Barriers, Policy & Industry Development

The Picture in Europe

Daniel Mugnier

TECSOL

Australian Solar Cooling Interest Group Conference

Canberra – 16/03/2011

Outline

Main international R&D action: IEA SHC Task 38

Economics & politics

R&D initiative: cost reduction & quality assurance for solar cooling systems

Conclusion
Main international R&D action: IEA SHC Task 38

Economics & politics

R&D initiative: cost reduction & quality assurance for solar cooling systems

Conclusion

IEA Task 38
Solar Air-Conditioning and Refrigeration

- Task 38 just ended in December 2010
- Many reports already on www.iea-shc.org
- Among them
  - Solar Cooling Position Paper
  - 3rd completely revised edition of Handbook for Planners (next year)
Task 38 structure
Duration: 09/2006 – 12/2010

Subtask A
Pre-engineered systems for residential and small commercial applications
AEE INTEC (Austria): Dagmar Jähnig

Subtask B
Custom-made systems for large non-residential buildings and industrial applications
EURAC (Italy): Wolfram Sparber

Subtask C
Modeling and fundamental analysis
INES (France): Etienne Wurtz

Subtask D
Market transfer activities
Politecnico di Milano (Italy): Mario Motta

Subtask A - Pre-engineered systems for residential and small commercial applications

<table>
<thead>
<tr>
<th>WP</th>
<th>Work Package Name</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Market overview</td>
<td>State-of-the-art report describing market available equipment in the desired capacity range</td>
</tr>
<tr>
<td>A-2</td>
<td>Selection of system designs and control schemes</td>
<td>Collection of selected systems schemes (generic systems)</td>
</tr>
<tr>
<td>A-3</td>
<td>Field test monitoring including results</td>
<td>Technical report on the implemented experimental and monitoring activities</td>
</tr>
<tr>
<td>A-5</td>
<td>Installation and maintenance guidelines</td>
<td>Installation and maintenance guidelines for pre-engineered systems</td>
</tr>
</tbody>
</table>
**System performance**

- Significant progress in overall system performance
- Electric COP-values up to >8 shown in monitoring of Task 38: 8 kWh of cold production per 1 kWh of electricity for solar + cooling equipment (pumps, fans, heat rejection)

![Graph of COP vs. time](image)

**Subtask B - Custom-made systems for large non-residential buildings and industrial applications**

<table>
<thead>
<tr>
<th>WP</th>
<th>Work Package Name</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>Market overview</td>
<td>State of the art on existing solar heating and cooling systems</td>
</tr>
<tr>
<td>B-2</td>
<td>Selection of system designs and control</td>
<td>Solar Cooling System Design and Control</td>
</tr>
<tr>
<td>B-3</td>
<td>Monitoring of demo projects and pos-osal for evaluation procedures</td>
<td>Monitoring results of large scale installations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Monitoring procedure (technical report describing the methodology including performance figures and performance evaluation)</td>
</tr>
</tbody>
</table>
**Subtask B - Custom-made systems for large non-residential buildings and industrial applications (cont’d)**

<table>
<thead>
<tr>
<th>WP</th>
<th>Work Package Name</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-4</td>
<td>Method for fast pre-design of successful projects</td>
<td>Soft tool package for the fast pre-design assessment of successful projects Available on Tecsol website</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fast pre-design (technical report)</td>
</tr>
<tr>
<td>B-5</td>
<td>Guidelines for installation and call for tender</td>
<td>Installation and commissioning guidelines (technical report + checklist in ExCel)</td>
</tr>
</tbody>
</table>
Subtask D - Market transfer activities

<table>
<thead>
<tr>
<th>WP</th>
<th>Work Package Name</th>
<th>Deliverables</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-3</td>
<td>Life cycle analysis</td>
<td>Technical report about the results of the Life Cycle Analysis of Solar Cooling systems</td>
</tr>
</tbody>
</table>

- **D-5 Dissemination of results**
  - Policy paper
  - Training material (joint activity with EU-project SolAir)
  - (National) workshops
  - Electronic newsletter
  - Solar cooling position paper

Task Workshops / Conferences

<table>
<thead>
<tr>
<th>Meeting #</th>
<th>Place</th>
<th>Date</th>
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</thead>
<tbody>
<tr>
<td>Conference „Solar Air-Conditioning and Refrigeration“</td>
<td>Bolzano, Italy</td>
<td>October 18, 2006</td>
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<tr>
<td>Workshop „Solar Cooling“</td>
<td>Aix-les-Bains, France</td>
<td>April 25, 2007</td>
</tr>
<tr>
<td>Workshop for Industry</td>
<td>Barcelona, Spain</td>
<td>October 15, 2007</td>
</tr>
<tr>
<td>Workshop and Rococco Conference</td>
<td>Vienna, Austria</td>
<td>March 31, 2008</td>
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<tr>
<td>EUROSON 2008</td>
<td>Lisbon, Portugal</td>
<td>October 8-10, 2008</td>
</tr>
<tr>
<td>Workshop with Annex 34 of HPP</td>
<td>Freiburg, Germany</td>
<td>April 27, 2008</td>
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<tr>
<td>Task 38 Workshop linked to ASHRAE Trade Show</td>
<td>Orlando, Florida, USA</td>
<td>Jan. 23-27, 2010</td>
</tr>
<tr>
<td>Workshop „Solar driven cooling and air-conditioning“ with presentations given by Danish and Task 38 experts</td>
<td>Aarhus, Denmark</td>
<td>April 28, 2010</td>
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<tr>
<td>EUROSON 2010</td>
<td>Graz, Austria</td>
<td>Oct. 2-4, 2010</td>
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<tr>
<td>Task 38 Workshop linked to AHR</td>
<td>Las Vegas, Nevada, USA</td>
<td>Feb. 2-3, 2011</td>
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</tbody>
</table>
Main international R&D action: IEA SHC Task 38

Economics & politics

R&D initiative: cost reduction & quality assurance for solar cooling systems

Conclusion

Specific total costs of solar cooling kits in Europe *

17 000 AUD/ton

10 RT

* Solar cooling kits generally include: solar thermal collectors, hot water storage, pump-set, chiller, re-cooler, cold water storage, system control. The specific costs are without cold distribution and installation costs.
Cost Reduction Potential of Solar Cooling Kits

- **Solar Plant (Collectors and Storage):**
  max. 10% Cost Reduction Potential in the next 2-3 years

- **Small-Scale Sorption Chillers:**
  max. 20% Cost Reduction Potential till 2011, from 2011 up to 50% if Serial Production is started (Production Capacity larger than 500 Units)

- **Recooler:**
  Cost Reduction Potential between 40-50%

- **Control:**
  min. 60% Cost Reduction Potential, Increasing of the System Performance

- **Installation:**
  10-30% Cost Reduction Potential through Standardized Solar Cooling Kits

Source: Uli Jakob, SOLARNEXT

How do reduce costs?

High performance flat plate collectors + drainback

Performing, safe and cheap
Evacuated Tube collectors

Source: Viessmann

Compact packages solutions

Source: EDF Optimal Solutions

And above all...

Large scale production

Source: Broad
Examples of lobbying actions

**Green Chiller** – Verband für Sorptionskälte e.V.
Formed in March 2009 as an association in **GERMANY**
(8 Companies, 8 Institutes)

**ENERPLAN** : French Solar Association
Promoter in partnership with ADEME (French Energy Agency)
of the Emergence program in **FRANCE**

**ausSCIG** : an Australian Industry Interest Group
to develop the Solar Cooling Industry in **AUSTRALIA**
(Residential and Commercial Building Sectors)

Sources: Uli Jakob, SOLEM Consulting & Daniel Mugnier, TECSOL

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**Association for thermally driven cooling**

- **Goals**
  - Promoting and developing of the solar and thermal cooling markets in **Germany and Europe** (since Feb. 2010)
  - Demonstration of different applications
  - Development of design tools
  - Standardisation of chillers and solar cooling / thermal cooling systems

- **Application areas**
  - Solar cooling
  - Cooling in combination with district heat networks
  - Using waste heat for cooling (industry, combined heat & power)
A famous trilogy (Vedung et al., 1998):

- **Carrot**: financial incentive
- **Stick**: rules, compulsory requirements
- **Guidance**: information, training, marketing

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12 countries of OECD with repartition of incentive schemes

Source: OECD/IEA 2007 RETD report

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### Overview of some major incentive programs

<table>
<thead>
<tr>
<th>Country</th>
<th>Grant level</th>
<th>Perf. Expect.</th>
<th>Requirements</th>
<th>Nb installations</th>
<th>Grant volume</th>
<th>Program duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>50 to 70%</td>
<td>145 MBTU/yr</td>
<td>Delayed payment</td>
<td>15 to 30</td>
<td>5.2 M$</td>
<td>2 years (2010-2012)</td>
</tr>
<tr>
<td>Austria</td>
<td>30%</td>
<td></td>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>40% to 50%</td>
<td></td>
<td>Monitoring</td>
<td></td>
<td>9 M$</td>
<td></td>
</tr>
<tr>
<td>Lombardia</td>
<td>50% max</td>
<td></td>
<td>GSR contract</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy (easy)</td>
<td>up to 80%</td>
<td>Min perf.</td>
<td>Monitoring</td>
<td></td>
<td>26 M$ (incl. sury, hydro)</td>
<td>1 year</td>
</tr>
<tr>
<td>Germany</td>
<td>up to 50%</td>
<td>Strict selection</td>
<td>Monitoring</td>
<td></td>
<td>Limited</td>
<td></td>
</tr>
<tr>
<td>Germany (MAP ; BAFA)</td>
<td>269$/ft²</td>
<td></td>
<td></td>
<td>2 installations</td>
<td>1 M$</td>
<td></td>
</tr>
</tbody>
</table>

Sources: TECSOL, SOLEM, SUNDAY, SOLARNEXT, UNIPA
Focus on the French Emergence program

- Wish of both French Government and Solar cooling professionnals to build a High Quality Solar Heating and Cooling Demo Projects Incentive Scheme
- Based on Selection criteria and public fundings (invest+monitor.)
- Highly supported by ENERPLAN (Solar Professionnal Association)
- Audit of existing solar cooling installations (20 in France since 1990)
- Operational program starting in 2010 and for 2,5 years (June 2012)

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Focus on the French Emergence program

- Open to systems with sorption chillers / DEC
- Products available on the French market (local distr. + O&M)
- Nominal solar cooling power range : up to 60 tons
- Reversible systems permitting to do Heating & Cooling (all year long valorisation)

No geographical limitations on the projects (balance between heating and cooling changing between areas)

Objective : 15 to 30 financed installations on 3 years
(3 to 6 installations in 2011 – 5 à 10/year afterwards)
Focus on the French Emergence program

Minimum annual performance level to reach

- **Minimum solar yield**: Estimated value (feasibility study) calculated from the useful solar thermal production for heating and for cooling:
- **Heating**: useful kWh out of the storage tank and without back up.
- **Cooling**: useful cooling kWh produced at evaporator divided by a ratio of 0.6 for absorption chillers and 0.4 on adsorption chillers (COP average value). Possibility to extend to double sorption chillers with value of 1.

Thermal useful energy (all over in France): **350 kWh/m².year**

Focus on the French Emergence program

Minimum electric annual efficiency

- Calculated value of efficiency on a full year monitoring and equal to the ratio between useful solar energy kWh (thermal energy out of the solar tank in winter and out of the evaporator of the chiller in summer) + overall yearly electric consumption of the auxillaries used in the solar system (except the distribution pump and the back ups).

- **Minimum electric overall efficiency of the system**: **5**
  (corresponding to an average yearly value for high efficiency actual heat pumps).

- Minimum value to reach in an average 2 full year monitoring campaigns (heating + cooling)

- Threshold value evoluting during the Program duration and permitting to increase the installation productivity & quality + enhancing the important benefit of valorising the solar cooling installation in heating mode.
Focus on the French Emergence program

Budget frame
Amount of incentive calculated on the total overcost of the project in comparison with a reference one (+O&M – energy savings on 5 years)

Limit:
- 60% on Large companies
- 70% on SME's
- 80% on Public buildings and VSME's

Financing agreement for the monitoring including:
- Monitoring material & monitoring work (compulsory during the 2 first years) with a minima 3 energy measurements (heating, cooling and parasitic electric) + inform the client if dysfunctioning within 1 week

Grant level:
- Monitoring material, 50% covered limited to 13,000 AUD (can do both control and monitoring)
- Monitoring work, 50% for the 2 first years limited to 19,500 AUD

SOLARTHERMIE 2000+
program feedback

Funding in Solarthermie 2000plus

Project Management Organisation PJ*

Solarthermie 2000plus
Pilot plants and demonstration of large solar thermal applications

Subsidy:
30% - 52% of solar thermal investment
(in general not for cooling equipment)

Applicant

Project funding:
Support activities, Monitoring, project evaluation

Monitoring and research partners

*on behalf of the Ministry for the Environment, Nature Conservation and Nuclear Safety
SOLARTHERMIE 2000+
program feedback

- Good interest in funding scheme;
  several requests for funding, but only 7 pilot und demonstration system
  realisations with solar cooling
- Different reasons for small number of realisations:
  - subsidies not available at the time of planned realisation
  - conceptional reasons
    (e.g., available district heat not used, solar fraction too low,
    little multiplier effect, ...)
  - formal reasons (no appropriate status of applicant,
    not sufficient added value for national companies, ...)
  - still too high share of investment cost for applicant
  - proposal procedure too complex for applicant
- Extension within Solarthermie 2000plus:
  Solar cooling system development in a field test project with small size
  adsorption chillers (first installations in 2010)

Realised systems:
- 10 kW to 1 MW of installed thermally driven cold production
- 33 m² to 1218 m² of collector area
- broad range of system concepts

Capacity of thermally driven cold production [kW]

<table>
<thead>
<tr>
<th>Capacity [kW]</th>
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<tbody>
<tr>
<td>1200</td>
</tr>
<tr>
<td>1000</td>
</tr>
<tr>
<td>800</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>400</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>0</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Conditioned building area [m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>1,000</td>
</tr>
<tr>
<td>10,000</td>
</tr>
<tr>
<td>100,000</td>
</tr>
</tbody>
</table>

- Installed
- Installation: 2010
- No Realisation
- Realised without funding
SOLARThERMIE 2000+
program feedback

- Different concepts of interest by commercial applicants:
  - extension of existing HVAC plants to solar assistance (large scale)
  - small scale autonomous solar cooling
  - support to process cooling
- Consequently, beside demand for standardised systems, also non-standard solutions will remain of interest
- Reliable system operations and environmental savings have been proven, but also …
- … Problems with financial weakness of small chiller producers
- Financial funding of solar cooling still necessary, however the funding procedure should be kept as simple as possible
- Evaluation of solar cooling concepts with respect to savings in primary energy and greenhouse gas emissions is still reasonable

Required: further efforts to increase thermal and electric performance of the systems
Main international R&D action: IEA SHC Task 38

Economics & politics

R&D initiative: cost reduction & quality assurance for solar cooling systems

Conclusion

Potentials

- Technical potentials
  - Components: many new developments on component level (new heat rejecters, integrated heat rejection in chiller, integrated collector/desorber, ...) → improved efficiency and/or lower cost and/or more compact
  - Systems: systems using concentrating solar collectors are still in an early phase of development
  - Systems: Improved long term performance and reduced cost by quality measures
Potentials (cont’d)

- **Cost saving potential**
  - Cost reduction on component level
    - mass production: small scale chillers, concentrating collectors
    - new concepts: solar collectors, integrated solutions
  - Cost reduction on system level: Reduced planning and installation cost by more standardized concepts and procedures

- **Market opportunities**
  - Overall, integrated solutions for heating, cooling and hot water adapted to specific buildings / load profiles / applications and climatic (solar) conditions
  - Niches of particular interest might be buildings with heat demand all year (heating, hot water, cooling like e.g. hotels)

Potentials (cont’d)

- **Market opportunities (cont’d)**
  - Good market potential for systems using concentrated solar collectors in regions with high fraction of direct solar radiation (e.g. food sector, solar poly-generation)
Needed actions

- Technology development
  - Technology development on component level (collectors, chillers, ...) needs mainly R&D activities from manufacturer side
  - This has to be supported / accompanied by national and international (e.g. EU) research programmes (sometimes high risk, often SME's)
  - Work on cross-cutting issues on technology level (e.g. heat rejection) might be organized in network projects organized by R&D institutes

- Quality procedures
  - Today quality is probably the most critical issue (beside cost) for the further market development
  - Establishment of quality procedures therefore is an instrument which can have a significant impact on a sustainable market deployment

Needed actions (cont’d)

- Market & policy
  - Appropriate incentives and/or other support schemes to encourage energy efficiency measures and the use of solar energy in the most appropriate way in a given building / application
  - Continued demonstration programmes with accompanying monitoring (in particular in countries with a high solar ressource)
  - Training and education programmes (for installers, O&M companies, planners)
Proposed new Task

Quality assurance measures for solar thermally driven heating and cooling systems

➢ Main objectives

- Develop and provide various measures which lead to highly reliable, durable and robust solar cooling (and heating) systems

- **Contribute to further** cost reduction at all levels of the chain and identify most promising market areas in terms of cost competitiveness

➢ Logic next step for a sustainable market development

Arguments

- Today **quality** is probably the most critical issues (beside cost) for the further market development

- Establishment of **quality procedures** therefore is an instrument which can have a significant impact on a sustainable market deployment

- Development of a quality procedure for all phases of a project:
  - Design ➔ Installation ➔ Commissioning ➔ Operation / Maintenance / Monitoring

- In contract with the customer this can lead to **guaranteed solar results** (heating, hot water, cooling)

- Possible effects
  - **Reduced planing time and effort** ➔ **reduced cost**
  - **Reduced risk of mal-function or non-optimal performance**
  - **Minimization of maintenance effort**
  - **Fast identification of any shortcoming**
Key activities

- **Rigorous selection of the** best markets (building, applications) with high potential for solar cooling due to given boundary conditions (high electricity price, etc.) and most efficient STDHC systems (performance versus life cycle cost)

- **Development of a** complete quality procedure for system design, installation, commissioning and operation to give the best chance for solar cooling projects to lead to reliability and good performance on the long term

- **Creation of a complete set of** quality criteria which can be transformed into a certification or labelling process leading to a conceptual equivalent of a "Solar Cooling Keymark"; this may perhaps limit the field of systems and applications but guarantee system quality worldwide and thus assure a sustainable market development in the long term

- **Dissemination of the results of the three activities mentioned above at the level of policy makers and key stakeholders of the solar cooling technology field: planners, installers, O&M company => ROADMAP**

Main target audiences & participants

**Main target audiences**

- Engineering companies, Industries (chillers, solar collectors, systems)
- ESCOs (and utilities), O&M (operation and maintenance) companies
- Policy makers and public authorities & professional associations

**Participants in the new Task**

- Companies in the above mentioned fields with strong interest (some expressed already strong interest, e.g. Solid (Graz/Austria))
- Associations for dissemination (e.g. ESTIF, Greenchiller, Enerplan, ...)
- Research institutes, universities, ...

**Supporting national/international activities have already started**

EU, France, Germany and Austria have ongoing RD&D activities in solar cooling which provide a useful starting point for the new Task
Duration

- **Preparation phase**: November 2010 to May 2011
  - First concept paper produced in January 2011
  - Task Definition Workshop: 28-29th March 2011, Paris

- **Operation phase**: October 2011 to September 2014 (3 years Task)

- **Task initiator**: Daniel Mugnier, Tecsol (France)
  supported by Mario Motta, Politecnico di Milano (Leader of Subtask D of Task 38) and Hans-Martin Henning (OA Task 38)

**PLEASE SUPPORT THIS ACTION !**
(send an email to daniel.mugnier@tecsol.fr)

Conclusion

- **Emerging technology** with big potential... even if quite small market at the moment

- **Difficulties** to be cost competitive
- **Large cost reduction perspectives** (big investments + larger volumes required + quality assurance/reliability)

- From **technology** companies toward **sales companies** & powerful lobbies

- **R&D and incentive** programs to create a success story for solar heating and cooling.

**Thanks for your attention !**
Daniel MUGNIER, TECSOL
daniel.mugnier@tecsol.fr
Solar thermal competitiveness versus PV?

- How to use solar active systems in buildings in the best way?

- Main criteria
  - Technical maturity, robustness
  - Energy saving
  - Cost

Example: simulation study for a hotel in Madrid

Methodology

Production of an annual load file

Perform a parameter variation based on annual simulations

Conventional reference system

Solar thermal system for DHW + heating

Solar thermal system for DHW + heating + cooling

Conventional system + PV system

Comparison of results:
- energy performance
- cost
Day 2 – Solar Cooling Conference - 16/03/2011
Venue: The Hall, University House (ANU), Canberra

System boundary and energy balance

- Heating $Q_H$
- Hot water $Q_{DHW}$
- Cooling $Q_C$
- Electricity $E_{load}$

Primary energy $PE$
- Fossil fuel $E_{fuel}$
- Electricity $E_{el}$

Solar heating
- Gas condensation boiler
- Solar thermal system
- Compression chiller

Load

Australian Solar Cooling Interest Group (ausSCIG) Conference 2011
www.ausSCIG.org
Methodology and made assumptions

- Annual simulation based on hourly load and meteo data
- Load: Hotel in Madrid (4 zones) ➞ hourly load file
- Components
  - Advanced flat plate collector tilted 30° towards south (variation from 100 m² ... 500 m²)
  - Heat buffer storage (variation from 30 litre/m² ... 80 litre/m²)
  - Thermally driven chiller with average thermal COP of 0.68 (variation from 0 kW ... 40 kW)
  - Cooling tower with a nominal COP of 25 (i.e. 25 kWh of rejected heat per 1 kWh of consumed electricity)
  - Vapour compression chiller with average EER of 3.0
  - Natural gas boiler with efficiency of 0.9

Assumptions and methodology

- PV system
  - Mono-crystalline Si-wafer PV modules tilted 30° towards south (variation from 8 kW_{peak} ... 80 kW_{peak}); cost 3 € per W_{peak} (including planning + installation)
  - Electricity produced higher than actual electricity load is fed into grid; reimbursement 50 % of the tariff for which electricity is purchased
- For all systems: no incentives, no subsidies, no tax reduction
- Operation strategy solar thermal system
  1. Cover heating demand
  2. Cover sanitary hot water demand
  3. Cover cooling demand in combination with thermally driven chiller
Cost curves of key components

Source for most cost curves: new cost models provided by Aiguasol/Spain within Task 38

Further parameters

<table>
<thead>
<tr>
<th>Other parameters</th>
<th>Planning</th>
<th>% of invest</th>
<th>20.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation</td>
<td>% of invest</td>
<td>30.0%</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>% of invest</td>
<td>1.5%</td>
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</table>

Energy cost

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>€ / kWh</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Peak electricity cost</td>
<td>€ / kW</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>€ / kWh</td>
<td>0.07</td>
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<tr>
<td>Increase rate electricity cost</td>
<td>% p.a.</td>
<td>3%</td>
<td></td>
</tr>
<tr>
<td>Increase rate fuel cost</td>
<td>% p.a.</td>
<td>3%</td>
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</table>

Other parameters

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<th>Lifetime</th>
<th>a</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest rate</td>
<td>%</td>
<td>5.0%</td>
<td></td>
</tr>
<tr>
<td>PE factor electricity f_{PE,el}</td>
<td>kWh_{PE} / kWh_{el}</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>PE factor fuel f_{PE,fuel}</td>
<td>kWh_{PE} / kWh_{fuel}</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>
System comparison: alternative versus reference

- Saved primary energy
  \[ f_{PE, saved} = \left( \frac{PE_{reference} - PE_{alternative}}{PE_{reference}} \right) \cdot 100 \ \text{[%]} \]

- Total annual cost ( = life cycle cost divided by lifetime)
  \[ C_{total, annual} = C_{capital, annual} + C_{maintenance, annual} + C_{operation, annual} \]

- Difference in total annual cost
  \[ \Delta C_{total, annual} = C_{total, annual, alternative} - C_{total, annual, reference} \]

Results

- Saved primary energy, %
- Difference in total annual cost, %
Results

- **Many systems are cost efficient under the assumptions made** (considering complete life cycle cost; 3 % increase in energy prices (electricity, natural gas))

- **Solar thermal system** (small to medium size) **without cooling is first priority** (lowest cost of saved primary energy)

- A large (**high solar fraction**) solar heating & cooling system (overall solar fraction about 65 %) leads to an **increase of total annual cost** compared to reference (4 %)

- A **large PV field** (similar area) leads to a **higher primary energy saving** at **lower increase of total annual cost**. However, this requires that electricity generated by PV which can not be used in the building can be fed into the electricity grid

- **The large solar thermal heating & cooling system is the only system which leads to a reduction of peak electricity consumption** (about 8 %)