



Wolfhagen 100% Renewable Energy:

A Contribution to the Energy Efficient Cities Competition



Solar Building Design

1.

Wolfhagen

► Initial Position

Research

Results

Initial Position

The German Federal Ministry of Education and Research set up the Energy Efficient Cities Competition for communities willing to

1. reduce their energy demand to achieve and exceed Germany's national target of 40% reduction in CO₂ emission until 2020.
2. use innovative strategies, technologies and business services to achieve conversion from a „normal“ to an „energy efficient“ city.
3. look at the city space as a systemic whole.

Wolfhagen, a town of about 14.000 people, had already made significant progress in the use of renewable energy when it decided to take on the challenge set by the competition.

In 2007 about 7% of the cities electricity demand were covered by photovoltaic generation in private households. The town launched a municipal utility company in 1998 and bought back the lease on rights for electricity distribution.

It is therefore well positioned to maximize the benefits from decentralized energy generation typical for renewable energies through demand side management.



Wolfhagen – a picturesque town in rural northern Hesse is on its way to a 100% renewable energy supply. Already, 7% of the cities electricity demand are covered by photovoltaic generation in private households.



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A Contribution to the Energy Efficient Cities Competition



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The focus of the projekt research is on three areas:

Housing Refurbishment: Based on a detailed inventory of the existing housing stock energy demand is modelled for varying scenarios of refurbishment

Optimized Energy Supply: Optimizing the grid for the increased use of renewable energy by supporting demand side management to respond to fluctuating supplies from renewables. Detailed analyses of the potential for use of all types of renewable energy will be carried out.

Electro-Mobility: The potential of using electric cars based on an analysis of typical patterns in the towns commuting and traffic patterns will be investigated.

Special attention will be given to making the research results available to and useful for the people of Wolfhagen. Banks for example will be able to set up conditions for loans to give the biggest „bang for the bug“ of refurbishment according to the analysis of housing stock.



A city-wide 3D-model of roof areas will be compiled and used in an analysis of the potential use of solar radiation.



Wolfhagen 100% Renewable Energy:

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Based on a detailed classification of the existing housing stock energy demand in the building sector was estimated to be 78 GWh/yr. 74% of this was projected to be used for room heating (58 GWh/yr), the rest is for drinking hot water, lighting and other process heat (cooking etc.). Buildings built before 1978 use the majority of energy, and 79% are used by one- or two-family homes.

This information will allow to design energy efficiency measures to address areas with the biggest potential for savings first.

One goal of the project is to raise refurbishment rates above 2% per year. The inventory shows that these refurbishments will be most effective when they are focused on private homes built before 1978. This is a very ambitious goal as home owners have to be convinced of make the necessary investments to refurbish their homes.



Example buildings from the detailed classification of the building stock in Wolfhagen.



Energy Strategy for the Ecological Residential District Oberzwehren



Solar Building Design

2.

Oberzwehren

► Initial Position

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Initial Position

The city of Kassel in Central Germany is carrying out an environmentally ambitious housing project in the city district of Oberzwehren. Buildings are to comply with high ecological standards to sensitise citizens to environmentally-friendly living in the city of Kassel.

The goal is to develop an ecological building estate with high urban and architectural quality and to implement an innovative energy supply system. The city of Kassel has set the goal of a CO₂-neutral energy supply for the project.

The concept aims at:

- Minimizing the CO₂ emissions caused by the heating and drinking and hot water (DHW) energy demand through high energy efficiency and the use of renewable energy sources;
- Reducing the overall material and energy flows over the life-cycle;
- Realizing the goals in an economic way and with reliable and commercially available technology.

Overall, the project aims at leading the way in adapting urban structures to changing climatic conditions.



Basic concept for the development of the Ecological Residential District Oberzwehren.



Energy Strategy for the Ecological Residential District Oberzwehren



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Oberzwehren

Initial Position

Research

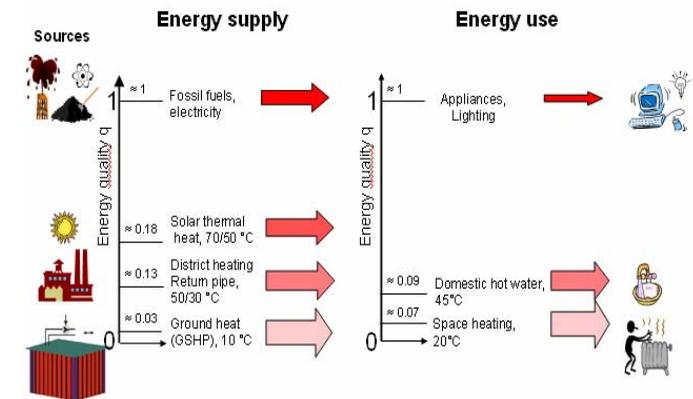
Results

Research

The single-family homes planned for the Ecological Residential District were modelled in TRNSYS using three standards for thermal insulation: the current German building code (EnEV 2009) resulting in a total energy demand of $75 \text{ kWh m}^{-2} \text{ yr}^{-1}$, a low-energy house standard that results in a 30% reduction compared to the current standard ($50 \text{ kWh m}^{-2} \text{ yr}^{-1}$) and a passive house standard that results in heating demands below $15 \text{ kWh m}^{-2} \text{ yr}^{-1}$ and a total energy demand for heating and DHW of $23 \text{ kWh m}^{-2} \text{ yr}^{-1}$.

In developing the energy supply system the objective was to match the supply not only in terms of *quantity* but to use a supply system that delivers energy of comparable *quality*, i.e. heat at temperatures used by low-temperature heating systems. The return line of the existing district heating system was chosen for this purpose (temperature: 50°C).

Matching of the energy quality of demand and supply



Matching the quality levels of energy demand and supply for the community of Oberzwehren



Energy Strategy for the Ecological Residential District

Oberzwehren



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2.

Oberzwehren

Initial Position

Research

► Results

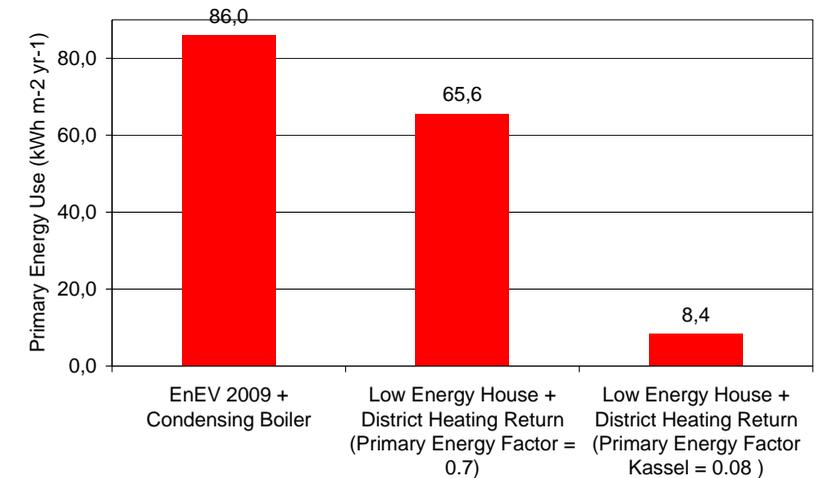
Results

On the right, primary energy supplies for three scenarios are shown. Apart from the reference scenario (current building code EnEV 2009 plus a condensing gas boiler) two supply options using the district heating return were investigated in combination with the low energy house insulation standard.

Compared to the reference case ($86 \text{ kWh m}^{-2} \text{ yr}^{-1}$) both low-energy house plus district heating return scenarios save primary energy. On average, district heating systems in Germany use 0.7 kWh of primary energy to generate 1 kWh of heat. In this case $65,6 \text{ kWh m}^{-2} \text{ yr}^{-1}$ of primary energy would be used to supply a single family home.

The Kassel district heating system only uses 0.08 kWh of fossil fuel to generate a kWh of heat. Therefore, only $8,4 \text{ kWh m}^{-2} \text{ yr}^{-1}$ of primary energy are needed to satisfy the projected demand.

The CO_2 emissions associated with this generation will be offset by equipping all houses with photovoltaic systems.



Primary Energy Use for a Single Energy Home for three Supply Options



Active Solar Façades (BIPV and solar thermal)



Solar Building Design

3.

Active Solar Façades

► Initial Position

Research

Results

Initial Position

- 40% of the CO₂-emissions in EU25 are caused by buildings
- Buildings with net-zero energy balance are targeted by the European Commission and many countries
- The use of renewables is very rare in case of large buildings, especially in non-residential buildings
- High fractions of the energy demand can only be met with renewable energy sources when, in addition to the roof, the façade is used for energy conversion. This is especially true for buildings with a small roof area compared to the floor area
- A main focus of our work aims at converting façades into multifunctional, energy gaining components



Torre de Cristal Madrid
Source: Emmer, Pfenninger Partner

Contact:

Dipl.-Phys. Tilmann E. Kuhn
Fraunhofer Institute for
Solar Energy Systems ISE
Freiburg, Germany
Phone: +49 (0) 761/ 4588-5297
tilmann.kuhn@ise.fraunhofer.de
www.ise.fraunhofer.de



Active Solar Façades (BIPV and solar thermal)



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3.

Active Solar Façades

Initial Position

► Research

Results

Research

- New façade components
 - transparent solar thermal collectors
 - unglazed façade collectors
 - new BIPV-components
- Research on new evaluation methods for multifunctional façades
 - calorimetric evaluation of semitransparent active façade components
 - total cost of ownership for BIPV
- New measurement services for the industry



Sonnenkraft – house of the future, Regensburg
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Active Solar Façades (BIPV and solar thermal)



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3.

Active Solar Façades

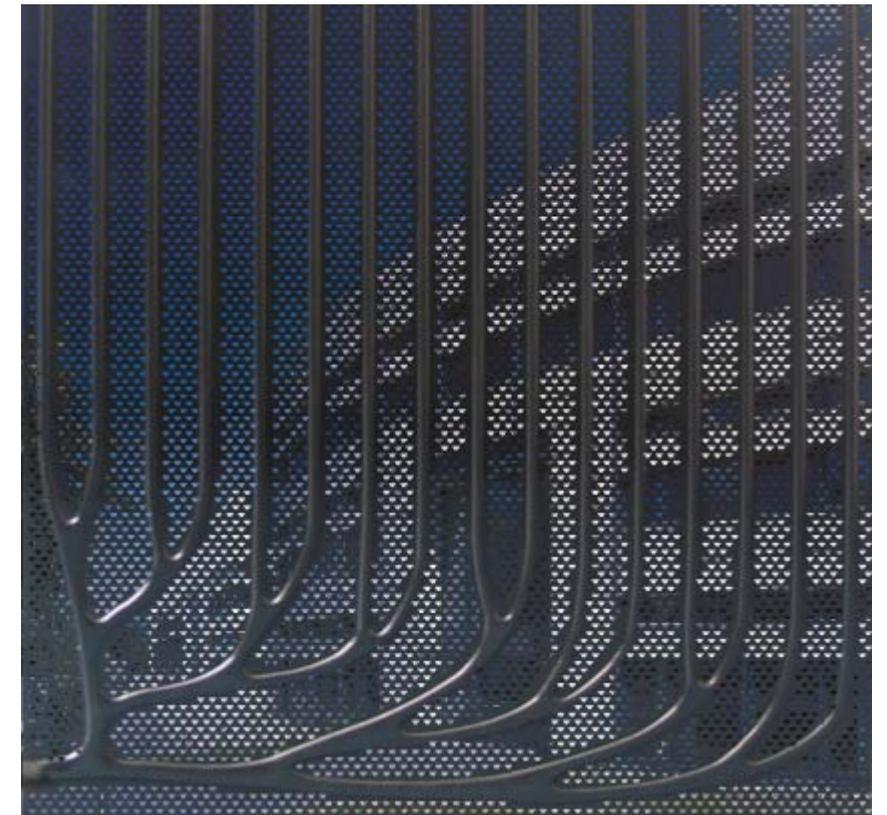
Initial Position

Research

► Results



Visual mock-up of new BIPV component
© Fraunhofer ISE



Virtual image of transparent solar thermal collector
© Fraunhofer ISE



MULTIELEMENT

PV Elements in Building Services Engineering



Solar Building Design

4.

PV Multielement

► Initial Position

Research

Results

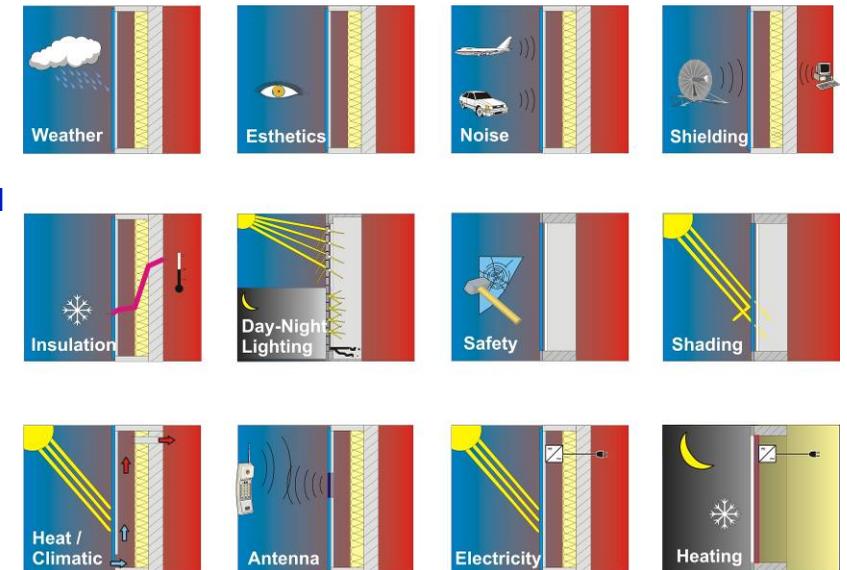
Initial Position

Photovoltaic (PV) panels are considered primarily as power producers from the planners and plant operators points of view.

However, when used as PV structural element numerous physical characteristics can be used beneficially.

Thus, besides current generation additional functions can be provided, which are taken up to now by the conventional building envelope. Some examples for these functions are

- Weather protection
- Thermal insulation
- Shading



Multifunctional characteristics of photovoltaic building elements in building integrated PV (BIPV) applications



MULTIELEMENT

PV Elements in Building Services Engineering



Solar Building Design

4.

PV Multielement

Initial Position

► Research

Results

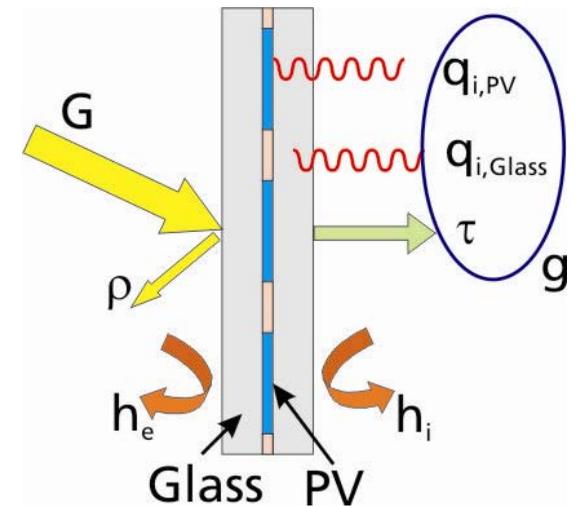
Research

The physical properties of PV modules for building integration are described systematically. Based on these investigation the research objectives are:

- Development of the technical and economical potentials for photovoltaic building elements
- Cost reduction by systematically including multifunctionality of PV building elements
- Development of guidelines that sufficiently describe the building component “PV building element” for a type approval

In many cases building codes and standards of glass elements are transferred to PV elements. For instance, if the total energy transmittance is calculated by means of available standards, the impact of PV cells is not respected.

Thus in order to apply existing standards to PV building elements, the deficits must be outlined. Existing standards must be adapted or new standards must be created.



Evaluation of the total solar energy transmittance g by means of a PV-glass laminate.

- G Solar irradiation
- g Total solar energy transmittance
- τ Solar direct transmittance
- q_i Secondary internal heat transfer factor
- $h_{i,e}$ Internal, resp. external heat transfer coefficient



MULTIELEMENT

PV Elements in Building Services Engineering



Solar Building Design

4.

PV Multielement

Initial Position

Research

► Results

Results

The building envelope as the interface between building and environment is significantly determined by aesthetic, indoor atmosphere, thermal insulation, internal energy consumption, noise and humidity protection as well as weather resistance.

The integration of multiple functions of a “PV building element” in buildings is often made difficult due to a lack of specifications, insufficient planning documentation, component descriptions and testing certificates.

The preparation of material-describing and quality-assuring guidelines or standards is a necessary precondition for a sustainable distribution of PV structural elements.

The qualification must be carried out with test equipment, which respects the application as multi-functional structural element.



Building façade with integrated photovoltaic modules

Contact: Dr. N. Henze
+49 (0) 561 7294-224
nhenze@iset.uni-kassel.de



Solar Heating and Cooling

with absorption chiller and latent heat storage



Solar Building Design

5.

Solar Heating and Cooling

► Initial Position

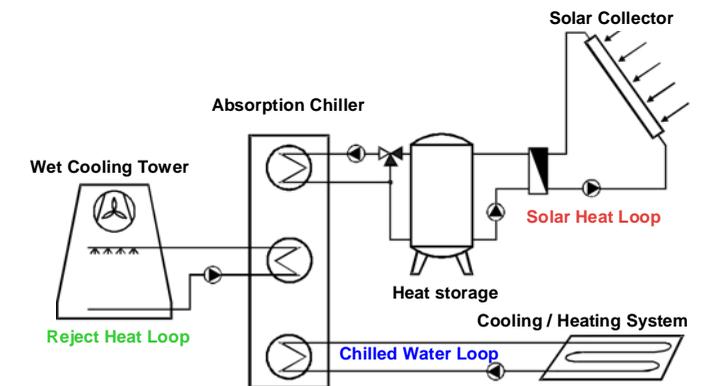
Research

Results

Initial Position

Absorption cooling driven by low-grade heat provided by co-generation systems or industrial waste heat is a well-established technology for larger building air-conditioning installations. State-of-the-art absorption chillers based on the working pair water/Lithium bromide provide chilled water with cooling capacities above 100 kW. Offerings in the low-capacity range are limited in number and technical maturity.

For application in solar heating and cooling systems compact chillers driven with heat from solar collectors with capacities ranging from 5 to 50 kW are in demand. With regard to varying solar input efficient performance of the sorption cycle throughout the whole operating envelope is crucial for reliable system operation. For wide-spread and trouble-free application even in hot climates the rejection of the cycles's waste heat should be accomplished by means of a dry air-cooler at elevated temperatures.



Conventional Solar Cooling System



Solar Heating and Cooling

with absorption chiller and latent heat storage



Solar Building Design

5.

Solar Heating and Cooling

Initial Position

► Research

Results

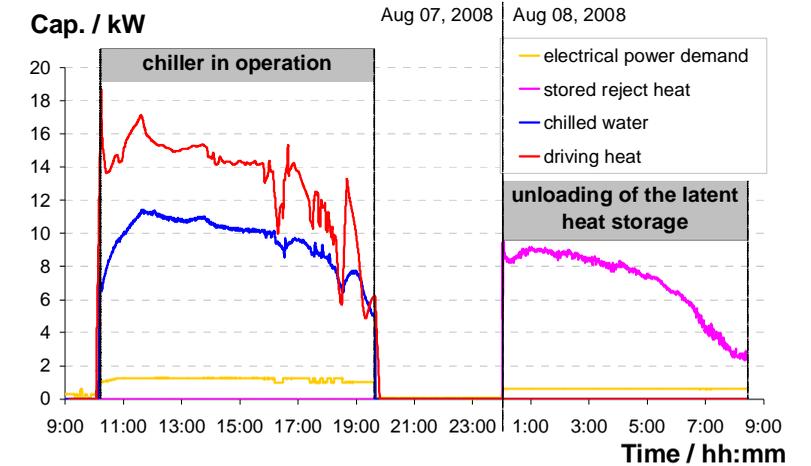
Research

By applying a low temperature latent heat storage together with a dry air cooler a substantial improvement for the design of a solar-driven absorption cooling system is accomplished: The reject heat of the sorption chiller is buffered by the heat storage and transferred to the ambient during periods of low ambient temperatures, e.g. night time or off-peak situations.

The described system concept has been implemented in the frame of a pilot installation for solar heating and cooling. For the latent heat storage the phase change material calcium chloride hexahydrate ($\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$) with phase transition, i.e. melting and solidification, in the temperature range of 27 to 29 °C is applied.

The latent heat storage provides a capacity of 10 kW and 120 kWh thermal storage content. Due to the limited temperature swing, available for the given application, the latent heat storage exhibits a 10 times higher volumetric storage density in comparison to a conventional water heat storage.

Funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, FKZ 329605D



Operation of solar cooling system with storage of reject heat in latent heat storage. Unloading of the heat storage during night time via dry air-cooler.



Solar Heating and Cooling

with absorption chiller and latent heat storage



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5.

Solar Heating and Cooling

Initial Position

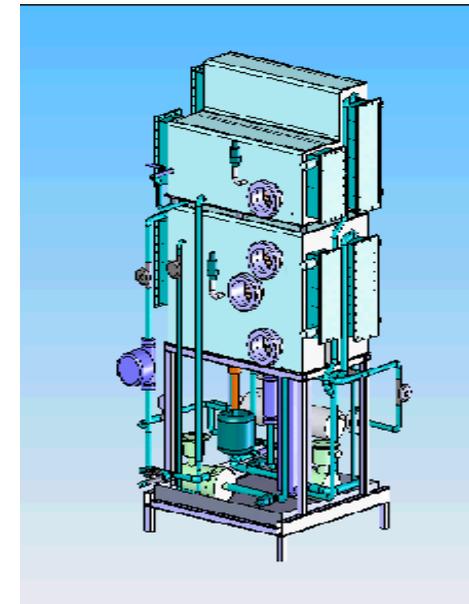
Research

► Results

Results

A compact absorption chiller with the working pair water/LiBr and a cooling capacity of 10 kW has been developed for solar cooling applications. The plant has been designed for driving hot water temperatures in the range of 60 to 100°C. In analogy to large capacity chillers falling film heat exchangers in rectangular vessels have been applied, guaranteeing efficient operation with COP >0,7 for all states above 40% part load.

Since 2005 the plant has been demonstrated and tested successfully in solar cooling systems and tri-generation by partner SK Sonnenklima.



10 kW water/Lithiumbromide
absorption chiller for solar cooling.



Production Technology for Vacuum Insulation Glass

(www.vig-info.de)

Solar Building Design

6.

Vacuum Insulation Glass

► Initial Position

Research

Results

Initial Position

Windows are the thermal weak spots of well insulated buildings. Double glazing “only” achieves U_g -values of $1.1 \text{ W}/(\text{m}^2\text{K})$, resulting in enormous heat losses compared to the opaque façade with U -values of less than $0.2 \text{ W}/(\text{m}^2\text{K})$.

While triple glazing achieves better U_g -values of $0.7 \text{ W}/(\text{m}^2\text{K})$ or slightly lower, this improvement comes with the drawback of a thicker construction and a higher weight. Large glazing dimensions in particular may demand special requirements for the fittings due to the weight, and additionally result in awkward handling and **painful** installation for the personnel.



Thermal image of a highly-insulated building. The windows are clearly the thermal weak spots.



Solar Building Design

6.

Vacuum Insulation Glass

Initial Position

► Research

Results

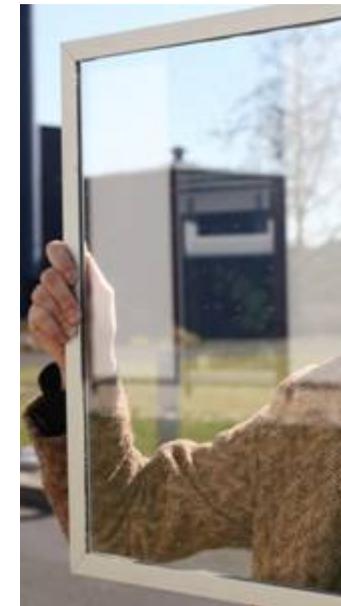
Production Technology for Vacuum Insulation Glass

(www.vig-info.de)

Research

Evacuating the gap in a double glazing to a pressure of 10^{-3} mbar reduces the thermal conductivity of the remaining filling gas to a negligible value. This concept is followed in the development of Vacuum Insulation Glass (VIG). It could be shown, that such an evacuated glazing can reach a U_g -value of $0.5 \text{ W}/(\text{m}^2\text{K})$, a thermal insulation value that can otherwise be reached with the best triple glazing only. However, the VIG is very thin and weighs only 2/3 of the triple glazing.

The main goal for the production of such VIG is the development of an airtight edge seal, that maintains the low pressure for 20 years or more.



Sample of a Vacuum Insulation Glass.



Solar Building Design

6.

Vacuum Insulation Glass

Initial Position

Research

► Results

Renewable Energy Research for Global Markets



Production Technology for Vacuum Insulation Glass

(www.vig-info.de)

Results

A manufacturing process was developed to enable a straightforward production with its main steps operated under vacuum:

First, metal foils are fused to the glass along the periphery of the panes by ultrasonic welding; then the spacers are positioned and fixed. Afterwards, the components enter the vacuum chamber and a plasma etching process dehumidifies and cleans the surfaces.

Under vacuum, the two panes are positioned and the metal foils are fused together by laser welding; the unit is sealed. Reaching atmospheric conditions, the metal edge seal is crimped over and final quality control takes place.

This process ensures a cost-effective fabrication of vacuum insulation glass.



Production line for cost-effective fabrication of Vacuum Insulation Glass (VIG).



Membrane Constructions for Increasing the Energy Efficiency of Buildings (www.mesg.info)

Solar Building Design

7.

Membrane Constructions

► Initial Position

Research

Results

Initial Position

Innovative, light and flexible membrane constructions have increasingly attracted the attention of architects in recent time.

The field of textile architecture offers novel possibilities concerning the creative and structural application spectrum.



Façade of the training center of the mountain rescue service in Bad Tölz.

Architect: Herzog + partner, realization: Hightex GmbH.

Photos: Jan Cremers.





Membrane Constructions for Increasing the Energy Efficiency of Buildings (www.mesg.info)

Solar Building Design

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Membrane Constructions

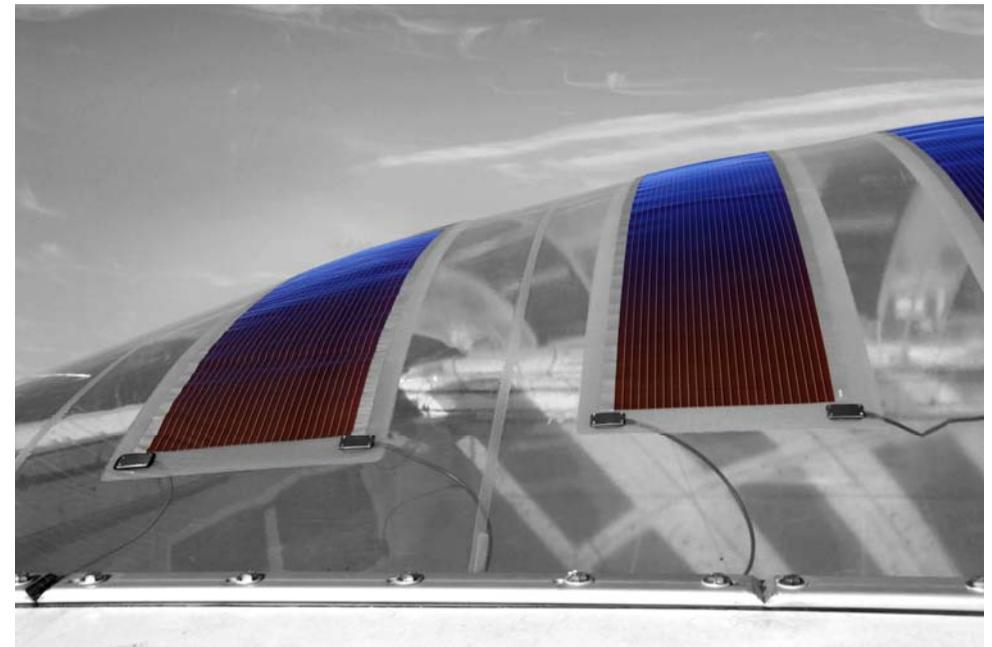
Initial Position

► **Research**

Results

Research

In this project new concepts for the application of membranes in buildings will be developed. The main focus lies on the energetic reconstruction of older buildings by using functional textiles and membranes. Another focus is the usage of membranes and foils in new buildings. In both cases the energy consumption for heat, cooling and lightning will be reduced significantly.



Membrane with integrated flexible photovoltaic elements.
Photo: SolarNext AG / Hightex Group.

LANG
HUGGER
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Solar Building Design

7.

Membrane Constructions

Initial Position

Research

► Results

Membrane Constructions for Increasing the Energy Efficiency of Buildings (www.mesg.info)

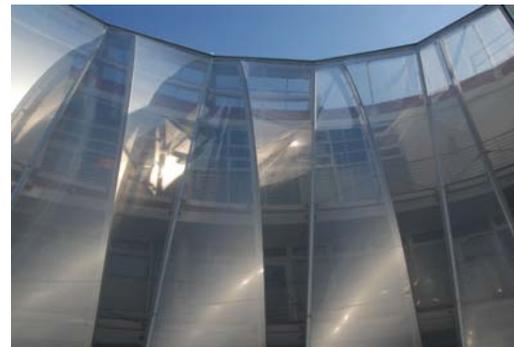
Results

Development of functional membranes:

- Reduction of the thermal emittance from 95% to 30% combined with a freely chosen color.

Energy saving constructions:

- Decrement of the heat consumption up to 70% by covering a courtyard with transparent or translucent membranes.



Centre for Gerontology in Bad Tölz with transparent ETFE-foils as double-skin facade.
Photos: Jan Cremers.





Renewable Energy Research for Global Markets



VIP-PROVE – Vacuum Insulation for Buildings in the Practical Application (www.vip-bau.de)



Solar Building Design

8.

Vacuum Insulation

► Initial Position

Research
Results

Initial Position

In the past basic research and first demonstration objects indicated that high performance thermal insulation based on evacuated insulation panels VIP also can be applied in buildings.

A wide use however still is hindered by skepticism on the reliability in practice.

The know how

- on the high potential of vacuum insulations, but also
- on the increased influence of heat bridges,
- on additional effort for planning/coordination,
- on special care needed for the installation needs to be spread to a much broader field of planers and users.



Objects in the monitoring program



Most of the objects in the monitoring program VIP-PROVE were realized commercially.



Renewable Energy Research for Global Markets



VIP-PROVE – Vacuum Insulation for Buildings in the Practical Application (www.vip-bau.de)

Solar Building Design

8.

Vacuum Insulation

Initial Position

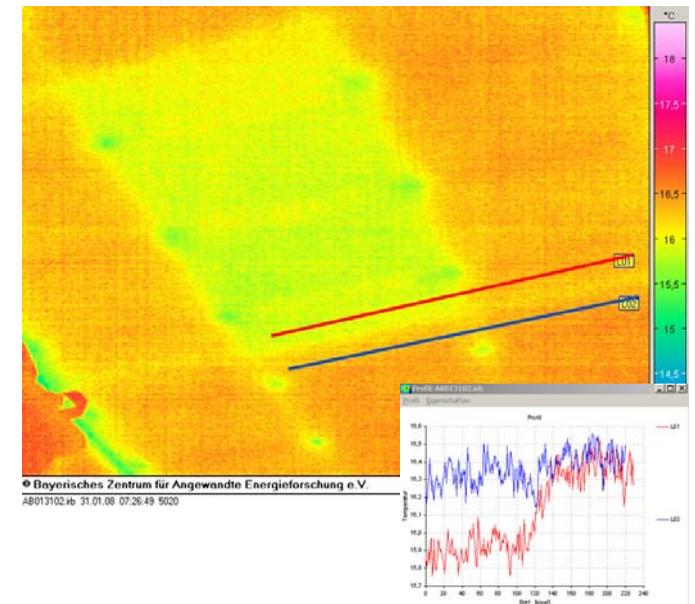
► Research

Results

Research

Three tasks:

- 1.) Communication and information for all interested in this technique (clients, manufacturers, planers, craftsmen, certification body).
- 2.) Transfer of know how and experiences from the R&D into education and advanced training (students, architects, craftsmen).
- 3.) Monitoring:
By describing, checking and monitoring of more than 20 commercially realized buildings, where vacuum insulation panels from all VIP manufacturers have been applied to, it should be shown that
a) this technique is used in practice in a variety of different application fields and
b) that its performance in practice is highly reliable.



Interior room thermography – VIP with a higher surface temperature on the ceiling.





Highly Insulating Window and Facade Systems

(www.hwff.info)

Solar Building Design

9.

Window and Facade Systems

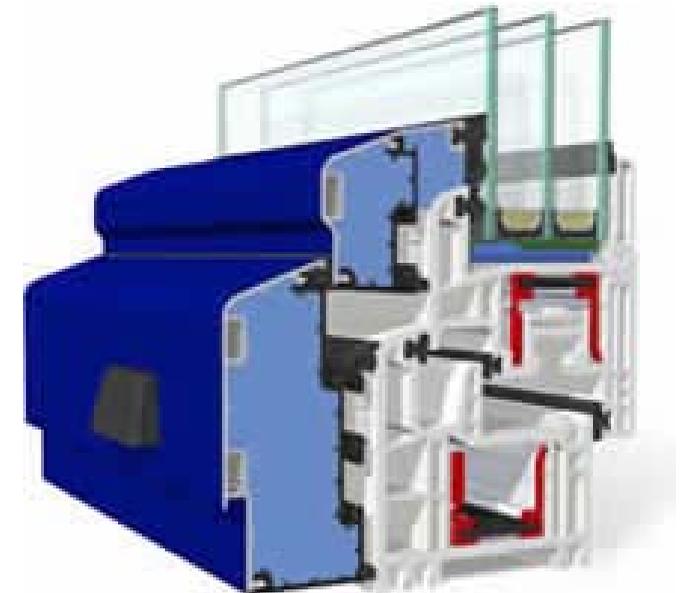
► Initial Position

Research

Results

Initial Position

Windows are the thermal weak spots of well insulated buildings. While triple glazing “only” achieves typical U_g -values of $0.7 \text{ W}/(\text{m}^2\text{K})$ - compared to U -values of less than $0.2 \text{ W}/(\text{m}^2\text{K})$ for the opaque façade - highly insulating window frames are even worse. Such window frames usually are very thick and bold and often heavy due to the steel reinforcements needed in plastic frames.



Conventional highly insulating window frame profile with complex structure, PU-foam insulation layer and steel reinforcement.





Renewable Energy Research for Global Markets



Highly Insulating Window and Facade Systems

(www.hwff.info)

Solar Building Design

9.

Window and Facade Systems

Initial Position

► Research

Results

Research

Due to a production technology commonly used in the automotive industry, a highly insulating, slim and lightweight window frame profile with the name TopTherm 90 could be developed. The core of the profile is PU foam, which is responsible for the excellent insulating properties of the TopTherm 90. The foam is surrounded by a thin casing of a dimensionally stable and weather-resistant plastic which safeguards the TopTherm 90's mechanical properties and design possibilities. The simple and cost-effective manufacture and assembly of the window is made possible by the adhesive technology used. Gluing the glazing and the frame also improves the static properties.



Cross-section of the newly developed window frame profile TopTherm 90.



Solar Building Design

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Window and Facade Systems

Initial Position

Research

► Results

Renewable Energy Research for Global Markets



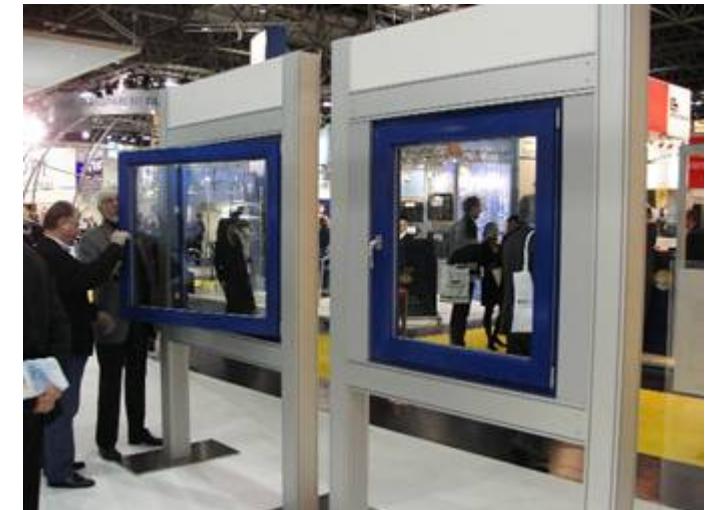
Highly Insulating Window and Facade Systems

(www.hwff.info)

Results

The TopTherm 90 has clear advantages over conventional passive-house window profiles:

- excellent insulating values at 90mm thickness:
 $U_w=0.8 \text{ W/(m}^2\text{K)}$ with three-pane insulating glass
 $U_w=0.7 \text{ W/(m}^2\text{K)}$ with vacuum insulation glass
- good static and functional properties
- simple window manufacture and assembly
- excellent prerequisites for joining with glass and metal
- practically any surface design possible



Presentation of two TopTherm 90 windows at the glasstec trade fair 2008 in Düsseldorf.



Glazing systems with light-redirecting prismatic films for seasonal shading



Solar Building Design

10.

Seasonal Shading

► Initial Position

Research

Results

Initial Position

Prismatic structures may be integrated in façade elements as sun-shading devices. They show an incident angle selectivity, based on internal total reflection of incoming solar radiation, resulting in a high solar gain in winter without overheating in summer.

Cost effective solutions are necessary to develop a larger market. Therefore microstructured films are advantageous compared to expensive macrostructured panes. In order to come to a suitable solution for buildings, these light-redirecting films have now to be integrated into glazing systems.

The purpose of the project is the development of a cost efficient and energy saving multiple glazing with following properties:

- suspended prismatic film for seasonal shading, resulting in a triple glazing unit with the weight and the thickness of a double glazing
- suitable for the use in glass façades or transparently insulated walls.



Large prototype of a triple glazing system with suspended light-redirecting film for seasonal shading



Glazing systems with light-redirecting prismatic films for seasonal shading



Solar Building Design

10.

Seasonal Shading

Initial Position

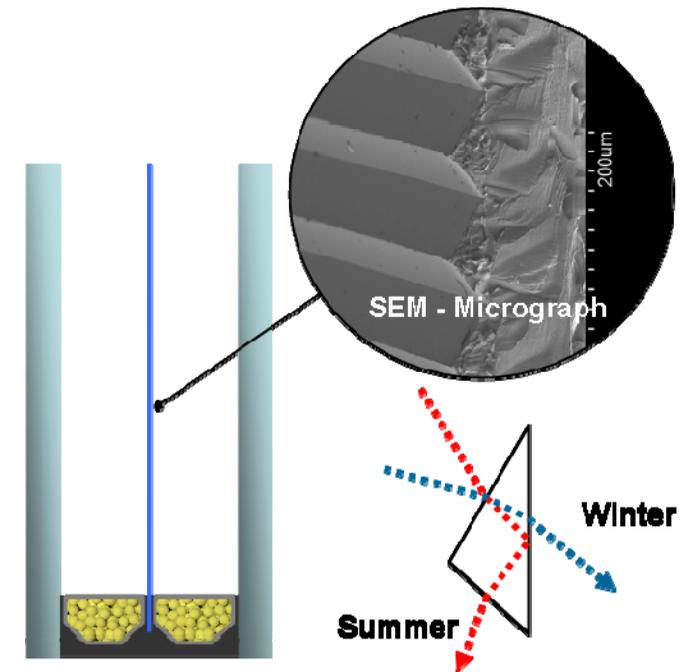
► Research

Results

Research

The research focuses on the following topics:

- Suitability tests on microstructured films for the use as suspended layers, i.e. optical and mechanical properties as well as UV-light durability
- Optical and thermal modeling of the glazing system
- Design and manufacturing of large prototypes
- Laboratory characterization
- Long term monitoring in real buildings for use as transparent insulation as well as daylighting system



Assembly of the investigated glazing system for static seasonal shading



Glazing systems with light-redirecting prismatic films for seasonal shading



Solar Building Design

10.

Seasonal Shading

Initial Position

Research

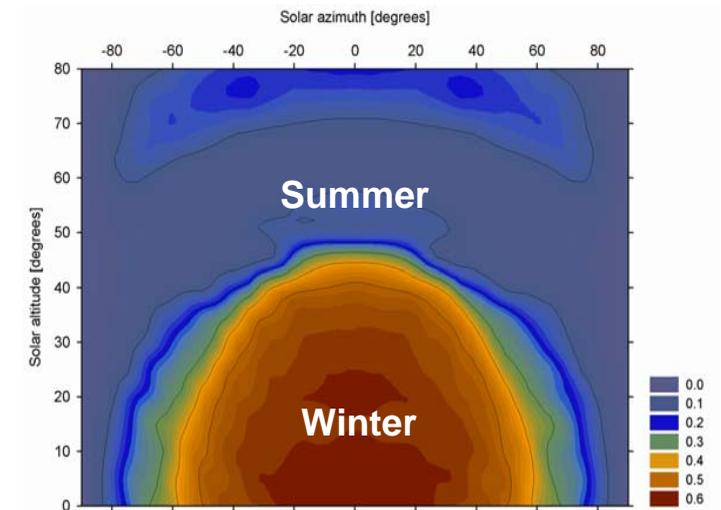
► Results

Results

Following results have been achieved:

- Suitable UV-light stabilized composite films have been identified
- Large prototypes with proved long-term reliability are now available
- Thermal transmittance (U-value) is equal to standard triple glazing
- Solar heat gain coefficient (SHGC) varies from 0.60 (winter) to 0.12 (summer), depending on solar incident angle
- Optical and thermal models have been validated

The project has been carried out with partners from the industry (Glasfischer Murr, Reflexite), funded by the “Deutsche Bundestiftung Umwelt (DBU)” (reference number 24673).



Solar altitude and azimuth angle dependent Solar Heat Gain Coefficient (SHGC, calculated)