly everywhere.
Realistically speaking, in Tunisia, PV pumping is restricted to demonstration projects for potable water supply.

Private farmers are mainly interested in irrigation. In order to deliver the necessary quantities of water, PV pumps demand considerable investments, so that economically they are not competitive with motor-pumps.

A market for supplementary modules for Solar Home Systems could have developed, if AME had limited its activities to covering the basic electricity needs with photovoltaics. The capacity of a standard system has increased from 53 Wp to 100 Wp. This luxury solution does not leave any margin for secondary sales.
Concerning the components, we have opened a regional office in the *Gouvernorat* of El Kef for the sale of solar batteries. In addition, we have a number of other components in stock for sale to private clients. There are, however, enormous problems in collecting money. All clients are small farmers, who are not able or willing to pay in any terms other than in instalments.

Q.: Could the banking sector be involved in this business?

Mr. Kanzari: It is impossible to sell SHS via bank loans because, as I have already explained, the productive applications of photovoltaics are very limited.
The banks can finance profitable projects in the field of agriculture (electrification of a farm via the grid), but for the moment the financing of PV systems is excluded.
Improving this situation may be a future task for the public authorities.

Q.: What is your experience in the field of rural solar electrification programmes?

Mr. Kanzari: The first projects were mainly carried out with the aim of creating a positive reference in Tunisia. The additional costs have been covered by the producers of the components and by our company.
For instance, for the programme of the 1000 PV systems in El Kef, we delivered charge regulators equipped with micro-processors instead of the classic charge regulators; and we installed a considerable number of tubular batteries, which have a lifetime of more than four to five years, instead of the batteries with thick flat plates, which are only operational for two years.

Nevertheless, we under-estimated the problems of technical viability, above all concerning the lamps (ballast). At the request of AME, we twice agreed to change all the ballast, which had already been installed. Now, the thousand systems are operating satisfactorily.

In total, we have to face a loss of 300 000 Dinars in this project, something which we are accepting without regret in the interest of saving the image of photovoltaics in Tunisia.

Q.: What are the reasons for the technical problems you mentioned in spite of detailed specifications in the tender documents?

Mr. Kanzari: We had confidence in the components because of the tests executed with samples in Europe as well as in Tunisia.
For the PV systems between 50 and 100 Wp, operating at 12 V, there is no big market in Europe. So, it is possible that certain components are produced in small series or under almost artisan conditions. Other components may have been designed for leisure applications, holiday houses or cars, but do not withstand the severe conditions of the countryside in Tunisia. The experiences of other countries in Asia, Latin America and Africa show similar problems.
The manufacturers are therefore forced to pass though a learning phase and optimise their products, taking into account the field experience. Of course, this demands financial sacrifices.

Q.: Among the non-technical obstacles to a large-scale dissemination of PV, the legislation concerning importation of components is often mentioned. How would you consider the situation in Tunisia?

Mr. Kanzari: Three years ago, the legislation regarding importation was positive and exemplary. In fact, technologies using renewable energy sources or applying rational use of energy ware exempted from VAT and could enter the country with only minimum duties.
Still, the procedure was a bit complicated, it was necessary to obtain several certificates and authorisations for each individual importation.
Now only the modules are exempted from VAT and charged with the minimum importation duty of 10%. For the other components, the duties vary between 20 and 43%, plus a consumption tax between 10 and 20%, plus VAT between 17 to 19%.
For example, in 1995 the total charge for duties and taxes on charge regulators and ballast was 84%, for solar accumulators (batteries) 67%, for solar water heaters 70.6%!

Some Tunisian manufacturers of charge regulators and ballast have received a certificate from the Ministry of Industry. This certificate was based on tests with prototypes only and, in addition, the Ministry of Finance agreed to protect producers against importation.
In practice, the quality of these products is often average and technical problems are frequently found.

In addition, local manufacturers have a tendency to harmonise the price of their products to the price level of imported products, which are taxed, and not to fix the prices on the basis of their production costs. The direct consequence is a general increase of the price of the PV systems, and so the State has been caught in the trap of its own policy of protectionism, now paying more than the real value for a product.

AME and the Ministry of Industry are conscious of these problems and have promised to solve them.

Q.: What are your recommendations?

Mr. Kanzari: In order to give more impetus to the private sector in the field of photovoltaics, the national authorities should take the following measures and restructure the market by

- drawing up a list of standards for components to be imported or produced locally;
- respecting quality labels (ISO 9000);
- reducing importation taxes and duties;
- improving the image of photovoltaics.

The organisation of round-table meetings with representatives from the public and the private sector, plus representatives from financing organisations interested in photovoltaics would be welcome as well.

"... 500 families in this region now benefit from "ettáka"..."

13.3. Interview with Mr. Mostapha OUHICHI, school warden and farmer
in the Sector of Farchène, Delegation of Sakiet Sidi Youssef, Gouvernorat of El Kef

The family of Mr. Ouhichi has possessed a Solar Home System (SHS) of 50 Wp since 1991 (Programme of solar electrification of rural primary schools at El Kef)

Question: Mr. Ouhichi, the Delegation of Sakiet Sidi Youssef has become the region with the highest concentration of Solar Home Systems in Tunisia...

Mr. Ouhichi: In fact, the first systems were installed here in nine households seven years ago. Later, solar electrification of the primary school at *Farchène* was the chance for me, being the warden of the school, to receive a system for my house, too. Then, two years ago, the programme of 1000 PV systems at El Kef gave priority to this region. Finally, about eight months ago, it was the "2626" programme, which also allowed a certain number of systems to be installed.

The majority of families, in this mountainous zone, live near or even in the forest and are small farmers. In this Delegation, about 500 families now have *ettáka* (solar electricity). There are 96 of them in our *Sector*, *Farchène*, but in total there are more than 800 families, which cannot be connected to the grid, even in the long term. The costs are too high.

Q.: You know the families living in this region very well. What have been their technical experiences with the PV systems?

Mr. Ouhichi: The users, who have had the system for seven years had to change the batteries every two years. Before, those who possessed a TV battery, had to bring it to town every two weeks for charging and this cost two Dinars every time.

The charge regulators, installed in the framework of the first two programmes, were good. If there is an electricity cut, the system starts to operate again after a short while. The regulators installed in the framework of the "2626" programme cause problems. If first a tube is switched on, and then the television set, there is an interruption in the electricity supply. The neon tubes rapidly become black, too.

The price of the batteries has increased considerably. It has nearly doubled in the last few years. A normal battery costs 135 Dinars, a starter battery 82 Dinars and 200 Millimes. Taking into account the low income of the population living here, many users are not able to buy the correct battery. So, the poor people, who do not have money, ask to be helped by the "2626" fund. Others want to buy the components on a credit basis.

Q.: How do people behave in the case of a breakdown of the system?

Mr. Ouhichi: In the beginning, it was the Regional Service of AME in El Kef, which ensured that repairs were made and spare parts were available. I have learnt from the technicians of AME, how to install a PV system and how to carry out maintenance. Sometimes, I am called to help out at a user household, for instance, when a fuse of a charge regulator has to be replaced.

The company *SES*, which installed most of the systems, is only present in the town of El Kef, which is quite far from here. During the warranty period, in the case of a breakdown we contacted the administration of the Delegation of Sakiet Sidi Youssef or the regional service of AME. Sometimes, we had to wait for quite a long time, before the technicians from *SES* went for repairs.

As a result of the knowledge I have acquired (I am also used to repairing radios and TV sets), I would like to take over maintenance and repair of the systems here in our region. As far as charge regulators are concerned, I could manage small repair works. Regarding the ballast, in the case of a breakdown, it is only possible to change them, as we do not have the electronic elements needed for repairs.
But in order to be able to start this work, I would still need at least a voltmeter and a densimeter for the batteries.

Q.: What is your experience with the PV systems installed at the school?

Mr. Ouhichi: Several systems have been installed here: one system for the two classrooms, another one for the house of the director, a third for the house of the teachers. The system for the classrooms is only used in winter, and then only for some hours in the morning. The other systems are used all the time, with the exception of the holiday period.
When the operation of the initial batteries stopped (after about one and a half years), the *Gouvernorat* had not budgeted the necessary money for buying new batteries.
Therefore, the system for the classrooms stayed out of operation for a long time, but the director bought himself a small battery, which he used for the system at his house.
Meanwhile, the *Gouvernorat* has bought new batteries. The maintenance of these systems is one of my duties as a school warden.

Q.: Have there been cases of refusal of PV systems by the population?

Mr. Ouhichi: First, those who own a SHS are worried that a component might break down, once the warranty has expired. The families hardly have enough money to live and would have a lot of problems paying for new components and repair works. With STEG, things are much more easy: you only pay for your electricity consumption, and that's all.

Secondly, there are some people who still do not trust photovoltaics and are therefore spreading bad publicity about it. They say that a PV system can only operate when the sun shines and that the battery, once it is empty, can never be recharged again. But as soon as these people have seen that an SHS is working properly at a user household, they also want to have such a system at home.

"...We have accepted photovoltaics as a temporary solution ..."

13.4. Interview with Miss Noura EL AMRI,

Douar Sidi Amer, Delegation of El Fahs, Gouvernorat of Zaghouan

Ms El Amri works as a teacher. The inhabitants of the "douar" (hamlet), identified as a shadow zone, profited from a project of the "National Solidarity Fund" (FNS): Each household has had a PV system of 100 Wp since 1994.

Question: Miss El Amri, you are living in a *douar*, which has been assisted by a "2626" action...

Ms El Amri: Our *douar* is very far from town. Near-by, there was neither electricity, nor a road, only a track in very bad condition, inaccessible for cars. In order to go to the nearest town, first you had to go to the neighbouring hamlet, where you could catch a bus or the pick-up-car for rural transport. So, when we heard that our *douar* had been selected in 1995 for the "Action 2626", we were very happy.

Q.: What improvements have been achieved by this action?

Ms El Amri: A representative of the *Gouvernorat* came here to announce the different measures: the road, water and electricity.
Some improvements proposed from our side were refused, such as a rural school and a local health station. We also proposed a rural telephone and I even offered a room for the installation of a pay phone, but this was refused as well. A pay phone is very important, for instance, when somebody is ill or in case of an accident.

Q.: Were any income-generating activities planned?

Ms. El Amri: Yes, bee-hives and wool for women's work.

Q.: In respect of electrification, did the responsible person speak about the solar solution?

Ms. El Amri: Yes, but in the beginning, we refused it. There was complete opposition from the inhabitants of the *douar*, even when the Governor came here. We had been waiting a very long time for electricity. We wanted a sustainable solution. For photovoltaics, there is just a two-year warranty period. If the battery fails afterwards, it's up to the user to buy a new battery himself.
We would accept buying a new tube for the lamps, but if a battery or a module breaks down, this is just too much.

Finally, we told the officials that if they wanted to give us photovoltaics, we would insist on having a big system, allowing the operation of a colour TV, a radio with cassette player, lamps and a refrigerator.

They told us that the extension of the grid to our *douar* was not possible for the moment, due to the high cost. We have therefore accepted photovoltaics as a temporary solution.

Q.: How many families live in this *douar*?

Ms. El Amri: There are 55 families.

Q.: Almost all families without grid connection attribute a high importance to the refrigerator. But only one third of the grid-connected rural households really possesses a fridge. Do all families in your *douar* have the necessary financial means to buy a refrigerator?

Ms. El Amri: Not all families, but the majority. A refrigerator is a good thing in summer. You can have chilled water, conserve meat, etc..

Q.: Do you think that the government should give every rural household the chance to connect a refrigerator and a colour TV? The FNS projects should supply minimum electricity, for example, to help the children do their homework in the evening. Don't you think that those, who want a system offering more comfort for a fridge and a colour TV should buy additional PV modules and an inverter themselves?

Ms. El Amri: But why? This costs a lot...

Q.: A colour TV and a refrigerator cost together about 1 500 Dinars. The argument, that spare parts for PV cost a lot of money, seems a bit surprising...

Ms. El Amri: Nevertheless, a solar battery costs more than a car battery; it costs about 100 to 150 Dinars.

Q.: The choice is up to the user: he may buy a starter battery which will function for six months or one year; he may buy a solar battery, which costs more, but stays operational for two years or even longer.
What is your technical experience with the photovoltaic system?

Ms. El Amri: We are two households living together in one house. We therefore received two systems, each of them with two modules. Each system has three lamps. In addition,

I have connected a radio-cassette player to one system, to the other one a small portable colour TV. The systems have been operating for two years.
In fact, one tube does not function, the rest of the systems is operating well.

Globally, PV is a considerable improvement, compared to the traditional solutions, like kerosene lamps.
Before, we had to change the battery for the TV once per week, which was very difficult due to the conditions of the rural tracks.

"First a regular job..."

13.5. Interview with Mr. Abdelmajid BEN FRAJ,

Douar Sidi Amer, Delegation of El Fahs, Gouvernorat of Zaghouan

Mr. Ben Fraj is a small farmer and day-labourer.
The douar of Sidi Amor is a zone of intervention by the National Solidarity Fund ("Action 2626"). The Ben Fraj family has had a Solar Home System (SHS) of 100 Wp since 1994.

Question: Mr. Ben Fraj, the "Action 2626" has assisted you in obtaining a photovoltaic system. What was your financial contribution?

Mr. Ben Fraj: I am day-labourer. I worked with the company which prepared the rural road up to our hamlet. So, I saved some money and I paid hundred Dinars in cash for my system. As you see, I am living in difficult conditions. I have five children, and we are living in only two rooms. Three of my children go to school. I have many problems buying the school articles and the school clothes for my children. For example, two of my children share the same slate.

A neighbour: I also had to face of lot of difficulties in order to save the money to get a system. For one week, my family had to live on bread, oil and water. Every day only bread, oil and water...

Q.: Why was the PV system so important for you?

Mr. Ben Fraj: In the beginning, I thought that *ettâka* would be like the electricity from the grid. It would be possible to connect a small welding machine or a sewing machine. Afterwards, it became apparent that PV can only improve the conditions of daily life. But they told us that we must proceed step by step: today the PV system, and tomorrow, perhaps, STEG...

Q.: You have now had the system for two years...

Mr. Ben Fraj: My experience with the television and the lighting is good, but STEG allows you to connect more equipment: small machines, a colour TV, a fridge...

Q.: Taking into account your living conditions, why are you attributing so much importance to the television and the refrigerator?

Mr. Ben Fraj: The most important thing for me is to find a job in order to have an income. This is more important than the electricity for lighting. I can content myself with a *fnar* for lighting for some time, if I find a stable job. With regular income, I could improve my living conditions myself. I still have some hope that the "2626" will offer me the means to buy ten to fifteen sheep, for example.

Q.: Once you repaired the connection of your TV set to the SHS. Did the owner of the company, which installed the SHS here, propose that you could take over small local repairs and the sales of spare parts in your *douar*?

Mr. Ben Fraj: I have some all-round experience. I can work in the construction of roads, in the construction of houses, as well as with electrical installations in houses. We would have liked to work with the owner of the company for the PV installations, when he came here. But he always said "I will see...", and he left without giving me the professional training or the chance to work on small repairs and maintenance of the PV systems.

"We opted in favour of "ettáka"..."

13.6. Interview with Mr. Elmekki BEN AMOR,

farmer in Dyr El Kef, Delegation of Kef-East, Gouvernorat of El Kef

The family of Mr. Ben Amor has had a Solar Home System (SHS) of 70 Wp since 1994 (National programme, first stage)

Question: Mr. Ben Amor, how did you manage to acquire a PV system?

Mr. Ben Amor: Some households in our *Sector* already had *ettáka chemsía* (solar energy) seven years ago. In addition, we saw the installation at a rural school not far from here.
Some time afterwards, I was told by our *Omda* (Head of *Sector*) and the technicians of AME that the whole of our *Sector* was programmed for rural solar electrification.
For many years, we had hoped that the grid of STEG would come here, but evidently, this is too costly for STEG. So, we opted in favour of *ettáka.*

Q.: How much did you pay for your installation?

Mr. Ben Amor: I paid 100 Dinars, as did all the user households in our *Sector.* Some paid when the technicians of AME came to register the interested households. Others went to the administration of AME in El Kef in order to pay cash.

Afterwards, we had to wait between five and seven months before the system was installed. The installation itself was done very quickly, it didn't take more than three hours.

Q.: What sources of energy did you use before?

Mr. Ben Amor: For lighting, we used the *fnar* (kerosene lamp). For our small black and white television set, we used a battery, which we had to recharge in town every 15 days. We had to buy a new battery at least once a year. In addition, we used dry batteries for the radio-cassette-deck. Such batteries lasted only ten days.

In fact, the system now supplies electricity for television, radio plus three lamps. One lamp is fixed outside the house in the courtyard. This is important in summer.
We have one lamp for each of our two rooms.
We would appreciate additional lamps for the kitchen and the shed of the animals, but this was not possible.

Q.: Do you consider the quantity of available electricity as sufficient?

Mr. Ben Amor: We live here in a mountainous region with frequent cloudy and foggy periods. In winter, there is often no sun.
During this season, we sometimes have cuts in our electricity supply.

With time, we have adapted our consumption to the available energy. In case of clouds, we reduce lighting in order to be able to watch television.

I have neighbours, who even use the *fnar* during such periods and also give priority to television.

Q.: What do you do in the case of breakdowns?

Mr. Ben Amor: During the first two years, the system was still under warranty. In the case of a problem, I could contact the technicians of AME to help me *blesh* (free of charge).
Now, the system is no longer under guarantee. If a component breaks down, I do not know how to repair it. In addition, I do not know where I will find the spare parts.

Above all, we fear the end of the lifetime of the battery. It's a solar battery, which is costly. Our income depends of the harvest, which was very bad in the last two years. In our *douar*, some people work as day-labourers and get only 40 Dinars per month. Worse still, others are jobless and have no income at all.

Perhaps it will be possible to buy a new battery at a dealer on credit, or perhaps we can borrow some money from relatives or neighbours in order to buy a new battery.

Nevertheless, we hope that the state will help us to buy new components.

Anyhow, we consider electricity now as a necessity, we have got used to it.
Especially the women have grown accustomed to it. Lighting helps them in the evening to prepare the wool and to do some weaving.

Now, that we have electricity, the only problem which persists in our *Sector* is the supply of potable water.

"It has become a necessity..."

13.7. Interview with Mr. and Mrs. Mohamed Hédi Ben Salah JBALI,

farmers at Oued Ermal, Delegation Kef-West, Gouvernorat of El Kef
The Jbali family has had a Solar Home System (SHS) of 53 Wp since 1989 (SEP, Pilot Dissemination Phase)

Question: Mr. Jbali, when was your first contact with photovoltaics?

Monsieur Jbali: It was exactly on June 28th, 1989. At that time, by means of a sort of lottery, the regional service of AME identified nine households in our *Sector*, to be equipped with photovoltaic systems. For this purpose, they first contacted our *Omda*, and then they installed a system in our house.

Q.: For what electrical equipment are you using your solar system?

Monsieur Jbali: The system gives me lighting for two rooms and a lamp outside the house. In addition, I have a portable TV set and a modern radio-cassette player.

Q.: Has the electricity supplied been sufficient?

Monsieur Jbali: It's a system with just one module.
In winter, there are often electricity cuts, especially when the battery has become old. Then I reduce my consumption by using the *fnar* again for lighting.
But I have neighbours in this *Sector*, who have received systems with two modules, allowing them to connect up to four lamps without electricity cuts.

Q.: Which components have been changed up to now?

Monsieur Jbali: During the seven years of operation, the technicians changed the charge regulator, after the first two years. In addition, I have consumed three batteries. The neon tubes are still those I had in the beginning.

Q.: And who bought the new batteries?

Monsieur Jbali: It was me.
I own just a small piece of land, two cows and a flock of 15 sheep and goats. During the last years, the harvest was bad. So, I was obliged to sell some sheep at a very low price in order to buy fodder for the other animals.
In spite of this difficult situation, I saved some money to buy a new battery.
Finally, a dealer sold me a car battery on a credit basis.

Q.: Madame, what are your impressions in respect of photovoltaics?

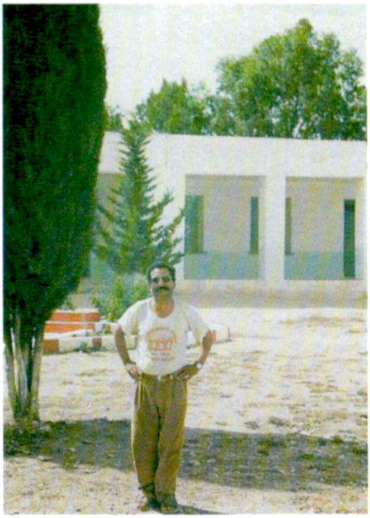
Madame Jbali: We, the women, are very satisfied with solar electricity, because it helps us to do many things in the evening: weaving, washing clothes, preparing cheese, tidying the house. The *taka chemsía* (solar energy) has become a necessity, we have grown accustomed to it.

In fact, people living near-by, who do not have a PV system, often stay here at night in order to watch television with us.

Interviewees

Mr. Ali Kanzari, General Manager of the company Solar Energy Systems

Mr. and Mrs. Mohamed Hédi Ben Salah Jbali, farmers



Mr. Mostapha Ouhichi, school warden and farmer

Mr. Abdelmajid Ben Fraj, farmer and day labourer, with his son

Ms. Noura El Amri, primary school teacher

Mr. Elmekki Ben Amor, with young people from his douar

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[1] Total text (translation):
«The operational criteria for the evaluation of systems for electricity supply in the framework of the co-operation with developing counties foresee:
- in respect of the system, 100 % of the costs must be passed on to the user,
- a transfer of the charges of more than 65%, but less than 100% is acceptable, if at least 60% of the electricity consumption serves productive applications. In this case it is nevertheless necessary that a coverage of 100% will be possible in the forseeable future. Lighting of individual houses is not considered as a productive utilisation, whereas the electricity supply of all installations of basic infrastructure is (this includes water supply, rural health stations, primary schools etc.).»

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