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COMMISSION OF THE EUROPEAN COMMUNITIES

Multiannual programme
of the Joint Research Centre
1980-83

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Annual Status Report

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SOLAR ENERGY

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Projects:

1. ESTI: European Solar Test Installation
2. Habitat and Low Temperature Applications
3. Solar Power Plants: Materials
4. Photoelectrochemistry and Photochemistry

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1. INTRODUCTION

To develop alternatives able to complement present energy sources, thus reducing the dependency from non-renewable or imported primary energies, is the main motivation of European activities on solar energy.

In accordance with the general science and technology policy of the Commission the objective of the JRC Solar Energy Programme is to contribute by specific activities to the development and application of solar energy technologies within the Community. The programme has two main orientations:

— to give a support to an extended application of solar energy technologies in the European Community, particularly with the operation of test facilities and the definition of testing procedures and methodologies.

— to pursue exploratory research in some specific areas, where industrial applications are still uncertain and preliminary information could be useful for orienting future development work.

The programme is structured in four projects.

Project I: ESTI (European Solar Test Installation)

This project deals with the construction and operation of a number of indoor and outdoor test facilities, for thermal and photovoltaic converters and with related «methodology» services as public service to interested organizations and industries within the Community. The specific testing activities are carried out in conjunction with an action for the definition, with the collaboration of national expert groups, of recommended procedures for the qualification of solar components and the development of test methods. Important activities, dealing with the identification of degradation mechanisms and ageing processes, are also performed in the frame of the project, to prepare the necessary background for the evaluation of reliability of solar technologies.

Project II: Habitat and low temperature applications

The project deals with the study and modelling of integrated systems for heating and cooling. Experiments with complete systems are performed, during winters and summers, using a «solar laboratory», and evaluations and comparisons are made. In the studies on low energy building design a growing attention is given to passive technologies. Systems of chemical and ground-seasonal storage are also tested. These studies are closely linked to corresponding actions of the EC Energy R and D Programme and IEA international cooperations.

Project III: Solar power plant materials

The activities aim at the improvement of solar power plant performances in relation to their efficiencies through appropriate contributions in the field of selective materials.
Special attention is given to the European Community 1 MWe power plant EURELIOS which was built in Sicily (Energy R and D Programme).

Project IV: Photoelectrochemical and photochemical conversion

The objective of these orientative studies is the exploration of advanced techniques for the conversion of solar energy into electrical or chemical energy. Main approaches which are followed are related to liquid-semiconductor junction solar cells and photochemical water splitting.

2. RESULTS

2.1 ESTI (EUROPEAN SOLAR TEST INSTALLATION)

2.1.1 OBJECTIVES

The final goal of solar energy research consists in the development of a cost effective solar energy conversion technology.
Any progress in this field requires an assessment of continuosly improving devices with performance and endurance tests. In view of the inherent variability of the incident radiation it is essential that these measurements are made under well-defined and reproducible conditions.
These conditions should take into account the climatological and irradiation situation of the place chosen for installation.
The project ESTI intends to treat part of these problems by means of laboratory measurements: this requires the constructions of «indoor» test facilities and the definition, selection and validation of suitable testing methodes.
There are a number of critical problems for the indoor method, as for example the true correlation between indoor and outdoor results, the eventual non-linear superposition of external parameters or the non-reciprocity between an artificially enhanced treatment and the real long time behaviour of a given device. A caution application of the indoor method is therefore necessary, especially during the initial phase. On the other hand, the advantage of being able to measure technical and scientific progress against reproducible and always available reference conditions should by far outweigh those difficulties. These facilities allow to verify if material corresponds to specifications, to differentiate between meteorological and material risk and to eliminate additional costs due to too large safety margins. This reduction in risks both for producers and for users in considered to be an essential step for the development of a cost effective solar industry.
Since the main obstacle to a large scale use of solar energy lies in the high cost per unit of useful energy, it is necessary to decrease investment costs and to maximize the total energy output.
Therefore the conversion efficiency must be high and the life time of the conversion system should be large against its energy pay-back time. Since this condition is to some extent in contradiction to the need to diminish material and maintenance costs, careful qualification and efficiency tests are necessary.
Testing facilities can be used for testing photovoltaic converters, thermal collectors or both. With the development of applications of solar energy, emphasis in testing is more and more shifting from the components to the overall systems. Moreover it is evident that the behaviour of a thermal collector may be better evaluated when measured as a component integrated in a complete, thermal system (habitat). To follow this evolution, the presentation of results in the frame of ESTI project is concentrated on photovoltaic conversion (components and systems) and the problems and results related to thermal collectors testing are discussed in the frame of the Project Habitat and low temperature applications.
The specific tasks for this project, concerning Photovoltaic Conversion, are the following:

— performance of terrestrial solar *cells* including calibration of reference cells;

— performance, qualification and control of photovoltaic *modules*;

— on-site acceptance testing of large photovoltaic *arrays*;

— continuous monitoring of EC-funded photovoltaic *plants*, including collection, storage and evaluation of all relevant data, leading to the preparation of monthly and yearly performance reports;

— *survey* of advanced devices and innovative concepts in the field of solar cells.

In summary the long-term objective for the project is to support the development and implementation of photovoltaics as large scale energy source, by systematic performance and reliability testing and the continuous monitoring of EC-projects and advanced research trends.

After a description and the state of the art of facilities, the activities and the results are reported.

2.1.2 FACILITIES

The project is in full operation; main facilities are here described, subdivided in the following groups:

Light Simulators

LS0: a simulator usin a filtered Xenon lamp and producing sunlight on test area of 20×20 cm². Used for calibration of solar cells and for references purposes.

LS1: installation able to perform measurements on a test plane of 3×4 m² under uniform and uncollimated light and

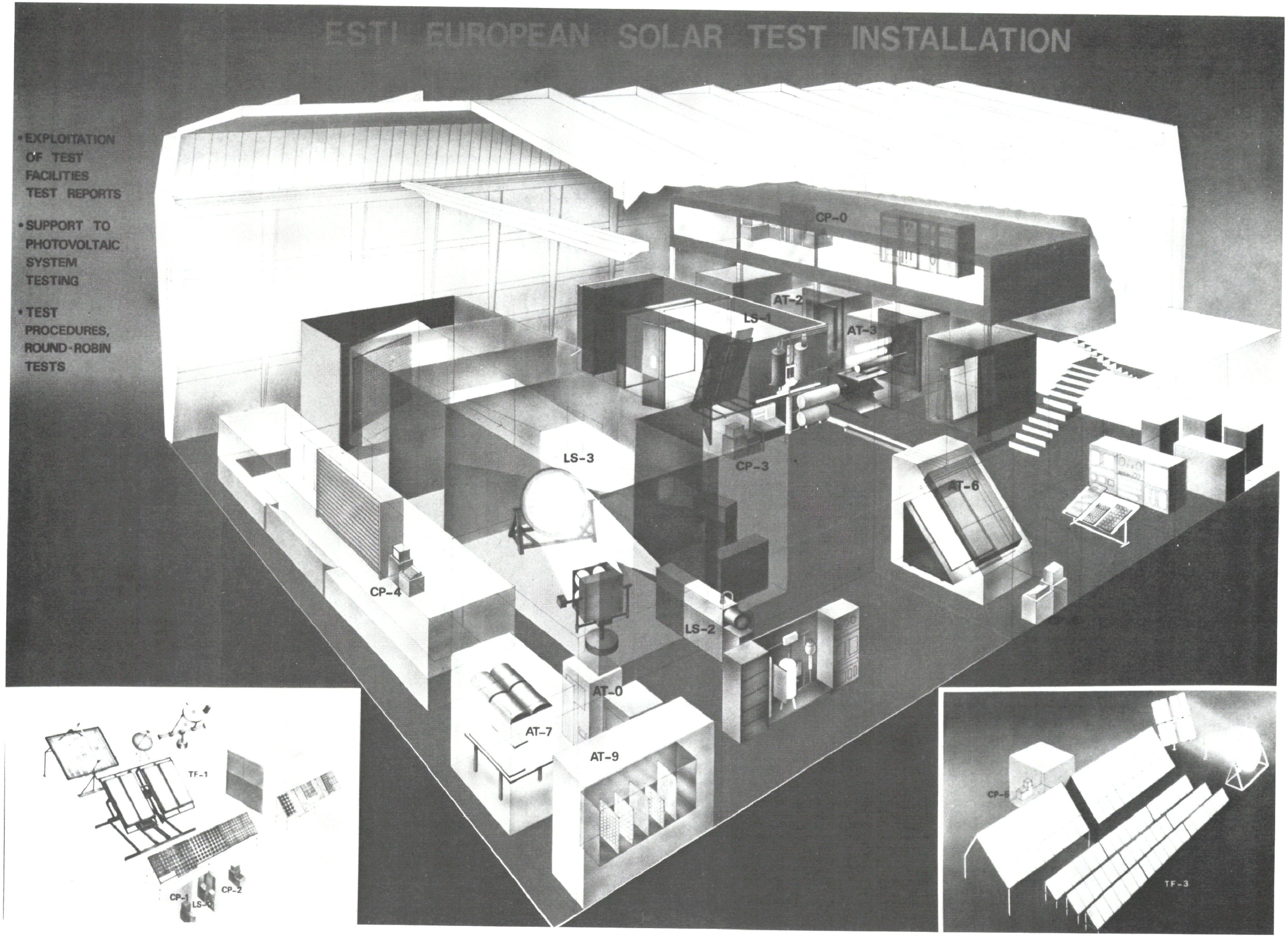


Fig. 1. Artist's view of ESTI FACILITIES

over a range of temperature conditions from -40°C to +60°C.
The light source consists of 295 discharge lamps (250 W each) producing an uniform irradiance which may be selected between 250 and 1170 W/m².

LS2: solar simulator consisting of 25 kW xenon lamp and a collimator mirror. It allows to measure angular incidence effects and the efficiency of concentrator cells. The same simulator without mirror is also used for indoor NOCT measurements, and for hot-spot qualification tests.

LS3: a large area pulsed solar simulator allowing measurements on photovoltaic modules and arrays under good irradiation uniformity and without cell heating, at standard test conditions.

LS4: a pulsed simulator with a fast current-controlled electronic load.

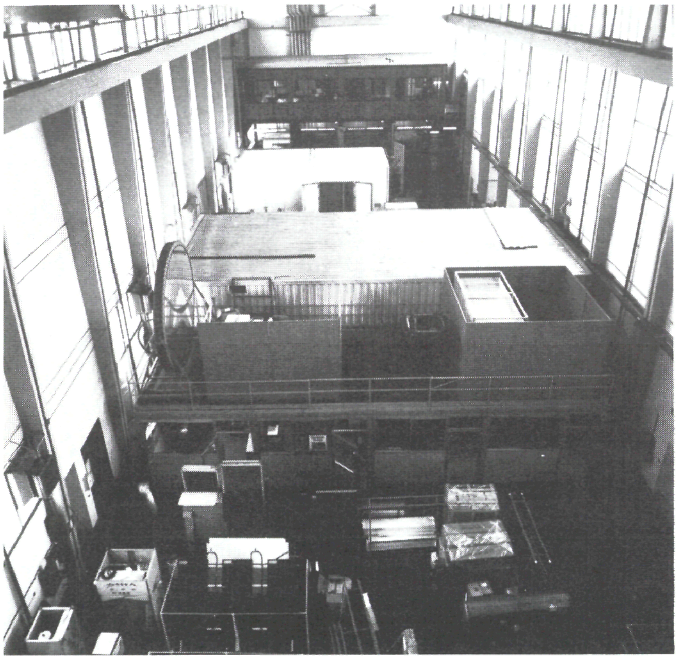


Fig. 2. View of the hall with "indoor" facilities

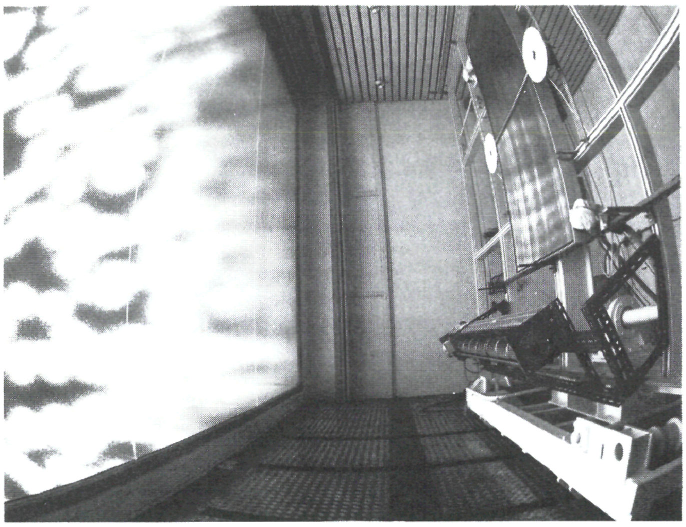


Fig. 3. Ligth simulator LS1 in operation

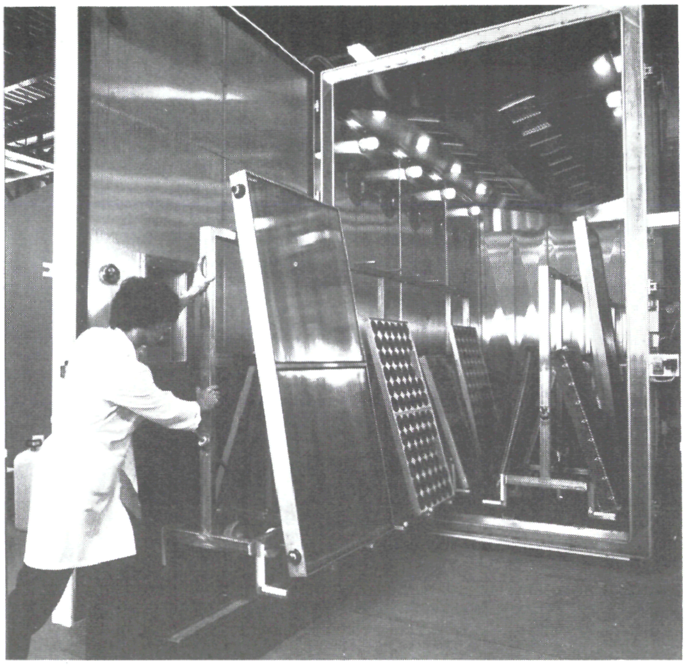


Fig. 4. Load of thermal collectors and photovoltaic modules in AT1 facility

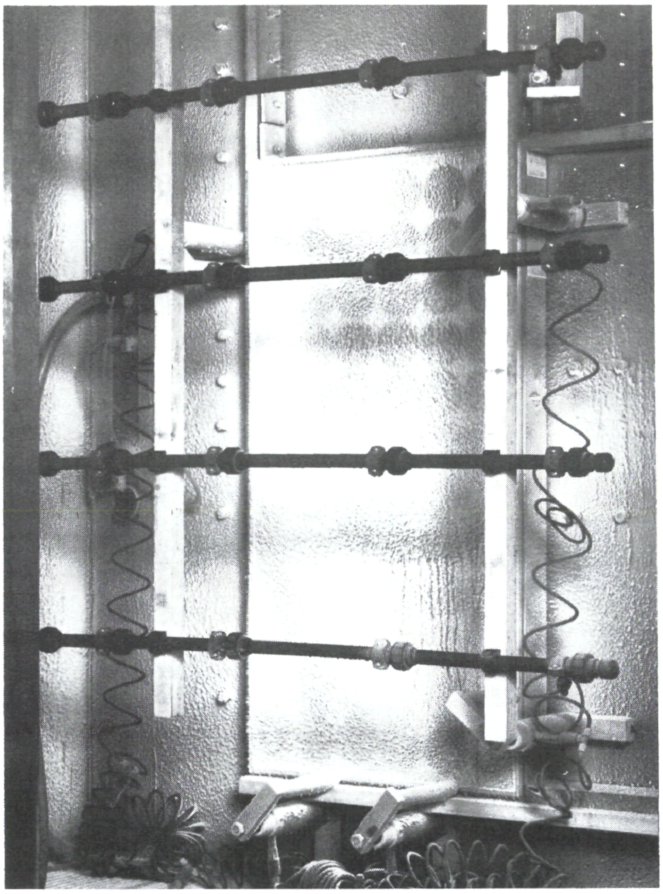


Fig. 5. Ice formation test in AT3

Durability and Qualification Test Facilities

AT0: Chamber for temperature - humidity freeze cycling of photovoltaic cells.

AT1: a climatic chamber for accelerated ageing tests in a corrosive atmosphere (humidity, sulphur dioxide, ozone).

AT2: a facility for accelerated ageing under intense ultraviolet irradiation.

AT3: a test chamber for rain penetration and for the determination of mechanical resistance to static and dynamic pressure loads. A uniform air pressure can be applied up to 6500 Pa in pressure or up to 4000 Pa in suction.
The inside size of the chamber is 220 × 70 cm. Rain can be simulated with spray nozzles while the collector is in underpressure.
The temperature of the chamber can be varied between room temeperature and -15°C. By a special technique ice layers can be formed on the specimen.

AT4: a hail gun. Hail balls between 12 and 40 mm of diameter can be shot, one at a time, with velocities between 10 and 50 m/s.

AT5: facility for testing the pressure resistance of absorbers of thermal collectors and their eventual leakage.

AT6: a solar simulator which allows irradiation of one collector for long time. The light source consists of eightyeight 250 W power star lamps giving an irradiance adjustable between 850 and 1050 W/m^2. The irradiation area is 120 × 240 cm. The purpose of this facility is longtime ageing of collectors in dry or stagnant conditions causing thermal degradation.
The facility allows to simulate thermal shocks caused by «cold filling» of by «water spraying» of hot collectors.

AT7: an irradiation device for ultraviolet and visible light on an area of 100 × 150 cm^2.
The irradiation temperature can be varied by means of adjustable air blowers between 40° and 90°C.

AT8: a test chamber which allows storage in damp atmosphere; it has inside dimensions of 1.5 × 1 × 1.5 m^3.

AT9: a salt mist chamber.

AT10: high temperature storage chamber.

Data Acquisition Systems

A system is available with a two-level computer hierarchy to ensure a flexible and individual control of different experiments combined with a powerful back-up in mass storage facilities and power.
It consists of peripheral units (small computers of type PDP-11-03) interfacing directly with the experiments for control and data collection, and a central computer of type PDP-11-60, available for off-line computational and editorial work.

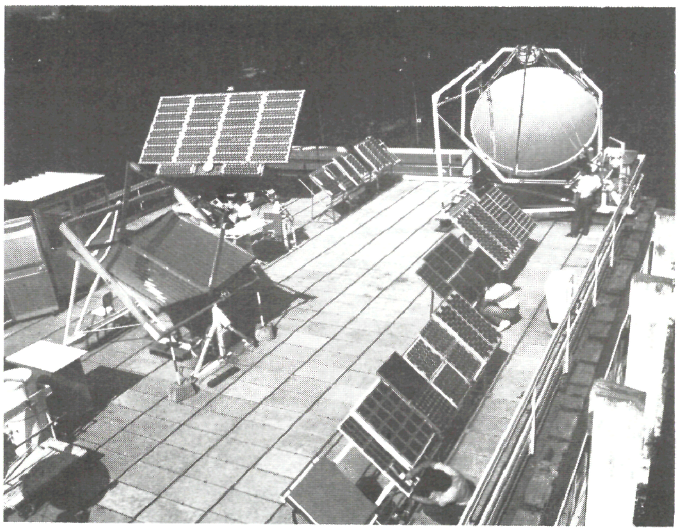


Fig. 6. PV outdoor facilities

Outdoor Facilities

The development of significant test procedures simulating various atmospheric conditions requires the execution of outdoor correlation tests. Correlation test facilities are available for different purposes.

2.1.3 PHOTOVOLTAIC TESTING

Activities on Photovoltaic Testing during the reporting period were concentrated around the support to the Photovoltaic Pilot Plants Project of the Energy R and D Programme managed by the General Directorate XII, with an extensive test programme.

Comparisons with other products and improvements in test methodologies were also continued.

Main results are here mentioned, according to a subdivision in four sections, covering the following topics:

— solar cell measurements,
— module measurements,
— acceptance testing of large arrays,
— monitoring programme for PV plants.

For the measurements, it is recalled that reference is made to the publications «Standard Procedures for Terrestrial Photovoltaic Performance Measurements» CEC Specification No. 101 (Issue 2), Report EUR 7078 EN (1981) and «Photovoltaic Module Control Test Specifications» CEC Specification No. 501 Report EUR 7545 EN.

a) Solar cell measurements

Measurements were made on 90 types of cells, produced from various manufacturers and covering a wide range of technologies. A universal computer program was developed for handling and analysing all experimental data, for a systematic comparison of cell measurements as a function of various characteristic parameters. Results of these intercomparisons

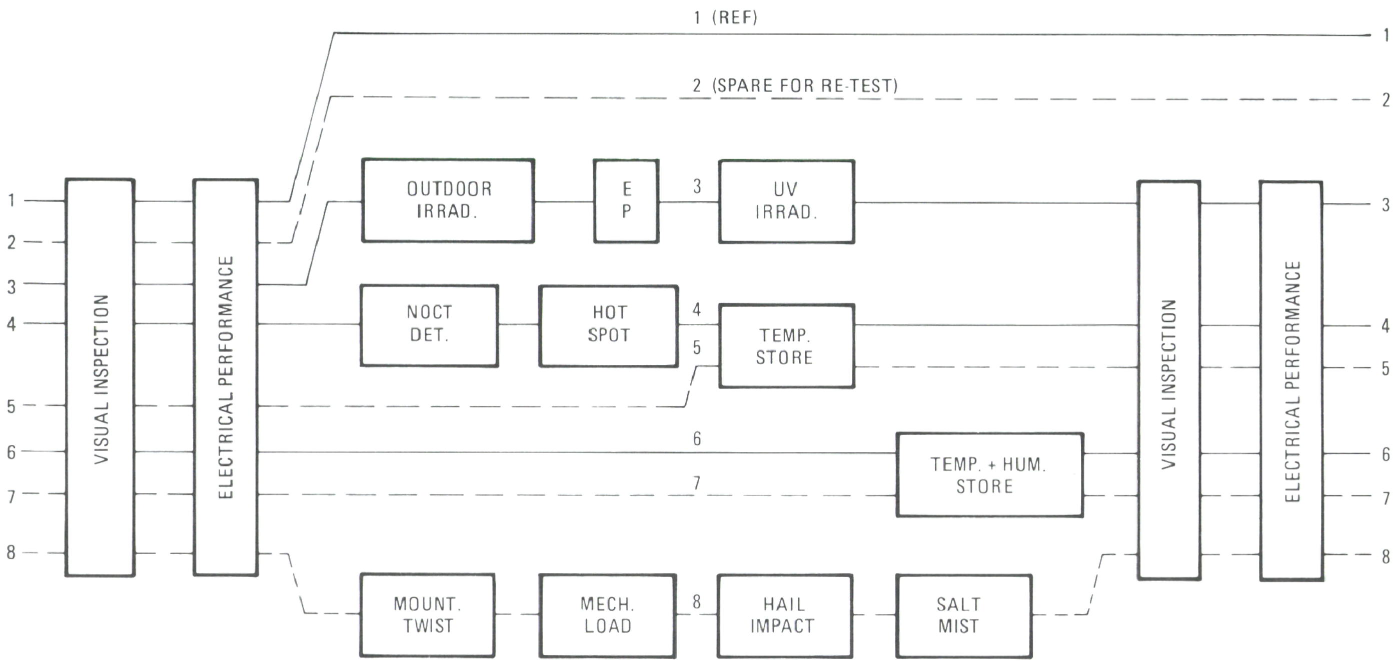


Fig. 7. Qualification test scheme for photovoltaic modules

allow to distinguish between industrially achievable standards and products which have not yet reached that level. For instance the minimum values of efficiency for good cells are 11.9% or 9.2% for monocristalline and polycristalline cells, respectively.

b) Module measurements

A basic requirement for module measurements are reference cells either to set simulators to standard conditions or to measure under outdoor conditions the correct irradiance. On the basis of experience done, recommendations were defined for these reference cells and these measurements.

Testing of photovoltaic modules were done on all modules of the EC Pilot Projects, and on other modules to increase the data for intercomparison of photovoltaic technologies (european and US products).

Results are already available, obtained with tests on 195 modules covering 34 types and 14 manufacturers.

Concerning the *electrical performance*, it was possible to define as for the solar cells, the achievable characteristics for competitive technologies. For instance, the minimum values of efficiency for photovoltaic modules should be 8.5% and 7.3% for monocristalline and polycristalline modules, respectively.

Concerning *qualification*, results are based on a series of 1928 qualification test made on 195 modules. Fig. 8 summarizes main defects observed and their relative importance.

Defects may be specified and classified as follows:

i) imperfect manufacturing methods causing delaminations, air bubbles, extended voids, contact corrosion, front or back surface defects,

ii) insufficient manufacturing control leading to chipped or broken cells, variation of colour of antireflective coatings, inaccurate positioning of cells or displaced contacts,

iii) bad choice of materials and processing for encapsulation or contacts, leading e.g. to light-induced degradation effects,

iv) design problems, like e.g. module edge or hot-spot effects or functional defects due to a bad choice of terminals.

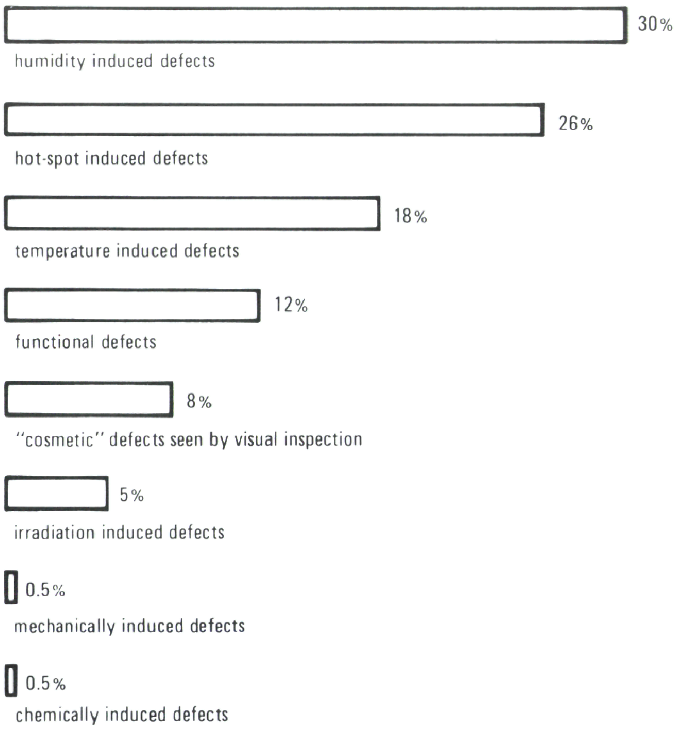


Fig. 8. Main effects leading to defects as a result of the qualification tests performed on photovoltaic modules

A selection of photos has been made in order to document this «pathology» of PV modules and to allow later a comparison with results from long-term field observations (which in the end should lead to improved indoor test methods). Whereas defects arising from i) and ii) were drastically reduced during the prototype phase, degradation effects of type iii) were still noticeable in some of the pilot plants. Power ratings based on flash measurements of virgin modules may thus not always agree with later on-site controls. However, it is hoped and expected that the degradation rate will level off within a short time. It will be one of the main objectives of the monitoring and control programme to check this carefully.
Many of the defects observed during prototype testing were eliminated by changes in the production process resulting in the large scale production of almost faultfree modules.
The on-site inspection of the EC plant modules (31580 modules) has shown that the failure rate of visual defects amounts at present to less than 0.5%.
This control performed up to now on 10 plants, with a total of 31580 modules approved through on-site measurements represents an extent which probably no other team in photovoltaics has ever tried.
As a consequence of present testing experience the previous test scheme will be modified, in order to allow a faster throughput and to concentrate measurements on the most critical tests.

c) Acceptance testing of large arrays

A major part of the work in 1983 consisted in the execution of on-site acceptance tests of 13 European power plants in 7 countries, with a series of intense measurements operations mainly in the frame of the implementation of the PV pilot plant programme of the Commission.
Special test equipments, methodologies, instrumentation and software had to be developed and applied.
The main purpose of the acceptance tests is to determine the rated power output of the array field and the losses therein in order to verify if contractual requirements were met (installed power within ±5% of rated power as measured by JRC, total array losses less than 5% of nominal power).
The list of the photovoltaic plants tested is given in Table I.
The actual test procedure consisted essentially of the following:

- sub-array measurements inside the control cabin, including thus all cable, diode and matching losses,
- direct measurements of the sub-arrays in the field,
- control measurements on module level,
- irradiation measurements using 1 or 2 reference cells (with the same spectral response and an encapsulation system as the modules under test) and 2 pyranometers (one in-plane, the other horizontal),

Table I. Photovoltaic plants tested (situation at the end of 1983)

Country		Site	Power (kW)	Main application	Module Manufacturer
1	B	Chevetogne (Namur)	63	Power for solar heat heated swimming pool	I.D.E.
2	IRL	Fota Island (Cork)	50	Dairy farm	AEG
3	NL	Hoboken	30	Hydrogen production	I.D.E.
4	GR	Kythnos Island	100	Village power supply	Siemens
5	UK	Marchwood (Southampton)	80	Grind-connected power supply	B P Solar
6	F	Mont Bouquet (Montpellier)	50	Power to TV/FM transmitter	Photowatt
7	F	Nice Airport	50	Navigation aid and emergency power control	Photowatt
8	D	Pellworm Island	300	Power for vacation centre	AEG
9	F	Kaw (La Guyane)	60	Rural electrification	France-Photon
10	GR	Aghia Roumelli/ (Crete)	50	Electricity for isolated village	France-Photon
11	F	Rondolinu (Corsica)	44	Electrification for isolated village	France-Photon
12	NL	Terschelling Island	50	Power supply for school	AEG
13	CH	Lugano Trevano	10	Grid-connected power supply	ARCO Solar

Note: All the photovoltaic plants, except the n. 13, are part of the Photovoltaic Pilot Projects partially funded by the E.C. Commission, Energy R and D programme managed by General Directorate XII, Brussels.

— measurement of ambient temperature and wind speed,

— determination of the module temperatures,

— visual inspection of the complete PV array.

All photovoltaic measurements are done using the portable electronic load and the computer program specially developed by JRC. The measurements performed with this system during the acceptance tests in various countries showed that it was suitable for field use and could easily be transported to rather remote sites. It can be used to determine the performance of 15 W modules as well as that of subarrays of 15 kW peak power; in some case the actual current intensity was 40 Amps, and voltage reached 500 V.
As a result of 13 acceptance tests, it has been shown that the rated power measured during the acceptance tests is in the average about 3.4% lower then JRC simulator measurements, with peak values of +1% and —8%.
This indicates:

1) the measurement method at the site is well established. In particular, the choice of a global calibrated reference cell of the same type as those installed in modules is essential. Otherwise one would not achieve such good agreement between the AM 1.5 simulator measurements and those performed outdoors under various weather conditions.

2) The tendency, that the outdoor measurements are in the average 2% lower than our simulator measurements is easily explained by wiring- and missmatch-losses.

3) In those cases, where single module (indoor-) measurements are influenced by thin connection-cables, the outdoor measurements show higher rated power values for a module due to the series connection of many modules. On the other hand, degrading of installed modules could be the reason for the relative low rated power with respect to simulator measurements.

In conclusion, it can be said that it is possible to measure outdoors the actual power output for all different installations. With the correction method which has been developed it is possible to determine the Standard Test Condition power output, which is in good agreement with all JRC simulator results. The measurement procedures are precise enough, to detect other large-installation effects such as degrading, missmatch losses, dust effects and wrong interconnection of modules. The reproducibility of JRC measurements has been checked and is better then 1%.

d) Monitoring programme for PV plants

For a good exploitation of the results of photovoltaic installations it is necessary to measure the performance of the systems under actual operating conditions. The ESTI project prepared and tested monitoring systems to perform these measurements.
A monitoring programme was defined for the EC Photovoltaic Pilot Projects: all these plants should in the end be covered by the JRC test programme, and included in a network of test sites to collect and analyse performance data.
To allow a significant comparison of data it was defined a common recording format and a minimum set of characteristic

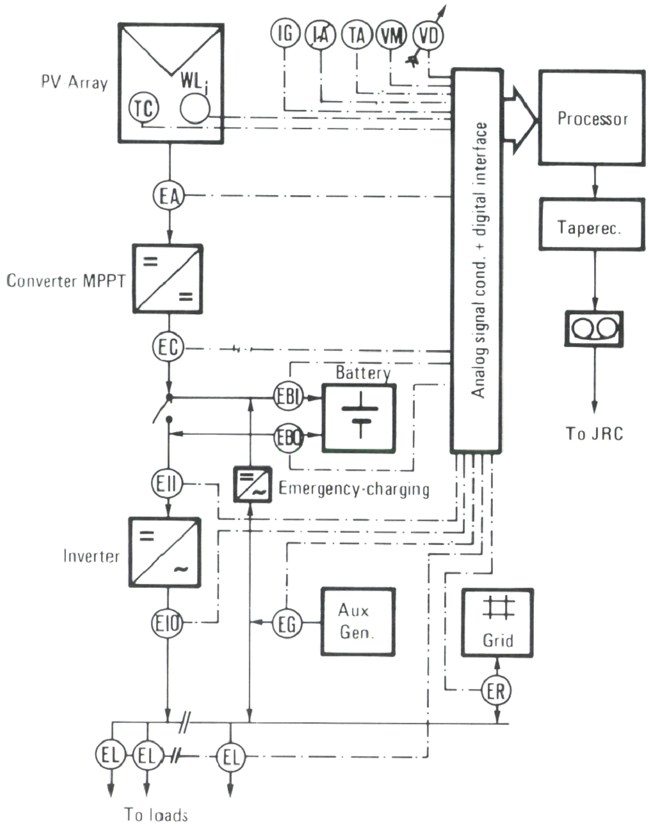


Fig. 9. Typical layout for PV monitoring system

parameters (insolation, wind, ambient temperature, cell temperature, energy at converter, battery, inverter, etc.).
The objective is:

— to study input/output relations

— to collect information on the performance, efficiency, reliability, and lifetime of components and systems

— to establish operational experience

— to obtain information about the «pathology» of modules and other system components

— to compare the economics of specific applications, and various design options

— to publish the results in a form suitable for future development of photovoltaic technology

2.1.4 CONCLUSION

After the design and the construction of a complete set of test facilities, a large number of measurements on photovoltaic modules has been done, for qualification and performance tests.
A computer program has been developed which allows a multiparameter analysis of all previous measuring results on cells and modules. An assessment of the achievements in this area on the basis of these measurements indicates clearly that at least 2/3 of all devices tested need improvements to meet today already achievable standards.

At the end of the 1980-83 programme of the JRC, it can be said that this classification of devices, products or manufacturers is one of the main achievements of ESTI; the objective for next pluriannual programme is to go towards a similar scheme on system level. For this reason major efforts are and will be devoted to the implementation of a comprehensive data exploitation system using as input the results of a monitoring program which should cover all EC-funded photovoltaic projects. In agreement with the long-term strategic goal for the JRC to assist the development of solar energy as an energy source, and not merely of new commercial products, testing efforts, design of innovative test facilities and improved procedures will continue as main objective of the Solar Energy Programme on Photovoltaic Conversion.

2.2 HABITAT AND LOW TEMPERATURE APPLICATIONS

2.2.1 OBJECTIVES

The activities of the Project are oriented to the evaluation of possible utilization of solar technologies in the field of Habitat, using solar heat for heating and cooling buildings.
Studies for thermal conversion of solar energy, at low temperature, had an evolution in the last years, taking into account also the general situation on renewable energies in Europe, characterized within the European Community by different policies from the Member States.

Work in 1983, the last year of the 1980-83 Programme of JRC, was influenced also by the preparation of the future Pluriannual Programme, which is emphasizing the concept of Energy Management in Habitat, where solar energy contribution is only one aspect of the more complex energy system represented by a building.

Efforts were continued in the field of the study and verification of high systems, and of the problems of durability of thermal collectors. New activities were started, or emphasized, in the field of performance measurements of Domestic Hot Water Systems, and of test cells for passive technologies.
All these studies were closely linked to the corresponding activities of the Indirect Action, the Energy R and D Programme of the EC Commission managed by the General Directorate of Science, Research and Development.
Cooperations are also in progress in the framework of ongoing programmes of the International Energy Agency.
The activities, and main results are reported, following the subdivision in the various subprojects.

2.2.2 THERMAL COLLECTOR TESTING

Main objective is the study of the essential problem of collector testing: the correlation between the behaviour of a collector as integrated part of a system and its performance when tested as single component, measuring simulated or accelerated degradation.

This subproject is concerning all the activities related to testing of thermal collectors, performed with outdoor and indoor facilities of ESTI, as described in chapter 1.
The activities are well integrated in the programme of work of the European Collector Testing Group of the Indirect Action (Energy R and D Programme of the G.D. XII). This programme involves 22 european laboratories and covers a large range of topics, in most of which the JRC is active. These activities are also in connection with the collector testing work in the frame of Task III of the IEA Solar Heating and Cooling Programme.
Work on collector testing can be subdivided into two categories:

— thermal performance testing

— durability studies

During the year 1983 the experimental installations have been significantly increased with new test facilities which are already operational:

— test facilities for air collectors

— installations for concentrating collectors

— installation for Domestic Hot Water Systems (DHWS)

Concerning **Thermal Performance Testing**, main results are been summarized:

— **Liquid Collectors**
Main effort has been focussed on evacuated collectors more particularly on the comparisons between outdoor and indoor results concerning some specific effects as the angle modifier and the influence of back reflection. Array performance data of two different types of evacuated collectors (Philips and Sanyo) covering a three years period are being analyzed. In the solar simulator LS1, a test loop is under construction, in which performance measurements of 4 collectors can be made independently.
A comparison of collector efficiencies measured in LS1 has been made.

— **Air Collectors**
The program on air collector testing is at an initial stage. In a round robin of the Collector Testing Group the air collector CEC6 has been tested. The main problems of efficiency measurements are related to the accuracy of the flow rate and to the in- and outlet temperature measurements.

— **Concentrating Collectors**
Activity on concentrating collectors is also at an initial stage. The points to be investigated are essentially two: the definition of a methodology for the determination of an efficiency curve and the assessment of the technological problems related to a high temperature loop.
A cylindrical parabolic concentrator has been tested with water. A high temperature loop (≃ 300°C) with thermal oils is in the starting-up phase.

— **Solar Domestic Hot Water Systems (SDHW)**
In the scale of the possible applications of solar energy, SDHW's seem to be closest to commercialisation in Europe. SDHW-testing is much more difficult and time

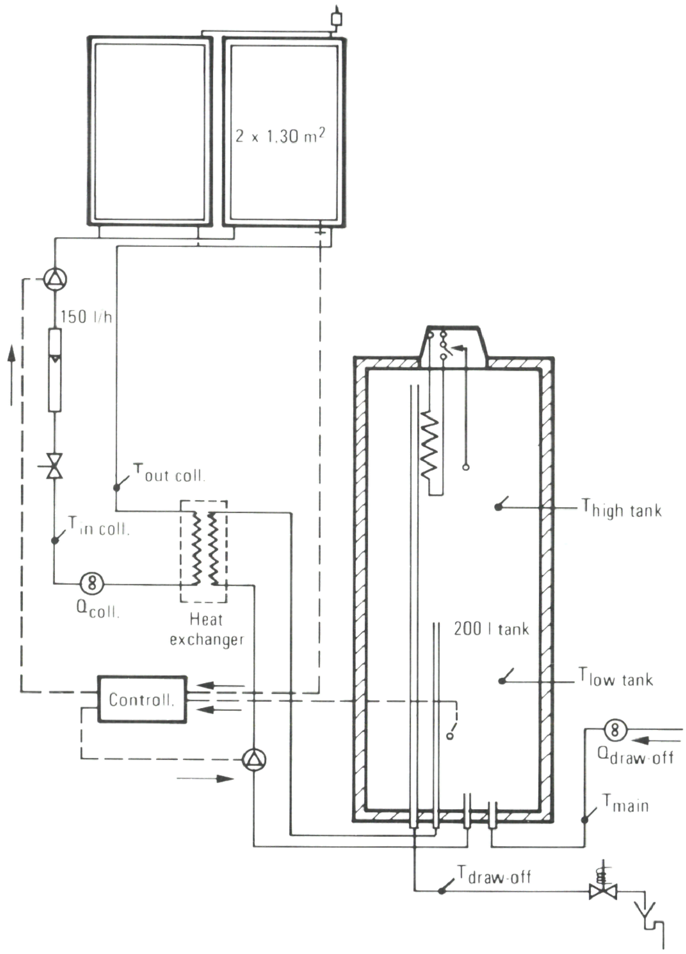


Fig. 10. Scheme of a pumped SDHW with compact heat exchanger

consuming than collector testing, because these systems consist of many components which could be interactive and have an influence on the global result. The aims are on one side the determination of the primary performance of the system and on the other side the long term performance.
The activities include both indoor and outdoor testing. The outdoor tests consist of the monitoring of the system covering a wide range of weather conditions. The long term performance is then calculated from the results with the help of a computer model, validated over the monitoring period.
The indoor tests are executed in a solar simulator under standardized average weather conditions, leading to one value of the system performance.
At the JRC 5 different SDHW systems are being mounted outdoor and monitored extensively. The same system will be tested indoor in the solar simulator LS1. Outdoor and indoor methods will be confronted and the limits and possibilities of each method determined.
This activity which represents an important part of the new testing program should contribute of the development of recommended test procedures for SDHW.
Besides participation to the EC and IEA programs the JRC has also performed a role of support to industry in the field of collector testing. In the last years more than 100 different types of collectors have been tested at the indoor and outdoor test installations.

This activity is oriented as a contribution to the industrial development of solar components and not as a certification activity which is the role of national laboratories.

Concerning **Durability Studies** main results are been summarized, on the basis of the experience and experimental work done in the last years.
From a large number of possible tests, the following tests were retained as the more promising for qualification and accelerated ageing:

— **Qualification Tests**
(Identification of destructive failures): static pressure, static and dynamic loads, hail resistance, thermal shocks.

— **Degradation Tests**
Rain water tightness, exposure to UV, exposure to sun and weather in dry conditions, exposure to simulated sun, corrosion tests including indoor exposure in climatic chambers with corrosive atmospheres (ozone, sulphur dioxide, humidity, saltmist) correlated to outdoor exposure in normal operation conditions in various geographic locations, internal corrosion tests from thermal fluids.

The selection of these tests was discussed with experts in the frame of the EC and IEA working groups in order to avoid double work and in order to complement national activities going on or being planned.
The tests are carried out in a number of test facilities of the ESTI complex, as previously described.
Experience from these tests show that collectors of the present generation resist well to certain tests which may be abandoned in the future.
Tests for mechanical resistance of the glazing to simulated wind pressure or snow and tests for hail impact resistance (except for evacuated tube collectors) can be limited.
The qualification tests which are considered to be important are test on the pressure resistance of the absorber especially in the case of roll-bonded absorbers, tests for minor thermal shock by filling the hot empty absorber with cold fluid, hail resistance tests on evacuated tube collectors.
Among the degradation tests, the exposure to artificial UV irradiation was found to be of minor practical importance. The indoor exposure test under high irradiation and temperature is still under evaluation. The other tests have proven to be significant.
From the group of the corrosion tests the damp heat cycling has been abandoned. Also ozone attack seems to be of minor importance for thermal collectors. It has been found that the combination of moderate SO_2 concentration (100-200 ppm) with high humidity and high temperature causes quite fast corrosive attacks. The optimum combination of these parameters is being studied.
The operation of the outdoor correlation test fields continues as these experiences will provide data for the comparison of accelerated ageing effects with real life ageing.
The prototype test field CTF.0 (first prototype experiment) has been in operation during 1983 without interruption. CTF.1 (clean air experiment) has been in operation since April 1983

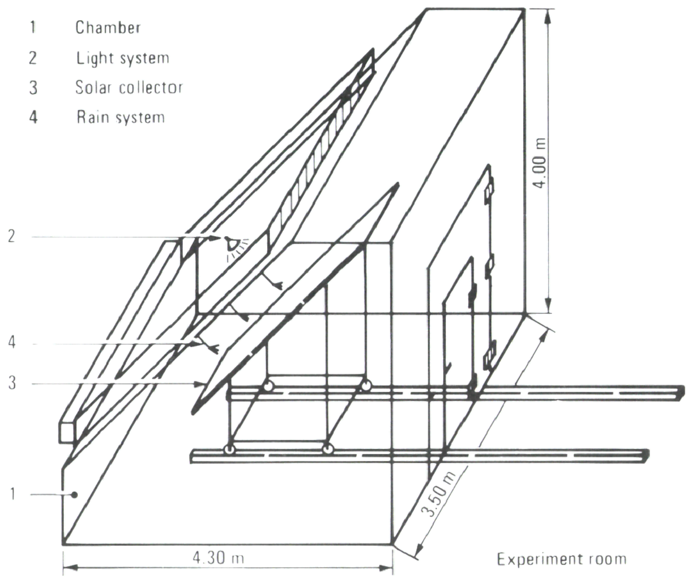


Fig. 11. Scheme of AT6 facility for dry exposure tests

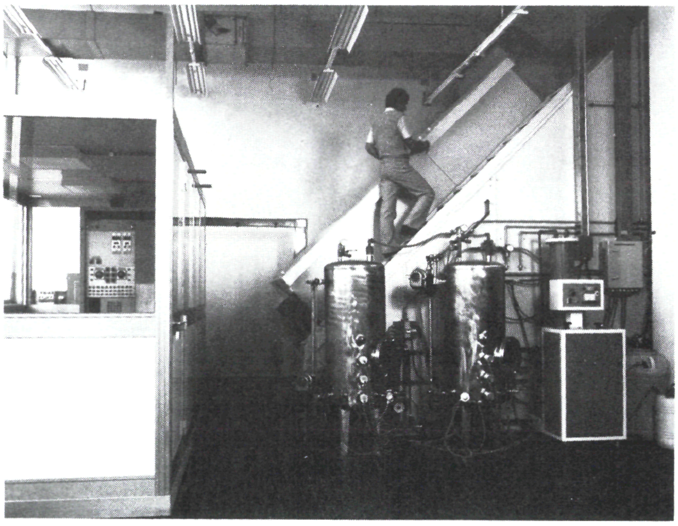


Fig. 12. View of the test facility AT6

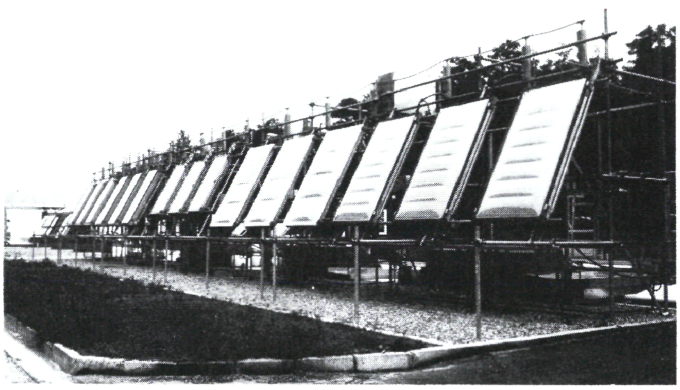


Fig. 13. Outdoor tests for corrosion on thermal collectors

and the operation of CTF.2 (industrial air) is about to begin. The decision on CTF.3 (coastal climate) is not yet made.
A research contract on corrosion of absorber surfaces is in course with the University of Leuwen.
In conclusion work will be concentrated in the areas already identified to be significant for qualification and accelerated ageing of collectors.
These tests will be applied to a series of collectors of the present generation including possibly a new family of ICS (Integral Collector Storage) collectors.
The contact with the national testing organisations shall be intensified and the results and experience available at the JRC integrated in efforts carried out on national and international levels.
Contacts with the European Union on Technical Agreement have been established and during two meetings held at Ispra on September and December 1983 the contribution of the JRC results and test facilities to the development of directives on solar collectors has been discussed. This can be an example of the utilization of the technical background and competences developed at the JRC, and of the type of collaboration with european organisations for standard definitions.

2.2.3 SOLAR HYBRID SYSTEMS

In the present european situation, the economics of active solar systems for space heating and cooling of houses appears doubtful, in part because of the general weather conditions in Europe, mainly because of the actual cost factors. This has lead the research on solar thermal systems to be more and more linked to a large concept of energy conservation and rational use of energy in dwellings, where direct solar energy utilisation is just one of the elements countributing to the energy needs. In view of this trend, which is emphasized in the future multiannual programme of the JRC, work carried out in 1983 at JRC in the field of solar energy utilisation at low temperature was concentrated on various problems related to solar assisted ground coupled heat pumps systems and to combined solar heating and cooling systems with absorption machines.

SOLAR SPACE HEATING WITH LONG TERM STORAGE AND HEAT PUMP

These systems from a thermal point of view present some inherent advantages which are mainly:

— the possibility of the year round utilization of the solar collectors
— the optimization of system efficiency through temperatures of operation which can be kept at low levels both for the collectors and the long term storage
— the introduction of flexibility due to the heat pump as a back up system.

The increasing interest for this concept is demonstrated by the efforts, both in research and demonstration projects, which are being carried throughout the world in this field.
Both the EC and the IEA programmes are strongly involved in the different aspects of the subject.

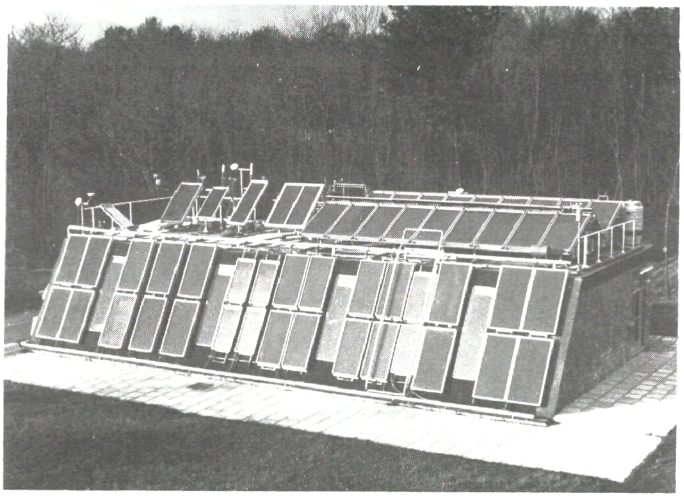


Fig. 14. The Solar laboratory

a) **Monitoring of the hybrid heating system in the Solar Laboratory**

This system which is operational at the Ispra Solar Laboratory, has been monitored now for more than 4 years. The technical feasibility and reliability of these kind of systems has been demonstrated very clearly.

It has also been demonstrated that this kind of heating systems can lead to savings of primary energy of the order of 70%, compared to a traditional heating system.

Though the system monitored in the Solar Laboratory does not correspond in the optimum scale, it produced a large amount of data which are very valuable for further assessment studies.

A simplified techno-economic model has been developed to evaluate the influence of the various technical and cost parameters. This model uses as input synthetized weather data which are obtained from monthly averages of the meteorological data.

b) **Seasonal storage**

The activities on seasonal storage have been continued on the facilities which are already operational. During the 1983 they have been characterized by the monitoring of discharge periods until the end of April followed by a charge period during the summer.

It is recalled that these facilities consist essentially of:

- $50\ m^3$ concrete storage vessel with water under the Solar Laboratory;
- a large $375\ m^3$ concrete water storage vessel burried in the ground;
- a test installation of heat storage in the soil by 36 vertical iron heating tubes 10 m long and 20 cm diameter connected with solar collector array of $180\ m^2$.
- *Large Underground Concrete Water Vessel*

  This non insulated vessel is heated with an electrical simulator in order to study heat losses in the surrounding soil during the change and dischange periods. The temperature probes are positioned both in the vessel and in the surrounding ground.

  Temperatures have been measured at different distances 30, 60 and 120 cm from the vessel wall and also at dif-

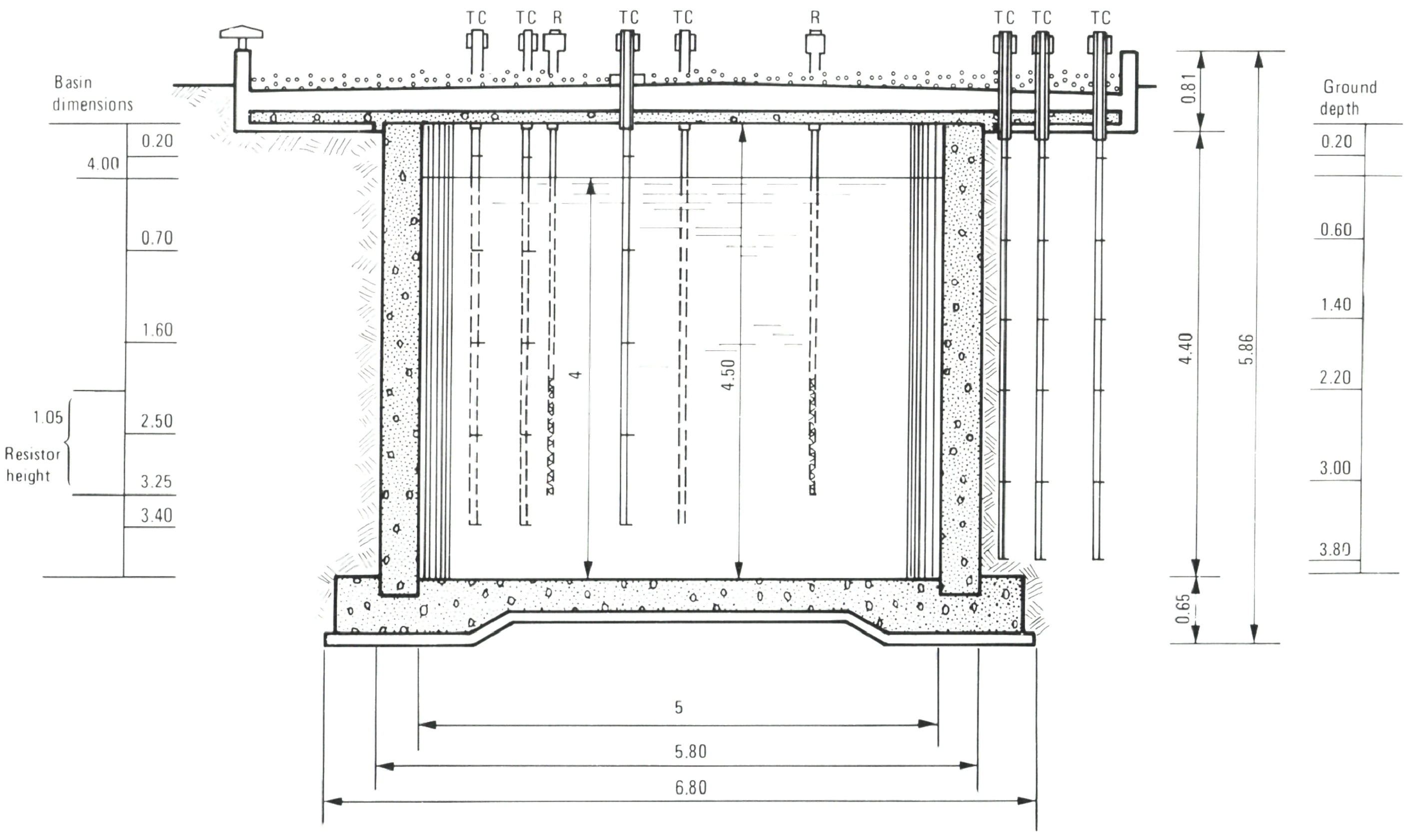
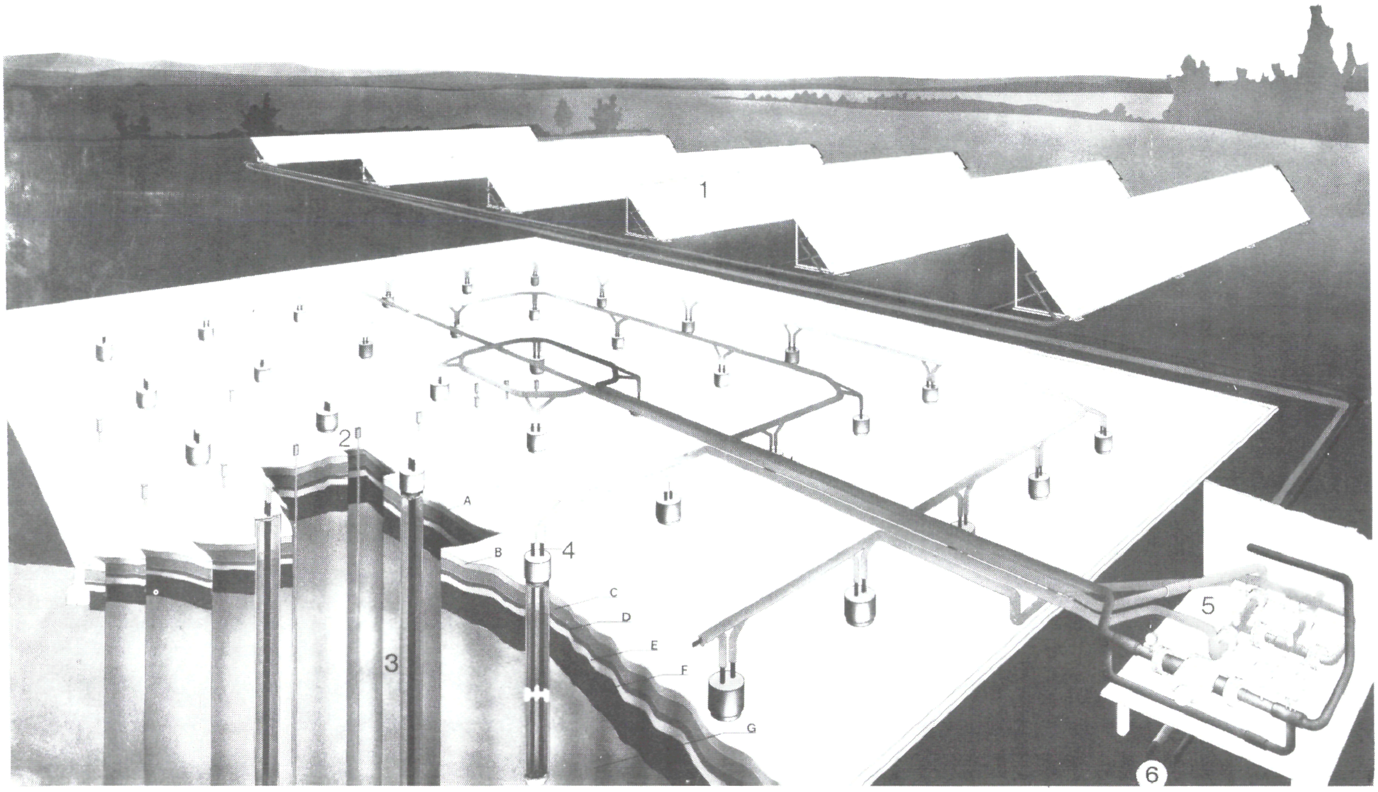


Fig. 15. Scheme of the concrete water storage



1) SOLAR COLLECTORS
2) THERMOCOUPLES
3) VERTICAL HEATING TUBES WITH BUFFER LIQUID
4) HEATING PIN
5) CONTROL AND REGULATION
6) HEAT PUMP UTILIZATION

A ASPHALT
B CONCRETE
C THERMAL INSULATION
D VAPOR BARRIER
E SAND
F GRAVEL
G CLAY-SOIL

Fig. 16. Seasonal solar coupled ground storages

ferent levels in the soil. In the same manner temperatures have been measured in the water at different levels. These data are being carefully analyzed on computer in order to evaluate diffusivity phenomena in the soil.

- *Ground Storage with Vertical Heating Tubes*
The ground storage with vertical heating tubes has been extensively monitored during the period and all the data (weather, solar system, energy input, temperature distribution in the ground) are being analyzed. These data cannot be treated in the simpler manner which is being used for the water vessel.
The circuit is being modified to allow energy extraction with a 10 kW heat pump in the system.
A detailed model of this rather complex system is underway but requires a careful evaluation of various coefficients which can only be obtained experimentally.

c) **Design study of full scale solar heating system with seasonal storage and a heatpump**
In the framework of Task VII of the IEA Solar Heating and Cooling Programme, a design study has been made of a solar heated highschool-complex located in Northern Italy. The solar system has been modeled and optimized with the computer programmes developed within this Task.
This study showed that such a system would have a simple pay-back time of about 16 years (price level Italy, May 1983).
This study showed also that for this climatic conditions the passive solar contributions can be substantial (about 15%) even for a compact building design.

d) **Monitoring of solar hybrid heating system in Treviglio (Northern Italy)**
The JRC is collaborating with the ENEA and the Politecnico of Milan for the monitoring of a large hybrid solar heating system which is used for the space heating and domestic hot water for 102 apartments in Treviglio. The data acquisition will start in the spring of 1984 and results will be partially used for general modelisation.

Last year the JRC has organised a workshop on this topic, jointly with the IEA. The JRC has accepted to assure, together with an IEA country, the continuity of this activity, and the preparation of a similar workshop to be held in 1984, has already started.

COMBINED SOLAR SPACE HEATING AND COOLING

In most mediterranean climates combined solar space heating and cooling may represent an interesting technical solution provided that the costs of such systems may be reduced. Specially as far as the absorption machine is concerned.

The activities on solar cooling are divided in two fields:

— experiments with solar cooling systems in order to study the technology and obtain performance data of systems and components

— assessment of combined solar heating and cooling systems for mediterranean climates with the help of computer models.

a) **Experiments**

The performance evaluation of advanced solar collectors has become an important part of the work on solar space cooling.

The reason for this is twofold:

- due to the high operation temperatures of space cooling systems, the collectors are a critical part of the system.
- there has been very substantial progress in the field of high performance collectors such as evacuated tubular collectors and improved flat plate selective collectors.

The solar space cooling system operating in the JRC Solar Laboratory has been equipped with three different types of evacuated tube collectors, which are monitored separately. The results of this installation are presented in Task IV of the IEA Solar Heating and Cooling Programme. Results show that with such advanced collectors daily efficiencies around 50% may be obtained with operating temperatures of 85°C. The COP of the lithium bromide absorption machine is of the order of .7 and the overall system efficiency may reach the range of 18-20%.

b) **Assessment studies**

In 1983 a detailed study has been made of a combined solar heating and cooling system which is used for the heating, cooling and preparation of domestic hot water of a small medical clinic located in Greece. With the TRNSYS-code and hourly weather data from Athens, the system was simulated and optimized. The use of both a heat storage and a chilled water storage was found to be very important for the system economics, since it permitted to satisfy a large cooling load with a relatively small chiller.

2.2.4 PASSIVE SOLAR TEST FACILITY

The passive solar technology has the potential to reduce significantly the energy requirements for buildings in virtually every climate of Europe.

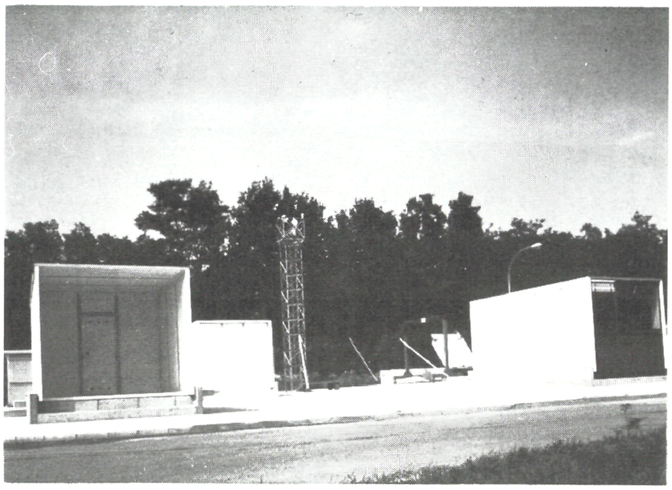


Fig. 17. The three test cells for the study of passive components and systems

In a vaste area of possible actions the specific lines of activities which have been retained for the JRC are:

— the assessment of latent heat storage materials for building components

— the development of methodologies for testing in passive test cells.

The development of standard test methodologies are considered an essential prerequisite for studies on passive systems and are actually being the object of increasing attentions within the various national and international programmes, particularly in the EC-programme.

The passive solar test facility at the JRC Ispra consists in: three test cells 3 × 3 m in cross section and 6 m deep, installed on a properly drained and insulated base, equipped with thermal sensors, which permits to control the heat transfer to the ground. The structural envelope of the cells is constituted by a sandwich of glass-fiber reinforced polyurethane.

The interior of the test cells is subdivided into two rooms of variable volume by a sliding wall in which a door and ventilation grids are located. This enables to study the heat transfer from the south-faced space to the north-faced space and to correlate energy balances in different volumes.

Two of the three test cells are used as «Variable Parameters» cells, in which front wall, ceiling, lateral walls and floor can be utilized as test field for passive components. The third one is the Reference cell, where the working conditions of an usual-(energy-efficient) building room are reproduced and accurately controlled. In that way, e.g. a performance index will be defined indicating the ability of a passive component to displace auxiliary conventional heating. The index is given by the ratio of the reference cell-heating (resp. cooling) energy to that of the test cell incorporating the passive component.

Studies are concentrated on:

a) **Instrumentation**

Problems related to the instrumentation of test cells are being carried out in collaboration with CNRS-France and the Institute of Applied Physics TNO-Delft. In particular the advantages of direct measurements of the heat losses through the walls of the test cells with heat flux sensors versus those of indirect measurements in a reference cell will be studied.

Each cell will be monitored by a minimum of 45 sensors-thermocouples, heat flux meters and humidity detector. The climatization is assured by a closed circuit heat exchanger coupled with a heating refrigerating recirculator.

Data are collected at intervals of 1/2 to 1 hour and treated by a data aquisition system.

b) **Testing of latent heat storage and passive components**
Previous activities on latent heat storage materials were mainly related with active solar systems. It has been considered now more interesting to reorient them toward applications in passive or hybrid systems.

A simple characterization method of latent heat storage materials under thermal cycling has been developed. The method is now applied to test the thermal response of latent heat storage materials containers of various shape and dimensions, such as plastic capsules, spheres, tubes, bricks, tiles and pouches. Such containers are integrated in a hybrid solar system for air conditioning, which is mounted in the south facade of a test cell for performance evaluation tests.

Another test installation is used to study the thermal performance of passive solar heating using heat storage in the outside walls of a building. Two different approaches are considered: one consists of an arrangement of thermal diode tubes acting as solar absorbers *and* as heat transfer medium to a water storage. The second approach consists in the use of collector storage vessels covered on the front side by a light transparent and well insulating material. The two systems are compared concerning absorbing storage-efficiency, heat transfer and thermal losses.

2.2.5 ENERGY AUDIT

An activity on **Energy Auditing** was integrated in this project, following previous work performed in the frame of a support to the Commission's Activities (Energy Conservation in Buildings) and with the aim to contribute to the development of advanced energy audit scheme for various categories of buildings, in connection and with the collaboration of european organisations active in the field.
The activity is also integrated in a new Task (Energy Auditing) of the IEA Implementing Agreement for Energy Conservation: JRC is acting as lead country for one of the two subtasks.

2.2.6 CONCLUSIONS

The activities of the project are concentrated on three main fields: collector testing, systems studies, solar passive testing. Orientation of the work is always on methodologies for evaluation, development of standard procedures, validation of models, instrumentation and monitoring techniques.

Most of the work is carried out within EC Energy R and D programmes, in connection with corresponding tasks of the IEA Cooperative programmes, in collaboration with national laboratories and institutions.

In the field of collector testing, new test facilities for air collectors, concentrating collectors and domestic hot water systems have been put in operation. The studies on durability are well integrated in european and international working groups. The problems related to corrosion damages are the object of increasing attention.

System studies deal principally with hybrid systems combined with heat pumps and seasonal storage. The development of large and cheap seasonal storage systems is considered an important aspect in middle and northern Europe.
Work at Ispra related to this field is mainly carried out within IEA tasks, with also a monitoring activity going on on actual realisations. Solar Cooling, also performed within an IEA task has given valuable information on the array behaviour and performance of advanced tubular evacuated collectors.

Solar passive testing is at an initial stage. Three passive test cells have been constructed. Instrumentation and modellization problems are being investigated in collaboration with two european institutes. Some passive components using latent heat storage have been mounted for evaluation tests.

2.3 MATERIALS FOR SOLAR POWER PLANTS

The conversion efficiency of solar radiation into heat is depending from the optical properties of the absorber material. An improvement in its solar absorptance and a decrease in its thermal emittance increases the photothermal conversion efficiency.
The aim of this activity is to develop selective metallic surfaces with a morphology particularly suitable to obtain a high thermal conversion efficiency for solar radiation, and a good stability at high working temperatures.
Examples of application are the various types of solar receivers designed for power and industrial heat production.
Two kinds of work are performed:

- preparation of special surfaces using various techniques;
- characterization of the surfaces with measurements of optical properties and thermal stability.

The activities related to the preparation of absorber surfaces are concentrated on a production method using the deposition of vapours of a corrosion resistant metal or alloy on a suitable substrate.
During the year 1983 work was particularly concentrated on Chromium surfaces, studying the influence of different parameters on the crystal growth obtained by physical vapour deposition with the optimal trihedric surface structure («pyramid» structure). The parameters taken into consideration are the direction of the incident vapour, the sample movement, the surface preparation.

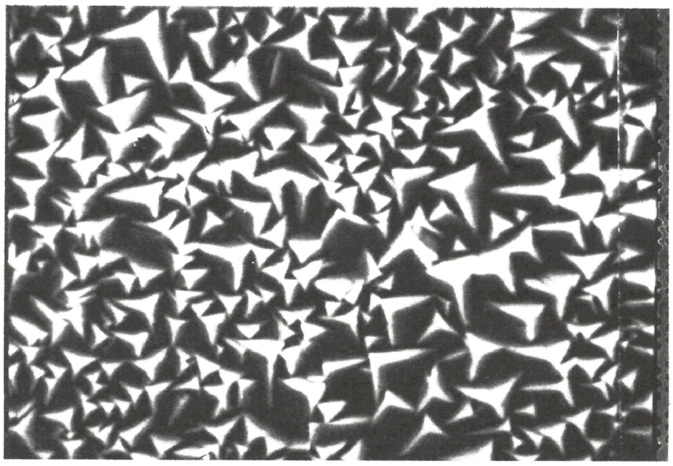


Fig. 18. "Pyramid" structure on chromium surface

Pure deposits of the material have been obtained in a reproducible way. Chromium layers have excellent absorption properties combined with a high corrosion resistance.
Another important work in the frame of the Project is the development of a measurement equipment for a calorimetric determination of the thermal emittance and the solar absorptance. On the basis of the experimental results already obtained a standard measurement procedure was developed.

2.4 PHOTOELECTROCHEMISTRY AND PHOTOCHEMISTRY

Research is devoted to techniques for the conversion of solar energy that are still in a state which does not allow short term applications, but could play an important role in the long term future if promising results are obtained.

2.4.1 PHOTOELECTROCHEMISTRY

The semiconductor/electrolyte (SE) photocells can be used like solid state solar cells (photovoltaic cells) for the direct conversion of light into electrical energy (regenerative mode of operation) or can be used for solar conversion into storable chemical energy (e.g. by photoelectrolysis). These SE-solar cells are still in a state where commercial application must be considered premature. Problems arise essentially from stability, in conjunction with limited spectral response and efficiency. Several approaches to solve these problems are under investigation in many laboratories. A first objective of the JRC research activity is to contribute by an investigation of the photoelectrochemical behaviour of less known and surface-coated semiconductors.
During the reporting period research was concentrated on the investigation of the catalytic effect of Ruthenium oxide on p-type semiconductors; surface stabilisation, and catalysis of cathodic photoelectrochemical reactions, have been demonstrated, due to a thin film of ruthenium dioxide on a semiconductor of technological importance, p-type silicon. The lower overpotential for hydrogen evolution in an acid electrolyte is noted. So also is the stabilisation under open-circuit conditions of the p-silicon electrode in a regenerative solar cell using the vanadium redox system, though in this case no overal enhancement of cell efficiency is achieved.

2.4.2 PHOTOCHEMISTRY

The main objective of activity is the study of the photoinduced splitting of water into hydrogen and oxigen.
The primary goal is to find out artificial systems which upon irradiation by visible light, i.e. having a wavelength between 400 nm and 700 nm, would produce water decomposition.
Experimental work was performed on systems $TiO_2/RuO_2/Pt$, on new sensitizers which absorb light, on photoadsorption of oxygen on TiO_2 colloids and powders. Further experiments are necessary for the interpretation of mechanisms.

3 CONCLUSIONS

The Solar Energy Programme, at the end of the 1980-83 programme, is confirming the central role of the JRC in support to the Commission programmes and EC activities oriented to an extended application of efficient and low-cost «solar technologies».
This confirmation is referring to the main orientation of the Solar Energy Programme: a contribution to (i) definition of test methodologies (ii) execution of performance measurements (iii) research on durability and reliability. These activities are related both the thermal converters and photovoltaic converters, and concerning components and systems.
All the experimental facilities which were planned are in full operation; the first procedures for measurements previously published are now in application for specific projects.

Concerning Photovoltaic Conversion, in the field of testing activities main emphasis has been on the module testing for the Photovoltaic Pilot Project of the EC programme of R and D on Solar Energy.
An extensive test programme has been performed, measuring so far 195 modules and executing about 2000 tests. As a results of these measurements, a lot of experience has been gained on the behaviour and the weak points of the present technology of photovoltaic production.
Special equipment and software were prepared to execute on-site acceptance tests of photovoltaic plants: 13 acceptance tests were already made, in different locations of seven european countries.
A computer program was developed for a multiparameter analysis of all results on cells and modules, with information on standards achievable by manufacturers.
This classification of devices and products, based on a unique experience of testing, is one of the main achievements of ESTI at the end of the 1980-83 programme of the JRC. Trend is now to extend a similar scheme on photovoltaic system level.

Concerning Thermal Conversion, the activities are developing countinuing the good connection with the similar actions in the frame of the Indirect Action - Programme Energy R and D managed by the General Directorate XII (Brussels).
Cooperations within the Agreement Solar Heating and Cooling of the International Energy Agency are also particularly active, with the joint organisation of meetings on specific subjects. Measurements and comparisons, which are the orientation of the JRC work, were concentrated on the following main fields: collector testing, systems studies, solar passive testing.
In the field of collector testing, new test facilities were built to test air collectors and concentrating collectors.
Tests were done comparing the performances of five domestic hot water systems using thermal collectors. Corrosion problems were also particularly studied.
In the field of systems studies experiments were performed with heating hybrid systems including heat pumps and seasonal storage systems. Evaluations are particularly concentrated on the seasonal thermal storage which is one of the critical parameters in the economic utilisation of solar energy. Experiments were also done with solar cooling systems, evaluating the overall performance and comparing different advanced, vacuum collectors.
The field of passive technologies is receiving increasing attention; this type of utilisation of solar energy has a good potential for future applications. Three passive «test cells» have been constructed for the measurement and comparison of performances of passive industrial components; particular attention will be given to the study of methodology for testing walls, windows, etc. using such cells; passive components with latent heat storage have been installed for evaluation tests. Study and development of instrumentation and modelisation were also started.

Research on selective materials for solar receivers progressed with particular studies on chromium surface. Results were interesting, with metallic layers having excellent absorption properties with high stability; a patent application was introduced. In the mean time a special equipment for measurement of thermal emittance and solar absorptance was developed.
Another research area is for longer term application: possible solar energy conversion using photoelectrochemical processes (semiconductor-electrolyte photocells) and photochemical processes (photoinduced splitting of water into hydrogen and oxigen). Several experimental tests were performed, investigating particularly the catalytic effect of some compounds. Research is in progress, also in connection with a cooperative programme of the International Energy Agency.
As a general conclusion it can be said that at the end of the 1980-83 programme the Solar Energy Programme at Ispra has reached the planned, full level of operation and a complete set of installation and investments for the evaluation of solar energy technologies and systems, with the related competences, is now available per the EC actions.
The results obtained with:

- applications of test procedures
- accumulation of experience and technical data after a number of tests
- contribution with tests and measurements to Commission's programmes
- active role within EC and IEA cooperations

confirmed the specific and central role of the Joint Research Centre.

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