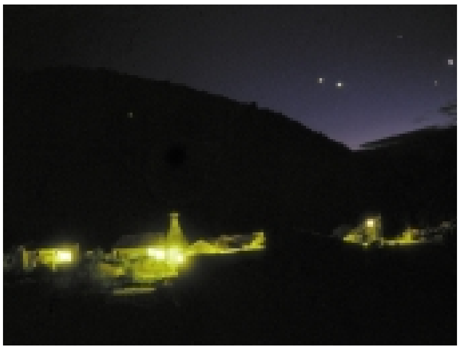
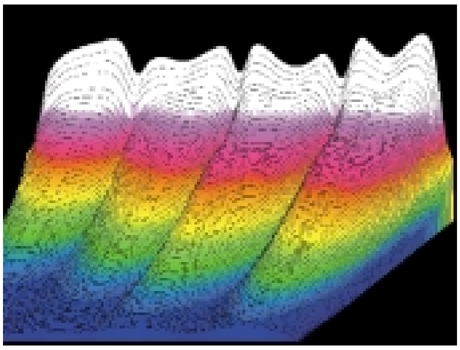
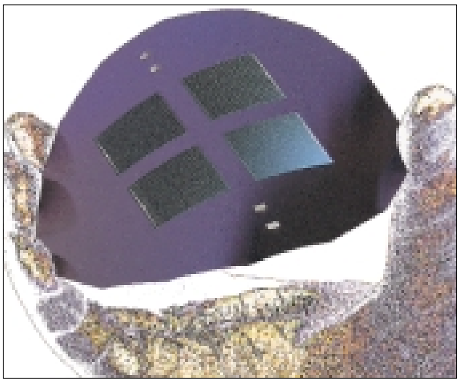
Fraunhofer Institut Solare Energiesysteme

Achievements and Results
Annual Report 2000







The Fraunhofer Institute for Solar Energy Systems ISE conducts research on the technology needed to supply energy efficiently and on an environmentally sound basis in industrialised, threshold and developing countries. To this purpose, the Institute develops systems, components, materials and processes in the areas of thermal use of solar energy, photovoltaics, solar building, electric power supplies, micro-energy technology, chemical energy conversion, energy storage and rational use of energy.

The institute's work ranges from investigation of scientific fundamentals for solar energy application, through the development of production technology and prototypes, to the construction of demonstration systems. The institute plans, advises and provides know-how and technical facilities as services.

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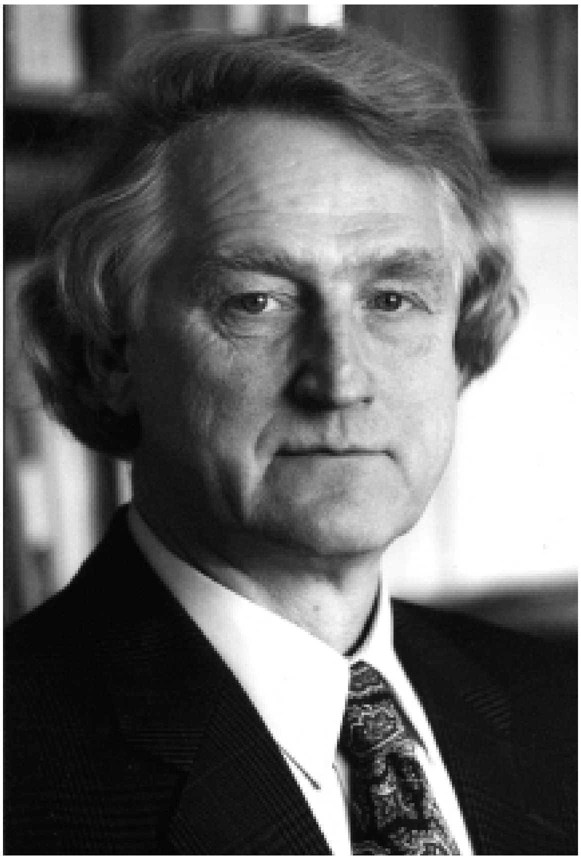


2000 was an extremely successful year for Fraunhofer ISE. Significant progress in the scientific-technological sector, a gratifyingly high level of commissions from industry and growth of about 7 % are indicators of this success.

As examples for the technological area, I would like to highlight our successes in achieving cost-efficient, solar "1-litre houses", the progress on miniature fuel cells and the peak values achieved for highly efficient tandem solar cells for space and terrestrial applications.

The new premises for the Institute in Freiburg, which are being financially supported by the State of Baden-Württemberg and the Federal Government with 35 million DM each, are rapidly approaching completion. We will be moving into the new building from July 2001 onwards. The official opening, which will be combined with celebrations for the 20th anniversary of Fraunhofer ISE, is planned for November 2001. At this point, I would like to express our sincere gratitude to the Federal and State governments for their high level of support.

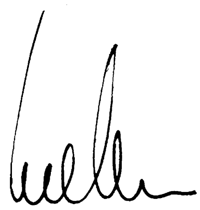
The State of North Rhine-Westphalia and the photovoltaic industry enabled us to open a new Laboratory and Service Centre in 2000. A highly flexible production line for silicon wafer solar cells was installed in our centre in Gelsenkirchen. With these unique facilities, we are able to produce cells under similar conditions to a factory and carry out experiments as in a laboratory. Dr Dietmar Borchert and his team in Gelsenkirchen as well as their associates in Freiburg deserve hearty thanks for their impressive work in establishing the centre.

Since Fraunhofer ISE was founded, its work has been actively accompanied by its Board of Trustees. In 2001, the long-standing trustees Prof. Hans Albrecht, Ulf Hecksteden, Jürgen Malsch and Dr Gerhard Paul ended their service to this valuable advisory board due to retirement or professional reorientation. On behalf of the whole Institute, I wish to thank them for their contributions. In future, five new trustees will accompany the Institute with their advice and criticism: Jürgen Berger, VDI/VDE; Martin Bitzer, Fresnel Optics; Dr Holger Jürgenson, Aixtron; Dr Thomas Pflüger, Ministry of Science, Research and the Arts of the State of Baden-Württemberg; Gerhard Warnke, MAICO.

During the past year, there was a change in the leadership of our Department for Solar Cells - Materials and Technology. I did not succeed in convincing Prof. Wolfram Wettling to remain at Fraunhofer ISE until his 65th birthday, so he left for early retirement on 31st March. Dear Prof. Wettling, may I again thank you most sincerely - also on behalf of the entire Institute and particularly your department - for your outstanding achievements. Dr Gerhard Willeke, formerly at the University of Constance, assumed the leadership of our Solar Cell Department on 1st April.

In the autumn of 2000, Dr Angelika Heinzel, leader of the Department for Energy Technology, was invited to accept a professorship at the University of Duisburg. The Institute will exert all powers available to persuade her to stay in Freiburg.

My thanks also go to all members of the Institute for their creative, highly motivated and successful work. Above all, I am grateful to those representatives of industry, ministries and the European Union, whose commissions indicated their interest and trust, and ultimately made our work possible.



Prof. Joachim Luther

Institute Profile

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The institute's work ranges from investigation of scientific fundamentals for solar energy application, through the development of production technology and prototypes, to the construction of demonstration systems. The institute plans, advises and provides know-how and technical facilities as services.

The Institute is integrated into a network of national and international co-operation. Among others, it is a member of the Solar Energy Research Association (Forschungsverbund Sonnenenergie) and the European Renewable Energy Centres (EUREC) Agency. There is particularly close co-operation with the Albert Ludwig University in Freiburg.

Research and Services Spectrum

The Fraunhofer Institute for Solar Energy Systems ISE is a member of the Fraunhofer Society, a non-profit organisation, which occupies a mediating position between the basic research of universities and industrial practice. The Institute finances itself with applied research projects and services on the technical application of renewable energy sources. Whether it concerns a major project or brief consultancy work, the working method is characterised by its clear relevance to practice and orientation toward the wishes of the client.

Organigram

Institute Director	Prof. Joachim Luther	
Departments	Thermal and Optical Systems Dr Volker Wittwer	+49 (0) 7 61/45 88-1 43
	Energy Technology Dr Angelika Heinzel	+49 (0) 7 61/45 88-1 94
	Solar Cells – Materials and Technology* Dr Gerhard Willeke	+49 (0) 7 61/45 88-2 66
	Electrical Energy Systems Klaus Preiser	+49 (0) 7 61/45 88-2 16
Administration, Technical Infrastructure and Services	Wolfgang Wissler	+49 (0) 7 61/45 88-3 50
Press and Public Relations	Karin Schneider M.A.	+49 (0) 7 61/45 88-1 47
Strategic Planning	Dr Tim Meyer	+49 (0) 7 61/45 88-3 46

*Prof. Wolfram Wettling until 31.3.2000

Research and Development

- solar passive houses in Neuenburg consume only 10 kWh/(m^2a) (1-litre house)
- gasochromic windows with a large switching range prove themselves in the practice
- micro-encapsulated phase change materials in plasters enable new heating and cooling concepts for buildings
- major project on "New Integrated Energy Supply Concepts for Buildings (NEGEV)" started; development of modular components for energy systems, e.g. compact ventilation units for passive solar houses, fuel cell systems and heat storage units
- monitoring and quality assurance of 100 passive buildings started for the utility, Energie Baden-Württemberg
- test stand for solar air-conditioning commissioned
- procedure developed for inexpensive, scratch-resistant, anti-reflective treatment of transparent injection moulding components

- numerical simulation model for small fuel cells validated
- Fraunhofer consortium to develop miniature fuel cells founded

- first tandem solar cell of $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ produced in the world, and an efficiency record > 30 % achieved with it for 1000-fold concentration of solar radiation (AM1.5d)
- concentrator module with monolithic tandem cells reached an efficiency value of 24.8 % outdoors
- tandem cell for space applications attains an efficiency value of 24.1 % (AM0)
- Si solar cells, with back surface contacts based on plasma etching and laser technology, and more simply processed, reach an efficiency value of 21.6 % over an area of 2 x 2 cm^2
- Si solar cell produced by Rapid Thermal Processing achieves an efficiency value of 18.7 % on 5 x 5 cm^2 float zone Si
- Si solar cell with an efficiency value of 17.2 % over 10 x 10 cm^2 produced for the first time with new in-line RTP equipment
- 100 cm^2 block-cast Si solar cell produced for the first time in the world applying industrially relevant pad-printing
- industrial screen-printing process for single-sided contacting developed
- crystalline Si thin-film solar cell on industrial silicon nitride ceramic reaches an efficiency value of 9.4 %
- Laboratory and Service Centre for production-orientated research, with in-line solar cell processing lines, opened in Gelsenkirchen
- measurement technology for concentrator solar cells with an optical concentration of 1200 suns developed

- highly efficient solar cell modules extend operating lifetimes for portable electronic devices
- largest PV system in Europe for testing, demonstration and training purposes taken into operation for the Trades Corporation in Cologne
- unique solar exhibits and models developed for Shell Solar Photovoltaic Information Centre in Gelsenkirchen
- photovoltaically powered system developed for water purification in remote regions
- photovoltaically powered water treatment systems developed for pumping and purification

University Appointments

Dr Angelika Heinzel was invited to accept a professorship at the University of Duisburg, Chair of Energy Technology.

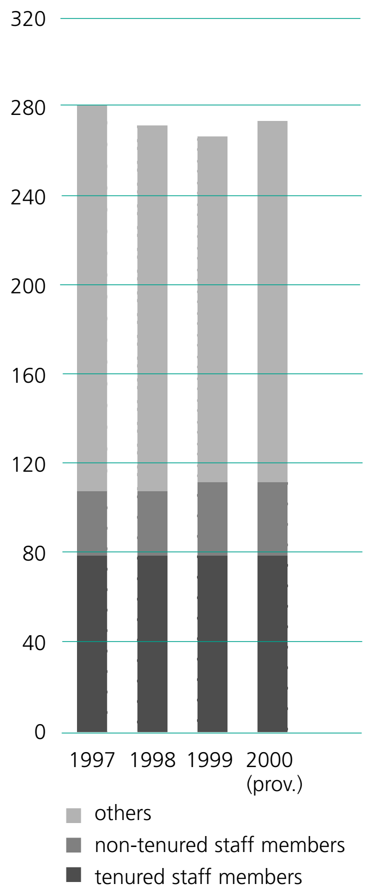
Dr Roland Schindler was appointed as a professor at the University of Hagen.

Examples of Innovation

The institute is looking for partners for development, production or marketing of these products and services, depending on the stage of development. None of the products is restricted by an exclusive licence.

Product	Market/Sector	Fraunhofer ISE contact person, phone, email
micro-structured light-redirecting and sun-shading elements	sun-shading devices	Christopher Bühler +49 (0) 7 61-45 88-2 96 Christopher.Buehler@ise.fhg.de Dr Werner Platzer +49 (0) 7 61-45 88-1 31 Werner.Platzer@ise.fhg.de
full-year simulation of daylighting autonomy	lighting design for buildings	Jan Wienold +49 (0) 7 61-45 88-1 33 Jan.Wienold@ise.fhg.de
testing and measurement of compact ventilation units	manufacturers of compact ventilation units with heat pumps	Andreas Bühring +49 (0) 7 61-45 88-2 88 Andreas.Buehring@ise.fhg.de
stochastic anti-reflective structures	polymer optics	Dr Andreas Gombert +49 (0) 761-4 01 66-83 Andreas.Gombert@ise.fhg.de
micro-energy technology	manufacturers of portable electronic devices	Dr Christopher Hebling +49 (0) 7 61-45 88-1 95 Christopher.Hebling@ise.fhg.de
thermophotovoltaic systems technology	PV industry, gas industry	Dr Christopher Hebling +49 (0) 7 61-45 88-1 95 Christopher.Hebling@ise.fhg.de
reformer systems for hydrogen generation	car industry, gas suppliers, oil industry	Dr Peter Hübner +49 (0) 7 61-45 88-2 10 Peter.Huebner@ise.fhg.de
fuel cells in the low power range	battery manufacturers and users	Mario Zedda +49 (0) 7 61-45 88-2 07 Mario.Zedda@ise.fhg.de.
optical concentrator systems	photovoltaic industry	Dr Andreas Bett +49 (0) 7 61-45 88-2 57 Andreas.Bett@ise.fhg.de
yield guarantee for grid-connected PV systems	utilities, contractors for large photovoltaic systems	Klaus Kiefer +49 (0) 7 61-45 88-2 18 Klaus.Kiefer@ise.fhg.de
water purification processes	water purification industry	Orlando Parodi +49 (0) 7 61-45 88-2 81 Orlando.Parodi@ise.fhg.de
socio-technological analyses of village power supplies	energy utilities, PV industry, governmental and non-governmental organisations	Dr Petra Schweizer-Ries +49 (0) 7 61/45 88-2 28 Petra.Schweizer-Ries@ise.fhg.de
active compensation for interference from electronic ballasts	manufacturers of energy-saving lamps, PV industry, energy utilities	Georg Bopp +49 (0) 7 61/45 88-2 40 Georg.Bopp@ise.fhg.de
state-of-charge meter for batteries	photovoltaics, electric vehicles, electric power supplies	Dirk Uwe Sauer +49 (0) 7 61/45 88-2 19 Dirk-Uwe.Sauer@ise.fhg.de Dr Heribert Schmidt +49 (0) 7 61/45 88-2 26 Heribert.Schmidt@ise.fhg.de

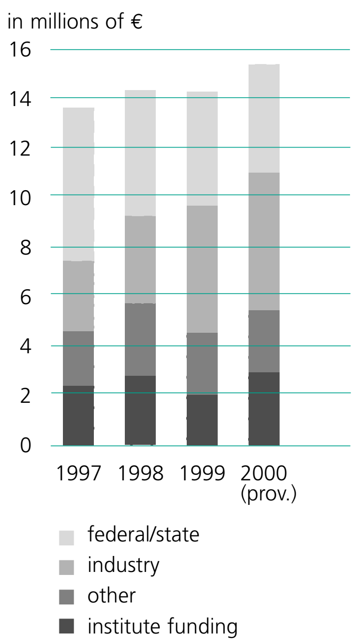
Personnel development



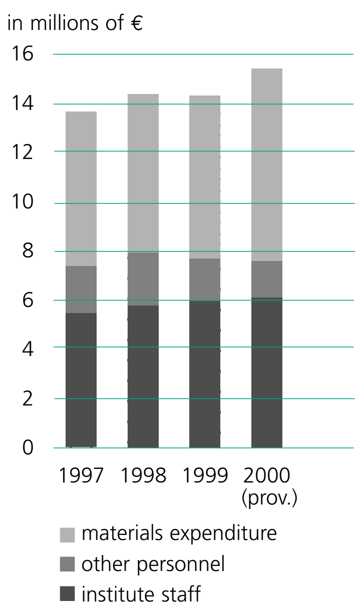
The "other" staff members are an important pillar of the institute, who support the work in the research projects and thus contribute significantly to the scientific results obtained. In December 2000, 25 doctoral candidates, 40 undergraduate students, 77 scientific and 20 other assistants were employed at the Institute. In this way, Fraunhofer ISE provides essential support to the education system.

In addition to the expenditure documented in the graph, the Institute made investments of 3.1 million € in 2000.

Income



Expenditure



Board of Trustees

The board of trustees assesses the research projects and advises the Institute directorate and the Fraunhofer Society Executive with regard to the working programme of Fraunhofer ISE.
January, 2001

Clients

The Fraunhofer Institute for Solar Energy Systems has co-operated successfully for years with clients from all sectors and company sizes.

Clients, who have agreed to publication of their names:

- Abac GmbH, Eningen
- ACR GmbH, Niedereschbach
- Adam Opel AG
- AEG MIS GmbH, Ulm
- Aixtron GmbH, Aachen
- Akkumulatorenfabrik Sonnenschein GmbH (Exide German Group), Büdingen
- Angewandte Solarenergie GmbH ASE, Alzenau und Heilbronn
- BASF AG, Ludwigshafen
- Bayer AG, Krefeld-Uerdingen
- British Petroleum BP Solar International, Sunbury, Great Britain
- Bundesministerium für Bildung und Forschung BMBF, Berlin (German Federal Ministry of Education and Research)
- Bundesministerium für Wirtschaft und Technologie BMWi, Berlin (German Federal Ministry of Economics and Technology)
- Caparol Farben, Lacke, Bautenschutz, Ober-Ramstadt
- Centrotherm GmbH, Blaubeuren
- Compagnie Européenne d'Accumulateurs CEAC, Gennevielliers, France
- Creavis GmbH, Marl
- Daimler-Chrysler AG, Stuttgart
- Degussa-Hüls AG, Hanau
- DETA Batterien, Bad Lauterberg
- Deutsche Bundesstiftung Umwelt, Osnabrück (German National Foundation for the Environment)
- Deutsche Everlite GmbH, Wertheim (Main)
- Deutsche Gesellschaft für Technische Zusammenarbeit GmbH GTZ (German Society for Technical Co-operation), Eschborn
- Deutscher Alpenverein DAV (German Mountaineering Club), Munich
- Deutsche Solar GmbH, Freiberg
- Dmc^2 AG, Hanau
- ECN, Petten, Netherlands
- EKRA Maschinenfabrik GmbH, Bönnigheim
- Energie Baden-Württemberg AG, EnBW, Karlsruhe
- E.ON Energie AG, Munich
- European Union EU, Brussels, Belgium
- Flabeg Holding GmbH, Gelsenkirchen
- Freiburger Energie- und Wasserversorgungs-AG FEW, Freiburg
- Fresnel Optics GmbH, Apolda
- G+H Isover, Ladenburg
- Gaia Kapital-Beteiligungsgesellschaft mbH, Cologne
- Gebäudemanagement Schleswig-Holstein (GMSH),Kiel
- Gebr. Märklin & Cie. GmbH, Göppingen
- Grammer KG, Amberg
- Grundwert Verwaltungs- und Projektent-wicklungs- GmbH (GVP), Frankfurt
- H.C. Stark GmbH & Co. KG, Goslar
- Haas-Laser-GmbH & Co. KG, Schramberg
- Hagen Batterie, (Exide German Group), Soest
- Handwerkskammer zu Köln, Cologne
- Heraeus Quarzglas GmbH / Co. KG, Kleinstheim
- Hochbauamt der Stadt Mannheim
- Hüppe Form, Oldenburg
- Institut für Mikrosystemtechnik IMTEK, Freiburg
- Institut für Angewandte Photovoltaik INAP GmbH, Gelsenkirchen
- Instituto Nacional de Tecnologia Agropecuaria, San Juan, Argentina
- Interpane E & BmbH, Lauenförde
- Ist EnergieCom GmbH, Augsburg
- Karl Süss KG-GmbH & Co., Garching
- Labor für Bildschirmtechnik, University of Stuttgart
- Landis & Steafa, Stuttgart
- M + W Zander GmbH, Stuttgart
- Maico Haustechnik, Villingen-Schwenningen
- Maxit Baustoff- und Kalkwerk Mathis GmbH, Merdingen
- Merck KGaA, Darmstadt
- Ministerium für Wissenschaft, Forschung und Kunst, Baden-Württemberg, Stuttgart
- Okalux Kapillarglas GmbH, Marktheidenfeld

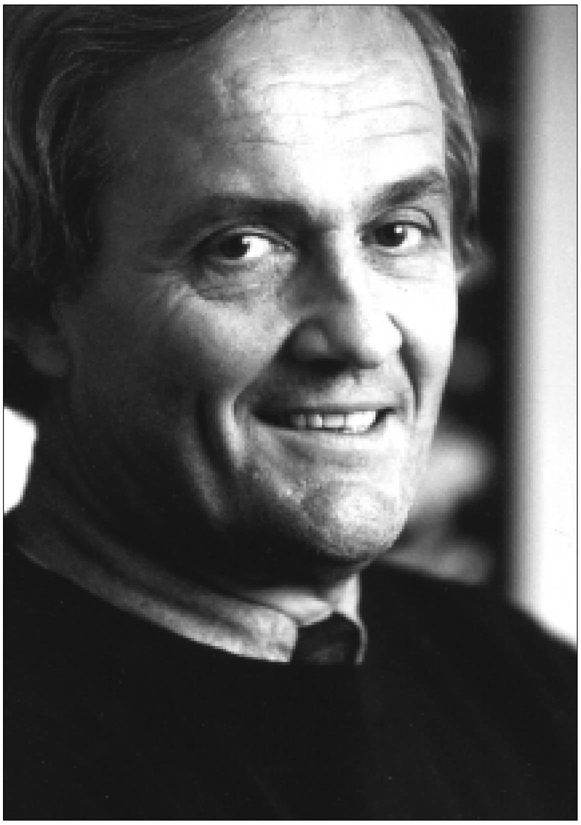
- Prokuwa Kunststoff GmbH, Dortmund
- PV Silicon, Erfurt
- RENA Sondermaschinen GmbH, Gütenbach
- Robert Bosch GmbH, Stuttgart
- RWE Energie AG, Essen
- RWTH Aachen, Aachen
- S. Siedle & Söhne Stiftung & Co., Furtwangen
- S. E. del Acumulador Tudor, S.A., Madrid, Spain
- Saint Gobain Glass, Herzogenrath
- Schott Rohrglas GmbH, Mitterteich
- Shell Solar Deutschland GmbH, Gelsenkirchen
- Siemens Solar GmbH, Munich
- Solar World, Bonn
- Solar-Application GmbH, Freiburg
- Solar-Fabrik GmbH, Freiburg
- Solarwatt GmbH, Dresden
- Stadtwerke Karlsruhe, Karlsruhe
- Stadtwerke Aachen AG STAWAG, Aachen
- Steca GmbH, Memmingen
- Stiftung Energieforschung Land Baden-Württemberg (State Energy Research Foundation)
- Sto AG, Stühlingen
- Süd-Chemie AG, Munich
- Sunlight Power Maroc, Rabat, Morocco
- Suptina Grieshaber, Schapbach
- TeCe, Selb
- Trama Tecno Ambiental, Barcelona, Spain
- Transénergie, Lyon, France
- TÜV Rheinland Sicherheit und Umweltschutz GmbH, Cologne
- Unaxis, Hanau
- Vegla GmbH, Aachen
- Velux A/S, Vedbaek, Denmark
- Warema Renkhoff GmbH, Marktheidenfeld
- Wirtschaftsministerium NRW
- World Bank, Washington, USA
- Würth Elektronik Systemtechnik, Marbach am Neckar
- Zentrum für Sonnenenergie- und Wasserstoff-Forschung ZSW, Stuttgart/Ulm

An increasing number of our projects involve co-operation with international partners.

- Agricultural University of Athens, Greece
- Air Liquide S.A., Sassenage, France
- Alcatel Standard Electricia S.A., Madrid, Spain
- Altai Centre for Non-Traditional Energy and Energy Saving, Barnaul, Russia
- APEX Ingénierie, Laverune, France
- A.S. Joffe Institute, St. Petersburg, Russia
- Arge Erneuerbare Energie, Gleisdorf, Austria
- Australian National University - ANU, Canberra, Australia
- Berner Fachhochschule, Hochschule für Technik und Architektur, Burgdorf, Switzerland
- BPP Teknologi LSDE, Technical Implementation Unit, Energy Technology Laboratory, Serpong Tangerang, Indonesia
- British Petroleum BP Solar International, Sunbury, Great Britain
- CEA-GENEC – Centre de Caderache, Saint-Paul-Lez-Durance, France
- Centre National de la Recherche Scientifique CNRS, Palaiseau/Meudon/Strasbourg/Marseille/Montpellier, France
- Centre Scientifique et Technique du Bâtiment CSTB, Grenoble, France
- Centro de Investigación en Energía y Agua, CIEA, Las Palmas de Gran Canaria, Spain
- CIEMAT Instituto de Energías Renovables IER, Madrid, Spain
- Compagnie Européenne d'Accumulateurs CEAC, Gennevielliers, France
- Consejo Superior de Investigaciones Cientificas CSIC, Madrid, Spain
- Council on Renewable Energy CORE in the Mekong Riparian Countries
- Curtin University of Technology, Perth, Australia
- De Nora s.p.a., Milan, Italy
- Det Norske Meteorologisk Institutt, Bergen, Norway
- Ecole des Mines, Paris (Centre d'Energétique, Sophia Antipolis), France
- Ecole Nationale des Travaux Publics de l'Etat ENTPE, Lyon, France

- Elkem, Kjeller, Norway
- ENECOLO, Mönchaltorf, Switzerland
- Esbensen Consulting Engineers, Virum, Denmark
- Georgia Institute of Technology, Atlanta, USA
- Hebrew University, Jerusalem, Israel
- Hydrogen Systems, Sint-Truiden, Belgium
- Instituto Catalan de Energía ICAEN, Barcelona, Spain
- Instituto de Energía Solar IES, Madrid, Spain
- Instituto de Investigaciones Electricas, Cuernavaca, Morelos, Mexico
- Instituto Nacional de Tecnica Aerospacial "Esteban Terradas" INTA, Madrid, Spain
- Instituto Nacional de Engenharia e Tecnologia Industrial INETI, Lisbon, Portugal
- International Energy Agency IEA, Paris, France
  Photovoltaic Power Systems Programme PVPS
- Task 5: Grid Interconnection of Building-Integrated and Other Dispersed PV Power Systems
- Task 7: Photovoltaic Power Systems in the Built Environment
- Task 9: PV Deployment in Developing Countries
  Solar Heating & Cooling Programme SHCP
  - Task 21: Daylight in Buildings
  - Task 25: Solar Assisted Air Conditioning of Buildings
  - Task 27: Building Envelope Components
  - Task 28: Solar Sustainable Housing
- Interuniversity Microelectronics Centre IMEC, Leuven, Belgium
- Joint Research Centre ISPRA, ESTI Group, Ispra, Italy
- Kema Nederland B. V., Arnhem, The Netherlands
- Microelectronic Centre - MIC; Copenhagen, Denmark
- National and Kapodistrian University of Athens, Athens, Greece
- National Institute for Chemistry, Ljubljana, Slovenia
- National Renewable Energy Laboratory NREL, Golden, USA
- National Testing and Research Institute, Boras, Sweden
- Naval Research Laboratory, Washington, USA
- Netherlands Energy Research Foundation ECN, Petten, Netherlands
- Reusselaer Polytechnic Institute, Troy, USA
- Rutherford Appleton Laboratory CCLRC, Chilton, Great Britain
- Solar Energy Research Training Centre SERT, Naresuan University, Phitsanulok, Thailand
- Solarenergie Prüf- und Forschungsstelle, Rapperswil, Switzerland
- TNO Building and Construction Research, Delft, The Netherlands
- Tokyo University of Agriculture and Technology, Tokyo, Japan
- Toyota Technological Institute, Nagoya, Japan
- Trama Tecno Ambiental, Barcelona, Spain
- University Center of Excellence for Photovoltaic Research, Atlanta, USA
- University of Indonesia, Jakarta, Indonesia
- University of New South Wales UNSW, Sydney, Australia
- University of San Juan UNSJ, San Juan, Argentina
- University of Uppsala, Uppsala, Sweden
- University of Utrecht, Utrecht, Netherlands
- Vergnet S.A. Ingré, France
- World Bank, Washington, USA

Thermal and Optical Systems
Dr. Volker Wittwer



Research Areas
- optically selective coatings, anti-reflective coatings
- transparent insulation
- optically switching windows and façades
- systems with automatic protection against overheating
- light-redirecting components
- thermal collectors for domestic hot water and process heat
- thermo-chemical storage and solar cooling
- optical and thermal measurement of complex window and daylighting systems
- improved simulation programmes to model optical and thermal systems
- controls for energy supply systems
- visualisation of the light distribution in buildings
- energy efficiency in buildings
- compact heat pumps, ventilation equipment, earth-to-air heat exchangers
- integrated energy concepts for buildings

Services
- spectral measurements for quality assurance
- optical coatings as desired
- durability (accelerated ageing) tests
- fluid dynamics simulations
- thermal and optical test laboratory (TOPLAB): determination of optical and thermal system characteristics
- characterisation of sorption systems
- performance measurements of domestic hot water and high-temperature collectors (DIN testing centre)
- ray-tracing simulation for designing optical systems (e.g. solar control systems)
- measurement of energy flows and lighting characteristics for façades in an outdoor measurement facility, FASTEST
- energy concepts and energy planning
- lighting design
- dynamic building and system simulation: TRNSYS, ESPr, SMILE, ColSim
- lighting simulation including video animation of the results: RADIANCE
- software development to model thermal and optical systems
- integrated energy concepts for buildings and settlements
- conception and energy analysis of demonstration buildings
- tests and measurement of residential ventilation equipment

Equipment
- optical characterisation laboratories
- PVD coater (1 m^2 area)
- field emission scanning electron microscope
- thermo-chemical analytical laboratory
- laser exposure stand to produce large-area sub-micron structures
- climatic chambers for accelerated ageing tests
- outdoor test area (collectors)
- two rotatable daylighting measurement rooms
- apparatus for 3D-visualisation of lighting simulation results
- facade test stand
- storage tank and system test stand for solar collector systems and solar air conditioning
- test stand for compact ventilation units

Energy Technology
Dr Angelika Heinzel

Research Areas
- electrochemical, chemical and thermal energy converters
- polymer electrolyte membrane fuel cell
- micro-energy technology
- hydrogen production by electrolysis, reforming of carbonaceous fuels and treatment of gas from biomass
- catalytic burners for natural gas, oil and hydrogen
- safety and storage technology for hydrogen

Services
- advice and supervision in the implementation of hydrogen systems
- conception of energy supply systems with fuel cells
- characterisation of fuel cells and fuel cell components
- simulation of fuel cell processes
- development of components for fuel cell systems
- development of low-emission burners
- scientific studies, studies on market potential relating to micro-systems technology

Equipment
- prototype laboratory for hydrogen technology
- fuel cell laboratory for electrochemical characterisation procedures, spatially resolved measurements, impedance spectroscopy and production of membrane/electrode units
- burner laboratory with exhaust gas analysis and characterisation of catalysts
- measurement and analysis laboratory: mercury porosimetry, gas chromatography, differential scanning calorimetry DSC
- scanning electron microscope with energy-dispersive X-ray micro-analysis
- Fourier Transform Infrared FTIR spectrometer
- micro-milling
- test stands for kinetic and integral characterisation of catalysts for reforming and gas purification
- IR thermography to determine heat distribution in fuel cells
- test stand for thermophotovoltaic systems

Solar Cells - Materials and Technology
Dr Gerhard Willeke

Research Areas
- high-efficiency silicon solar cells
- multicrystalline silicon solar cells with high efficiency values
- thin-film solar cells of crystalline silicon
- development of solar cell materials from Si and III-V semiconductors
- III-V concentrator solar cells
- III-V epitaxy
- gas-phase deposition of silicon for crystalline thin-film cells
- recrystallisation of silicon films with optical heating
- characterisation procedures for silicon
- plasma technologies for photovoltaics
- innovative metallisation techniques for solar cells
- industrially relevant solar cell technology
- texturing, structuring and passivation of silicon surfaces
- development of production equipment for Si ribbons (SSP), Si deposition (CVD) and Si recrystallisation (ZMR)
- production of Si CVD layers
- recrystallisation of Si layers

Services
- technology optimisation for solar cells
- development of semiconductor characterisation procedures
- small series of high-efficiency solar cells
- optimisation of manufacturing processes for solar cell materials
- characterisation of semiconductor materials
- studies on photovoltaics
- calibration and characterisation of solar cells
- evaluation of novel processing sequences

Equipment
- clean-room laboratory
- standard solar cell technology
- industrially relevant production line (screen-printing, pad-printing, in-line RTP oven, in-line RTP diffusion oven)
- characterisation of solar cells: I-V characteristic curve measurement, SR, LBIC, PCVD, MSC, diffusion length mapping
- characterisation of materials: MW-PCD, MFCA, DLTS, CV, SPV
- chemical vapour deposition of Si: RTCVD
- plasma etching system
- liquid phase epitaxy for GaAs: LPE
- MOVPE for III-V epitaxy
- optical heating systems for silicon production and processing
- thin-film technology: plasma deposition, evaporation, galvanisation, contacting
- characterisation: X-ray diffraction, charge carrier lifetime measurements, photolumi nescence, ellipsometer, IR Fourier spectrometer, glow discharge mass spectrometer, scanning electron microscope with EBIC, ECV profiling
- screen-printing and pad-printing for solar cells
- calibration laboratory for solar cells
- solar simulator for continuous exposure
- filter monochromator
- grating monochromator
- RTP equipment

Electrical Energy Systems
Klaus Preiser

Research Areas
- products with integrated photovoltaic power supplies
- electronic components for batteries and photovoltaic systems
- charging strategies for storage batteries
- stand-alone photovoltaic power supplies
- operation management for stand-alone systems
- rural electrification in areas remote from the grid
- rural water supply and treatment
- grid-connected photovoltaics
- photovoltaics in buildings
- computer simulation and energy flow analyses
- development of precision measurement technology for photovoltaics

Services
- planning, construction and evaluation of photovoltaic systems
- prototype development and accrediting of photovoltaically powered products
- measurement data acquisition and analysis of photovoltaic systems
- off-grid power supplies for telecommunications and information systems
- calibration and characterisation of solar modules and solar generators
- visualisation and optimisation of photovoltaics in buildings
- training and consultancy in the solar energy sector
- electromagnetic compatibility (EMC) measurements of components and systems

Equipment
- calibration laboratory for solar modules
- pulsed solar simulator
- DC laboratory for testing and development of PV system components and consumer appliances
- lighting measurement laboratory
- development laboratory for photovoltaically powered industrial products
- test stands for multiple-cell batteries, hybrid storage units and power-conditioning devices
- outdoor test area for solar components
- AC laboratory with an inverter test stand and instruments to characterise electromagnetic compatibility EMC
- EMC measurement chamber
- pump measurement stand
- test stand for drinking water purification systems

Research Trends in 2001

In many economic sectors, renewable energy and energy efficiency already belong to the standard technological repertoire. The market share is growing strongly, penetration of mass markets is starting. The best example is the building sector: Low-energy solar houses are proving to be increasingly competitive in the private market.

Research which aims to support this diversification of applications must cover a wide spectrum: Bringing forth new materials, components, technology and application ideas is one constantly recurring aspect. The other aspect is orientation towards products and customers, which is determined by the market and responds to the needs of commercial enterprises. This type of research facilitates application, improves the economic viability, polishes up the final product, and guarantees quality and user satisfaction. The approaches encompass efficient calculation and simulation tools for professional planning and consultancy, rational production technology, quality control of components and dissemination of "lessons learned" from demonstration projects, without losing sight of the overall effect - the object is to optimise the complete system, taking all technical, ecological, economic and social factors into account.

Fraunhofer ISE demonstrates this comprehensive philosophy particularly clearly in the integrated systems approach: Psychologists and sociologists help to introduce Solar Home Systems in developing countries, the local users are involved in determining the introduction process and are able to service the technology themselves at the end of the project.

Simultaneously, research still depends on the existence of an unrestricted space for creative thoughts and strokes of genius. Some examples can be found in the report in your hands: Converting solar heat to air-conditioning coolness, keeping surfaces clean for a lifetime by microstructuring, approaching efficiency values of 40 % with tandem cells.

Solar research in 2001 will consist more than ever of interdisciplinary teamwork. From the high-flying visionary through the systematic calculator to the pragmatic engineer, all team members must be actively involved, so that good ideas are converted to successful products quickly and effectively. Applied research means supplying not only the basic idea but also the tools for production and marketing.

Thermal and optical systems

The buildings of the future will be largely self-sufficient with regard to energy. Fraunhofer ISE will combine with almost a dozen industrial partners in a major strategic project to establish the technical, planning and organisational basis needed for a fundamentally new approach to building, which regards buildings as complete energy systems.

Simulations make the complex interactions transparent and thus allow targets to be defined, also with regard to economic factors: Exact predictions mean that expensive tolerance factors can be avoided during planning, paving the way to "lean buildings". The accuracy is constantly being improved. At present, we work with one-minute averages for daylight, meteorological data and energy flows in buildings. Stochastic models will soon be able to represent individual user behaviour.

Integrated planning of the total energy supply gives the designer maximum freedom: The building owner can select from short-term economic viability as the highest priority, through additional solar options, to a building which supplies more energy than it consumes. Technical elements supporting this development in residential buildings include e.g. compact heating units with miniature heat pumps to supply solar passive buildings with heat, and sorption storage units for seasonal thermal storage.

The more a building profits from solar gains, the more significant solar control also becomes. The research trend for clerestory and overhead glazing is moving away from mechanical elements: Switchable glazing changes the transmittance of windows and skylights as desired, without moving parts. Microstructured surfaces deflect direct light in pre-determined directions.

Multifunctionality represents a general trend, not only for buildings. Whereas protective properties or aesthetics were the most important functions for a building envelope up to now, the surfaces of the future will also collect energy or be easy to clean - as with the "lotus effect"®.

Commercial solar collectors for domestic hot water represent the technological state of the art. Research is now concentrating on two topics:

- Large systems: Optimised control strategies guarantee efficient operation e.g. when generating process heat.
- New application areas: Non-corroding collectors can be used for seawater desalination to obtain drinking water, and desiccant cooling processes offer an environmentally acceptable method of air-conditioning, with water as the cooling agent and the sun as the driving power. Low-energy buildings shift solar space heating back into focus, with new materials and storage options.

Energy technology

The focus on "micro-energy technology" reflects a general trend: smaller and more powerful. Fuel cells, which act as miniature power stations in battery format, could reflect a qualitative leap in electricity storage. Highly efficient, device-integrated solar modules guarantee power for recharging. Thermoelectrics and thermophotovoltaics convert heat into electricity without mechanical movement - with 100 % reliability even under the harshest environmental conditions, at remote locations.

The fuel cell has become a topic of major interest. Like a solar cell, it is modular, can be adapted as required to the demand and does not contain any moving parts. It supplies environmentally acceptable electricity from hydrogen with a high efficiency value. In the future, the generation of hydrogen by reforming gaseous or liquid fuels will play a central role, particularly for transport. Reforming is also the key needed to use natural gas in fuel-cell cogeneration plants, to provide energy for buildings.

Solar Cells - Materials and Technology

The common denominators for cells of crystalline silicon and III-V compound semiconductors are industrial relevance, improvement of efficiency and cost reduction. The Institute is following three approaches in these directions:

- Further developing well-proven materials: There is still considerable potential to reduce the cost of the dominating market leader, crystalline silicon. The standard workhorses, block-cast and Czochralski silicon, can still win some races if spurred on by new production procedures. The aims of further work include rapid processing, the application of thin and extremely thin wafers and the industrial im plementation of 10 x 10 cm^2 cells with an efficiency of 20 %, which has already been achieved in the laboratory.

- Researching the technology of the next and the following generation: This includes the crystalline silicon thin-film cell, with its efficiency value of just on 20 %. The goals of further work are inexpensive substrates and large-area, continuous deposition processes. A different strategy is adopted with III-V high-performance cells, which are conquering the space market due to their superior performance characteristics. For terrestrial applications, it makes sense to use them in concentrating systems, where significant cost advantages are achieved. The cell efficiency value of 31 % can be further improved to 40 %, but the primary focus must be on the system components.

- Narrowing the gap between research and production: The production capacity is becoming larger, innovation cycles shorter, and the competition keener. Thus, research will include a growing component which accompanies production. Fraunhofer ISE acted vigorously to convert this trend into focussed development. This included the major extensi on of our production technology laboratory in Gelsenkirchen

Electrical Energy Systems

Photovoltaics is overtaking a multimillion market in giant steps. The new Federal 100,000 Roofs Programme and the renewable energy law have opened wide the door to the market for grid-connected photovoltaics in Germany. Portable appliances and telecommunications are booming and Solar Home Systems have become a mass product. At the instant when the market finally begins to "pull", it is important that the market development be actively accompanied, so that the positive image of photovoltaics is preserved in its broad application. Examples include:

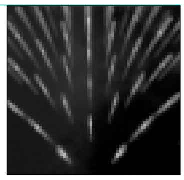
- Monitoring: ensuring energy gains; certifying "green" electricity rates
- Energy distribution: preparing the reorganisation of grids to intelligent, customer-friendly, decentralised circuit structures in co-operation with electric utilities and industrial partners
- Rural electrification: involving local users, removing economic barriers with micro-finance, guaranteeing project sustainability with national testing laboratories
- Measurement technology: developing procedures and instruments for production-relevant quality control
- International standards: guaranteeing comparability, quality standards and planning certainty

Hybrid systems are becoming increasingly popular for applications such as telecommunications equipment with stringent demands on reliability. In addition to PV systems for individual houses, power supplies for complete villages are growing in importance. In developing countries, the provision of clean drinking water is an increasingly significant application.

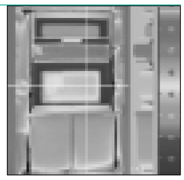
As has already been found in Solar Home Systems, it is becoming evident in all other stand-alone applications that batteries represent the weak link in the chain with regard to reliability and costs. Research is responding to this challenge with battery management concepts and the development of specifically tailored batteries.

Reports from the Departments

Research and Development in Thermal Solar Energy and Optics



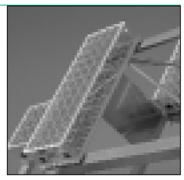
Measurement and Testing in Thermal Solar Energy and Optics



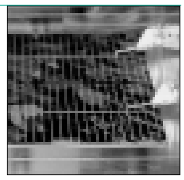
Solar Engineering – Advising, Planning, Implementing

Energy Technology

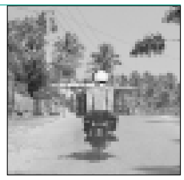
Solar Cells – Materials and Technology



ISE CalLab – Precision Measurements for Photovoltaics

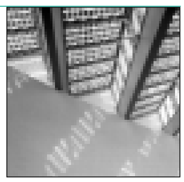


Electricity for Areas Remote from the Grid

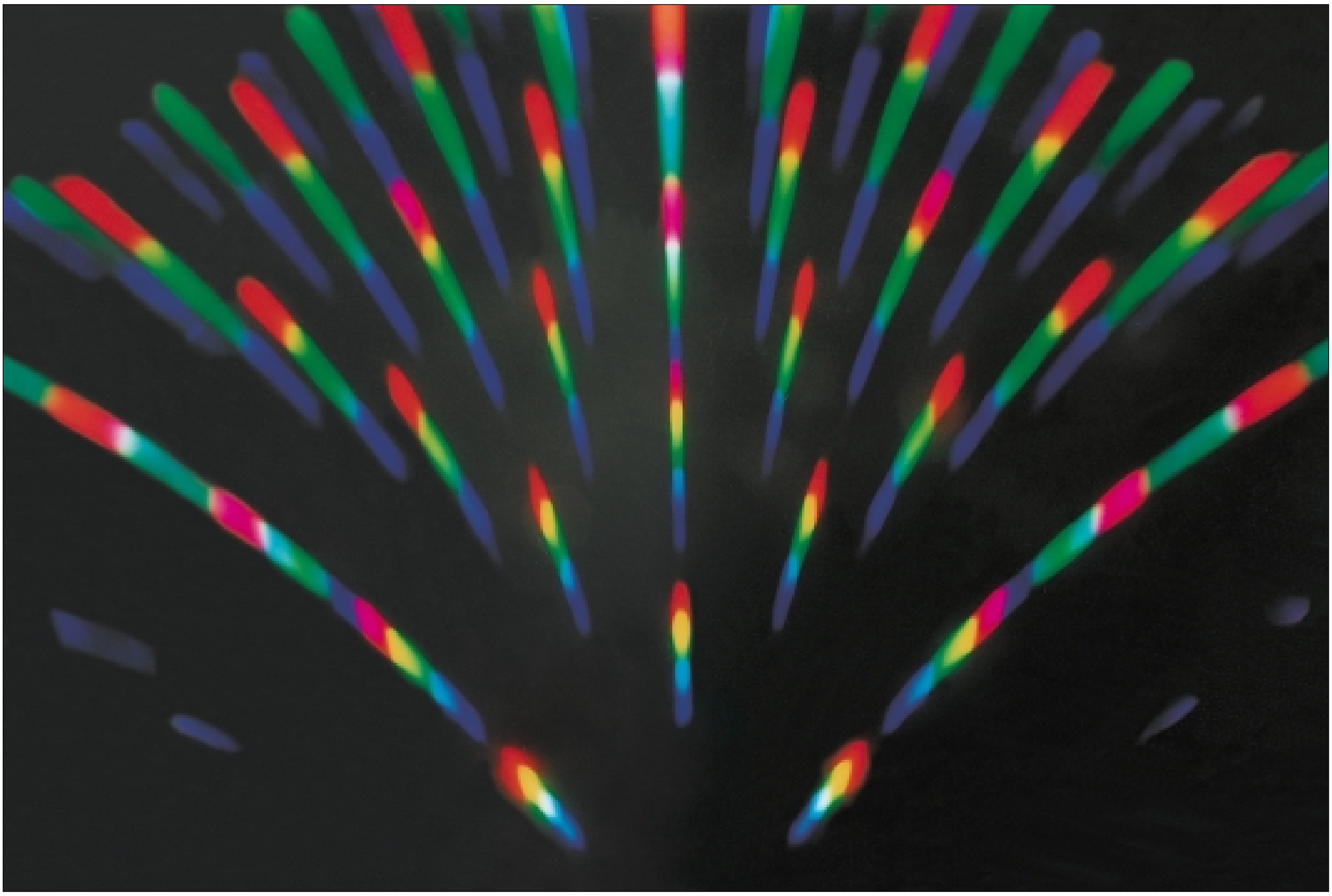


Development of Products and Components

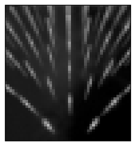
Grid-Connected Photovoltaics



Research and Development in Thermal Solar Energy and Optics



Dispersion of white light by diffraction with a periodic surface structure (optical grating). Large areas of periodic and stochastic structures are employed in anti-reflective, light-scattering, dirt-repellent and other functional surfaces.



Building construction and residential applications represent major markets for the future from both an ecological and an economic perspective. On the one hand, about a third of the end energy consumed in Germany is for heating and hot water. An enormous potential to reduce CO_2 emissions could be tapped with energy efficiency and solar energy. On the other hand, many of these measures are already economic today; rising energy prices open the market to an increasing number of concepts which only recently were still confined to research and demonstration.

This is our starting point: We co-operate closely with manufacturers to develop materials and processes, so that we can always be well ahead of the established market with new ideas. This applies not only for the classic fields of thermal solar systems and solar building, such as domestic hot water, space heating, cooling, energy storage and lighting, but also for integrated energy concepts, in which buildings take on an active role within the public electricity grid.

Two examples:
Surfaces possessing extremely fine structures, on the order of 100 nanometres to several micrometres, have special properties. With their optically functional properties, they transform conventional products into innovations with special features, e.g. anti-reflective covers for displays, or façade finishes which are self-cleaning in the rain.

Interconnected controls optimise the complete supply of electricity and thermal energy in buildings. As the buildings of the future will often be decentralised miniature power stations, these control strategies also take the requirements of the electricity grid into account and include weather forecasts and electricity tariffs among the inputs.

The common denominator of our activities is that we use the competence gained in research on renewable energy to prepare attractive products in a rapidly expanding and sustainable market.

Contact partners:

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Earth-to-air heat exchangers	Christian Reise	Tel.: +49 (0) 7 61/45 88-2 82 E-Mail: Christian.Reise@ise.fhg.de
Light scattering and thermotropic layers	Dr Werner Platzer	Tel.: +49 (0) 7 61/45 88-1 31 E-Mail: Werner.Platzer@ise.fhg.de
Nanostructured and microstructured materials	Dr Andreas Gombert	Tel.: +49 (0) 7 61/4 01 66-83 E-Mail: Andreas.Gombert@ise.fhg.de
New collector concepts	Matthias Rommel	Tel.: +49 (0) 7 61/45 88-1 41 E-Mail: Matthias.Rommel@ise.fhg.de
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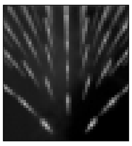
Sorptive materials	Dr Hans-Martin Henning	Tel.: +49 (0) 7 61/45 88-1 34 E-Mail: Hans-Martin.Henning@ise.fhg.de



Large-Area 3D Nanostructures and Microstructures - "Nanofab"

Microstructured surfaces can function as light-guiding or self-cleaning elements. A consortium of ten partners is developing procedures to produce homogeneously structured surfaces with an area of 800 x 1000 mm^2.

Benedikt Bläsi, Christopher Bühler, **Andreas Gombert**, Volker Kübler*, Michael Niggemann, Christine Wellens, Armin Zastrow

Microstructured surfaces can disperse light and guide it in the direction desired. In this way, a double glazed unit can become a daylighting element. Tiny retro-reflectors make it easier to see road markings or traffic signs. Self-cleaning surfaces, artificial shark skin, sanding papers, micro-reactors - these are all applications of surfaces structured with nanometre accuracy.

Production is economic, due to microreplication of the original structure in polymers with galvanic and forming processes, such as hot embossing, UV curing and injection moulding. The sophisticated original structure costs only a few pennies in the moulded part.

The demand is high, but until now, there was a lack of masters with both continuous structure profiles (3D structures) and relatively large, homogeneously structured areas for production.

The "Nanofab" joint project, which is supported by the German Federal Ministry for Education and Research BMBF, is thus developing tools to produce structures with contours on a nanometre scale over a large area. The vital condition which must be met here is the seamless, adjacent positioning of small, microstructured areas with embossing technology (fig. 1). This technology is called recombination. The state of the art is to produce seams with a width of around 100 µm. The "Nanofab" project is aiming for seam widths on the order of 1 µm.

The Fraunhofer Institutes for Production Technology IPT, for Silicon Technology ISIT and for Solar Energy Systems ISE are developing new structures and the recombination technology. The Kugler company is constructing the necessary positioning systems, Scana and Fresnel Optics replicate the structures, Creavis is developing self-cleaning surfaces, Nanofocus and FRT (Fries Research and Technology GmbH) are providing the measurement technology and Beiersdorf is responsible for the self-adhesive coating on the microstructured polymer films. The main emphasis at Fraunhofer ISE is on microstructures for daylighting purposes and a holographic structuring process for large areas.

For daylighting, we predominantly use prismatic arrays. The faces of the prisms serve to refract or totally reflect the light. We are also investigating parabolic elements. They offer optical advantages, but are more difficult to produce. The critical question concerns the dimensions of the structures: From what size on do diffraction effects destroy the functions which were obtained with geometric-optical methods?

Holographic exposure of photoresist allows certain structures to be produced over large areas in a single step. In the project, we intend to produce homogeneous embossing tools with anti-reflective moth-eye structures over an area of 600 x 800 mm^2, three times larger than the areas which have been structured to date. To achieve this, we cannot simply scale up existing processes, but have to redesign many of the components in the optical system - including an automated, extremely stable sample holder for the holographic exposure.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

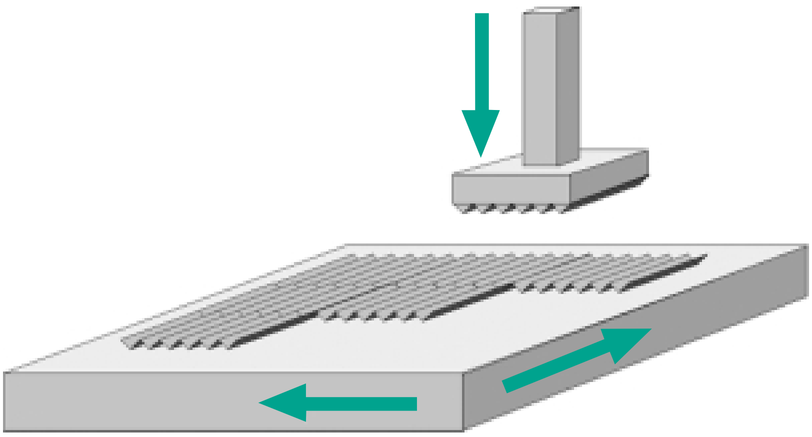


Fig. 1: Recombination process, in which small, microstructured areas are "stamped" next to each other without perceptible seams.

Photoelectrochromic Windows

The transmission of photoelectrochromic windows can be switched. The energy for colouring is provided by sunlight, so that a voltage supply is not required. Applications include protection against overheating and glare, e.g. in buildings or cars.

Andreas Georg, Anneke Hauch*, Wolfgang Graf, Volker Wittwer

Photoelectrochromic systems consist of a combination of an electrochromic cell and an electrochemical solar cell. The configuration illustrated in fig. 1 originated at Fraunhofer ISE, and is a particularly advantageous combination of the dye-sensitised solar cell and an electrochromic element. The colouring time is independent of the area, the transmittance can be varied also in the illuminated state, and the system can also be switched by an auxiliary external voltage. Initial samples reduce their transmittance during illumination within three minutes from 61 % to 15 %. They take about 2 minutes to bleach.

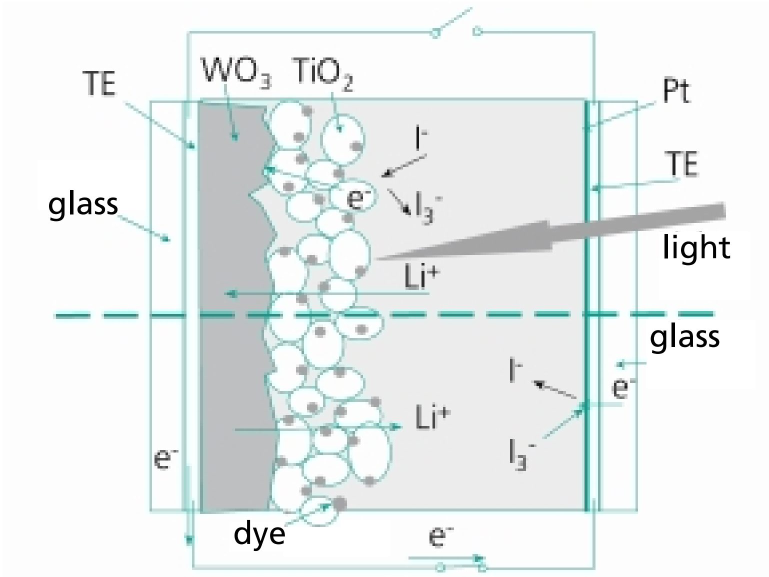


Fig. 1: Schematic diagram of the configuration and operating principles of the photoelectrochromic element (TE: transparent electrode). Upper half: Colouring during illumination, lower half: bleaching.

Configuration

A glass substrate is coated with a transparent electrode (TE) and an electrochromic WO_3 film. This is covered with a nanoporous TiO_2 layer. The porosity leads to a large surface area of the TiO_2, which is coated with a monolayer of a dye. The pores and the space between the TiO_2 and the counter-electrode are filled with an electrolyte, in which lithium iodide (LiI) is dissolved. The counter-electrode is a second glass substrate, which is covered with a TE film and coated with a thin, transparent Pt film. The two transparent electrodes are connected with each other via an external switch. In principle, the order of the TiO_2 layer and the WO_3 film could be reversed, or they could be combined in a single layer.

Principle of the colouring process

The dye is excited by illumination (upper half of fig. 1). It donates an electron to the TiO_2, which transfers it to the WO_3. There, it reduces the tungsten and colours it from transparent to blue. The dye regains its electron from an I^- ion from the electrolyte, which is oxidised to I_3^-. The excess Li^+ ions diffuse through the porous TiO_2 into the WO_3 layer, maintaining charge equilibrium. The TE coating does not play any role in the colouring process, the system operates as a passive photochromic element. As a result, in particular the switching time for colouring is independent of the TE layer and independent of the area of the element. This an advantage compared to previous electrochromic windows, in which the switching time is limited by the conductivity of the TE layer and depends strongly on the area.

Principle of the bleaching process

If the external switch is closed (lower half of fig. 1), the electrons from the WO_3 can flow via the switch to the counter-electrode. Here, the platinum catalyses the reverse reaction of I_3^- to I^-. At the same time, the Li^+ ions return through the electrolyte. This process can also happen during illumination, i.e. the transmittance can be increased by switching both during illumination or in the dark.

* University of Freiburg, Freiburger Materialforschungszentrum FMF, Freiburg

Concept for a Multiple-Stage Adsorption Heat Pump

Adsorption heat pumps can reduce the consumption of natural gas for heating appreciably. Simulation of a two-stage adsorption heat pump demonstrated the potential and the efficiency value which can be expected from this technology in seasonal applications.

Hans-Martin Henning, Frank Luginsland*, **Tomas Núñez**

In the novel process, we use two different adsorbents, in order to bring large amounts of ambient heat to a useful temperature level, using a small amount of heat at a high temperature. The high-temperature heat is generated with natural gas. The heating coefficient of performance (COP) is the ratio of useful heat to the applied energy from natural gas. If it is equal e.g. to 2, then the natural gas is used twice as efficiently as if it were burnt directly for space heating.

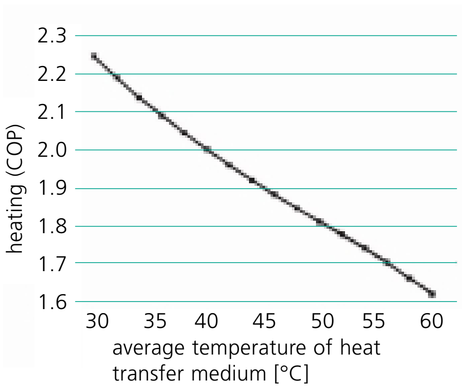


Fig. 1: Calculated characteristic curve for the multiple-stage adsorption heat pump (heating COP versus the average temperature of the heat transfer fluid). The material in the high-temperature adsorber is "Zeolith 13X", and a "Selective Water Sorbent" is used in the low-temperature adsorber. The driving temperature is 280 °C, the evaporator temperature is 7 °C.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

We were able to prove the fundamental feasibility of both the solid adsorption process for heat transformation and also the specific, multiple-stage cycle.

We determined the heating COP as a function of the average heat transfer medium temperature from simulation calculations. In addition, we used a single-chamber prototype adsorber to determine the parameters for mass and heat transfer experimentally, and used them in dynamic simulations of the multiple-stage process.

A simple simulation of the complete system, consisting of an adsorption heat pump, a building and its heating system, gave the following annual averages for the heating COP's, for a driving temperature of 280 °C and an ambient heat source, which provides heat at an average temperature of 7 °C:

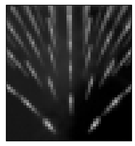
Adsorption heat pump and low-temperature heating (maximum temperature of heat transfer medium = 45 °C): average heating COP of 2 or more.

Adsorption heat pump and standard heating (maximum temperature of heat transfer medium = 65 °C): average heating COP of 1.7.

This results in fuel savings of 50 % or 40 %, respectively, compared to use of a modern heating boiler alone.

The project, which was funded by the Energy Research Foundation of Baden-Württemberg, has been completed.

Further investigations are concentrating on single-stage heat pumps for heating and cooling.



Micro-Encapsulated Phase Change Materials in Integrated Wall Systems for Heat Storage

The heat capacity of a wall can be raised in a certain temperature range by incorporating phase change materials (PCM) in the wall construction. This is often desirable, in order to flatten out load peaks and release the stored energy at a more favourable time. Especially for light-construction buildings, this technology results not only in energy savings but also in a considerable increase in comfort.

Hans-Martin Henning, Peter Schossig, Guido Weingarten, Alexandra Raicu*

Internal wall systems, e.g. plaster-board panels, are conceivable with integrated PCM's such as paraffins. They can prevent over-heating of office buildings in summer by shifting the peak loads into the night. Applying the same principle, the heating energy demand can be reduced by shifting superfluous energy gains to the times when heating is needed.

The PCM must be encapsulated so that it does not adversely affect the function of the construction material, e.g. plaster. Previous experiments with large-volume (or macro-) encapsulation failed due to the poor conductivity of the PCM. When it was time to regain the heat from the liquid phase, the PCM solidified around the edges and prevented effective heat transfer. With micro-encapsulation, the dimensions are so small that this effect does not occur.

Micro-encapsulation also allows the PCM to be incorporated simply and economically into conventional construction materials.

In co-operation with our industrial partners, BASF, DAW, Maxit and Sto, we identified suitable application fields and are developing systems.

We simulate the thermal behaviour of building components in order to compare the dynamic performance of different types of wall constructions including PCM. The basis is an empirically validated model for the phase transition. The model is being experimentally validated with a measurement facility for wall samples with an area of 0.5 x 0.5 m^2. Building energy simulations help to estimate the potential for applications. We investigate the effect as a function of the temperature range of the phase transition, the proportion of PCM, and the structure and usage of a building.

The following thermographs illustrate qualitatively the effect of the PCM in construction materials: Fig. 2 shows four wall samples with differing amounts of PCM, which had been heated in an oven and were then monitored during cooling. The variation of temperature with time in fig. 3 clearly indicates the effect of the PCM. The larger the proportion of PCM, the longer the cooling process lasts.

Thus, in a certain temperature range, the thermal mass of a building component can be significantly increased due to the phase change process, so that the thermal comfort associated with massive buildings can be approached with light construction materials.

The project is supported by the German Federal Ministry of Economics and Technology BMWi.

* Sto AG, Stühlingen

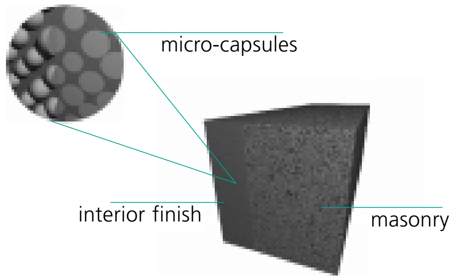


Fig. 1: Schematic diagram of micro-encapsulated PCM in interior plaster.

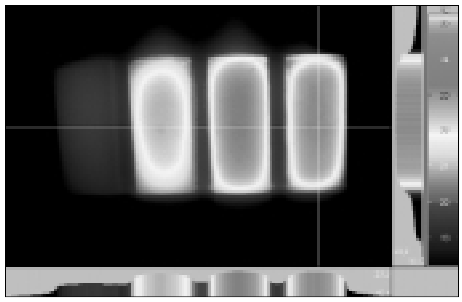


Fig. 2: Thermograph of 4 samples with differing proportions of PCM. The grey scale and the height of the profiles to the right and at the bottom indicate the temperature.

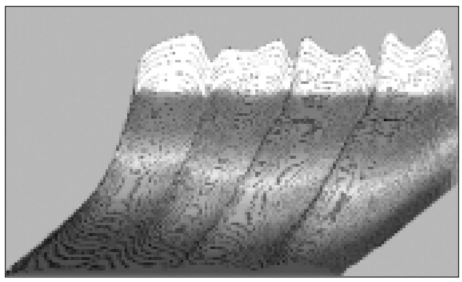


Fig. 3: Cooling behaviour of the four samples. The PCM content increases from left to right. The time scale runs from the back to the front, with 30 seconds between consecutive contour lines. The temperature is indicated by the height.

Thermotropically Controlled Façade Components

Thermotropic layers, integrated into façades and windows, reduce the input of undesired light and solar heat. Thermotropic overheating protection operates automatically and does not require a power supply.

Peter Nitz*, **Werner Platzer**, Alexandra Raicu**, Helen Rose Wilson***, Volker Wittwer

Fig. 1: System demonstration in the façade of a residential building: thermotropically controlled TEIFS variant (upper centre, clear state) and a TEIFS standard system (lower panels).

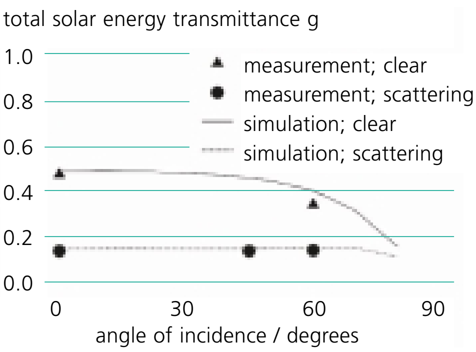


Fig. 2: Comparison of measured and simulated total solar energy transmittance g for thermotropic, heat-mirror glazing.

Thermotropic Layers

The optical properties of thermotropic materials vary with temperature. At low temperatures, they are clear, like window glass. If the material temperature exceeds a certain limit, a thermotropic layer becomes milky white and reflects a large proportion of the incident light. This property predestines thermotropic layers for use in automatically operating facade components. Integrated as thin layers into modern glazing units or transparent insulating systems, they allow solar light and heat to penetrate undiminished into the building during winter. In summer, in the switched state, they protect against excessive sunlight and the associated overheating and glare.

There are various concepts and materials for thermotropic layers. In co-operation with BASF AG (materials development), Sto AG (thermal insulation systems), and Interpane E&BmbH and Okalux GmbH (glazing), we have optimised the integration of thermotropic polymer blends into facades over the past years. Here, we present some examples of the project results. In parallel, we are investigating alternative thermotropic materials, layers and systems in other projects.

Work at Fraunhofer ISE

We characterise the optical and thermal properties of thermotropic layers and system prototypes, support the materials and prototype development by simulating the light-scattering characteristics and the effect on building energy consumption, test the long-term stability of layers and systems and monitor prototypes under real meteorological and installation conditions in our façade test stand.

Thermotropically controlled, transparent exterior insulation and finish system (TEIFS)

The transparent finish was modified for a TEIFS variant with integrated, thermotropic overheating protection. It now provides effective protection against UV radiation for the thermotropic layer. The system is currently being tested on a demonstration building in Stühlingen (fig. 1). It is characterised by good switching performance and a high transmittance in the clear state.

Thermotropic glazing

We used our calorimeter to determine the total solar energy transmittance g of heat-mirror glazing with an integrated thermotropic layer. The switching range is good, even for the large incident angles typical of summer. The measurement agrees with the values from simulation, which were based on the physical properties of the components (fig. 2). Measurements from the façade test stand confirmed similarly good values for the solar transmittance.

Outlook

The publicly funded project described has now been completed. The aim of further work is to achieve a durable, commercially marketable facade element with thermotropic properties.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg
** Sto AG, Stühlingen
*** Interpane E&BmbH, Lauenförde

Building Simulation Improved by Higher-Frequency Modelling of Radiation Data

We improved a stochastic model for solar radiation in order to generate 60-second averages from hourly averages. This increases the simulation accuracy for thermal and daylighting performance of buildings.

Oliver Walkenhorst,
Christoph Reinhart*

Many thermal and daylighting simulation programs to model the variation with time of heat flows or daylighting conditions require time series of the solar radiation. These are available for representative sites throughout Germany with a time resolution of one hour. However, information on short-term variation in the solar radiation - for example, that caused by passing clouds - is lost when these hourly averages are used (fig. 1).

In particular, when the daylighting potential in buildings is simulated, the use of hourly averages can lead to significant errors: After all, a short-term radiation excess cannot compensate for a subsequent deficit.

For this reason, we improved a stochastic model which generates higher-frequency data with a 1-minute resolution from hourly radiation data. We were able to improve the reliability of daylighting simulation e.g. to predict the annual demand for artificial lighting (fig. 2).

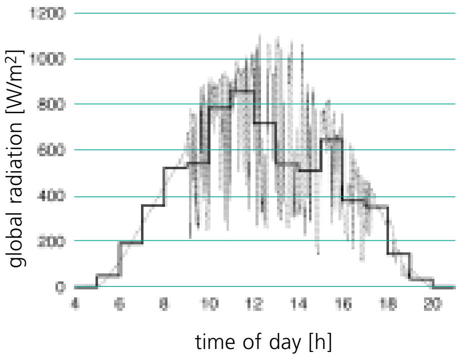


Fig. 1: Daily profile of the global radiation measured in Freiburg on 17th May, 1998: The sky was clear until about 9 o'clock and the 1-minute averages (dashed line) agree well with the hourly averages (solid line). Afterwards, cloud movement resulted in rapid variation of the 1-minute averages, which is not registered in the hourly averages.

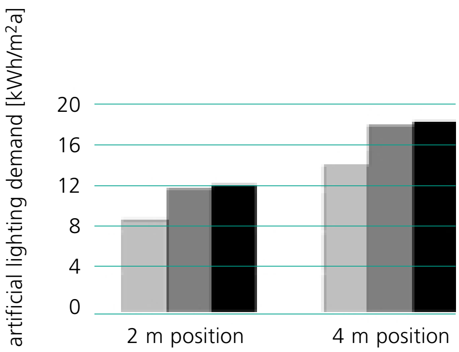


Fig. 2: Predicted annual artificial lighting demand for two office desks, 2 m and 4 m from the window. Simulation for a model office in Freiburg for 1998, with the artificial lighting automatically controlled to guarantee a nominal illuminance of 500 lux. When hourly radiation data are used (light grey), the artificial lighting demand is underestimated by about 25 % compared to a simulation with measured 1-minute averages (dark grey). This more accurate value for the artificial lighting demand, based on 1-minute measured data, is reproduced well by simulation based on the modelled 1-minute averages.

* University of Freiburg, Freiburger Materialforschungszentrum FMF, Freiburg

Simulation-Supported Controls Development to Optimise the Integration of Fuel-Cell Cogeneration Plants into Hybrid Solar Energy Supply Systems

The ColSim software developed at Fraunhofer ISE simulates both the individual components of an energy supply system and the control of the entire system. At present, work is concentrating on the integrated control of a fuel-cell heat/electricity cogeneration plant, which is operated with natural gas. The predictive control strategy takes account of weather forecasts, energy prices and user behaviour.

Matthias Vetter, Christof Wittwer

Heat/electricity cogeneration plants reduce the emission of pollutants and CO_2 from energy supply systems (see page 48). If several energy sources (fossil and solar) are to be combined, higher-level system controls are needed. In the electricity grid of the future, decentralised electricity generators will need to be cross-linked with the utilities.

At present, we are developing control concepts for a grid-connected fuel-cell cogeneration plant, which is operated with natural gas in combination with a thermal solar system. We analyse the complete systems on the basis of yearly simulations made with the ColSim simulation software. The system is linked to the Internet, so that weather forecasts and dynamic electricity or gas tariffs can be integrated for predictive strategies. The control algorithm "learns" cyclic user behaviour during operation.

After development with ColSim and implementation in ANSI C, the control algorithms are ported directly to the control hardware of the cogeneration plant. At present, this is achieved as an "embedded system" in the multi-tasking Linux operating system.

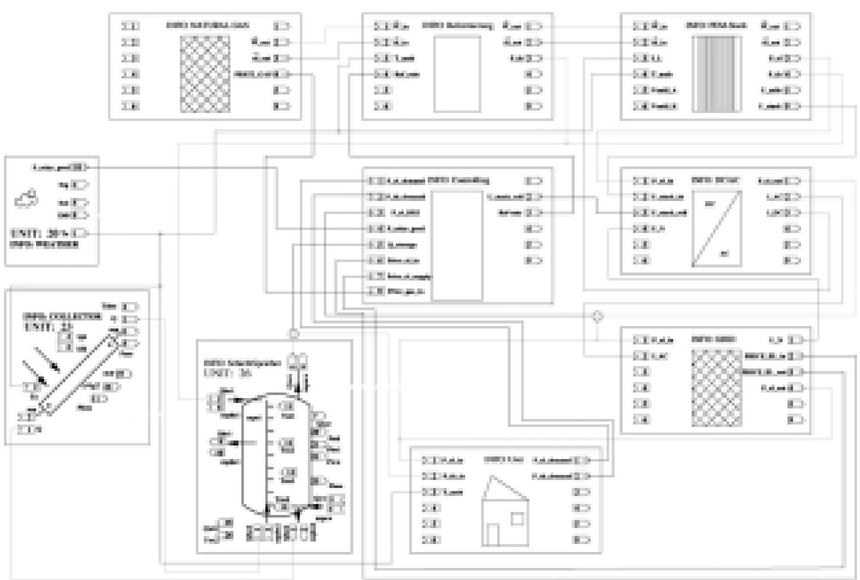


Fig. 1: Simulation of a building energy supply in ColSim. The individual units correspond to the components, gas connection, reforming, fuel cell as a cogeneration plant, inverter, grid electricity connection, solar collector, heat storage unit, meteorological data, the house as a "load", and the central controls. ColSim simulates both the individual components and their interaction in the overall system.

Earth-to-Air Heat Exchangers

Earth-to-air heat exchangers are intended for installation in the ground. They make use of the storage capacity and thermal inertia of the ground. In summer, they can cool the inlet air for buildings, whereas in winter they pre-heat it, such that under favourable conditions, a conventional air-conditioning unit may become unnecessary.

Christian Reise

In non-residential buildings, earth-to-air heat exchangers are particularly attractive if the cooling load can be removed by air change alone. In these cases, the earth-to-air heat exchanger can replace an active cooling system. Precise simulation tools are needed to determine the economically optimal dimensions for an earth-to-air heat exchanger. We develop such tools and quantify the remaining uncertainties. To this purpose, we monitor the interaction between earth-to-air heat exchangers and ventilation systems in detail in measurement projects involving systems of all dimensions.

Our clients, whom we advise individually during the planning phase of their projects, profit directly from these measurements, as well as from the resulting improvements we make to our calculation tools.

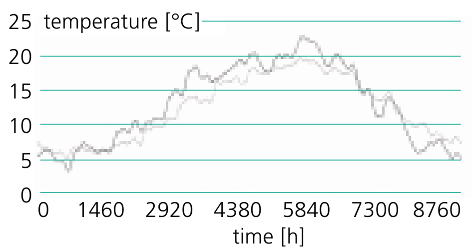
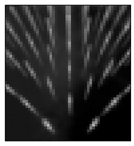


Fig. 1: Comparison of measurement (solid line) and simulation calculation (dotted line) for an earth-to-air heat exchanger. The lines show moving averages for calculated and measured outlet temperatures. The results calculated by the program used here are still too optimistic.



Ray-Tracing to Analyse and Optimise Optical Reflectors

We improve the optical yield of reflectors, e.g. those used in evacuated collectors for thermal solar systems.

Matthias Rommel,
Andreas Häberle*, Arim Schäfer

We use 3-dimensional forward ray-tracing to calculate the total amount of radiative power absorbed and the ray density distribution on the absorber, taking the material parameters of reflectors and transparent components into account. This allows us not only to optimise the reflector geometry, but also to apply sensitivity analysis and determine the effect of inaccuracies in the geometry or the surface quality resulting from production. The aim is the economically optimal compromise between production costs for the reflectors and their solar energy yield.

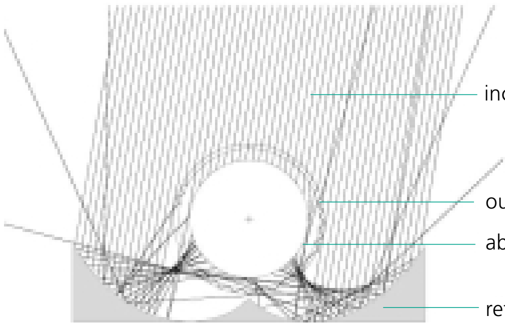
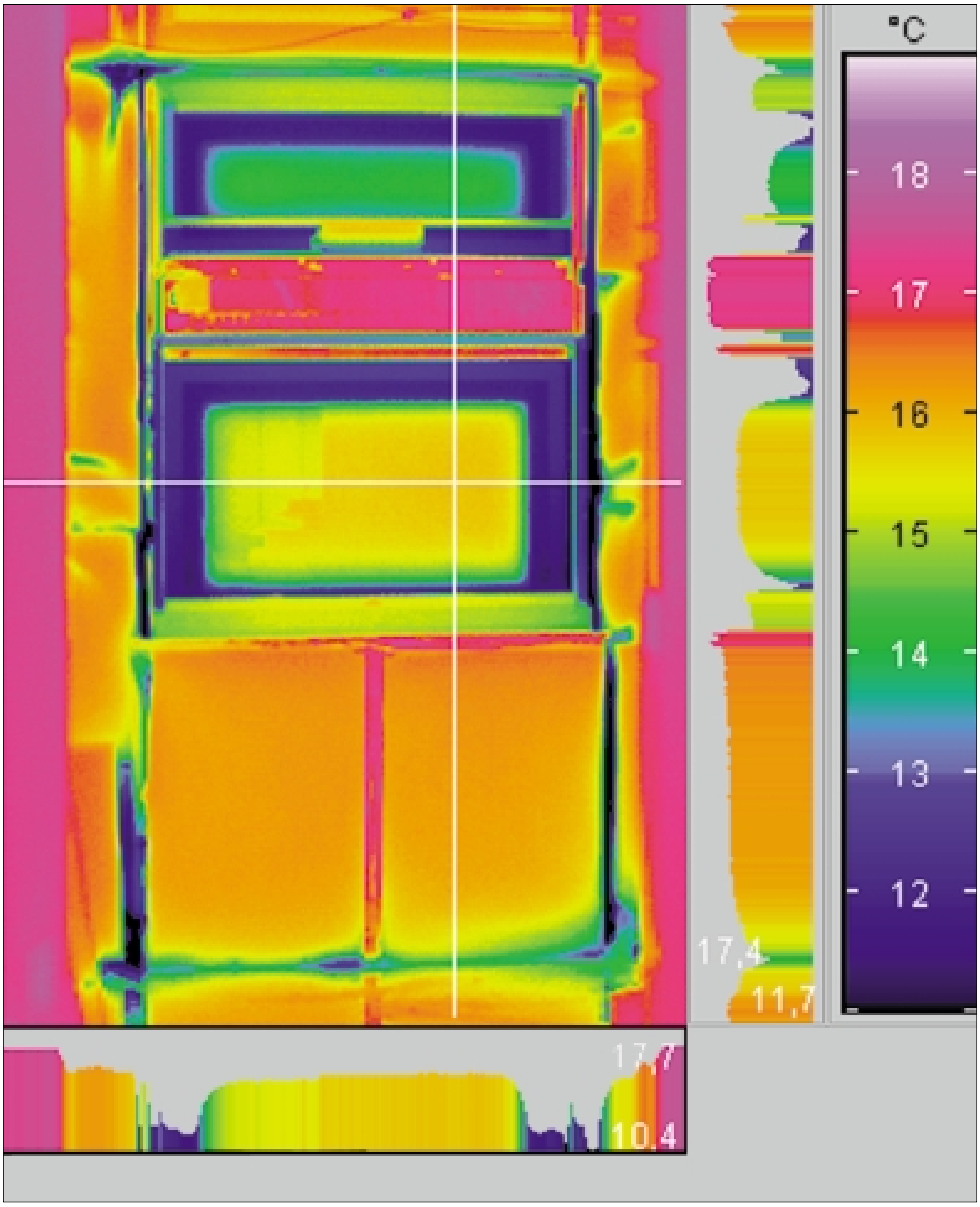


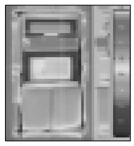
Fig. 1: The diagram shows the ray paths in an evacuated tubular collector with an external reflector, for an incident angle of 10° (cross-hatched area). Only a few rays miss the absorber (circle) and are re-directed upwards or sidewards.

Fig. 2: Detail of an evacuated tubular collector with an external reflector.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg



Thermography of a segmented facade element, viewed from the building interior. The surface temperatures of the various components, e.g. glazing, frame, spacer, ventilation element and spandrel, are represented in a colour code. Prototypes are tested under real climatic and installation conditions with the facade test stand at Fraunhofer ISE, and the long-term performance is monitored if required.



A young market is like a young plant. It needs greater attention and care - in this case, quality assurance. Solar energy affects many aspects of everyday life and competes with technology which was new 100 years ago and has had time to mature since. If a new product does not bring the performance or lifetime which the user expects, the widespread friendly attitude toward renewable energy can quickly turn into general scepticism.

We thus co-operate with the industry and standardisation bodies in drawing attention to high quality. We develop measurement procedures for new products, and conduct extensive long-term measurements to check whether the technology will still perform as well after 20 years of usage as it originally did in the laboratory.

Our clients benefit in three ways:

Tests under defined conditions allow the user to compare products and enable manufacturers to assess new technology.

As globalisation expands, standardisation becomes increasingly important. By participating in international projects (EU, IEA) and standardisation committees, Fraunhofer ISE is involved in defining new testing and standardisation procedures, and can represent the interests of the German economy.

The refinement of measurement technology and the development of accelerated ageing tests shortens the route from a prototype to the final product and provides the certainty needed for guarantees.

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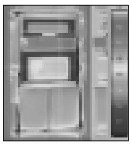


Compact Ventilation Units – Efficiency for Passive Solar Houses

We support our clients in the development of compact ventilation units with an integrated exhaust air heat pump. In combination with a solar collector, the units can supply passive solar houses completely with heat and fresh air.

Andreas Bühring, Sebastian Bundy
Carsten Dittmar, Bastian Greuel,
Wolfgang Guter, Christel Russ,
Tim Schmid, Bernhard Seigel

Development

We have developed new modules for simulation: component models for exhaust air heat pumps, air-to-air heat exchangers with condensation and variable air flows, and gas heaters for auxiliary heating. These are used to investigate new concepts for building services technology. We simulate the interaction with other building services components and the building itself for varying user behaviour and climatic conditions.

Laboratory testing

We have considerably extended our test stand to measure the energy efficiency of ventilation equipment and its components: We can now choose stationary test conditions from a wide spectrum. In addition, the automation of the test stand means that we can choose dynamically varying conditions. The measurements form the basis for our recommendations to the manufacturer for optimising the components and their interaction. Thanks to remote monitoring of the test stand, we will be able to visualise the laboratory measurements on-line, directly in the client's office: You are welcome to look over our shoulders!

Application

The performance of compact ventilation units from different manufacturers is tested practically with measurements in various occupied passive solar houses (see page 42). On the basis of daily data analysis, we make suggestions to optimise the operating mode, the equipment and its controls. Any possible defects are quickly identified and remedied.

Innovation

As our contribution within a major project supported by the German Federal Ministry of Economics and Technology BMWi (see page 48), we develop new concepts for heat pumps and their operating modes in co-operation with industrial partners. Additional modules extend the application field for compact ventilation units e.g. for operation with a fuel cell.

Fig. 1: Automated test stand with room for two separate ventilation devices with exhaust air heat pumps.

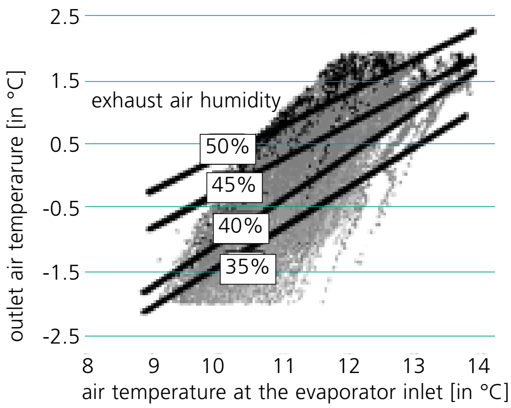
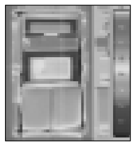


Fig. 2: Outlet air conditions behind the heat pump during heating operation in a field test. The exhaust air from the rooms is the heat source here. The higher the humidity, the more efficient is the heat pump operation. It accepts condensation heat when the exhaust air is cooled - and thus dehumidified - and does not have to cool the outlet air (to the surroundings) as much in order to gain the same amount of heat. For example: Let the air temperature at the evaporator inlet be 10 °C. Then the outlet air must be cooled to -1.5 °C, if the exhaust air humidity is 35 %. If the humidity is 50 %, cooling to +0.5 °C is sufficient.



Test Facility for Solar Desiccant Cooling Systems

Solar desiccant cooling systems (SDCS) present an environmentally friendly alternative to conventional air-conditioning systems. Integration of thermal solar systems is particularly promising due to the low operating temperature of SDCS. We have been working intensively on this topic for several years and set up a new test facility last year.

Carsten Hindenburg,
Volker Kallwellis, Barbara Fuchsberger, Mario Motta, Sascha Backes

The main components of the test facility are:

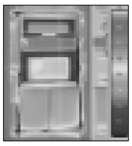
- sorption-assisted air-conditioning system with a nominal volume current of 4000 m^3/h. A system of these dimensions can provide air conditioning for seminar rooms with 40 - 80 persons.
- 20 m^2 solar collectors with a liquid heat transfer medium,
  20 m^2 solar air collectors,
  2 m^3 buffer storage tank

With the test facility (fig. 1), we can configure sophisticated hydraulic circuits and thus investigate 4 to 5 very different SDCS simultaneously. As specified by our clients, we investigate both the performance of the complete system and that of individual components under real, non-stationary solar operating conditions. Optional conditioning of the ambient air makes us practically independent of the prevailing ambient conditions.

We offer the following services to our clients:

- development and analysis of energy-optimised control strategies for SDCS
- measurement and further development of sorption wheels; close co-operation with the thermo-analytical laboratory of Fraunhofer ISE means that we can develop and directly test new sorption materials
- measurement and further development of thermal solar collectors specifically for air-conditioning applications
- development of cost-optimised combinations of thermal solar energy with SDCS
- system investigations and comparison with accompanying system simulations
- development of controllers for solar and non-solar SAAC systems
- development of customised software solutions to simulate SDCS

Fig. 1: Test facility. The following companies provided financial support for its construction: Solvis Solarsysteme GmbH, GREENoneTEC Solarindustrie GmbH, Sonnenkraft GmbH Deutschland, Grammer KG Solar-Luft-Technik, Landis&Staefa GmbH Region München, Viega, robatherm GmbH.



Experimental Investigations of the Stagnation Behaviour of Thermal Solar Systems

Solar systems for space heating support are often subject to extreme stagnation temperatures in summer. The aim of our investigations is to improve the operation and lifetime of these systems.

Matthias Rommel, Konrad Lustig, Dirk Stankowski, Arim Schäfer

Increasing numbers of collector systems are being installed in Germany, which not only heat domestic hot water, but also meet part of the energy demand for space heating. Austria has led the way in this development, where already 40 % of the recently installed collector area provides solar support for space heating. In these systems, the ratio of collector area to tank storage volume is considerably larger than in systems purely for domestic hot water. As a result, the systems often go "into stagnation" during summer. The collector rapidly heats up to its stagnation temperature. This is in the range between 180 and 200 °C for flat-plate collectors, and between 220 and 300 °C for evacuated tubular collectors. The water/glycol mixture in the collector loop then evaporates at the usual system pressures of 2 to 4 bar and later condenses again when the system cools down. During this process, pressure pulses with pro-nounced pressure peaks arise, and at the same time, all of the components in the collector loop experience a high thermal load. Together with partners from Austria and Germany, we are investigating the stagnation behaviour of thermal collectors in a project supported by the European Commission. Manufacturers of collectors, pumps, control systems and heat transfer media are represented in the project.

At the beginning of 2000, we installed two tubular collector systems with different internal piping configurations in the system test stand of Fraunhofer ISE. Since then, we have been measuring them continuously under various operating conditions, and monitor the evaporation of the fluid during stagnation in detail. We were able to gain significant insight into the energy and steam transport processes, as well as the load on the components, with our event-triggered, high-frequency pressure measurements. Measurements are made every 4 milliseconds and the result is stored temporarily. If one of the measured values exceeds a certain limit, all of the measurement data for the evaporation process are stored permanently. In this way, we were able to trace very rapid variations in the pressure. They occurred when the liquid heat transfer medium reached overheated areas of the collector.

The load on the heat transfer medium must be known for long-term operation of a thermal solar system. Thus, we set up one of the two collector systems as a reduced system without a storage tank, so that the fluid was subjected to the maximum stagnation load. Statistical analysis of the frequency distribution for temperatures and evaporation processes indicated the direction for improvement of the heat transfer medium.

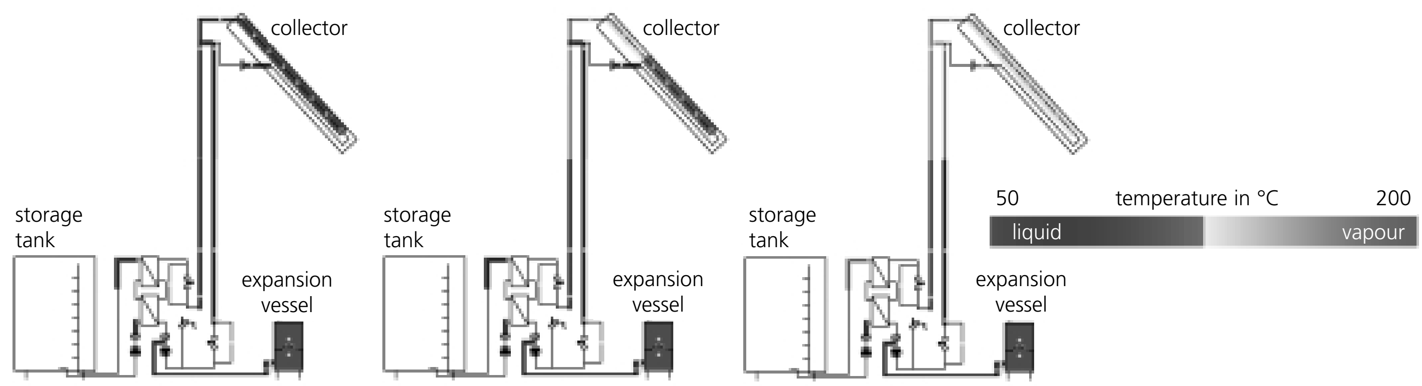
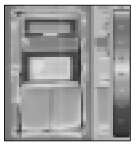


Fig. 1: Visualisation of the processes during stagnation in a solar system with a collector area of 40 m^2, prepared with the "Dview" visualisation tool developed at Fraunhofer ISE. It shows how the steam areas progress from left to right into the collector inlet and outlet.



Collector with a Corrosion-Free Absorber for Desalination of Seawater

We have developed a collector in which hot seawater (90 °C) can flow directly through the absorber.

Matthias Rommel,
Joachim Koschikowski*,
Michael Hermann, Arim Schäfer

The absorber consists of glass tubes (16 mm external diameter) with a selective absorber coating and feeder pipes of reinforced silicone. A zigzag pleated reflector is mounted under the absorber so that the aperture area of the collector is used efficiently. Figure 1 shows a sketch of the collector configuration, fig. 2 a photo of the collector. The absorber construction is such that a large-area module with external dimensions of 1.5 m x 4.8 m can be built.

We produced eight collector modules in our own workshop as a pilot plant for the SODESA seawater desalination project on Gran Canaria, which is supported by the European Union. The system (fig. 3) was installed on Gran Canaria in May, 2000 and taken into operation. It applies the Multi-Effect Humidification (MEH) process for distillation. The collector field with the 8 collectors has an aperture area of 47.2 m^2. A building can be seen behind the collectors. It houses the 6.3 m^3 storage tank for 90 °C hot seawater, the distillation unit and a photovoltaically powered water purification unit with mineralisation and UV sterilisation. The system is dimensioned for a daily production of 600 l drinking water in very good quality.

The new collectors with the corrosion-free absorbers have proven themselves well. They can be used universally in all thermally powered seawater desalination processes or to heat the inlet water in desalination units based on reverse osmosis.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg

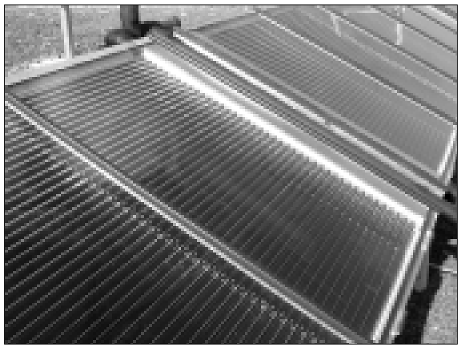


Fig. 2: The reflections from the folded edges of the reflector can be seen as bright lines parallel to the collector tube axes.

Fig. 3: SODESA collector system on Gran Canaria.

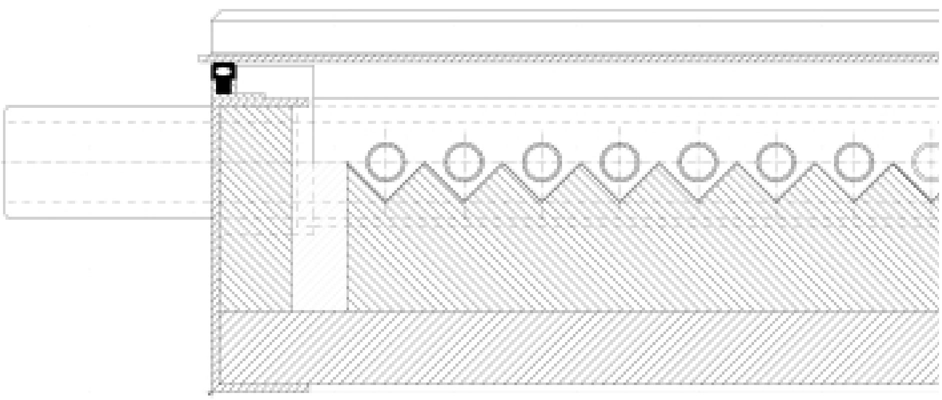


Fig. 1: Construction of the SODESA collector. A zigzag pleated reflector is located below the absorber tubes (circles).

IR Thermography as a Tool to Develop and Analyse Modern Façade Elements

Infrared thermography visualises the temperature distribution of a surface. It is an important, non-invasive investigation method, which we use primarily to characterise innovative elements in buildings and to localise building defects.

Alexandra Raicu*, **Werner Platzer**, Werner Hube, Volker Wittwer

* Sto AG, Stühlingen

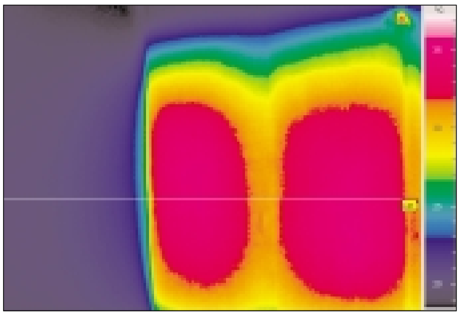


Fig. 1: Temperature distribution on the inside of an outer wall, which is insulated with 2 TI elements (right, 35 °C), compared to an outer wall with opaque insulation (left, 20 °C).

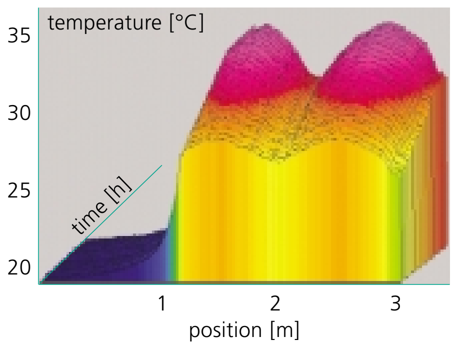


Fig. 2: Qualitative representation of the variation with time of temperature values along a horizontal straight line, as marked in Fig. 1. The baseline corresponds to 19 °C, the peaks to 35 °C. The temperature variation is shown between 6.30 p.m. (back) and 12.00 p.m. (front), measured at 15-minute intervals.

Transparent insulation for solar heating of buildings
Façade elements with transparent insulation (TI) have been installed e.g. in the demonstration project, "Solarhaus Gundelfingen". IR thermography helps us to investigate their performance when integrated into the building.

During a fine weather period in March, we investigated the façade, which is insulated with TI elements. A thermogram was recorded every 15 minutes, so that the dynamic variation of the inside wall temperature could be visualised. Figure 1 shows the interior thermogram of a corner of the building. The image was recorded on 21st March, 2000 at 6.30 p.m., and documents the highest temperature difference between the two surfaces recorded on that day: The TI wall was up to 15 °C warmer than the conventionally insulated wall.

The delayed release of heat from the solar heated, transparently insulated wall during the evening and the night is evident in fig. 2: The inside wall temperature is significantly higher than the room air temperature between 6.30 p.m. and midnight, although the sun had already set.

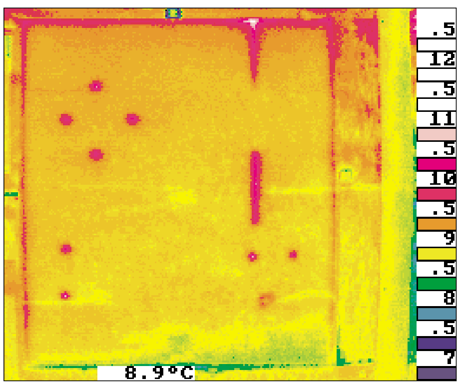
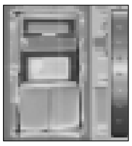


Fig. 3: Thermographically visualised defects in the insulation of a test façade (e.g. two joints, upper right and centre right). The element dimensions are 1.8 m x 2.3 m.

Visualisation of concealed defects and damage in a building
For the first time, we systematically investigated the use of IR thermography to reveal concealed defects and damage in a building, also under non-stationary temperature conditions.

A set of guidelines for users is the result of the investigations, which was funded by the German Federal Ministry for Transport, Building and Housing BMBau. It explains how the measured results are affected by the ambient conditions, controlled heating of the façade or the choice of measurement equipment. Up to now, it was accepted that IR thermography to detect defects was best done during cold winter nights. We demonstrated how good results can be obtained also under non-stationary conditions during the day and in summer. The boundary conditions are classified according to the radiation on the façade and the temperature difference between inside and outside into representative categories (e.g. overcast winter day, clear summer day, etc.). Recommendations for thermographic measurements were made for the different categories. Advantages and disadvantages, favourable and unfavourable situations were presented and explained.

Outlook
IR thermography is simple to apply and allows temperature fields to be presented accurately, with good temporal and spatial resolution. We intend to use it more intensively as a tool for the development and quality control of façade elements.



User Reactions to Sun-Shades and Glare Control

Daylighting and thermal simulations are becoming increasingly accurate. When the daylighting potential in buildings is being estimated, one of the main sources of uncertainty is information on everyday use of artificial lighting and variable sun-shading elements. Within a pilot study, which is running for a year, we are documenting how the users in an office building manually switch on the lights and adjust the blinds.

Christoph Reinhart*

Improved simulation tools allow physically accurate descriptions of the lighting and thermal conditions in rooms with complex facade configurations and for a growing selection of light-guiding elements (fig. 1). In addition, we can now simulate the internal room illuminance in 1-minute steps for the whole year, allowing qualified analysis of different planning options (see page 29).

As a result of these improvements, the greatest uncertainty in building simulation is now the user behaviour. For this reason, we have been investigating the behaviour of 20 users in a new office building in Weilheim (fig. 2). The users can manually adjust both the blinds and the artificial lighting, which is automatically dimmed in response to the daylight level, according to their own preferences.

Based on the information gained, we are developing a model which predicts the user reactions as a function of the climatic conditions (outside and in the office). We can then use the model as a reference case for coupled lighting and thermal simulations, allowing a general evaluation of automatic controls for artificial lighting and sun-shading devices.

Initial analysis indicates that:
- The presence of the users in their offices can be described satisfactorily by a stochastic model based on several specific user parameters.

- The blinds are retracted during those periods when artificial lighting is needed in the investigated office, which was optimised for daylighting (fig. 3). This statement indicates that the use of blinds and artificial lighting can be modelled separately for the investigated office type, and that artificial lighting is switched on only when there is insufficient daylight.

- There is a clear correlation between the nominal illuminance at the desk and the probability that artificial lighting will be switched on when the user enters the office.

The collated results will be integrated into building simulation programs and will be validated and refined by comparison with further buildings in future.

The investigation is supported by the Deutsche Forschungsgemeinschaft.

* University of Freiburg, Freiburger Materialforschungszentrum FMF, Freiburg

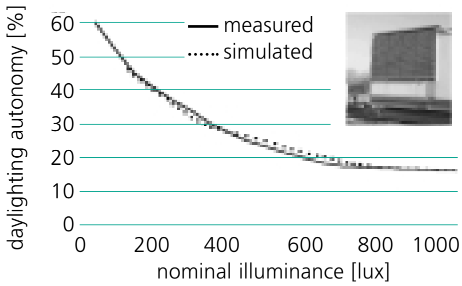


Fig. 1: Measured and simulated daylighting autonomy in the measurement container on the roof of Fraunhofer ISE, for more than 10000 sky situations and three different blind settings. The daylighting autonomy describes the proportion of working time for which a task-dependent nominal illuminance limit is exceeded.

Fig. 2: The pilot study was carried out in the 10 south-facing offices of the new building for the engineering and measurement office belonging to Hans Lamparter GBR (architects: Werkgemeinschaft Maier, Weinbrenner, Single).

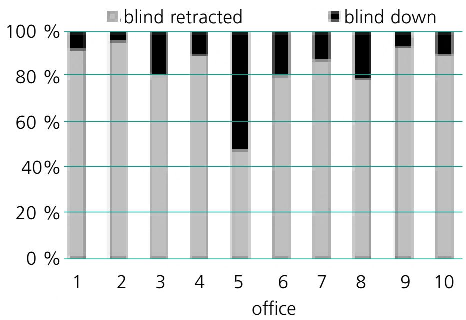


Fig. 3: Blind position in the investigated offices during the periods when artificial lighting was switched on. The high correlation between retracted blinds and artificial lighting demonstrates that in the investigated building, artificial lighting was switched on only when there was insufficient daylight.

Solar Engineering - Advising, Planning, Implementing

These solar passive terrace houses in Neuenburg/Rhein consume only 8 kWh per m^2 and year. The integrated energy concept has five essential components: very good thermal insulation, solar collectors for domestic hot water, controlled inward and outward ventilation with heat recovery, pre-heating the inlet air in an earth-to-air heat exchanger and an innovative, compact unit with a small electric heat pump to supply the remaining heating energy. The electricity for the entire building services technology can be supplied to 100 % by solar energy with 10 m^2 of photovoltaic modules.

Sustainable buildings for the future demand that the energy consumption be clearly reduced. The revised energy-saving regulation expected in 2001 will stimulate a continued decrease in the heating consumption of new buildings. Beyond this, already constructed buildings demonstrate that buildings up to the standard of a zero-emission house can be built today with the available strategies and technology. Increased energy efficiency is the basis for a major contribution by solar energy to the building energy balance.

Whereas the energy demand for residential buildings is still dominated by the heating demand for space heating and hot water, electricity is already the major form of energy consumed in office buildings today.

Appropriate solar concepts for office buildings are based on extending the use of daylighting and passive cooling, so that the electricity consumption for technical building services can be reduced, while maintaining high user comfort. Greater use of daylighting and passive cooling are goals which already have a large effect on building planning during the design phase. Success depends greatly on dedicated application of simulation tools for lighting and indoor thermal conditions. The savings in technical building services (lean building) require additional investment in the planning phase.

The following articles report on concepts, technology and projects for buildings designed for sustainable living and working in the future.

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Solar Building - Residential Buildings

The complete project development for solar passive buildings, as well as the development and assessment of systems and components for building services technology, are services offered by the Institute (see page 14).

Andreas Bühring, Christel Russ, Karsten Voss, Christof Wittwer, Werner Hube

Fig. 1: View of the solar passive houses in Neuenburg.

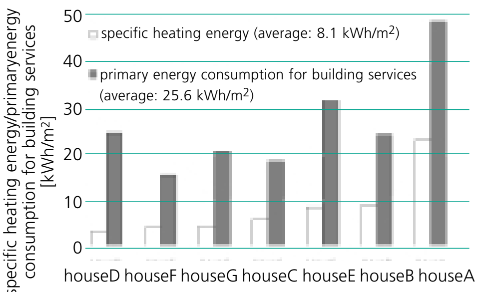


Fig. 2: Heating energy consumption and primary energy demand for the building services in the solar passive houses in Neuenburg during the heating season from October 1999 to April 2000.

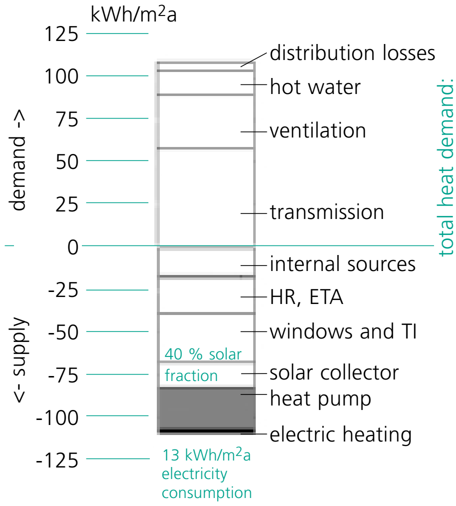


Fig. 4: Annual heat balance for the solar passive house in Büchenau. The balance is based on measured data for one year. The total heating demand of 110 kWh/(m²a), including around 20 kWh/(m²a) for space heating, is met by consuming 13 kWh/(m²a) electricity. Major contributions are provided by solar energy gains through windows and with collectors. HR: heat recovery, ETA: earth-to-air heat exchanger

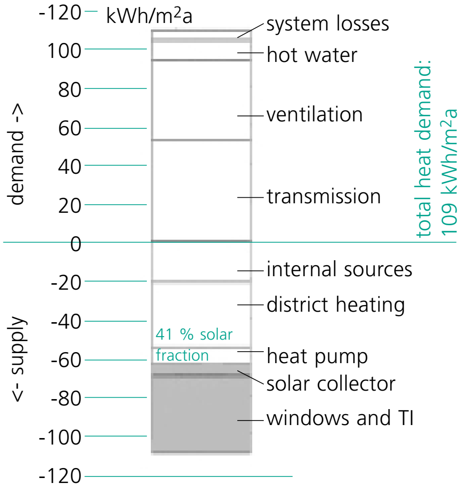


Fig. 5: Annual heat balance for the solar apartment building in Gundelfingen. The balance is based on measured data from one year. The aim of achieving a 3-litre building in the practice was reached, with a heating energy demand of 28.5 kWh/(m²a). More than one third of the energy demand for space heating and domestic hot water is met with solar energy. TI: transparent insulation

In a monitoring programme, we evaluate the energy efficiency in occupied houses of novel energy concepts for so-called "solar passive buildings", on commission to industry and with financial support from the Foundation for Energy Research in Baden-Württemberg. At present, we are evaluating further systems in the funding programme for 100 solar passive houses throughout Baden-Württemberg for the utility, EnBW Energie Baden-Württemberg AG. The terrace houses in Neuenburg and the free-standing house in Büchenau were supported within this programme.

In general, solar passive buildings are characterised by a major reduction in heat losses through the building envelope or due to ventilation. The solar energy gained through windows is then sufficient to keep the annual demand for conventional heating energy to less than 1.5 l heating oil per square metre (=15 kWh/m²) under Central European climatic conditions. The pre-requisite is not only a very high standard of thermal insulation, but also controlled room ventilation with heat recovery.

Fig. 3: Two examples of buildings supported within the "Passive House Funding Programme", sponsored by the utility, Energie Baden-Württemberg AG. The energy consumption of all buildings involved is recorded and analysed as part of a monitoring programme.

BWe have improved this standard still further in the 1-litre solar houses in Neuenburg: The newly developed, compact ventilation unit from the Maico HaustechnikSysteme company combines ventilation, heating and domestic hot water. The favourably priced, system-integrated model uses the spent air as a heat source to pre-heat the incoming air (heat recovery) and as the heat source for a heat pump.

A further practical test with the compact ventilation unit ran successfully in a free-standing house in Büchenau, near Bruchsal, although the heating energy demand was 2 l heating oil per square metre. This demonstrated that innovative building services technology opens up new possibilities for sustainable living in future, with major savings in CO_2 emissions. The implemented concept for building services indicated an efficient and ecologically responsible way to use electricity for heating, in contrast to direct electric heating (fig. 4).

The measurement results from one year were also summarised as an annual balance for the "Solarhaus Gundelfingen", an apartment building (fig. 5). With its heating energy demand of 28 kWh/(m^2a), it reached the aim of a 3-litre building. Solar energy meets 40 % of the total heat demand for the building. The project will be continued with extensive detailed analyses, in co-operation with the University of Karlsruhe and with support from the German Federal Ministry of Economics and Technology BMWi.

Solar Building - Commercial Buildings

The costs associated with energy supply usually represent only a fraction of the total costs in a building: In office buildings, the salaries of the employees are the dominating cost factor, whereas the immediate energy costs total only about 1 %. Due to the high personnel costs, optimal working conditions have a high priority in the planning process, so that the employees feel motivated to work efficiently. Thermal and visual comfort are decisive aspects of the working environment, and are closely associated with the planning concept for ventilation, cooling and lighting.

Sebastian Herkel, Jan Wienold, Tilmann Kuhn, Karsten Voss

New building for the headquarters of the Fraunhofer Society

A double envelope is planned for the 16-storey building in Munich. It will provide natural ventilation and plenty of daylight within the offices, while offering acoustic insulation against the nearby railway line at the same time. The potential users are at the centre of this planning process: Sophisticated control of ventilation flaps in the facade will ensure that the cavity is well ventilated, and will reduce the wind pressure on the windows in the upper storeys. The user can open the window for ventilation at any time, without any danger of overheating or draughts. We are supporting the optimisation with simulation calculations and measurements with a prototype facade (fig. 6). As part of the measurement programme, we analysed the effect of different options for the facade and sun-shading devices on summer comfort. In addition to the qualitative assessment of the various options, the simulation results were also confirmed.

Fig. 6: Test cell from a high-rise building with a double envelope, for the new headquarters of the Fraunhofer Society in Munich.

Fig. 7: New premises for Fraunhofer ISE, in autumn 2000.

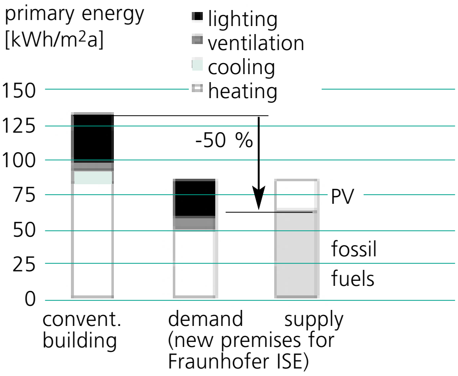


Fig. 8: Comparison with a conventional building of the primary energy demand for the office areas in the new premises for Fraunhofer ISE.

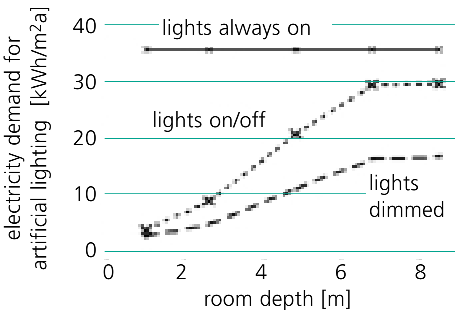


Fig. 9: Electricity demand for artificial lighting according to various lighting strategies, for the renovation of the Collini Centre in Mannheim.

The new premises for Fraunhofer ISE will be completed in the middle of 2001. In comparison to conventional buildings, we reduced the primary energy demand for the office areas by 50 % with improved thermal insulation, passive cooling, daylighting and photovoltaic electricity generation. An energy supply based on a combined heating, power and cooling system was the logical answer to the high energy demand created by the use of laboratories and clean rooms. The building will be monitored for two years and intensively analysed. Further information in text and illustrations can be found in the Internet at: www.solarbau.de (in German).

Collini Centre

The Collini Centre in Mannheim is a typical office complex from the beginning of the seventies. We determined the energy-saving potential offered by renovation of the facade in preparing a concept report. We used combined daylighting and thermal simulations to evaluate various renovation options with regard to the internal air quality and lighting conditions in the offices.

Galileo

We are supporting the planning team for the "Galileo" skyscraper of the Dresdner Bank in Frankfurt with model calculations, calori-metric g value measurements and tests of elements to prevent glare.

	building concept	thermal simulation	lighting simulation	consultancy	product testing	monitoring
DB Hamm		•		•		•
Fraunhofer ISE	•	•	•	•	•	•
Collini Centre	•	•	•	•		
Fraunhofer Headquarters				•	•	•
Pollmeier			•			
Mensa, Kiel	•	•	•	•		
Galileo				•	•	
Sapfina	•	•	•	•		
Lamparter	•	•				•

Tab. 1: Selected projects from the year 2000.

Solar Building - Cross-Sectional Analyses

We document and evaluate concepts and results in cross-sectional projects for national and international demonstration programmes on the basis of a common analytical platform.

Karsten Voss

The subject of marketable residential buildings, with a primary energy consumption which is only a quarter of the current standard, is being addressed by a group of experts within the International Energy Agency IEA. We are participating in the Task on "Sustainable Solar Housing" within the IEA Solar Heating and Cooling Programme with research on energy supplies (see chapter on Measurement and Testing for Thermal Solar Energy and Optics) and are leading the working group on "Monitoring and Evaluation". We are able to include many of our own demonstration projects in this work. The aim is to define an internationally accepted platform, which allows comparable documentation and analysis of buildings. The German Federal Ministry of Economics and Technology BMWi is supporting this work.

Solar concepts for office buildings are based primarily on improved use of daylight and replacement of active air-conditioning by "passive cooling". These buildings are characterised by low investment and maintenance costs for the technical building services, coupled with a higher budget for the building construction. The aim is comparable or lower total buildings costs for high-quality working conditions and a low energy consumption. Integrated building planning, using modern simulation tools, can reproduce the multi-facetted effects of the building on the lighting conditions and the indoor summer air quality in detail, and provide planning certainty early in the process. The necessary further development of programs, user interfaces and program links will facilitate use in everyday planning processes.

Examples of such "lean buildings" are currently being supported, with funding for the additional planning effort and measurement-based evaluation during operation, within the "SolarBau" programme of the German Federal Ministry of Economics and Technology BMWi. Comprehensive documentation, which we have prepared with BMWi funding together with the Faculty for Building Science and Technical Building Services from the University of Karlsruhe and the architectural office, sol°id°ar, from Berlin, is available on the Internet: www.solarbau.de. At the end of the year, an 80-page journal was published with the topics studied in individual projects and the first results of the analysis. The journal can be obtained for a small fee from BINE Bürger-Information Neue Energietechniken
Tel: +49 (0)2 28 / 92 37 90,
Fax: +49 (0)2 28 / 92 37 20
http://bine.fiz-karlsruhe.de.

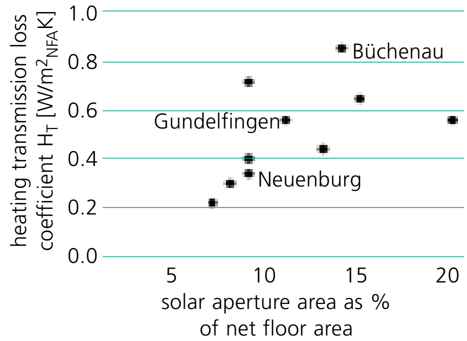


Fig. 10: Characterisation of building envelopes from various projects as a function of the transmission heat loss coefficient (H_T) and the passive use of solar energy (relative aperture area). The demonstration projects of Fraunhofer ISE which were discussed earlier are highlighted.

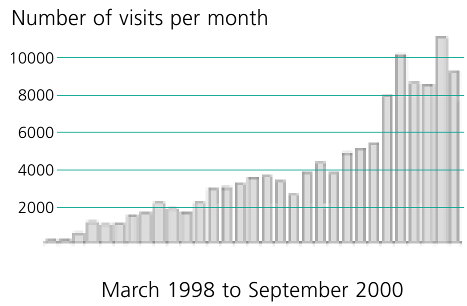


Fig. 11: Statistics on visits to the Internet site: www.solarbau.de.

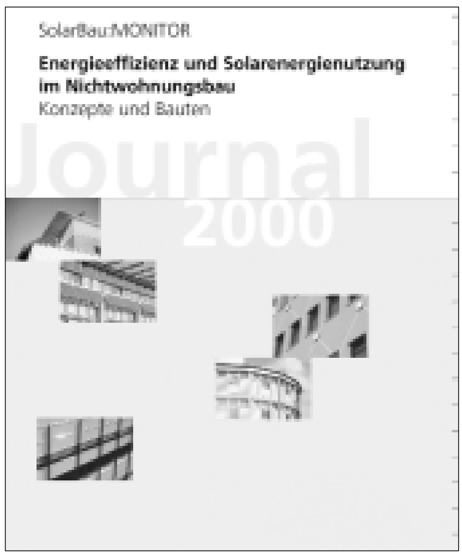
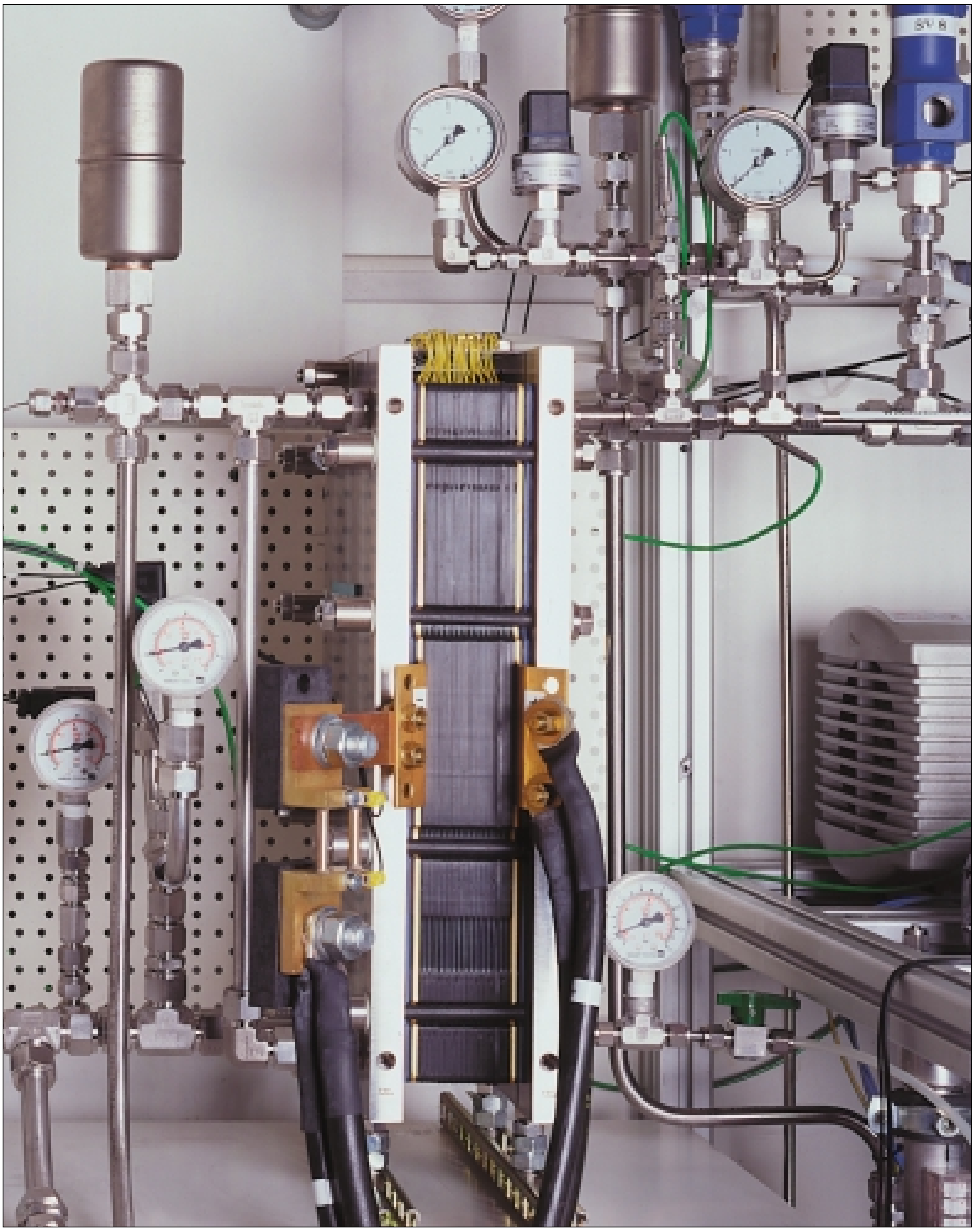


Fig. 12: Part 1 of the scientific evaluation of the SolarBau Funding Programme appeared at the end of 2000 as the "SolarBau:MONITOR Journal 2000". It can be obtained from BINE Bürger-Information Neue Energietechniken, Internet: bine.fiz-karlsruhe.de.



Test stand for a 3.3 kW_{el} fuel cell stack. The PEM fuel cell supplied by SIEMENS is part of a heat/electricity co-generation plant, which is powered by natural gas and was developed and constructed as part of a project commissioned by E.ON Energie AG on "Innovative Domestic Energy Supply".

A fuel cell instead of oil heating? New building concepts need a new type of energy supply. In energy-saving solar houses, only a minimal heating demand still needs to be met. A conventional heating system is not warranted and is also not desirable ecologically. Low-temperature heat is produced during electricity generation as a "waste product". Polymer membrane fuel cells now generate electricity from hydrogen with an efficiency value of around 50 %. Thus, with a power rating of several kilowatts, they could provide all the electricity and heat that a building needs. Surplus electricity is fed into the grid. In this way, a house will become part of the decentralised energy economy of tomorrow. If a reformer is used, conventional natural gas can be used as the fuel.

Reforming is a chemical process which extracts hydrogen from gases or alcohols. It offers two advantages: On the one hand, it enables fuels such as natural gas to be used, which are already widely available, so that consumers do not have to wait for solar hydrogen. On the other hand, fuels with a high storage density such as methanol can be applied, e.g. in the transport sector.

The application in buildings is typical for the trend to use fuel cells in lower and lower power ranges. Our micro-energy technology group is working on systems with 0.1 - 5 W. Replacing rechargeable batteries with fuel cells opens up a new dimension in operating times for appliances, be they notebooks or camcorders, and allows customised design: The electricity supply and the operating time are independent parameters. The fuel cell determines the former, the storage unit the latter.

A completely new technology also benefits from our technology in the micrometre range: thermophotovoltaic energy conversion. A thermophotovoltaic converter functions like a solar cell for infrared radiation and can convert heat with a power density exceeding 1 W/cm2 into electricity. As it does not have any movable parts, it requires very little maintenance and is predestined for applications in remote areas, e.g. for telecommunication repeaters.

The common aim of all our work is to provide efficient and low-maintenance energy converters which make the sustainable use of energy still more convenient and economically attractive.

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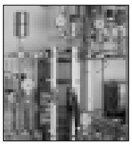
Micro-Energy technology	Dr Christopher Hebling	Tel.: +49 (0) 7 61/45 88-1 95 E-Mail: Christopher.Hebling@ise.fhg.de



Natural Gas Reformer for a Fuel-Cell Cogeneration Plant to Supply Energy for Buildings

Fuel cells can generate electricity with high efficiency from hydrogen, and the associated thermal energy can heat buildings. We are developing a reformer which prepares hydrogen from natural gas. This technology supplies energy to buildings with practically no emission of pollutants, with the exception of CO^2.

Peter Hübner, **Angelika Heinzel**, Christof Wittwer, Matthias Vetter, Walter Mittelbach, Andreas Bühring, Tim Schmid, Bernhard Seigel

Building services technology must meet specifications which cannot be fulfilled by the reformer for a fuel cell without further development. The criteria include flexible operation, a short start-up phase, low maintenance demand, long lifetime, compact construction and at least the operating reliability of a conventional energy supply system. We have conceived a system based on natural gas and intended for the power range of 1 - 2 kW_{el}. The main components of a fuel-cell cogneration plant are shown in fig. 1.

In the first process step, the reforming reactor generates a hydrogen-rich gas mixture by the reaction of natural gas and water vapour. Two subsequent catalytic converters convert the remaining fraction of carbon monoxide, about 10 vol %, into carbon dioxide and hydrogen. Finally, the CO fine purification step removes the carbon monoxide until only ppm concentrations remain. The gas then has the quality required for use in membrane fuel cells.

Important criteria for the reforming reactor include the thermal losses through the outer wall, the load-dependent reaction yield in the reactor, the pressure loss through and the heat input into the catalyst system, and the (inner) heat exchange with the initial reactants. All of these effects must be taken into account when the efficiency of the reformer and the complete system is optimised.

We are aiming for high flexibility of the reformer with respect to the relationship between hydrogen and heat generation. The CO conversion is intended to guarantee stable values for the CO content, even when the load varies. It is performed according to the current state of the art in two steps, a high-temperature step at about 400 °C and a low-temperature step at about 200 °C.

The subsequent CO fine purification process must reduce the CO content for a membrane fuel cell to well under 100 ppm to avoid poisoning the anodic catalyst. For the present, we are achieving this with selective oxidation, but membrane separation procedures are also conceivable in the future.

Catalysts are tested for the various processing steps (project partner: Süd-Chemie AG, Munich), which ensure that the fuels used react efficiently. To this purpose, we have set up a new catalyst test stand with gas chromatography.

Depending on the flexibility achieved with the reformer and the user specifications, a heating boiler can be foreseen in the household energy supply system as a reserve heat source, and its integration into the

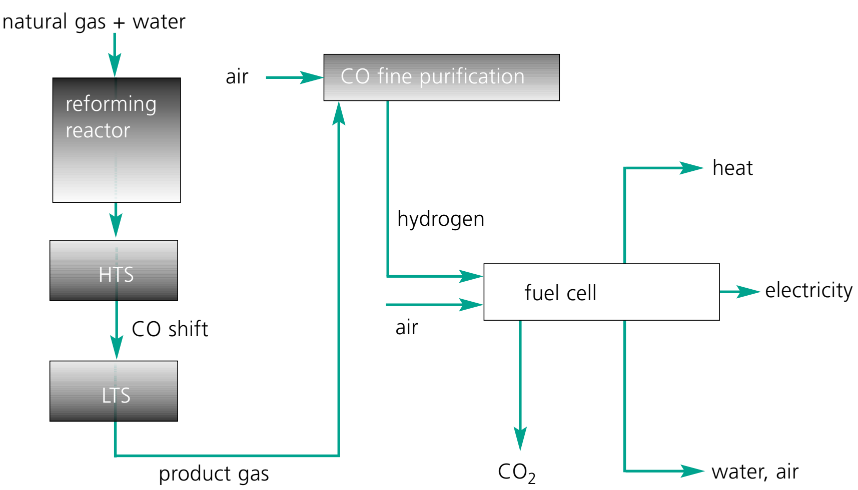


Fig. 1: Schematic diagram of a fuel-cell cogeneration plant. HTS and LTS are catalytic high-temperature and low-temperature CO shift steps.

hot water circulation system can be taken into account.

After selecting the peripheral components, such as heat exchangers, mixing valves, pumps and ventilators, we integrate the reformer and all the gas purification steps. We develop control strategies, investigate the gas quality which can be achieved in the laboratory for various operating conditions, and optimise the reformer system. Finally, the complete gas supply is combined with the fuel cell (Proton Motor, Starnberg) in a single system, and tested.

The natural gas reformer is a component in the major project on "New Integrated Energy Supply Concepts for Buildings (NEGEV)", which is co-ordinated by the Institute and funded by the German Federal Ministry of Economics and Technology BMWi. The main topics are a technologically orientated demand analysis, the development of components for building energy supply systems as modular elements, and their integration into complete systems, including the connection to the existing grids of public utilities. Together with industrial partners (fig. 2), technologies are being further developed, which can meet the low energy demand of modern buildings with high efficiency. These include solar systems, fuel cells, heat pumps and low-loss storage systems. At the Institute, we co-operate closely with the Department for "Thermal and Optical Systems" (see page 30).

Fig. 2: Partners in the major project, "NEGEV".

Innovative Energy Supply for Houses with a Fuel-Cell Cogeneration Plant

A fuel-cell cogeneration plant is being developed at Fraunhofer ISE, constructed, and installed in the Technology Pavilion of the Building Centre at the Munich Showground, as part of the "Innovative Energy Supply for Houses" project for E.ON Energie AG.

Dieter Schlegel, Sylvain Darou, Tobias Wartha, Robert Szolak, Christoph Strobel, Maurizio Palmisano, Angelika Heinzel

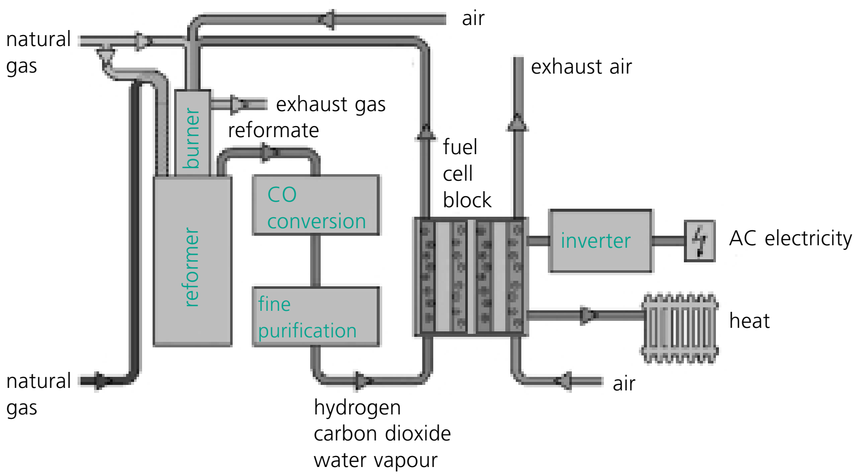


Fig. 2: Schematic diagram of a fuel cell system to run on natural gas (source: E.ON Energie AG).

Progressive energy supply concepts concentrate on environmental acceptability and the best possible use of the fuel. Fuel cells, with their extremely efficient and environmentally friendly energy conversion process and low emission of pollutants, meet these requirements. The Fraunhofer Institute for Solar Energy Systems ISE has been developing natural gas reformers to generate hydrogen for heat/electricity cogeneration plants for several years. Two reformer systems were constructed during this period, in 1997 at the Technological Centre in Riesa, Saxony, and in 1999 at the Technical College in Ulm.

If natural gas is to be used in a fuel-cell cogeneration plant, further components are needed in addition to the PEM fuel cell block (polymer electrolyte membrane). Figure 2 shows a schematic diagram of a fuel-cell cogeneration plant.

The fuel, natural gas, is converted in a reformer to hydrogen-rich synthetic gas. After further gas treatment (carbon monoxide conversion) and fine purification (e.g. selective oxidation of carbon monoxide), the reforming product, which contains 75 % hydrogen, is supplied to the PEM fuel cell for electricity generation. The resulting heat is used both in the process itself and also externally as heating energy. At present, there are no inverters commercially available for the DC voltage output from the fuel cell (12 V, 275 A under full load). Thus, the voltage must first be raised with a DC/DC converter to 350 V. The electricity is fed into the household circuit via an inverter. The

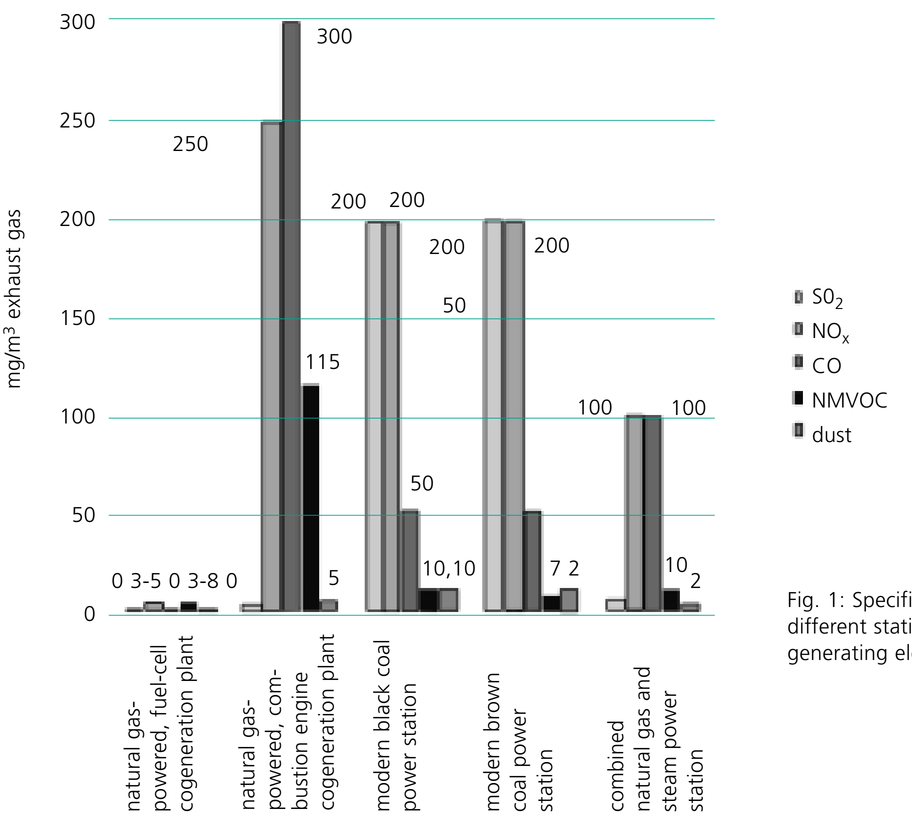


Fig. 1: Specific air pollutant emissions from different stationary technological approaches to generating electricity (source: VDEW).

DC/DC converter is being developed together with the inverter by the Kaco company.

The total efficiency value for the system, without electric loads and the inverter, should be at least 60 %. The fuel cell block, which consists of 20 individual cells, operates with 0.6 VDC per cell and 275 A at the nominal operating point. This operating point depends on the composition of the reformer and other operating parameters such as pressure and temperature.

The electric power of the system amounts to 3.3 kW, the thermal power is 4.5 kW. The fuel cell block was supplied by the Siemens company. The fuel cell system is automated with an SPS unit (programmable storage control) and can be remotely maintained via ISDN and a software tool. Authorised staff can modify the process data with a special access code, and carry out maintenance work. The process data are visualised on a PC, so that visitors can observe the data on-line.

The project is funded by the Bavarian State Ministry of Economics, Transport and Technology.

Miniature Photovoltaic Modules for Small Appliances and Sensors

At Fraunhofer ISE, highly efficient, miniature photovoltaic modules are being developed as solar power supplies for small, high-quality appliances such as mobile phones, organisers or sensors. The photovoltaic units extend the stand-by time or even allow complete independence from external power sources.

Christopher Hebling,
Helge Schmidhuber, Stefan Glunz, Heribert Schmidt, Werner Roth

Solar cells convert the light from the sun or a lamp into electricity. They are electrically connected to form modules, allowing easy handling. They need to have special properties, if they are to supply power to appliances indoors (fig 1).

The cells which we use include the high-efficiency solar cells produced at Fraunhofer ISE, which are distinguished by very good performance at low lighting intensities. Modules made of these solar cells achieve high efficiency values and high voltages, even under indoor lighting conditions.

Space is in short supply in small appliances. For this reason, the solar cells are connected to form high-performance modules and encapsulated. We contact the cells in the shingle configuration with a conductive adhesive, and then encapsulate them in a highly transparent silicone resin (fig 2). This reduces the area obstructed by contacts and means that our modules can achieve an efficiency value of 20 %.

The energy-saving circuits to recharge batteries, which were also developed

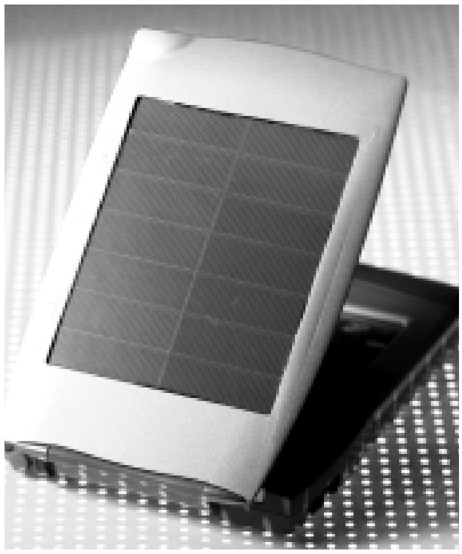


Fig. 1: Prototype of a solar-powered organiser. The rechargeable batteries, which are integrated into the device, are charged by the photovoltaic module. (Co-operation between Fraunhofer ISE, Casio Computer and AccuCell).

at Fraunhofer ISE, adapt the module electronically to the appliance required. They ensure that the generated electricity is used optimally to operate the device.

The performance of the miniature photovoltaic modules has already been demonstrated with operational prototypes for telecom-munications, portable computers and wire-less sensors. PV modules are the long-term power supply for these sensors. This significantly reduces the demand for service and maintenance.

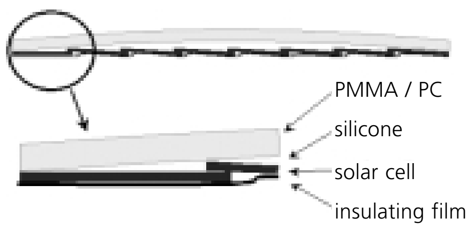
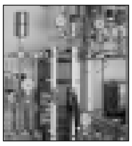


Fig. 2: Schematic configuration of a photovoltaic module with a curved cover. Modules with a minimum thickness of 1.5 mm can be produced.



Fuel Cells in the Low Power Range as Power Supplies for Portable Electronic Appliances

Miniature fuel cell systems are being developed to complement or replace rechargeable batteries within a joint project involving five Fraunhofer Institutes. All aspects needed for a mass-producible fuel cell system, from materials development to the evaluation of structure replication methods and micro-mounting technology, are being investigated.

Christopher Hebling, Mario Zedda, Andreas Schmitz, Ulf Groos, Alexander Hakenjos, Jürgen Schumacher, Klaus Tüber

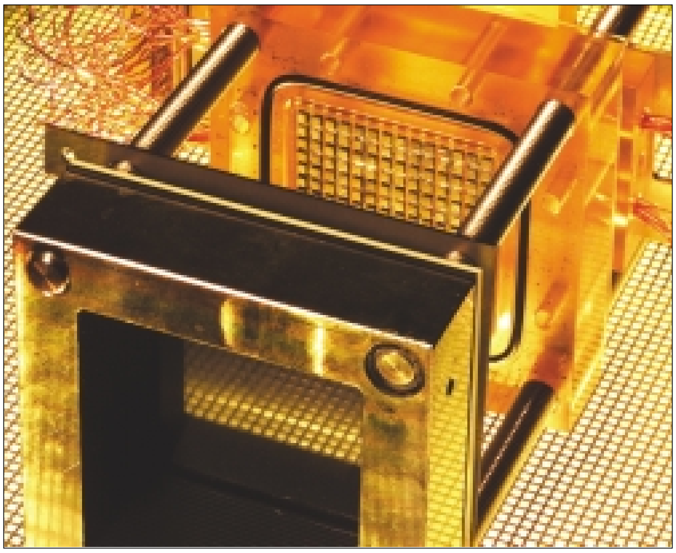


Fig. 1: Photo of the test stand for spatially resolved measurement of the current density, the impedance and the temperature.

Fuel cells are considered to be a promising technology of the future for off-grid power supply, with their high electrical efficiency value, unrestricted modular construction and pollutant-free energy conversion. Operational, durable systems have been achieved only in the past few decades. More recently, fuel cells have also been investigated for low-cost applications in mass markets such as portable electronic appliances.

Fuel cells in the power range between 0.1 and 5 W are being developed within a economically orientated, strategic alliance (WISA), which is led by Fraunhofer ISE and supported by the Fraunhofer Society. The Fraunhofer Institutes for Chemical Technology (ICT), for Reliability and Micro-Integration (IZM), and for Production Technology (IPT), and the Centre for Manufacturing Innovation (CMI) are each contributing with their specific competence toward the complete system. The combination of the individual competences is resulting in additional synergetic value, not only in the technical development of the fuel cell components, but also in setting up the manufacturing technology.

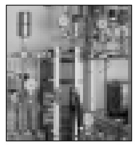
The reference product is a widely available camcorder, in which the rechargeable battery is replaced by a fuel cell system. All the relevant system aspects are being investigated on a prototype: fluid-mechanical simulations of the channel structure, material variations of the bipolar plate, integration of peripheral micro-elements, development of a special power management strategy and the evaluation of suitable manufacturing and mounting technology.

Parallel to the so-called "stack design", the series connection of fuel cells stacked on top of each other, an extremely flat configuration of series-connected cells is being implemented, which is mounted on the back of an MP3 player as its power supply.

Fraunhofer ISE is contributing to the project with its long-term experience in dimensioning, constructing and characterising fuel cell systems.
As a supporting measure, we have intensified our efforts in the fluid-mechanical, thermodynamic and electrochemical simulation of the mass transport and conversion. For example, we can now calculate the position-dependent production of heat and water as a function of the geometry of the gas channels and the volume current. In parallel, we have set up a measurement stand with a 5 x 5 cm^2 test cell, which is divided into 49 individual segments and allows spatially resolved measurement of the following parameters:

- temperature (highly sensitive IR camera with a macro-lens)
- current density (measurement of the I-V characteristic for each individual segment)
- water content of the membrane (impedance spectroscopy)
- pressure difference (manometers at the inlet and outlet of the gas channels)
- air humidity (hygrometers at the inlet and outlet of the cell)
- hydrogen humidity (hygrometers at the inlet and outlet of the cell)

The measurement results help us to improve the model definition for simulation and thus lead to a growing understanding of the processes in a fuel cell.



Thermophotovoltaic Energy Conversion with Micro-Structured Emitters

Thermophotovoltaics (TPV) is the conversion of thermal radiation into electricity with photovoltaic cells. TPV offers the potential for thermal-electric converters with high efficiency and reliability, particularly in the low power range. Further fundamental advantages of thermophotovoltaics include the possibility for cogeneration of electricity and heat, high power densities (> 1 W/cm^2) and a low maintenance demand due to the lack of moving parts.

Christopher Hebling, Jörg Ferber*, Johannes Aschaber*, Christian Schlemmer, Rolf Wiehle, Volkmar Börner, Andreas Heinzel, Andreas Gombert

A TPV market study conducted by Fraunhofer ISE identified attractive applications in the fields of off-grid power supply, camping/leisure (cogeneration of electricity and heat), telecommunications (PV hybrid systems) and grid-independent gas heaters, among others. A market potential could also arise from the use of industrial waste heat (e.g. from glass, aluminium or steel production).

We are pursuing a novel concept, which includes a micro-structured emitter heated by a burner, a vacuum system and photovoltaic cells of IR-sensitive GaSb (see page 61). The structuring of the emitter surface serves to adapt the spectrum of the heated material to the spectral response of the GaSb cells. At present we are investigating tungsten as the emitter material, as it is characterised by a natural radiative selectivity, which can be reinforced and optimised by the micro-structuring. The use of a selective emitter means that an additional filter to tune the radiation is not required. In addition, tungsten is suitable for use at the operating temperatures due to its high melting point.

Operating the system in vacuum offers the advantage of eliminating convective heat transfer, which acts to reduce the efficiency of the photovoltaic cells. The tungsten plates can be heated by any method, provided that temperatures of around 1250 °C can be reached. It is conceivable that bio-fuels could be used to this purpose.

Figure 1 shows the simulated emission spectrum of a micro-structured tungsten surface with a grating period of 1.45 µm and a depth of 0.3 µm, as a function of various angles of emission. As the angle of emission increases, the emission maximum shifts to longer wavelengths - an undesired effect, as GaSb cells can only convert radiation of wavelengths shorter than 1.7 µm into electricity. Simulation calculations show that deeper structures, on the order of micrometres, could prevent this angular selectivity. Initial measurements confirm this. Figure 2 shows the scanning electron micrograph of a deeper surface structure on a tungsten sample, with a grating period of 1.4 µm and a structure depth exceeding 1 µm. At present, we are working on optimising the structure and achieving long-term stability for the radiation emitter.

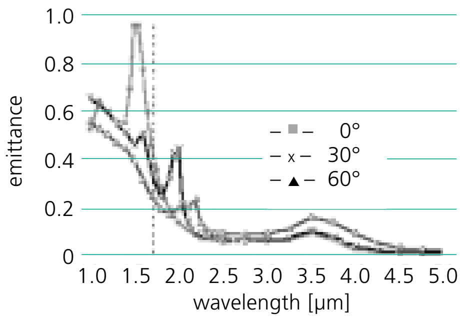


Fig. 1: Simulated emission spectrum at 1400 °C of a two-dimensional tungsten grating with a period of 1.45 µm, plotted for different angles of emission. GaSb cells can only convert photons corresponding to a wavelength shorter than 1.7 µm. The plotted spectrum has been calculated. At present we are preparing the equipment for measurements at the required high temperatures.

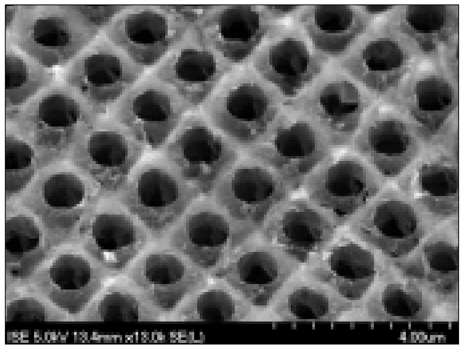


Fig. 2: Scanning electron micrograph of a micro-structured tungsten surface with a grating period of 1.4 µm and a structure depth of 1 µm.

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Solar Cells - Materials and Technology

Monolithic tandem concentrator cells, which achieve an efficiency value of 31.1 %, installed in a test module. Tandem solar cells consist of two or more spectrally adapted component solar cells, which convert different spectral ranges of the solar radiation into electricity with particularly high efficiency. Lenses concentrate the sunlight by a factor of 100 to 1000.

More than 80 % of the solar cells manufactured throughout the world are of crystalline silicon. The cost/ performance ratio, their long-term stability and reliable potential for further cost reduction indicate that these mainstays of terrestrial photovoltaics will continue to dominate the market for the next 10 years.

III-V semiconductors such as gallium arsenide form the second material class which we are investigating. At present it is associated with a niche market, which can be summarised by the concepts of space and special applications, and optical concentrators. The common trend for us in both areas: Research is approaching the commercial application yet more closely.

Some examples demonstrate this:
In October, we commissioned our Laboratory and Service Centre in Gelsenkirchen. Here, we can work under production conditions in the laboratory. Industry can transfer the results directly to production, without interruptions for the investigations.

We can now produce highly efficient solar cells, e.g. for portable appliances, in small series with a pilot production line in Freiburg.

The crystalline silicon thin-film solar cell combines the classic advantages of silicon with the advantages of thin-film technology. As well as investigating the physical fundamentals, we also develop the manufacturing technology: The energy-saving SIR process results in flexible films with a noteworthy efficiency value.

With respect to III-V solar cells, we are working on radiation-resistant tandem cells for space applications. For terrestrial applications, we are developing an economically attractive procedure to produce the Fresnel lenses in concentrator modules and construct complete modules for outdoor applications.

We also develop special III-V cells for laser power transmission and for thermophotovoltaic applications, which are optimised for the relevant radiation spectra.

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Monocrystalline Solar Cells with Highest Efficiency and Innovative Manufacturing Technology

About half of all the solar cells manufactured around the world are made of monocrystalline silicon. Over the last few years, a clear trend toward higher efficiency values and thinner wafers can be observed internationally. For that reason, some of our research activities concentrated on the processing of thin wafers with new, cost-saving production processes. In addition, we set up a pilot line to produce highly efficient solar cells and took it into operation.

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If high efficiency values are also to be achieved with thin wafers, new cell structures are needed for industrial production. The efficiency value of solar cells with an aluminium back-surface field decreases very strongly when the cell thickness is reduced. By applying appropriate measures, such as improved surface passivation and an internal reflector on the back surface, the efficiency value can be greatly increased, particularly for small cell thicknesses. Solar cell concepts, with which efficiency values well above 20 % can be achieved (see fig. 1), have been known for quite some time. Nevertheless, these concepts have not yet been introduced into industrial production, as they are complex and thus too expensive. Recently we have intensified our investigations of ways to simplify their implementation.

The most important feature of highly efficient silicon solar cells is that the surface is well passivated. This can be achieved by coating it with silicon dioxide or silicon nitride. However, when the contacts are applied, this insulating layer must be removed at some points (fig. 1). This was done with relatively sophisticated photolithographic steps up to now. We have now succeeded in piercing the insulating layer by laser ablation, which reduces the number of processing steps to produce the back surface point contacts by a factor of five. We tested the suitability of two laser systems:

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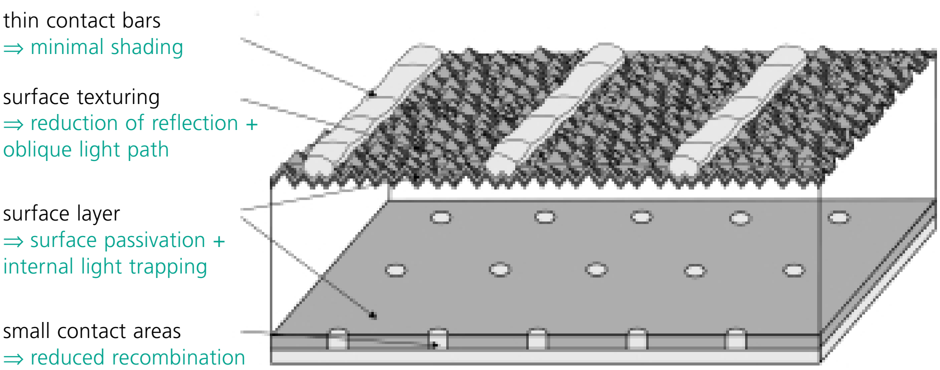


Fig. 1: Highly efficient solar cell (Passivated Emitter and Rear Cell PERC concept). The surface passivation is achieved either with thermally grown SiO_2 or a deposited SiN_x coating.

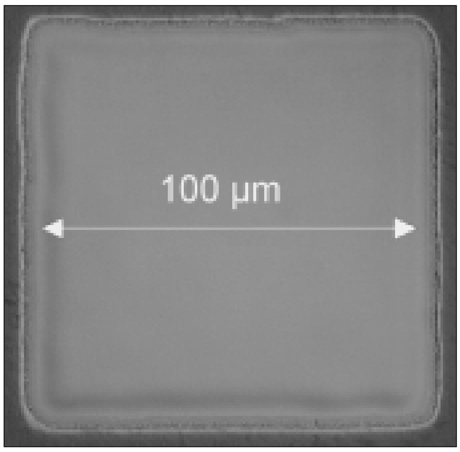
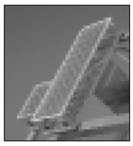


Fig. 2: Contact point pierced by an excimer laser in the dielectric passivation layer on the back surface of a highly efficient silicon solar cell.



a KrF excimer laser with a very short wavelength (248 nm) and a Nd:YAG laser with a long wavelength (1064 nm). Figure 2 shows a back surface contact point which was prepared with an excimer laser.

As silicon nitride absorbs radiation of this wavelength very strongly, the passivation layer is ablated very selectively. By contrast, the laser ray from the Nd:YAG laser, with its long wavelength, penetrates deeply into the underlying silicon and creates a type of crater in the silicon (fig. 3).

Despite the difference in the ablation results, the solar cells treated with both laser systems achieved efficiency values exceeding 20 %. The results are only slightly lower than the values for conventionally processed, high-efficiency solar cells.

These high-efficiency cell concepts allow the wafer thickness to be drastically reduced without decreasing the efficiency significantly. Thus, we achieved an efficiency value of 20 % with a 115 µm "thin" wafer of industrially relevant Czochralski silicon. An 85 µm thin, highly efficient Czochralski silicon solar cell is illustrated on the title page. In addition to the savings in material, another prominent feature of the cells is evident in the picture: they are flexible. This opens up completely new application fields.

Up to now, we were able to verify new, high-efficiency cell concepts only on a laboratory scale. On the one hand, this had the disadvantage of small production volumes, which meant that the potential costs of highly efficient solar cells could only be estimated approximately. On the other hand, we were not able to introduce any automated processing steps in this context, which in turn would contribute to cost reduction.

Therefore, we set up a pilot line for highly efficient solar cells this year and took it into operation. We identified those processing steps in laboratory operation which were particularly time-consuming, and automated them. We developed some of the new equipment for this ourselves.

An equally important goal for this pilot line is to provide sufficient quantities of highly efficient solar cells for the prototype development of solar-powered small appliances. Figure 4 shows a silicon wafer with 14 highly efficient solar cells. These cells have been optimised for series connection by shingle mounting, in which the solar cells overlap slightly: The main contact bus (horizontal metal strip in fig. 4) is covered by the adjacent cell. This appreciably reduces shading and wasted area due to empty spaces in the module. The module which is illustrated in fig. 4 (upper right) was manufactured with this technology. Whereas this module already brings about 60 % more power than a conventional module in full sunlight, the difference is still greater at lower intensities. With conventional cells, the voltage falls off so rapidly for lower radiation intensity that significantly more cells are required to guarantee the voltage required for a specific application. This effect does not occur with our high-efficiency cells. This is decisive in power supplies for electronic devices such as mobile phones, palmtops, etc., which are almost always operated indoors (see page 51).

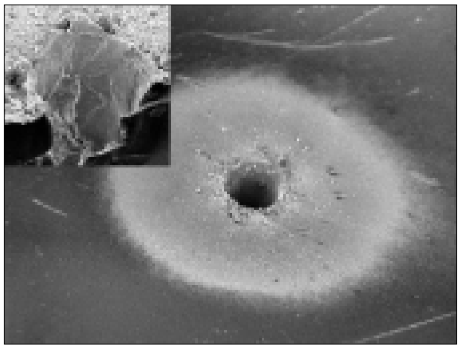


Fig. 3: Contact point pierced by a Nd:YAG laser in the dielectric passivation layer on the back surface of a highly efficient silicon solar cell.

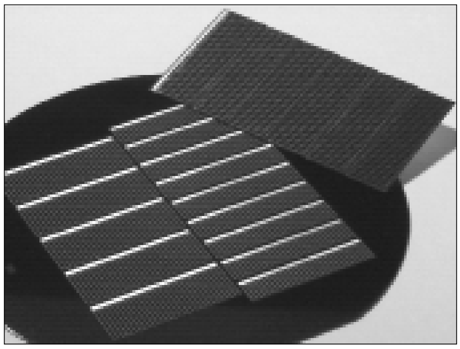


Fig. 4: Highly efficient solar cells on a wafer and after shingled connection to form a module (upper right).

Rapid Thermal Processing of Solar Cells

Solar cell production is currently aiming to further shorten processing times. A clear reduction can be achieved e.g. with the help of Rapid Thermal Processing (RTP). Extended processes at present can be completed within a few seconds when RTP is applied.

Harald Lautenschlager, Stefan Peters, Volker Radt, Christian Schetter, **Roland Schindler**

In comparison to monocrystalline cells, the efficiency value of multicrystalline cells is 2 - 3 percentage points lower, depending on the quality of the original wafers. This is true both for laboratory cells and for industrially manufactured cells. The lower efficiency value is attributed to the high density of dislocations and grain boundaries, and an inherently higher degree of contamination with metallic impurities.

Optimal processing can improve multicrystalline material, in some cases to the point that it closely approaches monocrystalline material. This can be achieved e.g. by so-called gettering steps, in which impurities are removed from the interior of the solar cell and are thus rendered harmless. However, this is usually associated with long processing times, which are difficult to integrate into industrial production. The simple, conventional solar cell process developed in the past at Fraunhofer ISE, which includes an integrated gettering step, had the same characteristics. In general, this type of high-temperature processing with resistance-heated ovens is described as "conventional processing".

Rapid Thermal Processing (RTP) represents a new direction for processing. In this technology, the silicon wafers are heated with light of short wavelengths. As the surroundings of the wafer remain cold, steep heating and cooling ramps can be applied with this method. In contrast to conventional processing, RTP thus allows very short processing times on the order of several seconds. Figure 1 shows the construction of a commercial RTP oven, such as is used for microelectronic production. We recently developed an in-line RTP oven to meet the requirements of the photovoltaic industry.

Our work has demonstrated that monocrystalline solar cells can be produced with RTP, which are just as efficient as those produced with the slower, conventional process. For example, we can produce a solar cell from industrial Cz Si with an efficiency value of 17.5 %, applying RTP to achieve an extremely short diffusion time. The RTP processes applied for the emitter diffusion and oxide passivation last less than one minute in total. Further, we succeeded in producing a solar cell from high-quality float zone silicon with an efficiency value of 18.7 %. In this cell, a screen-printed aluminium back-surface field for back surface passivation was formed by a specially adapted RTP process.

For block-cast multicrystalline silicon, however, the efficiency of RTP solar cells is somewhat lower. Surprisingly, this does not apply for ribbon material such as EFG (edge-defined, film-fed growth) or RGS (ribbon growth on substrate). The cell efficiency values for RGS and EFG silicon are shown in fig. 2. In each case, we were able to achieve higher efficiency values with RTP than with the conventional process. The cause is probably the activation and segregation kinetics of the impurities: When the temperature load is increased, clusters or precipitates of impurities and other defects form. This is indicated in EFG material e.g. by a higher short-circuit current, together with a lower open-circuit voltage. Altogether, shorter processing times result in higher efficiency values. These effects depend strongly on the particular material and the drawing process applied in its production.

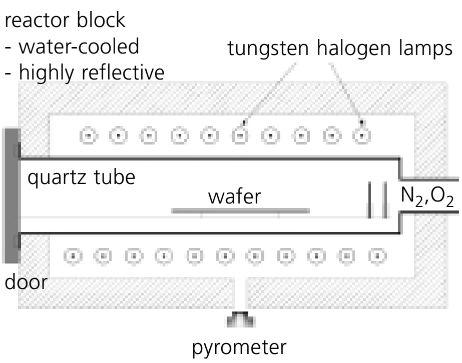


Fig. 1: Schematic diagram of the RTP oven used at Fraunhofer ISE.

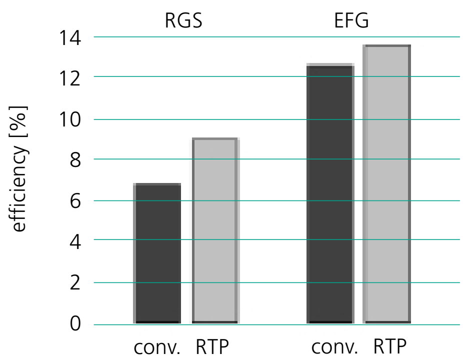


Fig. 2: Improvement in the efficiency value of laboratory samples of silicon sheet materials such as RGS (ribbon growth on substrate) and EFG (edge-defined film-fed growth) due to the application of RTP rather than conventional processing.

The SIR Process for Energy-Saving Production of Crystalline Silicon Thin-Film Solar Cells

The energy consumption is a significant cost factor in the production of crystalline silicon thin-film solar cells. Fraunhofer ISE contributed to the invention of the new SIR process, which can reduce the energy costs considerably.

Achim Eyer, Stefan Reber, Daniela Oßwald*, Albert Hurrle, Norbert Schillinger, Sandra Bau**, Andreas Roosen***, Christiane Lutz***, Hans-Jürgen Pohlmann****

In the production of crystalline silicon thin-film solar cells, not only the material costs but also the energy costs play an important role. In the so-called "high-temperature approach", there are two energy-intensive production steps with temperatures of 1400 °C and higher: firing the ceramic substrate and melting for recrystallisation.

In the SIR process - Simultaneous Infiltration and Recrystallisation - the firing and recrystallisation are combined in a single step. This makes significant energy and thus cost savings possible.

The basic idea underlying the SIR process is shown in more detail in fig. 1: A ceramic "green tape" of silicon, silicon carbide and carbon with an intermediate layer serves as the substrate. Next, the substrate is coated with silicon, either as silicon powder or by a deposition process. Then follows the decisive SIR process step: A narrow strip of the compound layer structure is heated to above the melting temperature of silicon in a zone-melting oven, and is simultaneously "scanned" along the sample. The single melting step has two effects: On the one hand, the fine-grained silicon is recrystallised above the intermediate layer and a coarse-grained silicon film results. On the other hand, the liquid silicon in the green tape reacts with the integrated carbon to form silicon carbide, converting the green tape to ceramic and thus hardening it. A "wafer equivalent" is formed by epitaxial deposition of silicon onto the recrystallised silicon. It can then be processed to a solar cell with conventional manufacturing procedures.

In co-operation with the University of Erlangen-Nürnberg and with support from TeCe Technical Ceramics GmbH and Shell Solar, we applied the idea of SIR processing in practice. The University of Erlangen-Nürnberg developed a procedure to produce the ceramic green tapes. The tape-casting method used allows large areas of tape to be produced quickly and inexpensively. The largest tapes which were produced there had a length of 2 m and a width of 25 cm (fig. 2).

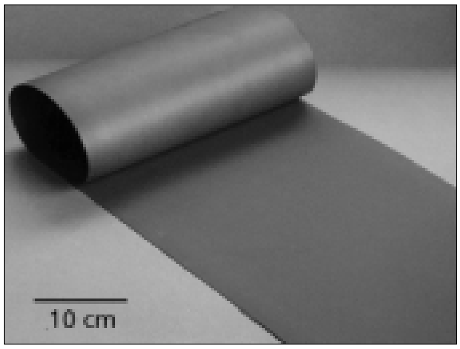


Fig. 2: Green tape of Si-SiC-C, which was produced by tape-casting.

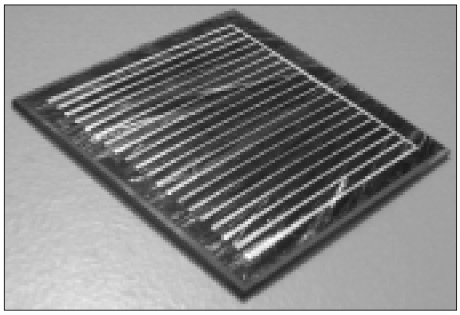


Fig. 3: SIR solar cell with an area of 5 x 5 cm^2.

The tape composition was successively optimised in Erlangen in co-operation with Fraunhofer ISE.

We carried out all the subsequent processing steps up to solar cell processing and characterisation. We produced solar cells with areas between 1 cm^2 and 25 cm^2. As an example, fig. 3 shows an SIR solar cell with an area of 5 x 5 cm^2. After only a short period of development, the best efficiency values for the solar cells were already about 6.4 %.

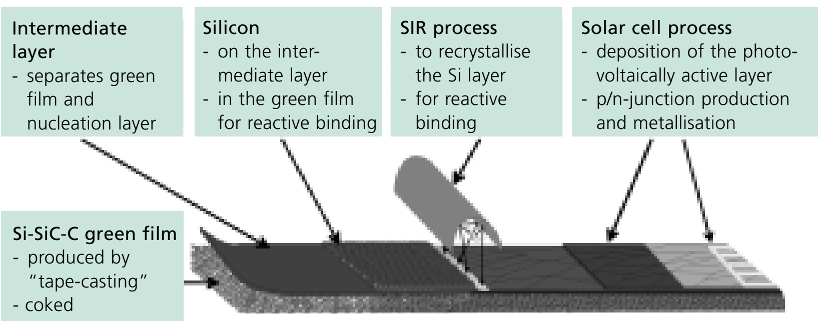


Fig. 1: Schematic presentation of the processing steps (from left to right) for production of a crystalline silicon thin-film solar cell according to the SIR process.

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**** TeCe Technical Ceramics GmbH

Front-Surface Contacting for Crystalline Silicon Thin-Film Solar Cells with Screen-Printing Processes

If crystalline silicon thin-film solar cells are produced on electrically insulating substrates, the contacts must all be made from one side. Screen printing is the appropriate, industrially relevant standard technology.

Dominik Huljic, **Ralf Lüdemann**, Gernot Emanuel*, Sebastian Schaefer, Daniel Biro, Stefan Reber

The films for crystalline silicon thin-film solar cells are usually deposited on inexpensive substrates. The substrate material is often electrically insulating. This can be a major advantage: by integrating the series connection of individual solar cells of strip form on the substrate, the production of strings of large, series-connected cells can be avoided. However, this property can also be a disadvantage: the electrically insulating substrate means that the solar cell cannot be contacted in the conventional way with a base contact on the back surface and a metal grid for the emitter contact on the front surface. Both contacts have to be made on the illuminated front surface.

The best-known concept is that of the "interdigitated grid" (fig. 1). The most obvious difference to conventional cells is the selective emitter structure: The emitter regions on the surface do not cover the whole area, but alternate with base regions.

We implemented this type of selective emitter structure with interdigitated-grid contacts several years ago very successfully with the help of photolithographic and masked diffusion steps. Excellent efficiency values of 19.2 % proved the high potential for crystalline silicon thin-film solar cells.

However, the process used then was too expensive for industrial mass production. Thus, we wanted to implement the interdigitated-grid concept with the quick and inexpensive screen-printing process.

We tested three approaches (fig. 2): Buried Base Contact (BBC), Grid Aligned Trenching (GAT) and Patterned Emitter (PE). None of the processes require expensive photolithographic or masked diffusion steps. The screen printing replaces the complex evaporation technology with its need for masks. The PE concept differs from the others in that the emitter is structured simultaneously during the emitter diffusion process. It is thus the concept requiring the fewest processing steps. However, substantial short circuits can form between the emitter and base regions if masking steps are not applied. The GAT concept also includes processing steps which can result in similar shunts. By contrast, the BBC concept is much less sensitive to processing tolerances. This was demonstrated clearly by the electrical properties of the solar cell samples produced according to the three different concepts (fig. 3).

In the first tests with multicrystalline silicon wafers, the BBC concept resulted in efficiency values of up to 7.6 %. The aluminium paste used for the base metallisation, which had not yet been optimised, caused relatively low fill factors of around 50 %. By further optimising the processes applied, in particular the screen printing of the base grid, we intend to explore the efficiency potential of the BBC concept, which certainly has not been exhausted yet.

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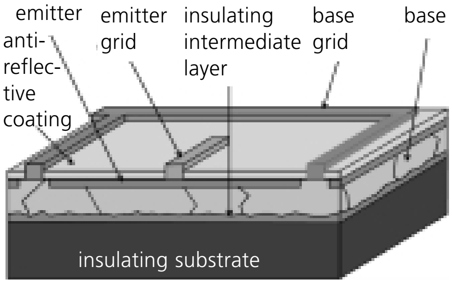


Fig. 1: Schematic diagram of a thin-film solar cell with front-surface, "interdigitated grid" contacts.

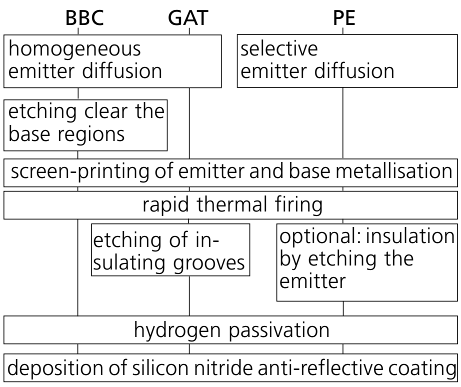


Fig. 2: Processing schemes for the three different concepts to implement a screen-printed interdigitated grid.

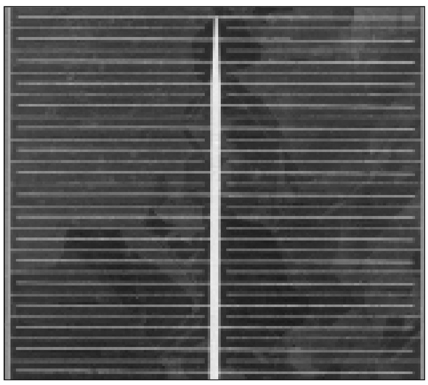


Fig. 3: Test solar cell with screen-printed, front-surface contacts on a multicrystalline silicon wafer.

III-V Solar Cells

We apply MOVPE, LPE and gas phase diffusion technology to form pn junctions in different combinations of materials. The aim is to make solar cells with efficiency values > 30 % and photovoltaic cells for special applications such as laser power transmission, thermophotovoltaics or space.

Carsten Agert, Rolf Beckert, **Andreas W. Bett**, Frank Dimroth, Mathias Hein, Vladimir Hinkov, Gerrit Lange, Peter Lanyi, Gergö Létay, Matthias Meusel, Sascha van Riesen, Ute Schubert, Oleg Sulima

Development of monolithic tandem cells using MOVPE

We use an industrially compatible MOVPE system from the AIXTRON AG company to produce monolithic tandem cells. We develop processes on the AIX2600G3 which our industrial partners can apply directly in production.

The standard combination for monolithic tandem cells is $Ga_{0.51}In_{0.49}P/GaAs$ on a Ge substrate. We suggested the use of GaInAs instead of the GaAs material, as the theory indicated that higher efficiency values could be achieved. We successfully developed this concept further this year. For space applications, we achieved an efficiency value of 24.1 % (AM0 spectrum) with a $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ tandem cell. Initial investigations with proton radiation demonstrated very good stability. Using our concentrator cells of the same material, we achie-ved a world record: an efficiency value exceeding 31 % at around 300-fold concentration of solar intensity. Even with 1300 suns, the efficiency value is still above 29 % (fig. 1). We have already constructed the first test modules with these concentrator cells.

Construction of concentrator modules

In order to test our tandem solar cells also in their foreseen applications, we constructed modules including Fresnel lenses and concentrators (see also the title page). The aim is to test the installed concentrator cells over a longer period of time under outdoor conditions. The modules have a concentration factor of 120 at present. We apply technology for the production which was developed jointly with the Ioffe Institute in St. Petersburg, Russia. To produce the lenses, we use PMMA matrices, with which the Fresnel lens structure is embossed in a 2 mm thin silicone coating on glass. It has become evident that the quality of the lenses prepared in this way depends almost entirely on the quality of the individually diamond-cut matrices.

We mounted the III-V concentrator cells, which we had developed, in small test modules with an aperture area of 64 cm^2 for the outdoor measurements. A test module with four $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ tandem solar cells achieved an efficiency value of 24.8 % (fig. 2).

Development of PV cells for laser power transmission

"Laser power transmission" means wireless power supply with laser light. Laser light is sent to a consumer e.g. through an optical fibre and is then converted there to electricity with a PV cell. This makes a safe power supply feasible e.g. in explosive atmospheres. It is also possible to transmit data from a sensor via an optical fibre. We have developed photovoltaic cells specially for this application, which have a diameter of only 1 mm and can be integrated into commercially available transistor housings. The monochromatic radiation means that very high cell efficiency values can be attained. The cells we produced achieved an efficiency value exceeding 50 % for a radiation intensity of 6 W/cm^2 (fig. 3). Better cells for this

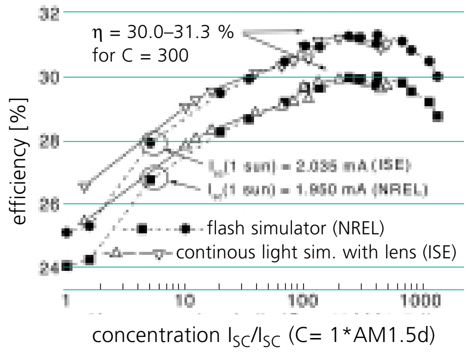


Fig. 1: Efficiency value of a $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ tandem cell under concentrated sunlight. Measurements from Fraunhofer ISE and NREL, Golden, USA are compared. The measurements differ essentially only in the short-circuit current under 1x AM1.5d. The concentration value is obtained, assuming a linear short-circuit current response, from $I_{sc}(C)/I_{sc}$ (at 1 sun).

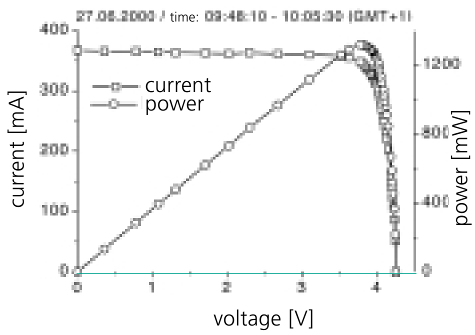


Fig. 2: Characteristic curve of a test module consisting of a Fresnel lens and four $Ga_{0.35}In_{0.65}P/Ga_{0.83}In_{0.17}As$ tandem solar cells. Specifications: η = 24.8 %, V_{oc} = 4.25 V, I_{sc} = 347 mA, FF = 84.4 %; P_{in} = 825 W/m^2 , Tamb = 15.6 °C. The aperture area is 64 cm^2.

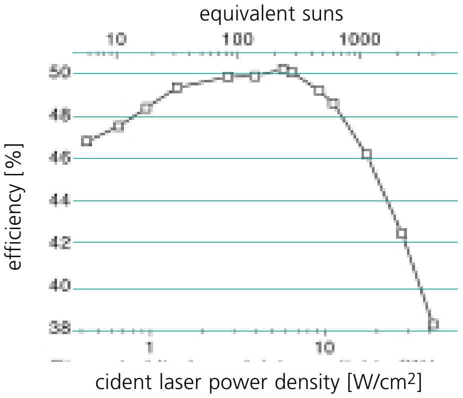


Fig. 3: Efficiency value of a PV cell with monochromatic radiation at 810 nm as a function of the incident radiation density.

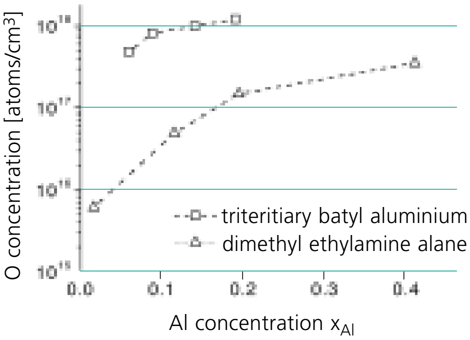


Fig. 5: Oxygen concentration as a function of the aluminium concentration for various source materials for MOVPE.

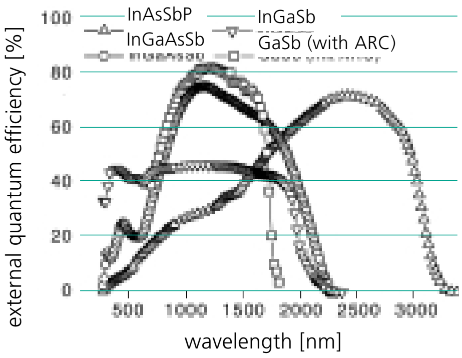


Fig. 4: External quantum efficiency of PV cells without an anti-reflective coating (ARC), produced from different low band-gap semiconductor materials. Only the GaSb cell had an ARC.

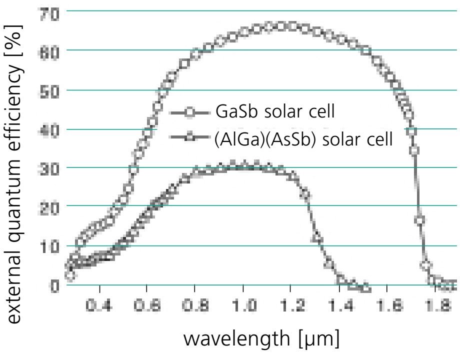


Fig. 6: External quantum efficiency of GaSb and (AlGa)(AsSb) photovoltaic cells without an anti-reflective coating, in which the pn junctions had been grown with MOVPE.

power range have not been reported in the literature. In the incident laser power range above 10 W/cm^2, significant improvements can still be expected.

Development of "low band-gap" photovoltaic cells

Gas phase diffusion process to produce pn junctions: Materials with small band gaps (e.g. GaSb, GaInAsSb, GaInSb) are used in thermophotovoltaic generators (see page 53). We apply Zn gas phase diffusion techno-logy to create pn junctions in these materials. This year, we continued our co-operation with the AstroPower company, USA and the Resselaer Polytechnic Institute, USA. We succeeded in developing photovoltaic cells with a spectral response up to an IR wavelength of 3 µm. Figure 4 shows the external quantum efficiencies of the following layer sequences:

- p-InAsSbP (Zn diffused) / n-InAsSbP (LPE) / n-InAs (substrate) epitaxial layer from AstroPower
- p-GaInSb (Zn diffused) / n-GaInSb (substrate); substrate from Resselaer Polytechnic Institute
- p-InGaAsSb (Zn diffused) / n-InGaAsSb (LPE) / n-GaSb (substrate) epitaxial layer from AstroPower
- p-GaSb (Zn diffused) / n-GaSb (substrate)

MOVPE of group III antimonides

III/V semiconductors containing antimony on GaSb substrates allow lattice-matched growth of crystals in the direct band-gap range between 0.5 eV and 1.1 eV. This means that solar cells of these materials are interesting both for thermophotovoltaic applications (see page 53) and also for stacked systems of the highest efficiency. The specific properties of crystals containing antimony present a particular challenge for the MOVPE process. The selection of suitable metal-organic source materials is a critical point for compounds containing aluminium. We investigated the suitability of tri-tertiary butyl aluminium (TTBAl) and dimethyl ethylamine alane (DMEAA) for depositing antimonides containing aluminium in our AIX2600G3 MOVPE system. The introduction of oxygen impurities into the material is of great interest. We were able to demonstrate that the purity achieved with DMEAA was clearly superior to that with TTBAl (fig. 5).

Drawing on the results from MOVPE for bulk crystals, we have begun to develop electronic component structures. We have already developed solar cells from binary GaSb, which function very well (fig. 6). Similarly, we were able to produce the first solar cells from a material with a 1 eV band gap, the system (AlGa)(AsSb), also shown in fig. 6. The development of a material with this band gap is of greatest interest in other areas of III/V MOVPE (e.g. semiconductor lasers).

Laboratory and Service Centre in Gelsenkirchen

The need to use increasingly large substrates and in-line processes with a high throughput in photovoltaic production makes it more difficult to transfer laboratory results into production steps. As a response to this development, Fraunhofer ISE has established an industrially relevant laboratory and service centre in Gelsenkirchen.

Christophe Ballif, **Dietmar Borchert**, Marco Gräßel, Stefan Peters, Alexander Poddey, Roland Schindler, Wilhelm Warta, Gerhard Willeke, Thomas Zerres

In the newly founded Laboratory and Service Centre in Gelsenkirchen, we carry out our research under conditions similar to those in industry. Almost a complete processing line is available, where production as in a factory and experimentation as in a laboratory can be carried out. Highly flexible, state-of-the-art, in-line processing equipment allows solar cell manufacturers to reproduce and improve their processes in the "laboratory", without having to interrupt industrial production. New processes can also be tested and optimised there, without the danger of disturbing production.

To this purpose, the "clean room" is equipped with a wet-chemistry bench, an in-line diffusion furnace with a rapid thermal processing module (see page 58), an in-line sintering furnace and an in-line PECVD unit. Substrates with dimensions up to 150 mm x 150 mm can be processed without difficulty.

Measurement technology, which enables the characterisation of the raw material, the individual processing steps and the final solar cell, is available to support the process development or optimisation.This measurement technology can also be used for fast trouble-shooting while production is running. The many different types of measurement technology, together with comprehensive know-how and further special procedures at Fraunhofer ISE in Freiburg, ensure quick response times if problems arise.

It is not only the photovoltaic industry which can benefit from the processing and measurement technology. Other semiconductor manufacturers can be assisted in particular aspects of semiconductor production or characterisation. Extensively automated, large-area measurement technology for substrates up to 6", or in some cases 8", means that very specific process monitoring of small series is possible.

Facilities:

Material characterisation:
- research microscope
- microwave reflection
- spectrometer
- ellipsometer
- film resistance mapping

Cell characterisation:
- solar simulator
- dark characteristic measurement stand
- filter monochromator
- stripping Hall
- SR-LBIC (spectrally resolved light beam induced current)
- thermography

ModuleTechnology:
- permanent outdoor test stand

Processing technology:
- 100 m^2 clean room
- wet-chemistry bench

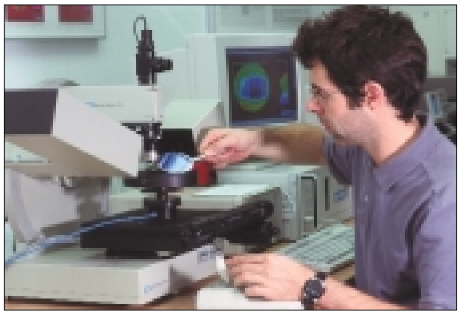
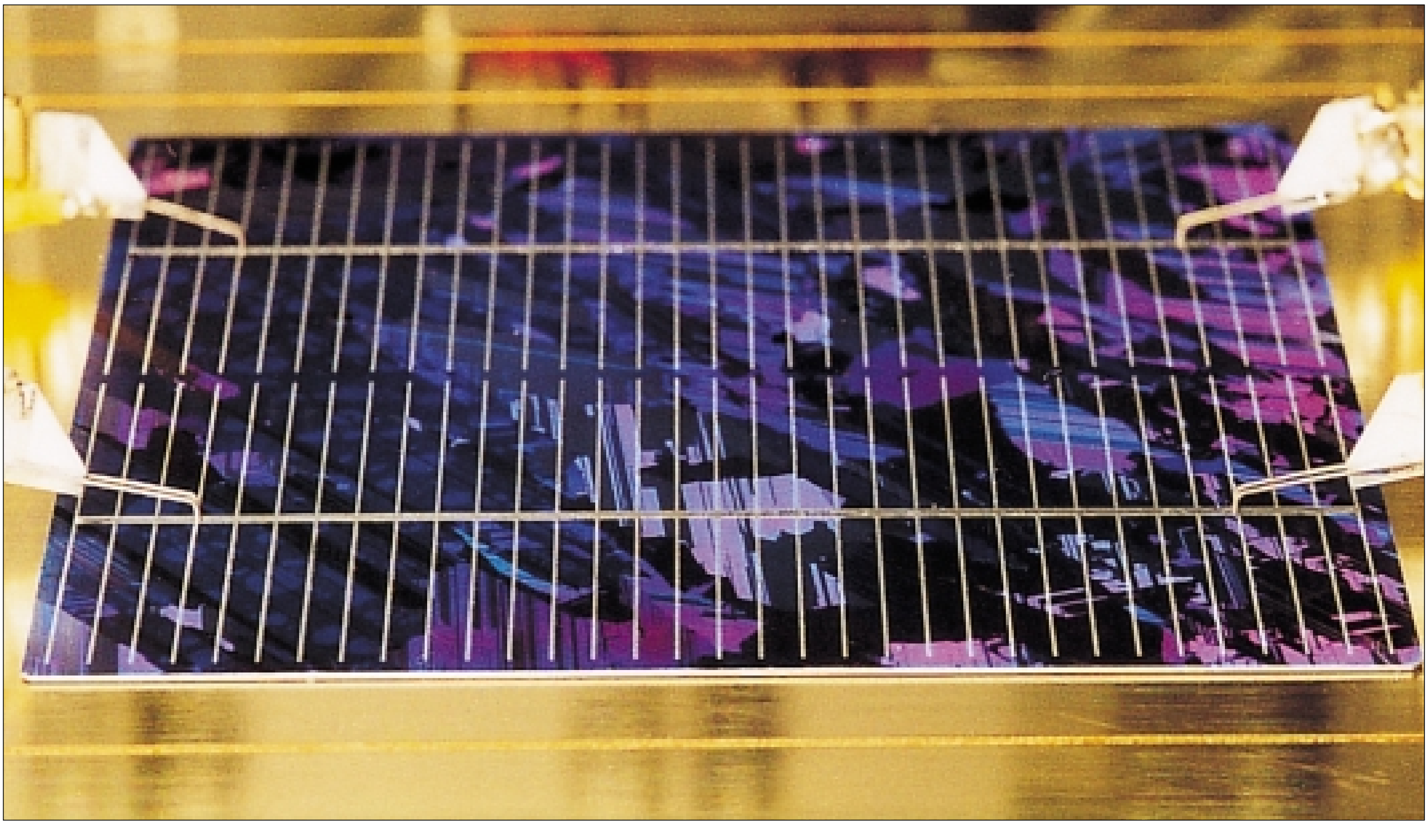


Fig. 1: Characterisation of anti-reflective coatings with the ellipsometer.

- spin coater
- evaporating unit
- in-line sintering furnace
- in-line diffusion furnace with RTP module
- in-line PECVD system with a deposition area of 450 mm x 450 mm

Services
- substrate characterisation
- contamination control
- process monitoring
- determination of diffusion profiles
- characterisation of solar cells
- processing of large-area silicon substrates, also as an in-line process
- reproduction and optimisation of in-line processes
- support to semiconductor manufacturers, in particular on questions concerning semiconductor production or characterisation
- deposition of silicon nitride and silicon oxide on commission to clients
- etching of silicon, silicon nitride and silicon oxide on commission to clients
- direct access to know-how at Fraunhofer ISE, Freiburg
- fast response times

ISE CalLab - Precision Measurement for Photovoltaics



Module measurement stand of "ISE CalLab", the photovoltaic calibration laboratory at Fraunhofer ISE, which is one of the internationally leading centres offering these services. High-quality facilities allow photovoltaic cells and modules of all types to be measured.

The characterisation of solar cells and photovoltaic modules plays a decisive role not only in research and development but also for production. It is equally indispensable for the comparison of products from different manufacturers as for the dimensioning and authorisation of photovoltaic systems.

The Photovoltaic Calibration Laboratory at Fraunhofer ISE (ISE CalLab) is one of the internationally leading laboratories in measurement technology for photovoltaics - with continuing quality assurance guaranteed by measurement comparisons and harmonisation with the Physikalisch-Technische Bundesanstalt (National Standards Laboratory) in Braunschweig. Not only internationally renowned manufacturers, but also the TÜV Rheinland have their reference cells measured by ISE CalLab.

The success of the calibration laboratory results from the fundamental aim of the Fraunhofer Society to combine research and applications: The scientific know-how is constantly kept up-to-date by research and instrument development at Fraunhofer ISE, and almost 20 years of experience with photovoltaic systems brings in the practical side. The orientation of ISE CalLab towards application is also demonstrated by its home page, http://www.callab.de. It provides information on technical details, gives prices and allows orders to be placed on-line.

One special feature of ISE CalLab is its bandwidth: The samples can be commercial silicon solar cells, dye-sensitised solar cells, thin-film technology or multiple-junction cells for 1000-fold concentration or even complete photovoltaic modules - ISE CalLab can measure any object which converts light to electricity via the photovoltaic effect. Researchers from all over the world come to Freiburg with their new developments, for a measurement result from ISE CalLab is internationally recognised at conferences and in the scientific journals.

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An Overview of the Photovoltaic Calibration Laboratory

The organisation of the Photovoltaic Calibration Laboratory "ISE CalLab" has been restructured to makes its services more efficient and transparent. In this contribution, an overview will be given of the three main areas, solar cell calibration, module measurement and instrument development.

Georg Bopp, Ulf Groos,
Heribert Schmidt, Wilhelm Warta

Our expertise

Thanks to our long years of practical experience in PV measurement technology, we can offer complete solutions to problems. In providing these services, our primary goal is to provide our clients with the solution which is most useful to them:

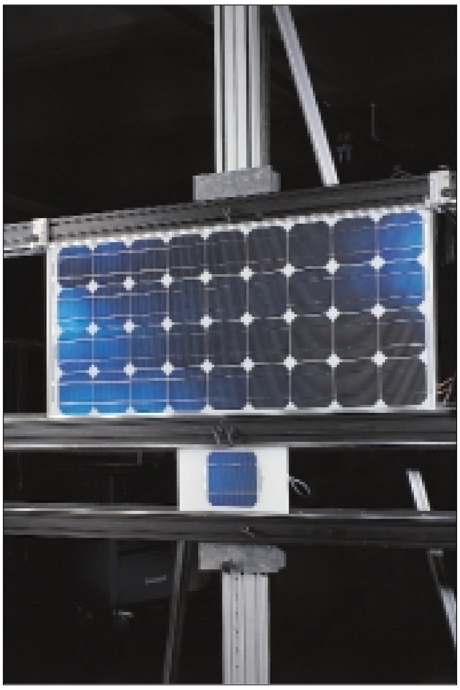


Fig. 1: Solar module and reference cell mounted for measurement with the pulsed solar simulator.

- reliable results, which are guaranteed by regular participation in round-robin tests with other internationally recognised measurement laboratories
- compliance with international standards in all calibration steps and in the use of reference elements and measurement facilities
- continuous further development of the measurement procedures in accordance with research activities at Fraunhofer ISE

Our services

- measurements for production control, testing of development results, preparation of product comparisons and ensuring guaranteed specifications
- intensive and competent advice on individual measurement requirements
- rapid, non-bureaucratic processing
- strict confidentiality guaranteed
- regular maintenance and testing of our measurement equipment

Cell calibration

We undertake extensive measurement series for characterising solar cells, detectors and PV mini-modules:

- calibration of standard solar cells (c-Si, a-Si, CIS, CdTe)
- calibration of dye-sensitised solar cells and IR solar cells
- calibration of concentrator cells and tandem cells
- calibration of reference cells
- spectral response measurement
- determination of the annual efficiency value of solar cells

Module measurement

We characterise PV modules of all constructions up to dimensions of 2 x 2 m^2:

- module measurement with a pulsed solar simulator
- outdoor module measurements
- determination of the NOCT temperature and power output
- measurement of the angular and temperature dependence of the module parameters
- determination of the annual efficiency value of PV modules

Instrument development

We develop and construct highly accurate measurement equipment to characterise solar cells and PV modules.

- steady-state radiation facility for cell and module calibration
- outdoor measurement stands
- pulsed solar simulator for cell and module calibration
- spectral measurement facility for cells and mini-modules
- WPVS reference cells
- instruments for quality assurance in module production
- software development for measurement data analysis

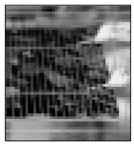
Our measurement facilities

ISE CalLab is equipped with high-quality measurement facilities to meet demanding measurement challenges.

- class A steady-state solar simulator (AM 1.5; AM 0)
- simulator with three light sources
- concentrating solar simulator (up to 1200 suns)
- pulsed solar simulator (AM 1.5)
- outdoor measurement stand
- filter monochromator (300 nm to 1400 nm)
- grating monochromator (300 nm to 1800 nm)
- various spectroradiometers
- measurement facility for dye-sensitised solar cells

Internet

For more detailed information, simply consult our Internet site at http://www.callab.de. From there, you can also place measurement orders simply by e-mail.



Calibration Reduces Costs for Photovoltaic Electricity

The work in ISE CalLab spans a wide range from fundamental to applications-orientated measurements. We present the characterisation of solar cells with highest efficiency values and the measurement of modules as examples.

Georg Bopp, Wilhelm Warta,
Rolf Beckert, Matthias Meusel, Tomislav Paradzik*, Gerald Siefer, Jürgen Weber

Multiple-junction solar cells are currently overtaking the power supply field in space. With efficiency values exceeding 30 % and concentration of the sunlight by more than a factor of 1000, these cells will also become extremely interesting for terrestrial applications in future. Fraunhofer ISE is at the international forefront in developing new structures for these cells (see page 61).

ISE CalLab is one of the few laboratories around the world which is able to determine the efficiency of these cells. International comparability is important not only for research: A difference of only a few percentage points in the efficiency values, if multiplied by high production volumes and high efficiency values, can have drastic effects on the costs of solar generators.

Solar cells with several pn junctions are very sensitive to details of the radiation spectrum. This makes it difficult to determine the efficiency value correctly under standard measurement conditions. Slight shifts between the red and blue portions of the spectrum can strongly affect the performance of the complete cell if one sub-cell is limiting the total current, which must flow through all cells due to the monolithic series connection.

To date, manufacturers of solar simulators have not succeeded in generating the standard spectrum so exactly ("close match" simulator) that measurement errors due to spectral effects are practically eliminated. The only accurate measurement method known consists of first measuring the spectral response of all the sub-cells, so that the operating state of the test cell under the standard spectrum and the simulator spectrum can be compared. The internationally practised, iterative procedure to match the operating state under the simulator spectrum to that under standard test conditions is very time-consuming.

We have developed a much shorter method, which replaces the whole iterative procedure by the solution of a system of equations. It provides the settings needed for our multiple-source simulator in a single step.

To check the reliability of our calibration, we compared our measurements with those from NREL, USA - beside ISE CalLab, one of the few laboratories around the world which can calibrate tandem solar cells. The values for not only the spectral response but also the efficiency value agreed very well.

Measurement of high-efficiency, large-area solar modules
Solar modules which are constructed of high-efficiency silicon, copper indium diselenide (CIS) or cadmium telluride (CdTe) cells, are difficult to measure correctly due to their high barrier layer capacity. In addition, large-area facade modules demand homogeneous illumination. Solar modules with an area of 2 x 2 m^2 can be illuminated homogeneously with the Class A pulsed solar simulator at Fraunhofer ISE. By applying the multiple-flash technique, also solar modules with a high barrier layer capacity can be measured accurately.

The standard measurement, with an accuracy of ±5 %, costs less than a standard 50 Wp module today. Thus, even for a 1 kW system, an initial measurement costs appreciably less than e.g. a ten-percent safety margin, which planners and installers often add to ensure "guaranteed yields" when they dimension their photovoltaic systems.

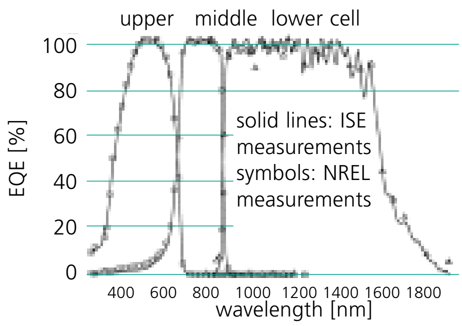
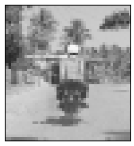


Fig. 1: Comparison of the measured values for the external quantum efficiency of the sub-cells of a triple solar cell from ISE CalLab and NREL. The high spectral resolution of the ISE CalLab measurement allows interferences to be seen for the lowest cell.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg

Electricity for Areas Remote from the Grid

Off-grid power with solar energy. Fraunhofer ISE is participating in numerous international projects on rural electrification. The work concentrates on optimising system components and quality assurance on site. The users are also involved in the project work with training sessions and initiation of micro-financing concepts. The photo shows a man in Indonesia transporting his Solar Home System before installation.



Whether power is needed for a telecommunications repeater in German mountains or for light in a mud hut in Morocco: Photovoltaics is often the cheapest alternative if there not a grid nearby. This is equally valid for the two thousand million people in threshold and developing countries and for the 400,000 houses in European mountainous regions.

In addition to Solar Home Systems, which with their rated power of 50 Wp represent the smallest "ray of hope" for rural areas in developing countries, we have been investigating photovoltaic systems of 1 - 20 kWp with increasing intensity for off-grid power supply. They make additional commercial activities or the operation of a clinic feasible. With regard to energy economics, they are interesting as the smallest unit in a decentralised, inter-connected grid. In grid-independent village power supplies, distribution of the electricity is a contentious issue. Our approach of developing the technology together with the local users has proven to be beneficial here. This is equally true for mountaineering lodges, where we have provided advice on planning, energy concepts and monitoring, in some cases for more than a decade now.

The conventional lead-acid battery is still the workhorse of photovoltaic systems technology. We develop new products for the battery industry and optimised charging procedures for solar applications. This results not only in higher usable storage capacities and efficiency values, but also extended lifetimes and thus reduced costs.

Clean drinking water is becoming an increasingly high priority. It affects not only the well-being of the consumers, but also the economic strength of a country. Often surface water is drunk without further treatment, with two thousand million cases of illness annually being the result. Photovoltaics can provide cheap and reliable electricity for disinfection with UV lamps, which do not alter the natural taste of the water.

When thousands of millions of people are affected, it means that there is also a potential market of several thousand million US dollars. We are involved nationally and internationally in promoting quality assurance and sustainable market development. In this capacity, we advise governments around the world and accompany market introduction programmes with our technical, sociological and economic expertise.

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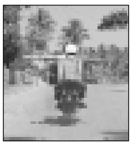


Strategies for Grid-Independent Village Electricity Supply - The Example of Rambla del Agua

At present, we are co-ordinating the installation of 17 photovoltaic village power supplies. Engineers and psychologists are working with technical and social concepts on the optimised use of community facilities, and are implementing these together with local enterprises.

Georg Bopp, Claudia Casper*, Johannes Koops,
Petra Schweizer-Ries, Gisela Vogt

Since January 2000, we have been co-operating with partner institutions from Spain, France, Portugal and Switzerland on the construction and further development of community-based, off-grid village power supplies in Spain.

In addition to the co-ordination, we are responsible for the following tasks:

- technical further development of information transfer and energy distribution; an infobus transmits data on the energy consumption of the individual households
- organisational and social support of the systems and their users to facilitate permanent operation

We are implementing research results from the engineering and social sciences directly in the demonstration project. While we are concerned primarily with the scientific aspects, the Spanish company, TTA, and the University of Vigo are constructing the demonstration systems in Spain and Latin America.

The work up to now has concentrated on socio-technological measures in the village of Rambla del Agua in Andalusia. There, 38 households have been supplied since 1997 with 230 V AC electricity from a system comprising a 10 kWp PV generator, a 3660 Ah/48 V battery and a 10 kVA back-up diesel generator.

We conducted 15 interviews with users of photovoltaic electricity, 3 with non-users and a further 6 interviews with key persons involved in the operation of the PV system at various levels.

Fig. 1: Solar festival in Rambla del Agua, Andalusia.

The interviews indicated:

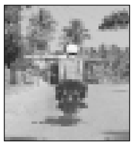
- The users are basically very satisfied with the power supply, but would welcome further technical improvements.
- There is great interest in more information on the system and its use.
- The household displays on "electricity distribution" and demand adaptation are not often used.
- Identification with the system is very strong in the village; the residents accept complete responsibility for service and maintenance.

We improved the automatic transfer of information on the status of the photovoltaic system. The status information determines the current electricity tariff via an energy monitoring instrument, and thus influences the user behaviour. Errors in the data transfer caused faults in the energy monitoring instruments; they were no longer able to fulfil their purpose. We introduced signal amplifiers, which rectified the errors.

In addition, we supported the organisation of a solar festival (fig. 1). The "Fiesta del Sol" was important to the whole process: It drew the attention of neighbours and politicians to the new technology, reinforced the identification of the villagers with their PV system and raised awareness about its sustainable use.

Further research work within this project, which is supported by the EU, will concentrate on another village. New technical and organisational measures are intended to guarantee permanent operation and an optimised distribution of energy there.

* free-lance



Village Power Systems in Indonesia

We conducted sociological and technical investigations in three Indonesian villages with central photovoltaic village power supplies. After staying in each village for several days, the investigation team, with German, French and Indonesian members, introduced technical and organisational improvements.

Michael Müller*, Klaus Preiser, **Petra Schweizer-Ries**, Sebastian Will, Birgit Uenze

We investigated the functionality and acceptance of three central photovoltaic village power supplies in Indonesia. Two of them had been installed by a French consortium in co-operation with the Ministry for Transmigration in Kalimantan and Sulawesi. They are operated according to the pre-payment scheme, which limits the supply of power to individual households and is based on the sales of energy units. The third system, which was equipped with Australian components, had been constructed by the Indonesian Ministry for Technology BPPT in Java. It did not include a pre-payment scheme.

We investigated the technical operation of all systems and interviewed users as well as those persons responsible for the maintenance, operation and electricity distribution in the village (figures 1 and 2). We came to the following conclusions:

- The French village power systems operate well. Only the satellite data transfer, allowing remote monitoring for research purposes, occasionally causes problems.
- The pre-payment scheme has the effect that much less electricity is used than originally planned. The users pay for their energy units in advance.
- The distribution of electricity was regarded as being fair in principle.
- Several inhabitants did not understand how the pre-payment scheme worked and wired bypasses to the meters.
- Operating weaknesses in "charging" the pre-payment systems additionally reduced the acceptance.
- Both the users and the Indonesian project managers would like to be more involved in the French project.
- The system on Java, with unrestricted access of the users to power and energy, is hopelessly overloaded and often has to be repaired.
- Measures to control the electricity consumption, such as subsequently installed power limiters, led to acceptance problems.
- Technical staff to operate the system and a village committee to organise the consumption were present in each village. Rules for usage are being prepared.

Together with the Indonesian partners, we implemented the following measures for one of the French systems:

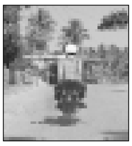
- correction of minor technical faults
- raising awareness of usage and energy consumption with the aim of controlling the increase in demand and discouraging bypasses to the meters
- involving the local government to assume responsibility for the technology at the end of the project
- preparation of a strategy for permanent use of the system, together with the future Indonesian owners

The conclusion to this project, which was supported by the European Union, is the evaluation of these measures and the preparation of recommendations for the introduction of future PV hybrid systems in rural areas of Indonesia.

Fig. 1: Investigation of a technical system: The photo shows on-site measurement of photovoltaic strings in operation. The measurements are made by an Indonesian staff member.

Fig. 2: Interview with a village inhabitant: With the help of staff from the University of Indonesia, we were able to conduct standardised and open interviews with 50 people from each village. The analysis was based on written records and tape recordings.

* PSE Projektgesellschaft Solare Energiesysteme mbH, Freiburg



Purification of Drinking Water with Photovoltaics for Remote Areas

Systems and methods to purify drinking water are available all over the world. Despite this, about 5 million people die every year from diseases which are transmitted via drinking water. Together with partners from Latin America and Spain, we have developed approaches for purifying drinking water and implemented them in five pilot villages.

Orlando Parodi, Klaus Preiser, Petra Schweizer-Ries

Fig. 1: Clean drinking water cannot be taken for granted in developing countries.

Fig. 2: San Antonio de Agua Bendita in Mexico: Disinfection of drinking water using a PV powered electrolysis cell.

Why, when water treatment with chlorine, ozone and UV radiation is widely known, are there still about two thousand million cases of diarrhoea each year caused by drinking water? We started the EU project on "Clean Water with Clean Energy" with this question.
Surveys in Morocco and 10 Latin American countries revealed the following information:

- In rural regions of developing countries, drinking water is often drawn from surface sources which are anthropogenically polluted.
- This water is usually not disinfected before consumption. From the consumers' perspective, the hygienic aspects of drinking water are secondary to taste, supply reliability and convenience.
- Rural regions often lack not only intact drinking water and sewage systems, but also electricity.
- Regulations on drinking water quality exist in almost every country of the world, but they are seldom enforced in rural areas.

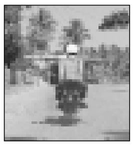
Commercially available chlorination systems, UV devices and systems based on the principles of anodic oxidation or microfiltration were all deemed to be fundamentally suitable for the boundary conditions listed above, but none of the tested systems could meet all the necessary specifications. Thus, we developed new, appropriate, PV powered systems. Finally, five different, energy-optimised systems were installed in five villages: Different dosing systems for sodium hypochloride, an electrolysis cell to produce chlorine gas and a UV system.

The fact that the inhabitants of most of the pilot villages now actually consume hygienically acceptable drinking water results from the interaction between the new technology and non-technical factors:

- At the beginning of the project, there was already a desire for clean drinking water or it was aroused by health education.
- Negative effects of disinfection, such as a change in taste, were largely avoided.
- The introduced technology was robust, easy to handle, largely automated and required little maintenance. Responsible persons were involved at the village level and within the appropriate government bodies.

After two years of operation, all of the systems are functioning reliably, without any breakdowns.

The results of the project on "Clean Water with Clean Energy" demonstrate that photovoltaically powered systems can make an important contribution towards supplying rural areas of developing countries with hygienically acceptable drinking water, if the technology and the introduction methods are chosen appropriately. We will therefore continue to develop such systems and methods to introduce them.



Monitoring by Fraunhofer ISE Maintains High Quality Standards for Solar Systems on Mountain Lodges

Fraunhofer ISE has already been co-operating with the German Mountaineering Club (DAV) for ten years in the application of solar energy to mountain lodges. Initially, there were only a few technically mature charge controllers and inverters on the market, so that the emphasis was on technological development and practical tests. Today, system optimisation, standardisation and quality assurance are the primary aspects. The Institute now supports about 30 lodges with its monitoring programme.

Klaus Kiefer, Georg Bopp, Martin Schulz*, Petra Schweizer-Ries, Eberhard Rössler*

In the "EURALP" joint project, which is funded by the Commission of the European Union, 17 off-grid photovoltaic systems on mountain lodges belonging to the DAV are being monitored and the measurement results analysed. This project allows valuable knowledge to be gained on the optimal interaction between system components such as the solar generator, storage unit and electric appliances.

On commission to the DAV, we are co-ordinating the technical aspects of the project with our European partners, the Austrian Mountaineering Club (OEAV) and the Spanish consumer association SEBA. The projects which have already been completed are located in the Austrian and German Alps and the Spanish Pyrenées.

* free-lance

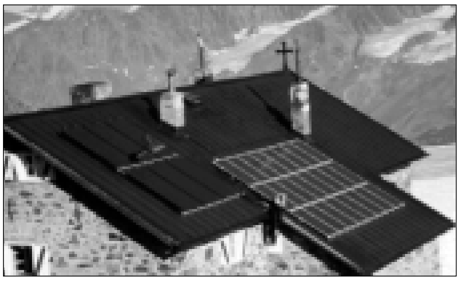


Fig. 1: Photovoltaic modules and collector field on the south-facing roof of the Brandenburger Lodge, the highest lodge of the DAV at an altitude of 3277 metres above sea-level.

All of the mountain lodges which were equipped as part of the project are electrically autonomous systems, as they are not connected to the public grid. The photovoltaic generator supplies most of the electricity in almost all of the systems. Diesel generators or wind generators increase the supply reliability during extreme demand peaks or overcast weather periods. These hybrid systems can often meet the severe demands on electricity quality and system reliability for a lower cost than purely photovoltaic systems.

A solar power supply does not simply imply that one source of energy is replaced by another, but also includes optimising the consumer side: For instance, the electricity consumption in the Tölzer Lodge was halved by installing compact fluorescent lamps and energy-saving appliances. Since the installation of the 3 kWp photovoltaic system, about 1200 litres of diesel oil have been saved each season.

We have summarised the experience and results from EURALP in a 16-page brochure (in German). This is available from the Munich office of the DAV, www.alpenverein.de.

Fig. 2: Tölzer Lodge, at an altitude of 1825 metres above sea-level. The entire electricity demand is met by 35 m^2 of solar cells with a rated power of 3.5 kWp and a 750 W wind generator.

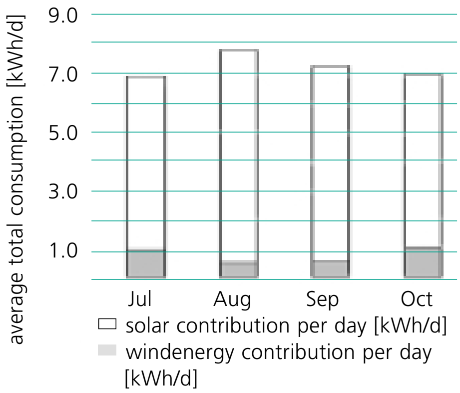


Fig. 3: Monthly electricity consumption of the Tölzer Lodge in kWh per day, from July to October. Solar energy provides 85 % and wind energy 15 % of the demand.

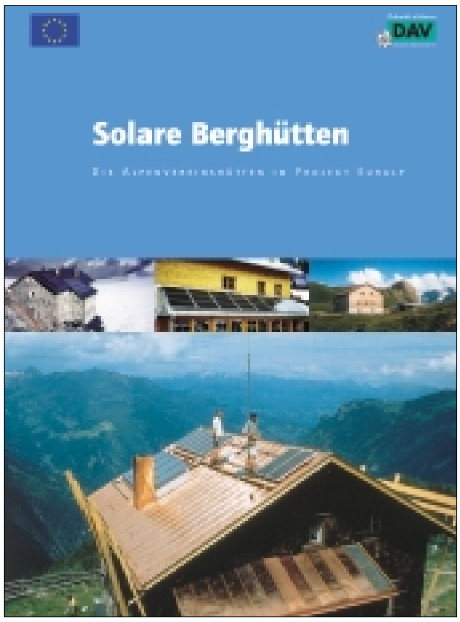
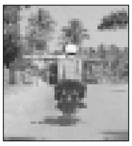


Fig. 4: Information brochure published by the DAV on the EURALP project.



Electromagnetic Compatibility of Photovoltaic Systems and Components

We help to ensure the electromagnetic compatibility (EMC) of new equipment under development and already installed systems, with our stationary and mobile EMC measurement technology and our experience in standardisation.

Georg Bopp, Thomas Erge, Steffen Schattner

Fig. 1: View into the EMC measurement chamber at Fraunhofer ISE.

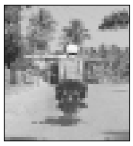
The increasing density and interference potential of electric components, devices and systems means that their electromagnetic compatibility is becoming an increasingly important quality aspect. "Electromagnetic compatibility" of a device means that it does not disturb its electromagnetic environment by more than a moderate amount. On the other hand, it should be sufficiently resistant to disturbing influences in its own environment. The limiting values are defined in extensive standardisation literature.

Of course, photovoltaic systems are not immune to electromagnetic incompatibility. On the contrary: Television and radio reception was disturbed by some of the photovoltaic systems in the 1000 Roofs Programme. Interference with telephone and radio systems was also reported. In Solar Home Systems, it is often impossible to receive medium-wave radio transmissions after lights with their electronic ballasts have been switched on.

In larger PV systems, it is primarily the extensive DC side with its - unfortunately - excellent antenna properties which is responsible for the disturbances. Awareness of this aspect of EMC has only developed gradually among the manufacturers of potential sources of interference, such as inverters and charge controllers. The boundary conditions are not conducive either: The technical standards are still being written. Nevertheless, the law obliges the manufacturer to ensure EMC. This is unsettling for the manufacturers. Often they do not know how to proceed or which standard is applicable.

We are able to help here: Within an EU research project together with the Dutch partner, KEMA and the Swiss partner, HTA Burgdorf, we have prepared an up-to-date overview of standards, measurement configurations and recommendations, and applicable limiting values. Specifically for the DC side, a line impedance stabilisation network (LISN) was defined for simple and reproducible measurements and limiting values were recommended for the international standardisation process. This limit must be observed whenever a new device is developed. Up to 500 kHz, the DC limit of EN 55014-1 is applicable; at higher frequencies it is about halfway between the AC and DC limits of this standard.

We advise our clients with respect to limits, accompany developments with measurements in our shielded EMC measurement chamber or certify products within the Fraunhofer EMC consortium. Improvement of a product to meet the standards at an early stage in its development is generally much less expensive than subsequent measures. However, we are also able to help with our mobile EMC measurement technology if disturbance from PV systems arises on site (this also applies to protective measures against lightning or overvoltage). For Solar Home Systems, we have developed a reliable and inexpensive recommended procedure for measurements in the laboratory and on site.



Batteries - Core Components for all Stand-Alone Power Supplies

The operating conditions for batteries in stand-alone power supplies differ appreciably from classical applications. We characterise various storage technologies in the laboratory and in field tests. We develop charging strategies, charging electronics and algorithms to give reliable indications of the state of charge and the ageing condition of the batteries.

Oliver Bohlen, Edward Gareis, Rudi Kaiser, Jérôme Kuhmann, **Dirk Uwe Sauer**, Heribert Schmidt, Birgit Thoben, Gerrit Volck

Battery storage units are needed in all stand-alone power supplies with a continuous energy demand. This applies for mobile devices (e.g. mobile phones, laptops), stationary technical devices (e.g. timetable displays, signal systems) and for household power supplies (e.g. Solar Home Systems, mountain lodges, village power supplies). Profound knowledge of the storage unit is an essential basis for successful system development. The primary aim of our activities is to optimise the complete system and minimise the costs of the storage system.

We investigate small batteries for applications in appliances. Currently we are studying lithium ion batteries and rechargeable alkali manganese (RAM) cells. We concentrate on typical stresses found in stand-alone power supplies, such as very low currents during charging and discharging, high and low temperatures, infrequent complete charging and long periods in the partly discharged state. We test the batteries both under controlled conditions in the laboratory and also under real operating conditions outdoors with detailed measurements.

Today, larger systems still use lead-acid batteries almost exclusively. In recent years, increased use has been made of closed, maintenance-free batteries. However, appropriate charging strategies are still being sought for use in photovoltaic power supply systems, which adequately meet the demands of both the batteries and the system with its users. Together with battery manufacturers, we investigate charging strategies in comparative field tests and analyse the results with respect to lifetime and system performance. The knowledge gained is applied in improvements to charge controllers or device and system controls.

In order to gain more insight into the ageing behaviour of batteries, we also develop detailed models. Suggestions to improve operation and the battery design are based on these. In future, we aim to determine the lifetime of lead-acid batteries after only a short testing period, using a combination of electrochemical tests and modelling. Simplified models are also used in our simulation programs for system design.

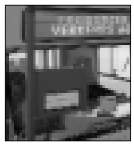
Modern power electronics and the general avoidance of current-smoothing elements like capacitors and inductors mean that batteries today are subjected to an increasing proportion of AC current components. The effects are still largely unknown or are the subject of considerable controversy. Within a project funded by the European Union, we are investigating the effect of pulsed currents on the electric performance and the ageing of lead-acid batteries. We were able to demonstrate that the real charge transfer in the batteries is appreciably higher than is measured with standard measurement technology. The reason is that charging and discharging currents occur simultaneously. The resulting battery current can reverse its polarity with a frequency between 1 and 300 Hz, which can result in a charge transfer which is up to 20 % higher than assumed, depending on the system.

In order to supply high system voltages, many individual lead-acid batteries must be connected in series. The weakest link (e.g. a damaged cell) determines the performance of the entire system. In order to guarantee maximal system performance even when individual cells are defective, we develop charge-equalising systems (CHargeEQualizer). They are now equipped with an integrated battery monitoring system with monitoring and analysis of the individual cells.

To enable integration of the storage unit into devices and systems, the system management requires continuous information on its state. This includes not only the state of charge but also the instantaneous capacity, an indicator for the ageing status of the battery. To this purpose, we are developing algorithms which do not require sophisticated measurement technology and which can be easily integrated into the microcontrollers of charge controllers, device controls and energy management systems.

Development of Products and Components

Fraunhofer ISE co-operates with industry to develop products with photovoltaic power supplies. Shown here is an information board for bus and tram stops, which displays the next connections and informs about delays. An energy management system monitors and controls all components involved.



Products which are powered by the sun are more convenient, save battery costs or replace expensive grid connections. Already in 2001, there will be more than four thousand million portable electronic appliances such as radios, mobile phones, camcorders or palmtops. Industrial applications of photovoltaics include decentralised facilities for telecommunications, information technology and traffic direction.

Each application has its own specifications for the power supply. For telecommunications, it is 100 % availability, which we can guarantee with hybrid systems. In the consumer sector, the trend is towards smaller and more powerful devices. Our answer to that is miniaturisation and efficiency, for good appliances demand excellent components: High-efficiency solar cells, sophisticated energy management, low-power electronic components, surface mounted devices (SMD), optimised battery periphery.

Solar power supplies are characterised by high flexibility and efficiency, so we adapt the electronics to each specific application. For instance, we have paved the way to a completely new family of products with our DC/DC converter for very high currents and extremely low input voltages. Another example is our energy management system, which efficiently combines very diverse electricity generators, loads and storage units. It "learns" from the user behaviour and can be adapted to very different applications. The future belongs to lithium ion rechargeable batteries for many applications. We determine their suitability with long-term investigations, both in the laboratory and outdoors, and define optimal areas of usage.

In addition to scientific competence, our second asset is the practical experience we have gained over 19 years of co-operation with manufacturers and users. After all, it is not the concept but the market success which is decisive. Thus, we observe what the market needs and ensure that we can provide it. As a consequence, we promote comprehensive quality assurance - not only at the Institute, but in national and international bodies - to ensure high-quality components and systems.

We also develop interactive exhibits for information and training purposes, which are not only unique but are also fun to encounter. Apart from their teaching value, also an attractive marketing idea!

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Photovoltaics for Appliances and Small Systems

The aim of our activities is to develop marketable appliances and small systems with photovoltaic power supplies. We specialise in supporting small and medium-sized enterprises to exploit the potential offered by photovoltaics for diverse, innovative products.

Sergej Aingorn, Jochen Benz, Jérôme Kuhmann, **Werner Roth**, Wolfgang Schulz, Andreas Steinhüser, Gerrit Volck

Photovoltaically powered products are the main focus of the programme on "Photovoltaics for Appliances and Small Systems", which is funded by the German Federal Ministry of Economics and Technology BMWi. Further, the development of components and measurement instruments for use in small photovoltaic systems can also be supported. Small and medium-sized enterprises, as defined by EU subsidy guidelines, are eligible to apply. They can choose between two different forms of support:

Co-operation between an enterprise and Fraunhofer ISE

This form is directed mainly toward enterprises which do not have much experience with photovoltaics, do not have suitable laboratory equipment or wish to draw on the experience of Fraunhofer ISE. We support the enterprise within the framework of a co-operation agreement. The spectrum ranges from consultancy to joint development of marketable products. We concentrate on system design, photovoltaic electricity generation, energy conditioning, energy storage, reduction of consumption and energy management.

Development work carried by the enterprise

Here, the enterprise is completely responsible for making the development. It receives a grant of maximally 35 % of the costs which are eligible for the subsidy.

This year, we co-operated with industrial partners to develop photovoltaically powered products for lighting technology, water purification, public transport, measurement technology and information technology.

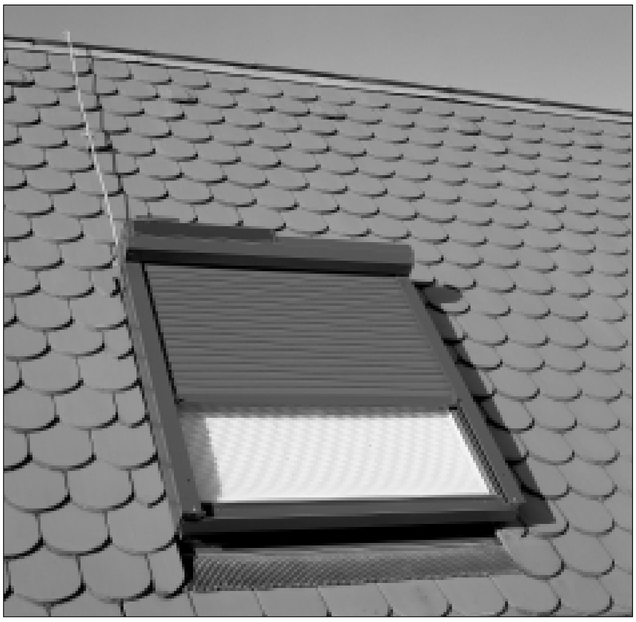
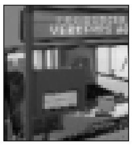


Fig. 1: Photovoltaically powered roller blinds: Maintenance-free and convenient to operate with remote control (photo: WAREMA).



Photovoltaic Information Centre for Shell Solar Deutschland GmbH

Solar energy is considered to be simple technology. But how many people really know how a solar cell operates? Who is well informed about the sun's path or the interactions between the components of a solar system? Who still has an overview of the current state of research? We have answered these and other questions posed by interested laypeople by setting up interactive high-tech exhibits.

Stefan Glunz, Andreas Häberle*,
Jürgen Ketterer, Hans-Georg Puls,
Bernhard Schmidt**,
Heribert Schmidt,
Andreas Steinhüser

On commission to Shell Solar Deutschland GmbH, Fraunhofer ISE designed and constructed interactive exhibits for the Photovoltaic Information Centre in Gelsenkirchen. The existing exhibits cover the following topics:

From sand to silicon wafers

Among other items, a sand pillar two metres high demonstrates the high silicon purity required for manufacturing solar cells (1:1,000,000,000). An original wire saw demonstrates how individual solar cells are sawn out of silicon blocks.

Production of silicon solar cells

An animated video illustrates absorption of light, generation of free charge carriers and recombination in an intrinsic (undoped) semiconductor. Active displays explain concepts such as "doping" and "p and n conduction". A unique mechanical model with liquids of different colours - like the popular "Lava Lamps" - demonstrates the operation of a solar cell.

Overview of a wide range of solar cell technology

Twelve different types of solar cell technology are exhibited in a showcase. The spectrum ranges from the monocrystalline silicon solar cell, through the dye-sensitised cell, to the monolithic tandem solar cell of GaInP/GaAs for space applications. Each exhibited solar cell is described briefly on an information board. This includes the graphical representation of the usable portion of the AM 1.5 spectrum. In addition, the physically possible efficiency value, the highest value achieved in the laboratory and typical efficiency values of commercial solar cells are specified.

From the cell to a system

A 50x magnified cross-section shows the construction of a solar module. The mechanical robustness of solar modules is impressively demonstrated by regularly dropping a steel ball from a tower onto a module. An electronic system construction kit combined with a professional simulation program allows visitors to become acquainted with different photovoltaic systems and their design.

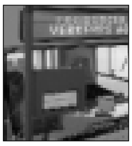
Laboratory bench for photovoltaic systems technology

Three experimental set-ups demonstrate all aspects of series and parallel connection of solar cells, MPP tracking and the effect of orientation, tilt and shading on the energy yield of solar modules.

Fig. 1: Visitors to the Photovoltaic Information Centre in Gelsenkirchen.

The demonstration of complex phenomena, e.g. of connecting solar cells, by the exhibits is physically correct, yet also entertaining. Facts which an engineer carefully clarifies for himself with formulae and functions can be appreciated immediately by the visitor by looking or touching: Partial shading with a hand results in a clearly visible downturn in the characteristic curve. A lower yield, i.e. less energy, becomes evident as a smaller amount of water pumped into a reservoir. Less power transforms a jet of water to a tired trickle. Even experienced technicians and scientists gain a new feeling for the interactions presented. Not to mention the pleasure of simply playing, which captivates visitors of all ages and educational levels.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg
**Ingenieurbüro Schmidt, Neunkirchen



Customised Measurement Units for the Photovoltaic Industry

Our spectrum of solar cell and module calibration services calls for comprehensive measurement units tailored to the various solar cell technologies. These measurement units are generally not commercially available. Each one is individually developed in the Calibration Labor-atory of Fraunhofer ISE (ISE CalLab) according to the specific requirements of the relevant solar cell technology. We now offer this know-how to the photovoltaic industry and supply complete measurement units as specified by our clients.

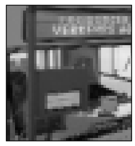
Sybille Baumann, **Stefan Brachmann**, Heribert Schmidt

Fig. 1: Solar simulator to characterise CIS modules, developed and constructed for the Siemens Solar company, Munich.

One particular feature of our offer is its diversity. Whether for thin-film technology, dye-sensitised solar cells, multiple-junction cells, cells for 1000x concentration or crystalline silicon solar cells - we develop customised measurements units distinguished by high accuracy and convenient operation.

These measurement units are used in the photovoltaic industry and in research institutions. The following have been constructed to date:

- spectral measurement unit for dye-sensitised solar cells. This equipment allows the reference and test solar cells to be measured simultaneously, thus reducing the calibration time considerably.
- combined measurement unit for the spectral response and I/V characteristic of solar cells. The special feature here is that the mechanically sensitive solar cell can be completely characterised at one position.
- filter monochromator measurement unit for large-area silicon solar cells. This equipment to determine the relative and absolute spectral response allows the sample to be illuminated very homogeneously with monochromatic light over a large area.
- spectral measurement unit with a grating monochromator for thin-film technology. In addition to the spectral response of solar cells, the transmittance of coated glass can be determined over a large spectral range with this facility.
- measurement unit to determine degradation effects in solar modules under outdoor conditions. With this set-up, the module is operated at the maximum power point (MPP) and I/V characteristics are measured and saved at freely programmable intervals.
- solar simulator to characterise solar cells and small modules up to 30 x 30 cm^2. Here, the sample holder can be moved out of the radiation plane to be contacted under better working conditions (fig. 1).



Stand-Alone Power Supplies for Telecommunications, based on Photovoltaics, Fuel Cells and a Hydrogen Seasonal Storage Unit

We develop stand-alone power supplies for telecommunications systems. They are based on photovoltaic generators with hydrogen-fuelled fuel cells as the back-up power supply. In a second step, an electrolyser makes complete autonomy feasible.

Jochen Benz, Beatrice Hacker, Angelika Heinzel, Hans-Georg Puls, **Dirk Uwe Sauer**

Repeaters for telecommunications are often located in remote areas. A combination of a photovoltaic generator, a fuel cell and a conventional battery can make them independent of logistically complicated fuel deliveries. For the first development stage, the hydrogen is still delivered in gas cylinders. In the second stage, we will integrate an electrolyser together with a hydrogen storage unit into the system. This will result in a completely autonomous system with seasonal energy storage. Minimised maintenance and 100% availability of electricity is given the highest priority.

At present, we are developing prototypes under the leadership of Alcatel, Spain, drawing on the experience gained with the self-sufficient solar house in Freiburg (commissioned in 1992). We are now further developing the system concept, which was demonstrated for the first time then, for broad technical application. In addition to developing concepts, we are involved in the project with planning tools and system components.

System design

In order to achieve continuous system availability at low cost, we are optimising the system design on the basis of lifetime costs. To this purpose, we are using and extending our TALCO simulation program (technical and least cost optimisation). The program optimises the complete system after all the technical and economic parameters describing the components have been entered. The output is the system cost and the dimensions of the individual components.

Seasonal Energy Storage System

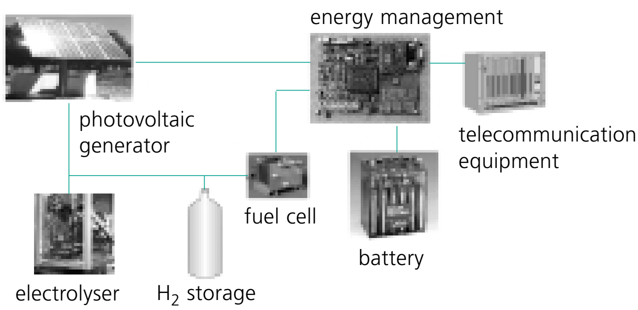


Fig. 1: Schematic representation of the stand-alone power system with seasonal hydrogen storage. This system will be implemented in the second project step, in co-operation with manufacturers of photovoltaics, fuel cells and telecommunications.

For the system to be implemented in the first stage, with a fuel cell and externally supplied hydrogen, the price of the hydrogen cylinders turned out to be the most critical parameter for the system dimensioning. The costs for generating a kWh electricity from hydrogen are two to three times higher than for photovoltaic generation. Thus the system design varies considerably, depending on the price development assumed for hydrogen.

Energy management system

The central control unit of the system is an energy management system (EMS), based on a microprocessor unit with an extremely low electricity consumption. The EMS controls and monitors all the energy flows and the system state. It calculates the battery state-of-charge, connects in the electrolyser and fuel cell at the optimal times and make automatic tests of all components, including the battery. Remote monitoring is possible via the EMS.

Elektrolyser

As illustrated in fig. 1, the stand-alone power supply will also become independent of hydrogen deliveries in the second stage. Hydrogen will be produced in summer with the excess electricity from the photovoltaic generator, and stored in a metal hydride unit. The hydrogen is produced in a pressure electrolyser with a polymer electrolyte membrane, which was developed at Fraunhofer ISE. The result is a system with seasonal energy storage (electrolyser - hydrogen storage unit - fuel cell). The power will be about 1 kW. Outdoor operation of the electrolyser at temperatures below the freezing point presents a particular challenge, if maintenance is to be kept minimal. At present we are working on measures to allow the electrolyser to "survive" the winter.

The PV fuel cell system will be taken into operation under real outdoor conditions in Madrid in the first quarter of 2001, and the system with seasonal storage will follow in the second quarter of 2002. The EU is funding the project.

Grid-Connected Photovoltaics

Photovoltaics is becoming increasingly popular as an element of solar building. Fraunhofer ISE is incorporating functional elements in its new premises. A view into the saw-toothed roof construction of the atrium: The photovoltaic modules integrated there are installed within the double glazed units. In addition to providing thermal insulation in winter, they also serve as sun-shading elements in summer.

The 100,000 Roofs Programme and the Renewable Energy Law have stimulated a rapid upswing for photovoltaics in Germany. We accompany market introduction programmes of this type and accept responsibility for planning, dimensioning, authorisation and monitoring of the systems. With payments of 0.99 DM/kWh for electricity supplied to the grid, careful planning for an optimal yield is certainly warranted. Ten years of monitoring have taught us where weaknesses can be expected and how they can be remedied quickly.

Not only operators, but also manufacturers profit from our experience. The best example is given by inverters, which are now characterised by an operating availability of 99 %, and have become an export success.
A strong increase in the number of enquiries from architects and civil engineers indicates that photovoltaics is developing swiftly in its role as an element of solar building. PV modules fulfil many different functions in buildings, including aesthetic purposes, daylighting and shading, as well as electricity generation. We identify the desired solution with simulation programs.

In co-operation with industrial partners, we are working toward the intelligent electricity grid of the future, which will allow a growing proportion of renewable energy to be incorporated. The most obvious new feature is the communication channel, which e.g. can switch decentralised power plants or storage units in or out as needed. Many complementary generators drawing on PV, wind, water and biomass, together with storage and control elements, will ensure that the electricity customer does not notice the transition to a sustainable energy economy, because the convenience and reliability of the grid will remained unchanged.

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Photovoltaics in buildings	Hermann Laukamp Dr Karsten Voss	Tel.: +49 (0) 7 61/45 88-2 75 E-Mail: Hermann.Laukamp@ise.fhg.de Tel.: +49 (0) 7 61/45 88-1 35 E-Mail: Karsten.Voss@ise.fhg.de
Energy storage in electricity grids	Dirk Uwe Sauer	Tel.: +49 (0) 7 61/45 88-2 19 E-Mail: Dirk-Uwe.Sauer@ise.fhg.de

The 120 kWp Photovoltaic Training System of the Cologne Trades Corporation - Butzweilerhof

We designed the technical part of this demonstration project for different types of photovoltaic technology and provide scientific support to the project.

Thomas Erge, Alfons Armbruster*, Klaus Kiefer, Eberhard Rössler**, Edo Wiemken

The photovoltaic system on the "Butzweilerhof" building of the Cologne Trades Corporation (Handwerkskammer) was installed in 1999 and 2000. In addition to the photovoltaic generation of electricity, the aim of this project is to demonstrate technical, architectural and economic aspects of photovoltaics, and to integrate these into the training programmes of the Trades Corporation.

Fig. 1: PV façade system as shading for the associated training rooms.

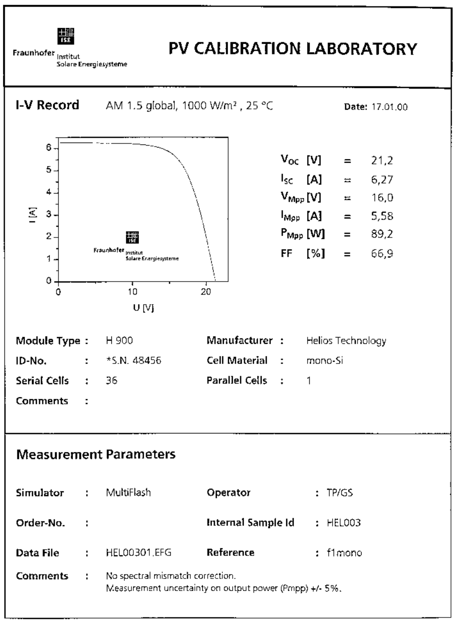
Fig. 2: Integration of PV roofing tiles into the roof of the "Butzweilerhof" Training Centre.

The complete system consists of about 1400 modules with a total power of about 120 kWp. They are distributed among three subsystems:

- 103.5 kWp flat-roof system, consisting of one system section with a central inverter (50 kWp), another system section with string inverters (44 kWp) and a third system section with module-integrated inverters (9.5 kWp).

- 9.0 kWp façade system consisting of vertical and tilted facade elements. The tilted modules are mounted above the windows and shade the associated rooms from the high-standing summer sun.

- 7.5 kWp training systems, which were installed as three separate small systems to illustrate different roof installation procedures on a specially constructed training roof. The demonstrated technologies are roof integration, stand-off installation and installation of photovoltaic roofing tiles. The installation here includes a small stand-alone battery system with special energy management.



Fraunhofer Institut Solare Energiesysteme

PV CALIBRATION LABORATORY

I-V Record AM 1.5 global, 1000 W/m², 25 °C **Date:** 17.01.00

V_{OC}	[V]	=	21,2
I_{SC}	[A]	=	6,27
V_{Mpp}	[V]	=	16,0
I_{Mpp}	[A]	=	5,58
P_{Mpp}	[W]	=	89,2
FF	[%]	=	66,9

Module Type :	H 900	**Manufacturer :**	Helios Technology
ID-No. :	*S.N. 48456	**Cell Material :**	mono-Si
Serial Cells :	36	**Parallel Cells :**	1
Comments :			

Measurement Parameters

Simulator :	MultiFlash	**Operator :**	TP/GS
Order-No. :		**Internal Sample Id :**	HEL003
Data File :	HEL00301.EFG	**Reference :**	f1mono
Comments :	No spectral mismatch correction. Measurement uncertainty on output power (Pmpp) +/- 5%.		

Fig. 3: Shortly before the systems were installed, the Calibration Laboratory at Fraunhofer ISE (ISE CalLab) characterised selected modules in detail.

We planned all the photovoltaic generators on commission to the Cologne Trades Corporation, taking not only the electrical concept but also the specific building and architectural requirements into account.

We are monitoring the system operation in a scientific monitoring and analysis programme. This provides us with extensive data series, which serve both in the training courses offered by the Trades Corporation and for scientific analysis at Fraunhofer ISE. One of our goals is to compare the different system concepts with respect to their operating performance, reliability and efficiency.

We are designing and programming Internet pages with on-line access to selected measurement data for the public presentation of the project. This will be found at the Internet site of the Cologne Trades Corporation: http://www.handwerkskammer-koeln.de.

The photovoltaic system complex was funded by the European Union and the State of North-Rhine Westphalia.

* PSE GmbH Forschung Entwicklung Marketing, Freiburg
** free-lance

Towards the Electricity Grid of the Future

We are working in a consortium of 17 partners from industry and research on a decentralised grid structure with an integrated communication system. The aim is a high-quality power supply and the greatest possible flexibility for technical and economic options.

Heribert Schmidt, Thomas Erge, Angelika Heinzel, Dirk Uwe Sauer, Dieter Schlegel

The Karlsruhe Stadtwerke (city utility), Fraunhofer ISE in Freiburg, EUS GmbH in Gelsenkirchen and Siemens AG in Erlangen are managing the consortium, which calls itself "EDISON". The consortium has set itself two tasks to be completed by 2003: adaptation of the energy distribution grids to the liberalised electricity market, and preparation for modern technology such as renewable energy.

EDISON combines energy distribution with information processing and is developing decentralised components for the new grid structure. Examples of components include:

- power quality equipment, which e.g. compensates for voltage breakdowns
- local electricity storage units, which ensure a homogeneous energy flow
- decentralised electricity generators such as photovoltaic and wind energy systems, or heat/electricity cogeneration plants with fuel cells.

Together with decentralised energy management systems, these components open up new options for demand-relevant control of energy flows in extended electricity distribution networks.

This applies, for instance, when cogeneration plants based on fuel cells are introduced, which can both meet peak electric loads and supply heating energy. The energy utility can use cogeneration plants particularly efficiently if their electric output can be controlled according to the demand. The decentralised communication structure allows access to the electricity generator at any time. This means that expensive grid extensions can be avoided.

Another application is to meet a temporarily raised demand for electricity in an environmentally friendly way in grid segments which were not designed for this load, e.g. the power supply for building sites or folk festivals. Mobile storage batteries with an energy management system can eliminate the need for large diesel aggregates or costly expansion of grid structures.

Thus, the introduction of additional decentralised generators and storage units may not be measured economically, purely on the basis of the electricity production costs or the savings in electricity trading which result from reducing the peak load. The essential savings for the utility arise from the avoided investments for extending the grid with power lines and transformers.

We are primarily responsible for two scientific sub-projects for EDISON:

- sub-project 2, "Energy storage and conversion units"
- sub-project 7, "Monitoring and analysis of results"

In sub-project 2, we co-operated with partners to initially document the state of the art concerning energy storage and conversion units. We are testing components in the laboratory to investigate their operating characteristics and to determine technical parameters. Based on this, we develop new hardware and software to optimise their operation.

In sub-project 7, we are comparing the currently used, decentralised energy conversion and storage units by analysing the system data on energy and power. The data are transferred on-line from the decentralised operation management system to the process management system and then stored in our data bank. In addition, we install measurement sensors and data loggers in selected systems or components.

The EDISON project is supported by the German Federal Ministry of Economics and Technology BMWi.

Building Integration of Photovoltaic Systems: The New Premises of Fraunhofer ISE as an Example

Five photovoltaic systems with a total rated power of 20 kWp will be installed on the new premises for Fraunhofer ISE. The planning is exemplary for the comprehensive approach applied by Fraunhofer ISE to solar building: optimisation of architecture, user comfort, thermal and electric use of energy in an integrated concept.

Sören Andersen*, Sebastian Herkel, Klaus Kiefer, **Hermann Laukamp**, Karsten Voss

The five photovoltaic systems (fig. 1 and table 1) will serve mainly as electricity generators, but some of them can also be used as test generators. The planning team placed great value on the balance between building aspects and electricity generation. The PV generators demonstrate different aspects of building integration:

In the southern façade and the saw-toothed roof, the solar cells are encapsulated within double glazing. They reduce the heat gains to the building and support the efforts to dispense largely with conventional air conditioning. The generator on the façade of the southern wing will demonstrate the application of photovoltaic modules as spandrel elements in vertical and tilted configurations. The generators on the roofs of the southern and central wings serve as cladding for the ventilation shafts behind them.

Façade of the access tract	2.5 kW_p
Saw-toothed roof over the atrium	4.9 kW_p
Spandrels of the southern wing	2.9 kW_p
Roof of the southern wing	4.5 kW_p
Roof of the central wing	5.3 kW_p

Table 1: Position and rated power of the PV systems.

The example of the saw-toothed roof over the atrium indicates how we developed the construction: The table in fig. 2 illustrates the optimisation of the saw-toothed roof geometry as part of the building concept.

Good daylighting conditions are essential for the use and the aesthetic effect of an atrium. On the other hand, enormous overheating loads arise in summer if transparency is high and there are no shading elements. We carried out simulations for the indoor thermal and daylighting conditions to take account of both aspects mentioned, in combination with the energy yield of the photovoltaic system.

Conclusion: The photovoltaic systems, with an annual yield of around 16 MWh, will meet the entire demand for office lighting in the new building.

The European Union is supporting the construction of the photovoltaic systems.

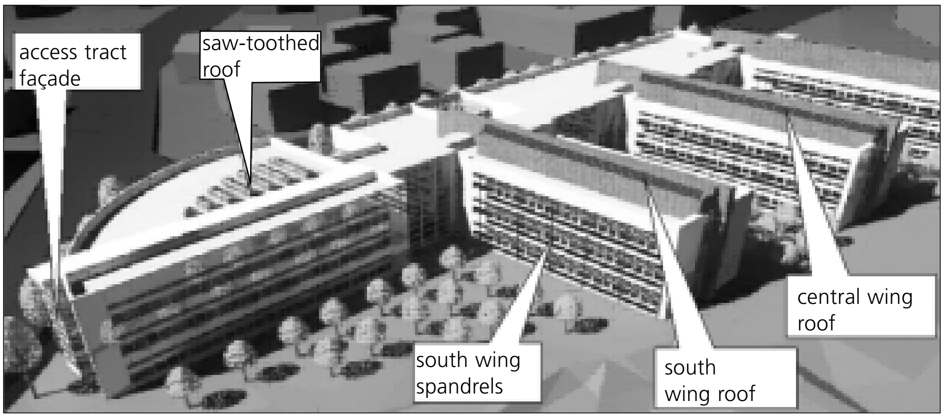


Fig. 1: The five photovoltaic systems on the new premises for Fraunhofer ISE.

Construction (PV ······, Glass —) N ←	⁄⋰ (variant 1)	⁄⋱ (variant 2)	⁄⋱ (variant 3)
Electricity	+	0	–
Daylight	–	0	+
Temperature	+	0	–

+ = favourable, - = unfavourable, 0 = neutral

Fig. 2: The slope of the photovoltaic generators on the saw-toothed roof is adapted to the energy concept for the building. Electricity generation, daylighting and reduction of heat gains to the atrium in summer were all taken into account when optimising the design.

Fig. 3: A view up to the top of the atrium. The photovoltaic generator projects a shadow pattern onto the curved wall of the atrium.

* Dissing+Weitling, Copenhagen

Facts and Figures

Visiting Scientists

Participation in National and International Associations

Congresses, Conferences and Seminars organised by the Institute

Lecture Courses and Seminars

Trade Fairs and Exhibitions

Patents

Doctoral Theses

Press Information

Lectures

Publications

Visiting Scientists

Claudia Casper
Universidad Barcelona
Barcelona, Spain
1.2.2000 - 30.5.2001
Research area: sociological studies on rural electrification

Dr Andres Cuevas
Australian National University
Canberra, Australia
16.7 - 31.8.2000
Research area: high-efficiency silicon solar cells

Mario Motta
Politecnico di Milano
Milan, Italy
1.7.1999-30.6.2000
Research area: solar air-conditioning

Maryam Kharrazi Olsson
University of Uppsala
Uppsala, Sweden
1.3.1998 - 29.2.2000
Research area: coating technology

Anders Ødegård
Norwegian University for Science and Technology (NTNU)
Trondheim, Norway
21.8.2000 - 21.2.2001
Research area: micro-energy technology

Prof. Valeri Rumyantsev
Ioffe Institute
St Petersburg, Russia
1.6. - 30.9.2000
Research area: III-V concentrator modules

Dr Oleg V. Sulima
Ioffe Institute
St. Petersburg, Russia
1.1.1997 - 31.12.2000
Research area: III-V epitaxy and technology

Participation in National and International Associations

Bundesministerium für Wirtschaft und Technologie BMWi
- Lenkungsausschuss "Solar optimiertes Bauen"

Deutsche Elektrotechnische Kommission DKE
- Komitee 373: Photovoltaische Solarenergiesysteme
- Komitee 221: Elektrische Anlagen von Gebäuden

Deutsche Elektrotechnische Kommission DKE
- Komitee 384: Brennstoffzellen

Deutsche Gesellschaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie Dechema e.V.
- Arbeitsausschuss "Elektrochemische Prozesse"

Deutsche Gesellschaft für Galvano- und Oberflächentechnik DGO
- Fachausschuss "Mikrosysteme und Oberflächentechnik"

Deutsche Gesellschaft für Psychologie
- Fachausschuss "Umweltpsychologie"

Deutsche Gesellschaft für Sonnenenergie DGS
- Vorstand der Sektion Südbaden

Deutsche Physikalische Gesellschaft DPG
- Arbeitskreis "Energie"

Deutscher Wasserstoff-Verein DWV

Deutsches Flachdisplay-Forum

European Committee for Standardisation CEN / TC33 / WG3 / TG5
- Member

European Co-operation for Space Standardisation ECSS
- "Solar Cell Standard" Working Group

European Fuel Cell Group

European Renewable Energy Centres (EUREC) Agency
- President

Fachverband Transparente Wärmedämmung e.v.
- Arbeitskreis "Normung"

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. FhG
- Hauptkommission

German Advisory Council on Global Change
- Member

Hahn-Meitner-Institut HMI
- Wissenschaftlicher Beirat

Institut für Solare Energieversorgungstechnik ISET
- Wissenschaftlicher Beirat

International Solar Energy Society Europe (ISES-Europe)
- Governing Board

International Solar Energy Society ISES
- Board of Directors

ISO/TC 197 Hydrogen Technologies
- "Gas technology" Subcommittee

"Solar Energy", Pergamon Press/Elsevier
- Editor-in-Chief

Verein Deutscher Elektrotechniker
- ETG-Fachausschuss "Brennstoffzellen"

Verein Deutscher Ingenieure VDI
- Fachausschuss "Brennstoffzellen"

Verein Deutscher Ingenieure, VDI-Gesellschaft Energietechnik
- Fachausschuss "Regenerative Energien"

VMPA- Verband der Materialprüfämter e.V.
- Sektorgruppe "Türen, Fenster und Glasprodukte"

Zentrum für Solarenergie und Wasserstoff ZSW
- Kuratorium

Congresses, Conferences and Seminars organised by the Institute

OTTI Technologie-Kolleg Regensburg
6. Symposium Licht
Staffelstein, Kloster Banz, 27./28.1.2000

OTTI Energie-Kolleg Regensburg
Fachseminar "Photovoltaisch versorgte Geräte und Kleinsysteme"
Freiburg, 2./3.2.2000

OTTI-Energie-Kolleg Regensburg
15. Symposium Photovoltaische Solarenergie
Staffelstein, Kloster Banz, 15.-17.3.2000

2nd Workshop on Light Degradation of Carrier Lifetime in Cz-Si Solar Cells
Glasgow, United Kingdom, 3.5.2000

OTTI Technologie-Kolleg Regensburg
10. Symposium Thermische Solarenergie
Staffelstein, Kloster Banz, 10.-12.5.2000

OTTI Energie-Kolleg Regensburg
Fachseminar "Photovoltaik-Anlagen"
Freiburg, 23./24.5.2000

Monitoring
Hamm, 16./17.11.2000

BMWi Projekt "SolarBau: MONITOR"
Integrale Planung und Architektur
Seminare
Bonn, St. Augustin, 17/18.11.2000

Materialien in Solarkollektoren
Symposium
Salzburg, Österreich, 24.11.2000

Arbeitsgemeinschaft Erneuerbare Energien AEE
Institut für Solartechnik SPF
Fraunhofer-Institut für Solare Energiesysteme ISE
Materialien und Komponenten in Solaranlagen
Tagung
Salzburg, Österreich, 24.11.2000

Lecture Courses and Seminars

Prof. Joachim Luther
Photovoltaische Energiewandlung,
Vorlesung SS 00
Solarthermische Energiewandlung,
Vorlesung WS 00/01
Solare Energiekonversion,
Oberseminar SS 00, WS 00/01
Universität Freiburg, Fakultät für Physik

Prof. Roland Schindler
Photovoltaik Teil I und II,
Vorlesung WS 99/00, SS 00
FernUniversität Hagen

Dr.-Ing. Heribert Schmidt
Photovoltaik-Systemtechnik,
Vorlesung SS 00
Universität Karlsruhe

Dr. Petra Schweizer-Ries
Gemeinschaftliche Nutzung von Ressourcen:
Von sozial-ökologischer Dilemma-Forschung bis hin zur Gemeingutforschung,
Seminar SS 00
Universität Zürich, Umweltpsychologie

Prof. Wolfram Wettling
Halbleiter-Technologie und -Bauelemente,
Vorlesung WS 00/01
Universität Freiburg, Fakultät für Physik

Priv. Doz. Dr. Gerhard Willeke
Fundamentals of Semiconductor Technology,
WS 99/00,
University of Constance, Faculty of Physics

Priv. Doz. Dr. Volker Wittwer
Innovative Energiesysteme,
Vorlesung SS 00 und Seminar WS 00/01
Universität Freiburg, Fakultät für Angewandte Wissenschaften, Institut für Mikrosystemtechnik IMTEK

Trade Fairs and Exhibitions

Industrieausstellung im Rahmen des
15. Symposiums Photovoltaische Solarenergie
Staffelstein
Staffelstein, Kloster Banz, 15.-17.3.2000

light+building
Frankfurt, 19.-23.3.2000

Hanover Trade Fair 2000
Participation in the joint stand of the Fraunhofer Gesellschaft on "Surface Technology"
Participation in the joint stand on "Hydrogen and Fuel Cell Technology"
Hanover, 20.-25.3.2000

Sustainable Building 2000
Maastricht, The Netherlands, 22.-25.5.2000

Intersolar 2000
Freiburg, 7.-9.7.2000

Glasstec
Düsseldorf, 24.-28.10.2000

Intelligent Building Design
Stuttgart, 10/11.11.2000

MegaWatt
Gelsenkirchen, 24./25.11.2000

Patents

Patents Granted

Klaus Preiser, Jérôme Kuhmann
"Device to test stand-alone solar systems"

Dr Heribert Schmidt, Dirk Uwe Sauer
"Device to determine the density of an electrolyte"

Prof. Adolf Goetzberger
"Solar control glazing"

Prof. Adolf Goetzberger
"Configuration for light-guiding systems"

Dr Peter Apian-Bennewitz
"Projection system"

Dr Wilhelm Warta, Daniel Biró
"Semiconductor configuration and procedure to passivate the surface of a semiconductor material"

Konrad Lustig
"Heat exchanger unit and procedure to produce a heat exchanger unit"

Patent Applications

Dr Peter Nitz, Wolfgang Graf, Michael Wagner, Wolfgang Schnell, Rainer Lebacher, Clemens Roch
"Application of condensate-sensitive, low-emitting films and device to prevent condensation in cavities of double or multiple-walled envelopes of heatable rooms"

Michael Hermann, Peter Schossig, Carsten Hindenburg
"Active thermal building component with phase change material"

Uli Röltgen, Norbert Wiesheu, Dr Andreas Docter
"Autothermal reforming reactor"

Dr Andreas Georg, Anneke Hauch, Dr Elias Stathatos, Prof. Panagiotis Lianos, Nava Grošelj, Dr. Urška Lavrenčič, Prof. Boris Orel,
"Ion conductor for dye-sensitised solar cells"

Dr Andreas Bett, Dr Siegbart Kunz, Dr Jochen Buschmann, Christian Braun, Harald Humpfer, Volker Geneiß
"Implanted field and temperature probe for EMC measurements"

Prof. Adolf Goetzberger, Thomas Kuckelkorn
"Daylighting element based on a CPC"

Michael Köhl, Klaus Rose, Matthias Heinrich, Karl-Heinz Haas
"Multifunctional superphobic coatings"

Orlando Parodi, Ulrike Seibert, Konstanze Fleige
"WATER Pumping and Purification System" (WATERpps)

Daniel Biró
"Low-contamination transport through a high-temperature zone with a lifting-arm procedure with a flexible arm"

Dr Gerhard Willeke, Daniel Kray
"Damage-free wafer production"

Ralf Preu, Eric Schneiderlöchner, Dr Stefan Glunz, Dr Ralf Lüdemann
"Procedure to produce a semiconductor-metal contact through a dielectric layer"

Michael Köhl, Franz Brucker, Volker Lieske
"Procedure to improve biocatalytic reaction"

Dirk Uwe Sauer, Rudi Kaiser
"Concept for parallel operation of different storage technologies in autonomous power supplies"

Volkmar Boerner, Dr Andreas Gombert, Dr Benedikt Bläsi
"Procedure to produce light-scattering elements with non-gaussian scattering profiles"

Dr Andreas Gombert, Michael Niggemann, Hansjörg Lerchenmüller
"Procedure and device to produce coupling grids for integrated optical components"

Doctoral Theses

Benedikt Bläsi
Holographisch hergestellte Antireflexoberflächen für solare und visuelle Anwendungen
(Holographically produced anti-reflective surfaces for solar and visual applications)
Doctoral thesis, University of Freiburg
Freiburg, 2000

Frank Dimroth
Metallorganische Gasphasenepitaxie zur Herstellung von hocheffizienten Solarzellen aus III-V Halbleitern
(Metal-organic vapour phase epitaxy to produce highly efficient solar cells from III-V semiconductors)
Doctoral thesis, University of Constance
Constance, 2000

Peter Hahne
Innovative Druck- und Metallisierungsverfahren für die Solarzellentechnologie
(Innovative printing and metallisation procedures for solar cell technology)
Doctoral thesis, University of Hagen
Hagen, 2000

Ralf Preu
Innovative Produktionstechnologien für kristalline Silicium-Solarzellen
(Innovative production technology for crystalline silicon solar cells)
Doctoral thesis, University of Hagen
Hagen, 2000

Sebastian Schaefer
Plasmaätzen für die Photovoltaik - Plasmasysteme und -prozesse für die Herstellung von kristallinen Siliciumsolarzellen
(Plasma-etching for photovoltaics - plasma systems and processes for the production of crystalline silicon solar cells)
Doctoral thesis, University of Constance
Constance, 2000

Stefan Reber
Electrical Confinement for the Crystalline Silicon Thin-Film Solar Cell on Foreign Substrate
Doctoral thesis, University of Mainz
Mainz, 2000

Tim Meyer
DC/DC-Wandler mit kleiner Eingangsspannung für photovoltaische, elektrochemische und thermoelektrische Zellen
(DC/DC converter with low input voltage for photovoltaic, electrochemical and thermoelectric cells)
Doctoral thesis, University of Karlsruhe
Karlsruhe, 2000

Press Information

Press Releases

http://www.ise.fhg.de/Public_Relations/pi.html

7.2.2000
Moth-Eyes and Lotus Petals:
Micro-Structuring for Functional Surfaces
Hanover Trade Fair, March 20-25, 2000

7.2.2000
Miniature Fuel Cells for Portable Electronic Appliances
Hanover Trade Fair, March 20-25, 2000

26.7.2000
Small Devices - Large Markets
Fraunhofer Institute develops new photovoltaic products

7.8.2000
Solar Power Supply Remote from the Grid
Practical Tips for a Market of Millions

1.9.2000
Solar Cell Record at Fraunhofer ISE
Efficiency Value of Monolithic Tandem Concentrator Cells Exceeds 30 %

9.10.2000
Lifestyle for the Future in Neuenburg
1-litre solar houses with an innovative, compact, building services unit

20.10.2000
Photovoltaic Scientists at the Conveyor Belt
The Fraunhofer ISE Laboratory and Service Centre in Gelsenkirchen

8.12.2000
Calibration reduces costs for photovoltaic electricity
Fraunhofer ISE measurement technology for widespread application

Lectures

Lectures with published manuscripts are listed under "Publications"

Adib, R.
"The Vision: Financial Sustainable Rural Electrification. The Performance: Microfinance Institutions and their Technology", Proceedings 16th European Photovoltaic Solar Energy Conference and Exhibition, Glasgow, United Kingdom, 1.-5.5.2000, Poster

Agert, C.
"MOVPE GaSb-basierender HL und photovoltaische Anwendungen", Seminar, Universität Erlangen, Erlangen, 19.11.1999

Agert, C.
"MOVPE of GaSb, (AlGa)Sb and (AlGa)(AsSb) in a Multiwafer Planetary Reactor", Lincoln Laboratory, MIT, Boston, USA, 10.8.2000; Bandwidth Semiconductor LLC, Boston, USA, 11.8.2000; NREL, Golden, USA, 21.8.2000; Sandia National Lab., Albuquerque, USA, 23.8.2000; EMCORE Photovoltaics Division, Albuquerque, USA, 24.8.2000

Agert, C.
"MOVPE von GaSb-basierenden III-V-Halbleitern im Planetenreaktor", Seminar Materialforschungszentrum FMF Freiburg, Freiburg, 17.11.2000

Bett, A.W.; Sulima, O.; Dimroth, F.; Wettling, W.; Willeke, G.
"Tandem- und Tripel-Solarzellen aus III-V-Verbindungen für Anwendungen in Konzentrator- und Thermophotovoltaik-Systemen", 9. Kolloquium Materialforschungszentrum FMF Freiburg, Breisach, 3.-4.11.2000

Bopp, G.
"Netzferne PV-Versorgung am Watzmannhaus", Technologiebörse Bau, Congress Center, Nürnberg, 27.1.2000

Bopp, G.
"Ländliche Energieversorgung und die Perspektiven der Photovoltaik", 12. Internationales Sonnenforum, Freiburg, 7.7.2000

Borchert, D.
"ITO als Top-Coating für Silizium", 2. Workshop TCO für Dünnschichtsolarzellen, Forschungsverbund Sonnenenergie FVS, Jülich, 10.-11.2.2000

Borchert, D.
"Kristalline Silizium-Solarzellen: Materialien, Herstellung und Charakterisierung", Messe megaWatt, Gelsenkirchen, 24.-25.2000

Erge, T.
"Solar Electricity from a Thousand Roofs", PV Field Trial Consultation Meeting, Watford, United Kingdom, 3.4.2000

Ferber, J.[1]; Kern, R.[1]; Luther, J.
"Investigation of the Long-Term Stability of Dye-Sensitized Solar Cells", Workshop Quantsol2000, Wolkenstein, Italy, 11.-18.3.2000
([1]: Materialforschungszentrum FMF, Freiburg)

Glunz, S.
"Silicon Solar Cell Research at Fraunhofer ISE", Seminar bei Fa. Samsung, Suwon, Korea, 7.11.2000

Gombert, A.
"Neue Anwendungen nanostrukturierter Oberflächen", NATI-Seminar Kunststofftechnik, FH Osnabrück, 20.6.2000

Hahne, P.
"Drucktechnologien für die Solarzellenfertigung", SolPro III Expertentreffen Druck, Firma Merck, Darmstadt, 30.5.2000

Heinzel, A.
"Brennstoffzellen – ein neuer Energiewandler für mobile, stationäre und portable Anwendungen", Messe Zürich, 8.2.2000

Heinzel, A.
"Brennstoffzellen mit variabler Ausgangsspannung zur Energieversorgung elektronischer Geräte", Hanover Trade Fair 2000, Hanover 20.-25.3.2000

Heinzel, A.
"Kleine Brennstoffzellen für den mobilen Einsatz" VDI-VDE-Tagung Sensorik, Bad Kissingen, 3.-4.5.2000

Heinzel, A.
"Brennstoffzellen-Technologien und Stand der Entwicklung", WinGas-Forum, Kassel, 6.-7.9.2000

Heinzel, A.
"Brennstoffzellentechnologie", Hyforum 2000, Munich, 11.-15.9.2000

Heinzel, A.; Rampe, T.; Vogel, B.[1]; Haist, A.; Hübner, P.
"Reforming of Fossil Fuels – R&D at Fraunhofer Institute for Solar Energy Systems", Seminar on Fuel Cells 2000, Portland, USA, 30.10.-2.11.2000, Poster
([1]: DaimlerChrysler AG, Ulm)

Heinzel, A.
"Neue Gesamtenergieversorgungskonzepte für Gebäude", 5. Kasseler Symposium Energie-Systemtechnik, Kassel, 9.-10.11.2000

Heinzel, A.
"Brennstoffzellen – attraktive Energiewandler für den stationären, mobilen und portablen Einsatz" Zukunftstag WVIB Freiburg, 16.11.2000, Freiburg

Heinzel, A.
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Abbreviations

Ag	silver
Al	aluminium
AlGaAs	aluminium gallium arsenide
AM	air mass
APCVD	atmospheric pressure chemical vapour deposition
Bi	bismuth
BFC	bifacial cell
BMBF	Bundesministerium für Bildung und Forschung (German Federal Ministry of Education and Research)
BMWi	Bundesministerium für Wirtschaft und Technologie (German Federal Ministry of Economics and Technology)
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry of Economic Co-operation and Development)
BSF	back surface field
CIS	copper indium diselenide
CNRS	Centre Nationale de la Recherche Scientifique
c-Si	crystalline silicon
CV	capacitance/voltage
CVD	chemical vapour deposition
Cz	Czochralski
DLTS	deep level transient spectroscopy
EBIC	electron beam induced current
EBR	etchback regrowth
ECR	electron cyclotron resonance
EFG	edge-defined film-fed growth
EMC	electromagnetic compatibility
EU	European Union
FF	fill factor
FhG	Fraunhofer-Gesellschaft (Fraunhofer Society)
FCHC	fluorinated/chlorinated hydrocarbons
FZ	float zone
GaAs	gallium arsenide
GaInP	gallium indium phosphide
GaSb	gallium antimonide
Ge	germanium
GSM	Global System for Mobile Communication
IEA	International Energy Agency
IR	infrared
K	Kelvin
kW_p	kilowatt peak
LBIC	light beam induced current
LBSF	local back surface field
LPE	liquid phase epitaxy
mc	multicrystalline
mc-Si	multicrystalline silicon
MFCA	modulated free carrier absorption
MgF_2	magnesium fluoride
MOCVD	metal organic chemical vapour deposition
MOVPE	metal organic vapour phase epitaxy
MPP	maximum power point
MSCM	miniature solar cell mapping
MW-PCD	microwave-detected photoconductance decay
NOCT	nominal operating cell temperature
PCVD	photocurrent and voltage decay
Pd	palladium
PECVD	plasma enhanced chemical vapour deposition
PEM	polymer membrane
PERC	passivated emitter and rear cell
PV	photovoltaic
RCC	rear contacted cell
RIE	reactive ion etching
RPHP	remote plasma hydrogen passivation
RP-PERC	random pyramid, passivated emitter and rear cell
RRC	realistic reporting conditions
RTCVD	rapid thermal chemical vapour deposition
RTP	rapid thermal processing
S/C	steam/carbon ratio
SDCS	solar desiccant cooling system
SEM	scanning electron microscope
SME	small and medium-sized enterprises
Si	silicon
SIMOX	separation by implanted oxygen
SiN_x	silicon nitride
SiO_2	silicon dioxide
SIR	simultaneous infiltration and recrystallisation
Sn	tin
SPV	surface photovoltage
SSP	silicon sheets from powder
SR	spectral response
SR-LBIC	spatially resolved light beam induced current
TI	transparent insulation
Ti	titanium
TiO_2	titanium dioxide
TPV	thermophotovoltaics
VOC	open circuit voltage
WPVS	world photovoltaic scale
Zn	zinc
η	efficiency value

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