Experiences from design studies, simulation studies and installations

International Energy Agency
Solar Heating and Cooling Programme
Task 38: Solar Air-Conditioning and Refrigeration

Workshop
April 25th 2007, Aix les Bains, France

Edo Wiemken
Fraunhofer Institute for Solar Energy Systems ISE

System design and configuration

Aims at

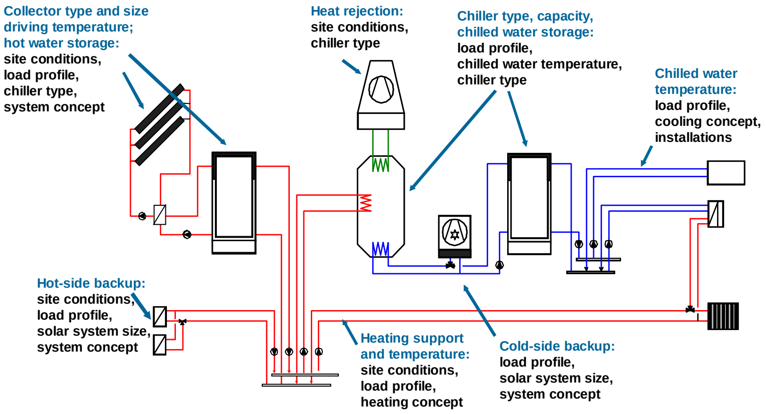
- Assessment of environmental benefits (savings in fossil fuel, reduction of greenhouse relevant emissions)
- Reliable technical solution
- Economics

System design and configuration

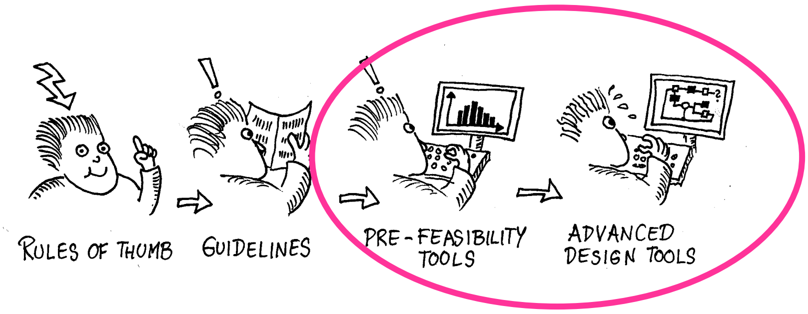
Pre-requisites

- Selection of climatic process / air-conditioning technology (chilled water system, full-air system, other heat sources, e.g., waste heat)
- Determine heating and cooling loads of the application (building simulation)
- Specify targets in primary energy saving, savings in CO_2-emissions,..

System design and configuration



Design methods



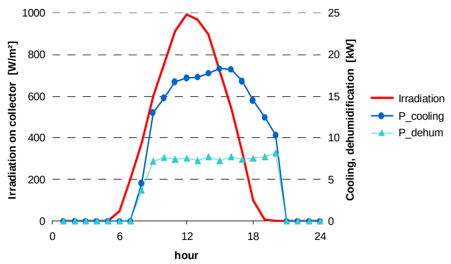
Precision, detailed results, flexibility

Number of required information and parameters

IEA SHC Task 38
Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Economic study within 'Solar Air-Conditioning in Europe (SACE)'

EU project, completed in 2003 www.cop.tudelft.nl/ev/res/sace.htm

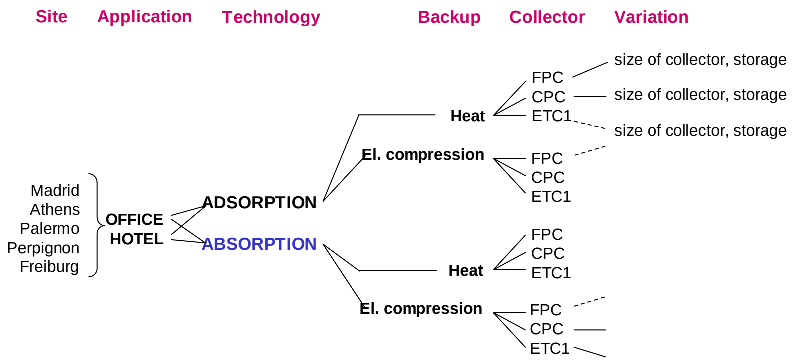


Example: summer day load and radiation profile (lecture room, Palermo site)

- Model buildings, defined in IEA Task 25
  - Hotel
  - Office
  - Lecture Room
- Annual heating and cooling load profiles (time series with hourly data) for five European sites
  - Madrid
  - Athens
  - Palermo
  - Perpignan
  - Freiburg

Fraunhofer Institut Solare Energiesysteme

SACE study - approach (closed cycle systems)



+ Reference calculation of a conventional system for each site and application

IEA SHC Task 38
Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

SACE study - approach

- Identification of most promising system size and configuration with respect to comparative primary energy savings (compared to the reference system); considering of complete energy balance (including pumps, fans, etc.)
- Cost figures
  - initial cost: complete investment for the entire system including cost for planning
  - complete annual cost: capital cost (annuity method) + operation cost based on annual energy balance + maintenance cost
  - "cost of saved primary energy" by comparison with a reference system

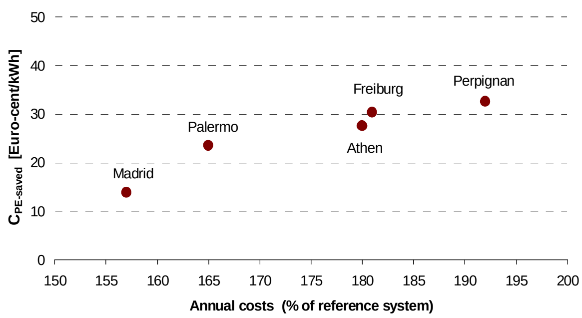
$$\textbf{cost of saved PE} = \frac{\text{extra annual cost of solar assisted system}}{\text{annual primary energy saving}} \left[€/kWh_{PE}\right]$$

SACE study - results (office building)

- Conditions:

  primary energy saving > 25%; annual net collector efficiency > 20%

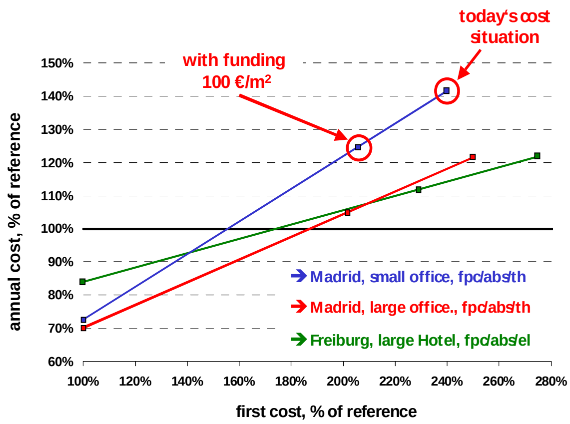
SITE	Collector type	Collector area per kW chiller	Heat storage size	Net collector efficiency	Chiller	Backup type	Annual cost of solar assisted cooling system	Primary energy saving	Cost of saved primary energy
Office at		m²/kW	hours	%			% of reference	%	Euro-cent per kWh
MADRID	CPC	3.3	4.2	21	ABS	heat	**157**	51	**13.9**
ATHENS	CPC	2.4	3.6	21	ABS	el. compr.	**180**	45	**27.6**
PALERMO	CPC	1.4	2.1	22	ABS	el. compr.	**165**	45	**23.6**
PERPIGNAN	ETC1	1.7	2.8	30	ABS	el. compr.	**192**	45	**32.6**
FREIBURG	ETC1	3.4	3.2	28	ABS	el. compr.	**181**	30	**30.4**



Experiences from design studies

- Results from other simulations:

  first cost higher by factor 2 to 3; annual cost higher by factor 1.2 to 1.5 (without funding)



fpc: flat-plate collector
abs: absorption chiller
th: thermal back-up
el: el. compression chiller back-up

Fraunhofer Institut Solare Energiesysteme

SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Experiences from design studies

- The specific combined energy-cost-performance parameter ‘cost per saved primary energy unit‘ supports the sizing and configuration of a solar assisted air-conditioning system
- Size and type of the collector and storage volume depends strongly on the site conditions, load structure and applied air-conditioning technology. A software tool is useful in the design of the system
- For thermal operated cooling processes with low COP and use of fossil fuels (heat back-up), a high percentage of solar thermal coverage is required in order to achieve savings in primary energy and CO_2 emmissions.
  Alternative: electrically driven compression chiller as cold side backup (‘fuel-saving‘ operation of solar thermal driven system) ⇒ more adequate for large systems
- In most cases solar assisted cooling is today not economically viable without funding, but shows a large potential in primary energy saving

Experiences from design studies

- Most effective in primary energy saving are systems with solar autonomous cooling operation. But comfort room air-states may not be guaranteed for all hours in this application.
  ⇒ favourable in buildings with dominating external loads and usage during day hours
- The exploitation of the solar thermal system should be maximised, using the system for space heating support and DHW as well (promising perspective for small scale applications)

Simulation study on solar thermal refrigeration

simulation of a prototype concept within the MEDISCO* project

- Food store cooling (0℃ store temperature)
- Concentrating solar thermal Fresnel collector
- NH3/H2O Absorption chiller (12 kW capacity prototype of company Robur)
- Air cooled
- Two North African sites

Prototype installation of a Fresnel collector (PSE, Freiburg) at Bergamo test plant, Italy

*** EU-project MEDISCO: Mediterranean Food and Agro Industry Applications of Solar Cooling Technologies; Co-ordinated by Politecnico di Milano (POLIMI), Italy**

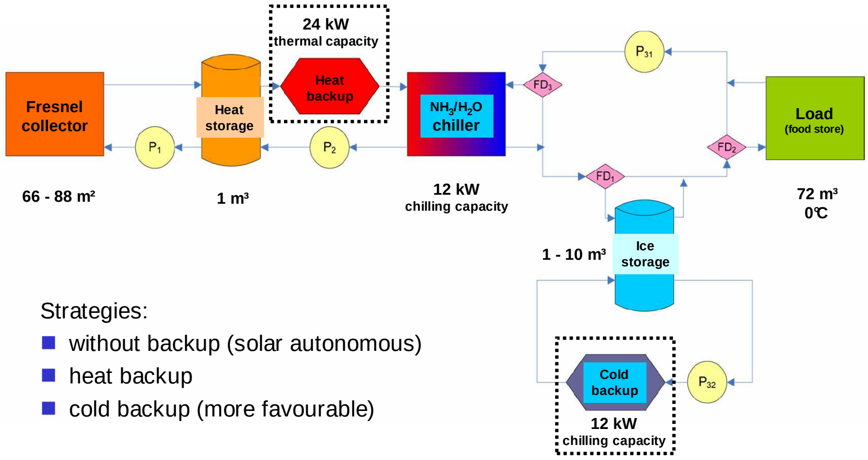
Simulation study on solar thermal refrigeration

simulation of a prototype concept within the MEDISCO* project

- Sites: Tunis (Tunesia), Quarzazate (Marocco)
- Cooled food store with 72 m³ store volume; store temperature: 0℃
  Internal load profile: exchange of food 3 times per day (with ambient temperature)
- Fresnel collector: operated with thermo-oil at temperatures 190℃ - 240℃; mirrors are tracked out of focus at operation limit temperature of chiller (‘lost radiation’)
  Optimised collector yield: at NE/SW orientation of mirror axis
- Cold storage: macro-capsulated ice storage (nodules) for improved charge/discharge capacity
- System modelling and simulation with TRNSYS (at ISE by Jochen Döll)

Fraunhofer Institut Solare Energiesysteme
SHC Solar Heating & Cooling Programme International Energy Agency

Simulation study on solar thermal refrigeration

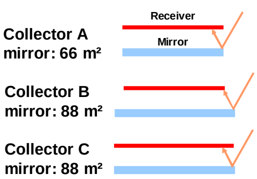


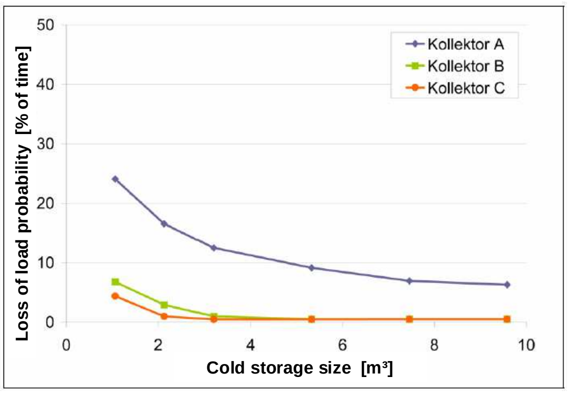
Strategies:

- without backup (solar autonomous)
- heat backup
- cold backup (more favourable)

Simulation study on solar thermal refrigeration
Results of annual simulations

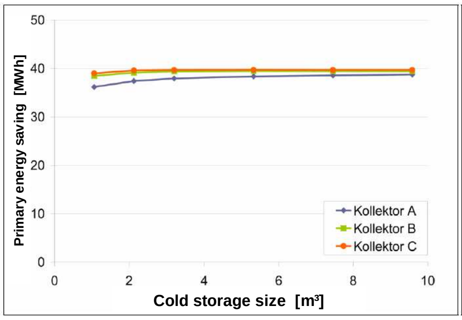
- Quarzazate
- solar autonomous cooling

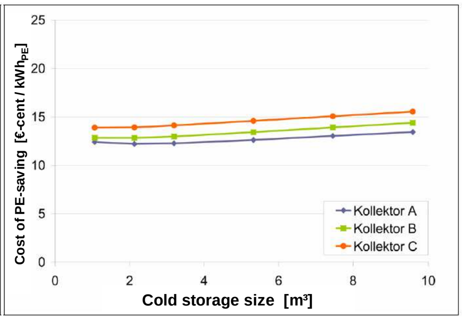




Simulation study on solar thermal refrigeration
Results of annual simulations

- Quarzazate
- solar autonomous cooling





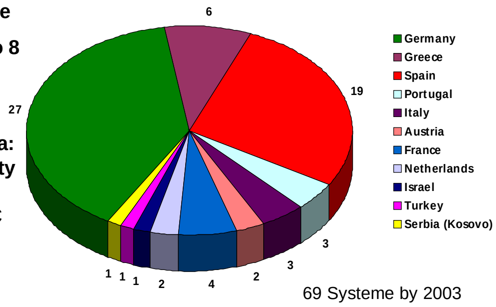
Simulation study on solar thermal refrigeration
Results of annual simulations

- Promising technology for high temperature lifts ($T_{heat\_rejection} - T_{chilled}$)
- Solar autonomous operation is possible (depending on the cooling requirements of the stored food)
- Highest cost reduction potential is seen in cost decrease of Fresnel collector
- New prototypes of the NH3/H2O chiller allow operation with lower driving temperatures ⇒ more efficient use of collector system
- MEDISCO project: installation of pilot systems are planned at North African sites

IEA SHC Task 38 — Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Solar air-conditioning installations in Europe

- Approx. 100 systems in Europe
- Installed capacity estimated to 8 MW
- Total collector area 20,000 m²
- Average specific collector area:
  - 3 m² per kW chilling capacity for chiller water systems
  - 10 m² per 1000 m³/h for DEC systems
- Many systems with chilling capacity of 35 kW, corresponding to market available products



69 Systeme by 2003

Fraunhofer Institut Solare Energiesysteme

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

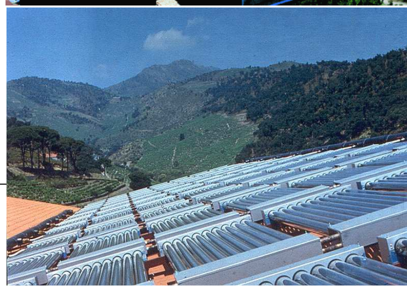
IEA SHC Task 38 — Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Solar air-conditioning of a cosmetics factory at Inofita Viotas, Greece

- chilled water for supply air cooling and fan coils for production facility
- 2 adsorption chillers with 350 kW chilling capacity each
- 2700 m² flat plate collectors
- Wet cooling towers
- 3 electrically driven compres-sion chiller with 350 kW capacity each
- Concept: electricity saving (prior operation of thermally driven chiller)
- in operation since 1999

Fraunhofer Institut Solare Energiesysteme

Solar thermal cooling of a wine cellar at Banyuls, France

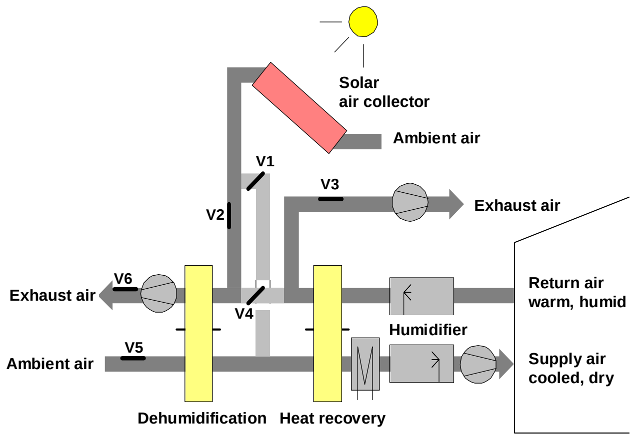


- Cooling of a wine cellar (3 million bottles) with three ventilation systems
  - total 250000 m³/h air volume flow
- Two absorption chiller with total 52 kW capacity
- wet-cooling tower
- 130 m² Vacuum tube collectors, 1 m³ buffer storage
- no backup, no large storage (load-side storage)
- In operation since 1991

Solar air-conditioning at the chamber of commerce (IHK südlicher Oberrhein), Freiburg, Germany

- Air-conditioning of two lecture rooms, total 213 m²
- Desiccant evaporative cooling (DEC) with silica-gel (rotor)
- 10200 m³/h nominal air volume flow rate
- 100 m² solar <u>air</u> collectors
- No storage
- Concept: solar autonomous summer operation (backup heater used for space heating only)
- In operation since 2001

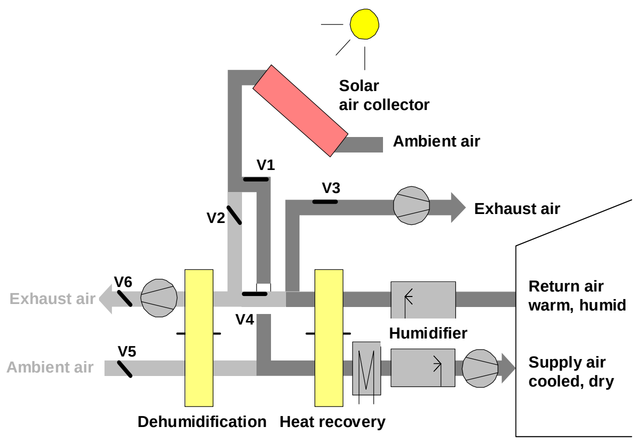
Chamber of commerce (IHK südlicher Oberrhein), Freiburg, Germany



Fraunhofer Institut Solare Energiesysteme

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Chamber of commerce (IHK südlicher Oberrhein), Freiburg, Germany



Fraunhofer Institut Solare Energiesysteme

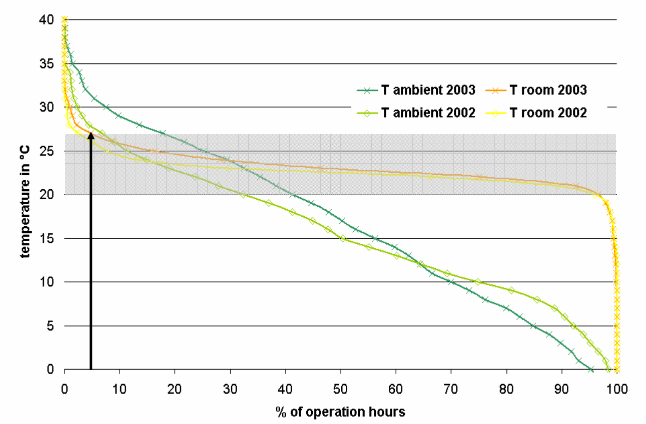
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Chamber of commerce (IHK südlicher Oberrhein), Freiburg, Germany

2002, 2003:

approx. 90% of operation hours within comfort area (20-25°C)

less than 5% of operation hours > 27°C

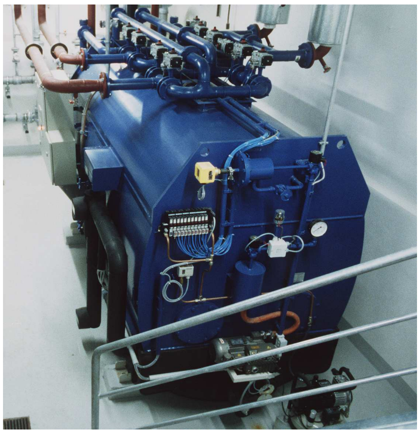


Chamber of commerce (IHK südlicher Oberrhein), Freiburg, Germany

- **Intensive commissioning of the system is essential (system control)**
- **Low-cost solar thermal system (approx. 10% solar system cost of the total installed system cost)**
- **Solar autonomous summer air-conditioning with solar air collectors and without storage is adequate for buildings with high glazing fraction and dominating use during daylight**

Solar air-conditioning at a laboratory building of the University hospital, Freiburg, Germany

- Supply air-conditioning of laboratory area
- Adsorption chiller with 70 kW chilling capacity
- Closed wet cooling tower
- 171 m² vacuum tube collectors (horizontal position, absorbers revolved to 30°/45°tilt angle)
- Heat backup: connected to University district steam network
- In operation since 1999

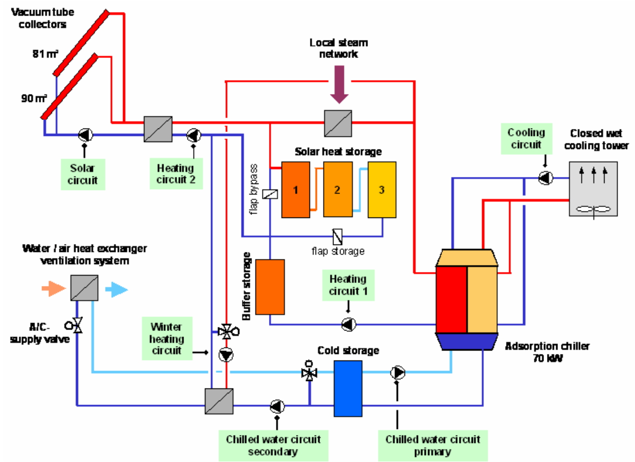


Fraunhofer Institut Solare Energiesysteme

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

Laboratory building of the University hospital, Freiburg, Germany

Chiller driven by steam heat ex-changer only



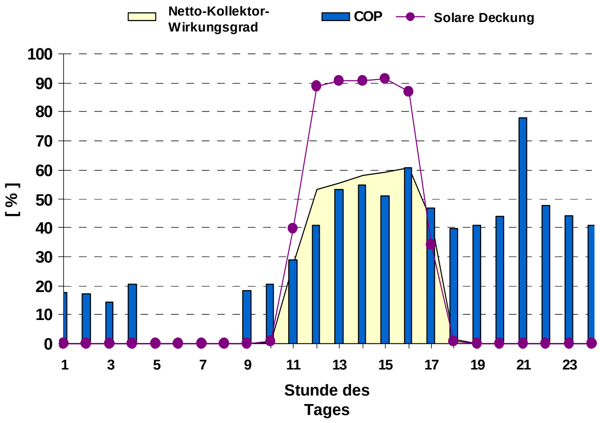
Fraunhofer Institut Solare Energiesysteme

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY

IEA SHC Task 38 Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Laboratory building of the University hospital, Freiburg, Germany

- High collector efficiency
- High solar coverage of heat input during day
- Low COP during night, caused by extensive part-load operation (chilling power < 10 kW)



18th August 2004

Fraunhofer Institut Solare Energiesysteme

IEA SHC Task 38 Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Laboratory building of the University hospital, Freiburg, Germany

- Overall reliable operation of the system
- Complex hydraulic scheme complicates optimised system control and effective exploitation of solar buffer storage. Some improvements during monitoring phase applied
- Unfavourable part-load operation of chiller during night
- Annual COP values below expectation; nominal capacity of the chiller could not be obtained
- High utilisation of the collector underlines the promising application of solar thermal air-conditioning
- High solar coverage during day
- Good acceptance of the system by the users

> - Net collector efficiency: 31%
> - Solar coverage: 28%
> - Collector yield: 360 kWh / m²*a
> - COP: 0.42
>
> Data uncertainty ± 15% relative due to monitoring uncertainties

Fraunhofer Institut Solare Energiesysteme

Solar air-conditioning at the European Academy EURAC, Bolzano, Italy

- Air-conditioning of Academy building area
- Heat production:
  - 480 m² vacuum tube collectors
  - co-generation 330 kW_{th}
  - condensation boilers
- Cold production:
  - absorption chiller 300 kW capacity
  - compression chiller 630 kW capacity
- Heat storage 10 m³
- Cold storage 5 m³
- In operation since 2005

Solar air-conditioning of a hotel at the Mediterranean coast, Dalaman, Turkey

- Air-conditioning of the hotel building and steam supply for hotel laundry
- 2-effect absorption chiller with 116 kW capactiy (4 bar saturated steam); COP > 1.2
- One-axis tracked parabolic trough collector for 180°C hot water generation; 180 m² aperture area
- Backup steam vessel with LPG
- First solar thermal cooling system with double-effect chiller
- concept applicable for sites with high direct radiation

Summary

- **Design and simulation studies supports the selection and sizing of the appropriate components and determines the potential savings in primary energy**
- **In most applications, solar air-conditioning is not yet economic competitve under present market conditions without funding measures**
- **Experiences from monitored systems reveals optimisation potential in system control and hydraulic scheme (often too complex); the system performance is often below the expectations**
- **The planning and installation of large collector areas requires special attention with respect to well balanced mass flow and stagnation safety**
- **Accurate commissioning phase is essential**

IEA SHC Task 38
Workshop Solar Air-Conditioning, April 25, 2007, Aix les Bains

Summary

- **More standardised system solutions for small and medium sized applications are necessary to decrease the investment cost**
- **The combination of heating support, domestic hot water preparation and solar cooling optimises the use of the solar thermal system throughout the year and improves the cost effectiveness**
- **Promising: new developments of small chillers (< 15 kW capacity) for residential and commercial use opens new market sectors, especially in southern European areas**
- **Interest of planners, building facility managements and solar companies in solar thermal air-conditioning increases**

Thank you for your attention!

Fraunhofer Institut Solare Energiesysteme
SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY