Technical and economic analysis of different solar cooling systems
Summary of IEA Task 53 results

Daniel NEYER
Introduction

- Solar cooling and heating can be complex
  - Solar Thermal or Photovoltaic driven
  - Demands (domestic hot water, space cooling, …)
  - System design & configurations (backups, storages,…)
  - Boundaries (system and time)
  - …

→ Assessment in a common comparable format
  - T53E4 Assessment Tool
  - T53 Energy Efficiency Economy Evaluation Tool
  - Assessment based on (monthly) energy balances
  - Measured or simulated (sub) system
Technical Key Figures

- Non-renewable primary energy ratio \( \text{PER}_{\text{NRE}} \)
  - Useful energy \( (Q_{\text{use}}) \):
    space heating, cooling, domestic hot water, …
  - Energy input / effort \( (Q_{\text{in}}) \)
    electricity (el),
    energy carrier (e.g. natural gas, etc.)
  - Primary energy conversion factors
    electricity: \( \varepsilon_{el} = 0.4 \, \text{kWh}_{\text{Use}}/\text{kWh}_{\text{PE.NRE}} \)
    natural gas: \( \varepsilon_{in} = 0.9 \, \text{kWh}_{\text{Use}}/\text{kWh}_{\text{PE.NRE}} \)

\[
\text{PER}_i = \frac{\sum Q_{\text{use}}}{\sum \left( \frac{Q_{\text{el.in}}}{\varepsilon_{el}} + \frac{Q_{\text{in}}}{\varepsilon_{in}} \right)}
\]
Technical Key Figures

- Standardized Task 53 reference system
  - Natural gas boiler
  - Air cooled vapour compression chiller
  - Calculation of $\text{PER}_{\text{NRE.ref}}$

- Non-renewable primary energy savings ($f_{\text{sav.PER-NRE}}$)
  - Comparison of non-renewable Primary Energy ($\text{PER}_{\text{NRE}}$)
  - Solar (SHC) vs. predefined reference (ref)

\[
f_{\text{sav.PER-NRE}} = 1 - \frac{\text{PER}_{\text{NRE.ref}}}{\text{PER}_{\text{NRE.SHC}}}
\]
Economic Key figures

- Annuity method & input values based on EN-standards
- Standardized (data base) to calculate annualized costs
  - Investment, replacement & residual value
  - Maintenance & service,
  - Operational costs (energy, water)
  - Solar Heating and Cooling and Reference

→ CostRatio (CR)

CostRatio(CR) = \frac{\text{annualized costs SHC}}{\text{annualized cost REF}}
Results obtained

- Assessment of 29 SHC plants with T53E4 Tool
  - Technical analysis
    - Energy balance check
    - Comparison to T53 Standard
    - System & Subsystem Analysis
    - $\text{PER}_{\text{NRE}}, \text{PER}_{\text{NRE,ref}}, f_{\text{sav,NRE}}, SPF_{\text{equ}}$
  - Economic analysis
    - Investment, Replacement & Residual
    - Maintenance, Energy (electricity, natural gas,...)
    - Comparison to T53 Standard
    - Spec. Invest, LCOE$_{\text{SHC}},$ LCOE$_{\text{REF}},$ CR

- Trend analysis
- Sensitivity analysis
Overview Examples

- Assessment of 29 SHC plants with T53E4 Tool
  - 17 examples (29 configurations)
  - System & Subsystem Analysis
  - Trend analysis
  - Sensitivity analysis

Technology

- PV; 12; 41%
- ST; 8; 28%
- ST+PV; 3; 10%
- ST+HP; 6; 21%

Demand

- C; 3; 10%
- DHW; 1; 3%
- DHW+SH; 4; 14%
- DHW+SH+C; 13; 45%
- DHW+C; 4; 14%
Overview Examples

**Capacity**
- small (<10 kW); 16; 55%
- medium (10-150 kW); 7; 24%
- large (>150 kW); 6; 21%

**Design, solar fraction**
- <30; 7; 24%
- 30-70; 16; 55%
- 70-90; 3; 11%
- >90; 3; 10%
- simulation; 19; 66%
- monitored; 10; 34%

**Source**
# Energy Supply

- Mainly 2 / 3 applications
- Huge difference in amount of energy!

<table>
<thead>
<tr>
<th>Technology / capacity [kW] / plants #</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST+boiler</td>
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<tr>
<td>ST + HP</td>
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<tr>
<td>ST&amp;PV</td>
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<tr>
<td>PV</td>
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<tr>
<td>cooling (C)</td>
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<tr>
<td>heating (SH)</td>
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<tr>
<td>domestic hot water (dhw)</td>
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</tbody>
</table>

- 15, 7, 1a, 1b, 1c, 17, 9a, 9c
- 6, 62, 320, 133, 320, 285, 235, 546, 299
- 7a, 7b, 3b, 2b, 2d, 10, 16, 2e, 2f
- 11a, 11b, 4, 5, 12, 13, 6, 14, 2a, 2c
- 9b, 9d

- 8, 69, 105, 105, 350, 500, 580, 630
- 10, 10, 39, 50, 50, 130, 5, 10, 10
- 2, 2, 2, 7, 10, 11, 11, 21, 50, 50
- 580, 630
Total Annualized Cost

- Small scale → investment dominated
- Large scale → energy costs dominated
Primary Energy vs. Costs

- $f_{\text{sav.NRE}}$ vs. CostRatio

![Graph showing $f_{\text{sav.NRE}}$ vs. CostRatio]
Overall Trend

- Exclude plants with no annual energy balance
Trend / Sensitivity Analysis

- Several trends can be shown
  - Location: south vs. north
  - Demand: DHW vs. Cooling vs. Heating
  - Technology: ST vs. PV
  - …

- Sensitivity: 6 Parameter with 7 Variations each
  - Investment Cost (€/kW) 40, 55, 70, 85, 100, 115, 130 [%]
  - Electricity price (10 ct/kWh) 50, 100, 150, 200, 250, 300, 350 [%]
  - Natural gas price (5 ct/kWh) 50, 75, 100, 125, 150, 175, 200 [%]
  - Auxiliary demand (kWh_{el}) 50, 60, 70, 80, 90, 100, 110 [%]
  - Energy output (kWh_{use}) 80, 90, 100, 110, 120, 130, 140 [%]
  - Conversion factor (0.4 kWh_{el}/kWh_{NRE}) 80, 90, 100, 115, 130, 145, 160 [%]
Sensitivity

- Investment cost
  - Only affect the CostRatio
  - Plants with higher $f_{\text{sav.NRE}}$ are more sensitive
Sensitivity

- Auxiliary demand (electricity)
  - Affects CostRatio and $f_{\text{sav.NRE}}$
  - Heat pump systems more affected
  - Higher $f_{\text{sav.NRE}}$ less sensitive
Summary

- **T53E4 Assessment Tool**
  - Simplified analysis of system / subsystem
  - Useful for benchmarking against reference and other RE
  - Focus on
    - non-renewable primary energy
    - CostRatio

- **Performance of SHC examples**
  - Non-renewable Primary Energy Savings 40-80%
  - Higher savings lead to higher costs
  - Economics are mainly investment dominated
Summary

- Sensitivity analysis
  - Effect of changes in boundaries
  - Trend wise comparison of results
  - Large differences for different systems
  - Sensitivity for certain type of systems to follow soon

- Advantage of ST or PV is depending on …
  - Local conditions
  - System design & Application

→ Both technologies can be optimized
→ Cost competitiveness can be reached
Thank you for your attention!