Technical and Economic Assessment

of solar heating and cooling systems
T53E4 evaluation tool

Daniel NEYER[1,2], Alexander THÜR[2], Rebekka Köll[3]

$$SPF_{th} = \frac{\sum Q_{out}}{\sum Q_{in}}$$

$$PER = \frac{\sum Q_{out}}{\sum \left(\frac{Q_{el,in}}{\varepsilon_{el}} + \frac{Q_{in}}{\varepsilon_{in}} \right)}$$

$$SPF_{el} = \frac{\sum Q_{out}}{\sum Q_{el,in}}$$

$$f_{sav.PER} = 1 - \frac{PER_{ref}}{PER_i}$$

$$\Delta SPF_{SHC} = \frac{Q_{WD.system} + Q_{HD.system} + Q_{hloss} - Q_{HB.system} * (1 - \%_{HB.C}) + Q_{HP.system}}{\frac{Q_{HB.system} * \%_{HB.C} * \varepsilon_{el}}{\varepsilon_{EC} * \eta_b} + E_{aux.SHC}}$$

$$SPF_{equ} = \frac{PER_{NRE}}{\varepsilon_{el}}$$

Introduction

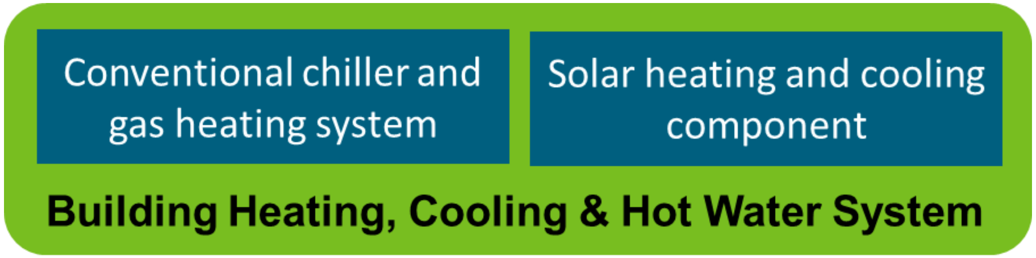
$$\mathrm{PER}_{\mathrm{NRE.ref}} = \frac{\sum \mathrm{Q}_{\mathrm{out}}}{\sum \left(\frac{\mathrm{Q}_{\mathrm{out.heat}} + \mathrm{Q}_{\mathrm{loss.ref}}}{\varepsilon_{\mathrm{in}} * \eta_{\mathrm{HB.ref}}} + \frac{\mathrm{Q}_{\mathrm{out.cold}}}{\mathrm{SPF}_{\mathrm{C.ref}} * \varepsilon_{\mathrm{el}}} + \frac{\mathrm{Q}_{\mathrm{el,ref}}}{\varepsilon_{\mathrm{el}}} \right)}$$

$$CAP_{solar} = \frac{\left(\frac{Q_{\mathrm{CD.system}} + Q_{closs} - Q_{\mathrm{CB.system}}}{EER_{ref}(f(kW))} - \frac{Q_{\mathrm{HB.system}} * \%_{HB.C} * \epsilon_{el}}{\epsilon_{EC} \eta_b} - \Delta E_{aux.C} \right)}{t}$$

Introduction

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

Component ↔ System ↔ Building



Introduction

? Which **key performance indicators** to use ?

? **Benchmarks** for and against SHC systems ?

? Combine gas and electricity in one key figure ?

? Steady state vs. dynamic behavior ?

→ Assessment in a **common comparable format**

- energetic, ecological, economic, evaluation
  → **T53E4 Assessment Tool**
- Assessment based on (monthly) **energy balances**
- Measured or simulated (sub) system
- **Data base** for technical and economic assessment
- T53 standard & specific results

System & Components

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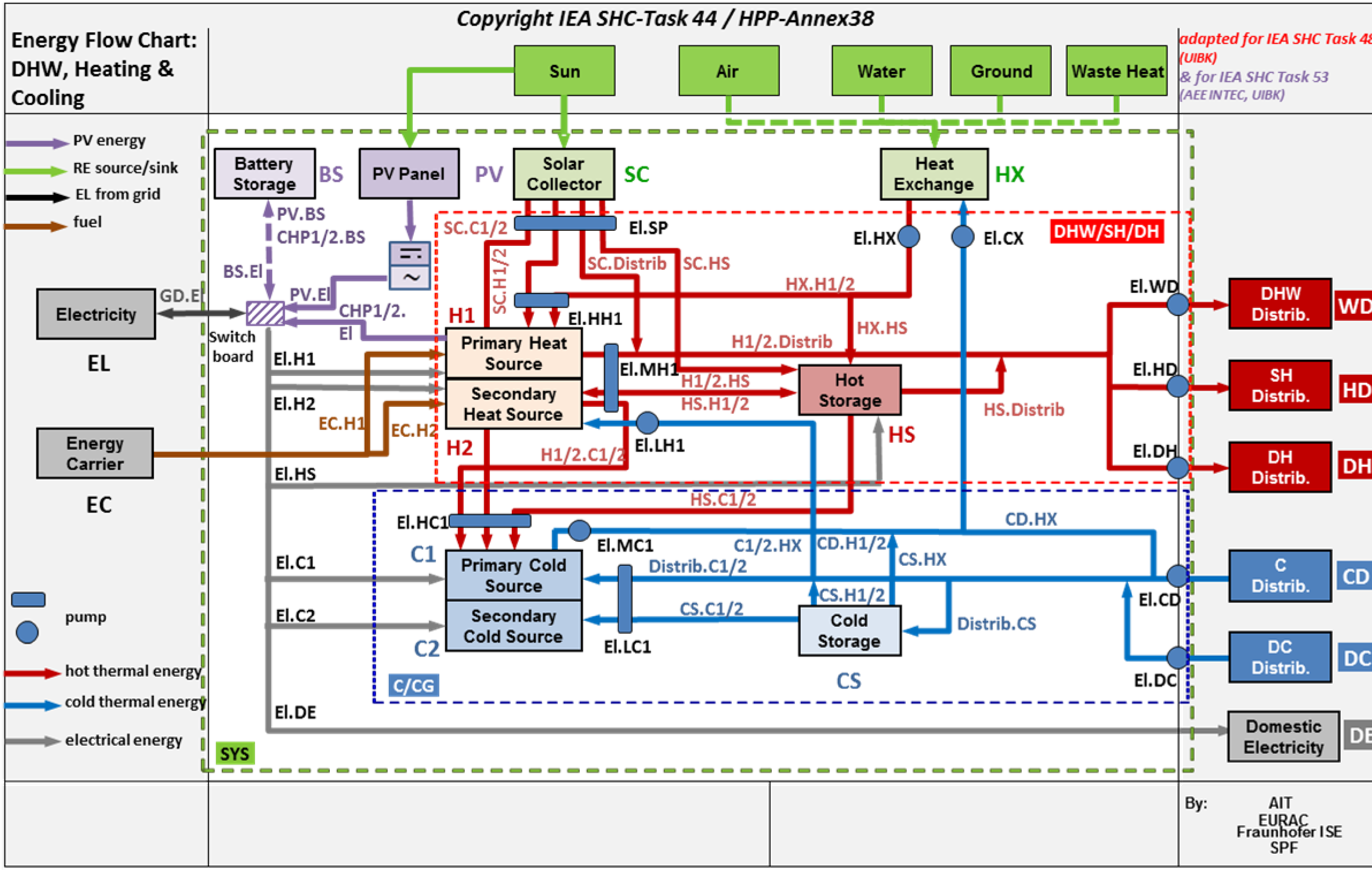
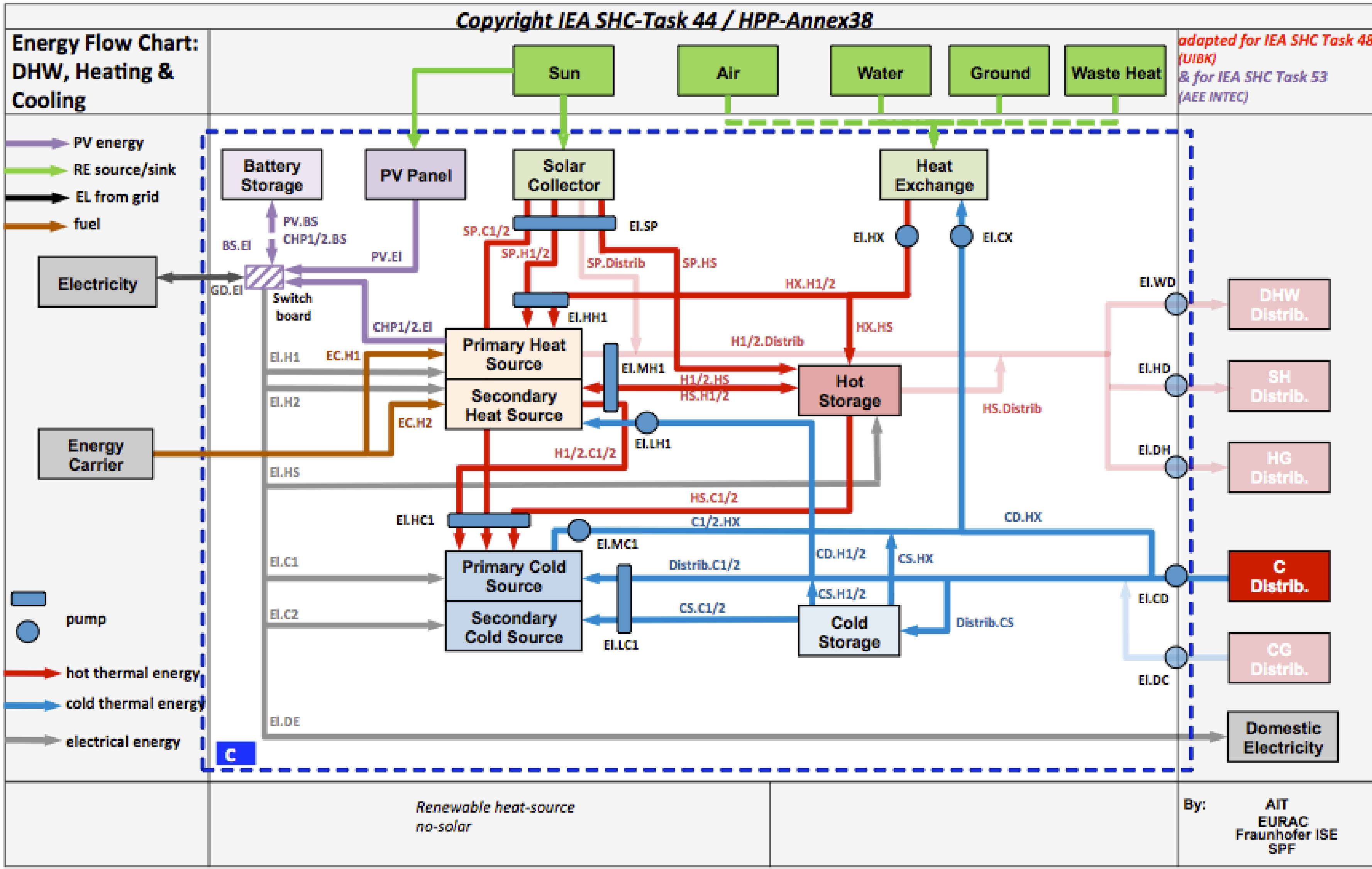


Boundary - Cooling



Boundary - Solar Cooling

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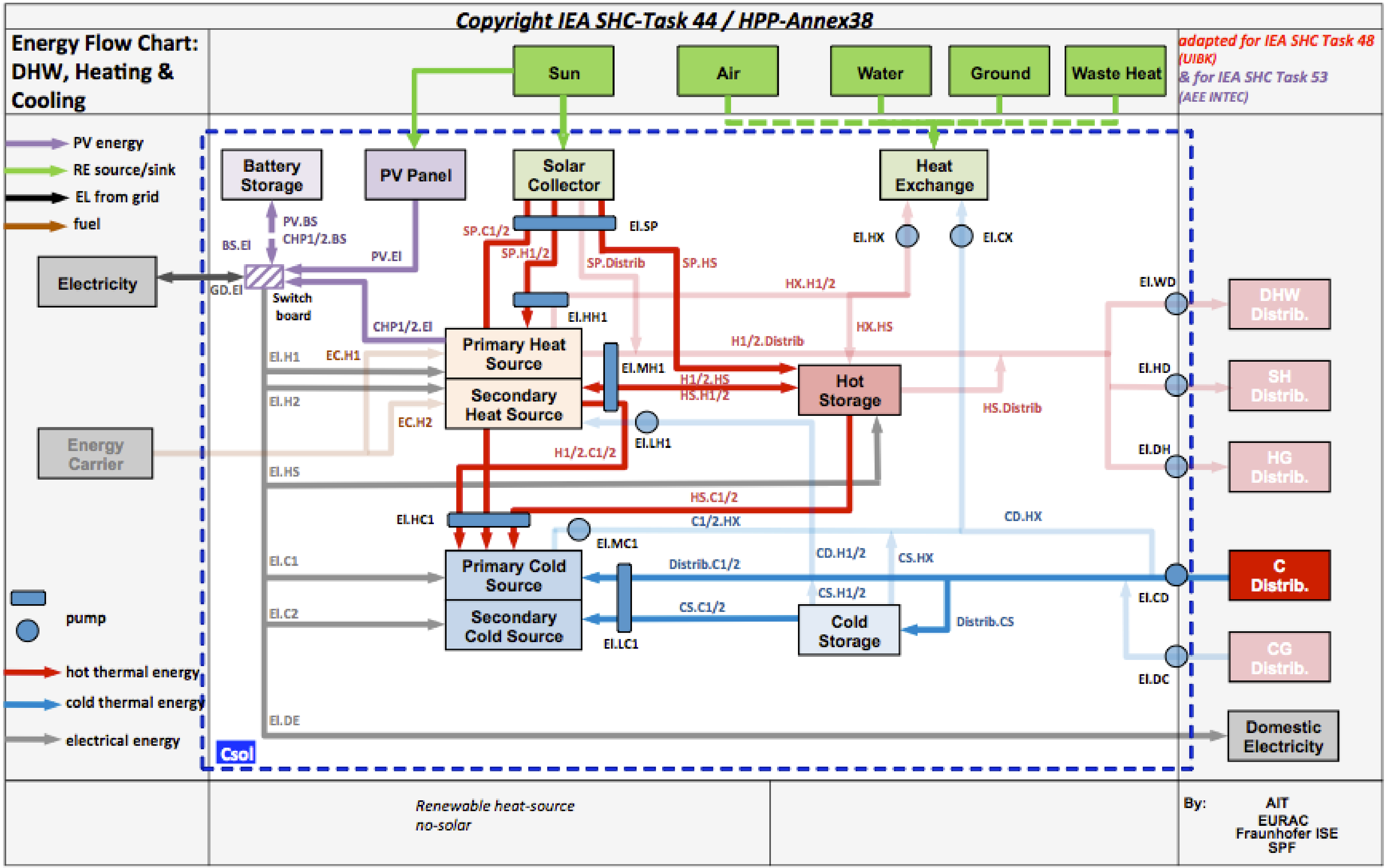

Systems & Components

- Technical and economic data available for

	components
Solar Thermal Collectors (SC)	• Flat Plate Collector • Evacuated Tube Collector
Photovoltaic (PV)	• Photovoltaic Panels • BOS (balance of system)-components
Heating (H1, H2)	• Natural Gas Boiler • Pellets Boiler • Heat Pump (not reversible/reversible) • Absorption Heat Pump (not reversible/reversible) • Combined Heat&Power Plant • District Heating (as heat source)
Cooling (C1, C2)	• Air-Cooled Vapour Compression Chiller • Water-Cooled Vapour Compression Chiller • Absorption Chiller (Single Effect & Double Effect) • Adsorption Chiller • District Cooling (as cold source)
Storage (HS, CS, BS)	• Hot Storage • Cold Storage • Battery Storage

Technical Key Figures

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- Non-renewable primary energy ratio (PER_{NRE})

  Energy input (Q_{in}) converted in primary energy

  electricity: $\boldsymbol{\varepsilon}_{el}$ = 0.4 $kWh_{Use}/kWh_{PE.NRE}$

  natural gas: $\boldsymbol{\varepsilon}_{in}$ = 0.9 $kWh_{Use}/kWh_{PE.NRE}$

$$PER_{NRE} = \frac{\sum Q_{out}}{\sum \left(\frac{Q_{el,in}}{\varepsilon_{el}} + \frac{Q_{in}}{\varepsilon_{in}} \right)}$$

- Standardized Task 53 reference system

  Natural gas boiler, air-cooled vapor compression chiller

$$\mathrm{PER_{NRE.ref}} = \frac{\sum \mathrm{Q_{out}}}{\sum \left(\frac{\mathrm{Q_{out.heat}} + \mathrm{Q_{loss.ref}}}{\varepsilon_{\mathrm{in}} * \eta_{\mathrm{HB.ref}}} + \frac{\mathrm{Q_{out.cold}}}{\mathrm{SPF_{C.ref}} * \varepsilon_{\mathrm{el}}} + \frac{\mathrm{Q_{el,ref}}}{\varepsilon_{\mathrm{el}}} \right)}$$

- Non-renewable primary energy savings ($\mathbf{f_{sav.PER\text{-}NRE}}$)

$$f_{sav.PER-NRE} = 1 - \frac{PER_{NRE.ref}}{PER_{NRE.SHC}}$$

Technical Key Figures

SPFequ = SPF in electrical equivalent units,

PER converted into a comparable magnitude for vapour compression chiller / heat pump

$$SPF_{equ} = \frac{PER_{NRE}}{\varepsilon_{el}} = \frac{\sum Q_{out}}{\sum \left(Q_{el,in} + \frac{Q_{in}}{\varepsilon_{in}} * \varepsilon_{el} \right)}$$

to compare the overall heating / cooling system with a vapour compression chiller / heat pump

Primary Energy

- Annual non-renewable primary energy conversion factors

	T53 Standard	Unit
Primary energy factor for electricity ε_{el}	0.40	kWh_{el}/kWh_{pr}
CO_2 factor for electricity	0.55	kg/kWh_{el}
Efficiency of the natural gas boiler η_{HB}	0.9	-
Primary energy factor for natural gas ε_{EC}	0.9	kWh_{el}/kWh_{pr}
CO_2 factor for natural gas	0.26	kg/kWh_{el}
Efficiency of the pellets boiler η_{HB}	0.86	-
Primary energy factor for pellets ε_{EC}	10	kWh_{el}/kWh_{pr}
CO_2 factor for pellets	0.05	kg/kWh_{el}

→ Specific values country wise

Electricity

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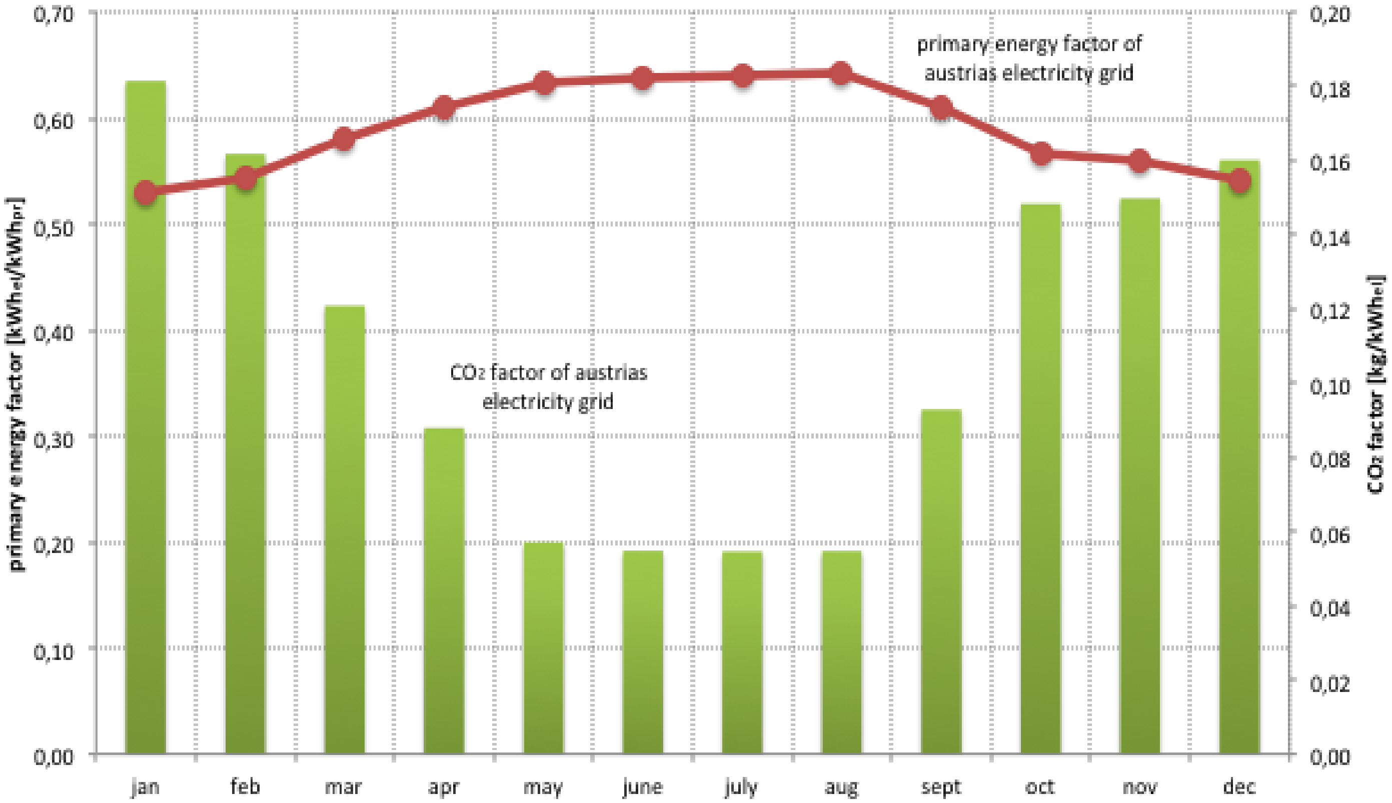
- Monthly T53 standard values for non-renewable primary energy and CO2 emissions
- Example for Austria, based 2015



Economic Key figures

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- Different views / interests
  - Customer, Investor, Facility management…
- Different methods & key figures (dynamic calculation):
  - Amortization method → pay back time
  - Discounted cash flow method → internal rate of return (IRR),
  - Present value method → net present value (NPV),
  - Annuity method → annualized costs
  → Levelized cost of energy

→ Comparing systems with economic life time of components
→ Many misleading KPIs…
→ Many decisions in early stage…

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)

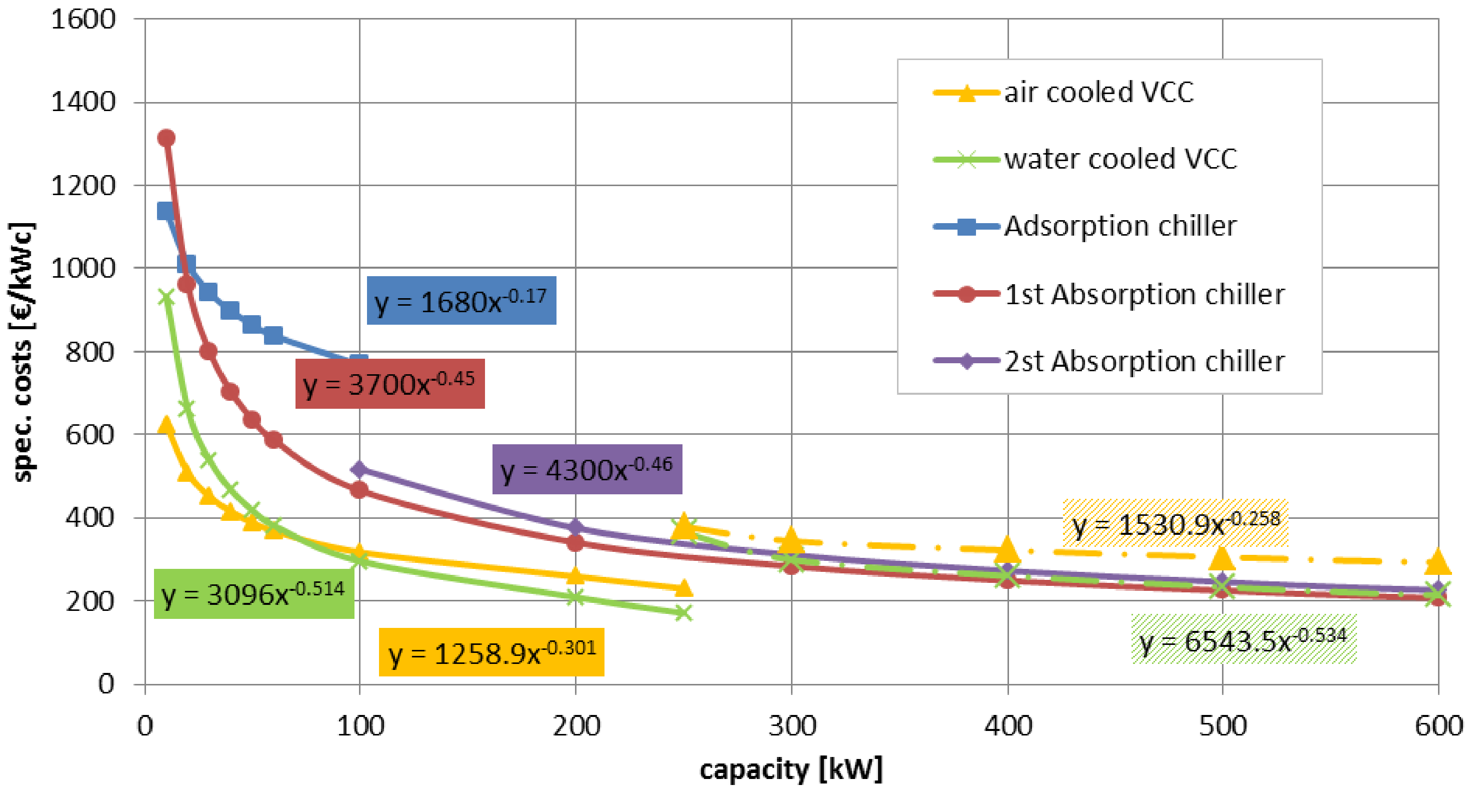
  - Solar Heating and Cooling and Reference
  - → Levelized cost of energy

→CostRatio (CR)

$$\mathrm{CostRatio(CR)} = \frac{annualized\ costs\ SHC}{annualized\ cost\ REF}$$

Investment Costs

- For all main components,
  - size dependent incl. economy of scale
  - e.g. vapour compression / absorption chiller



Economic Base

Economics	
Period under consideration	25 a
Credit period	10 a
Inflation rate	3 %

Energy costs	
Electricity (energy)	10 ct/kWh
Electricity (power)	80 €/kW.a
Feed-in tariff without subsidies	3 ct/kWh
Natural gas	5 ct/kWh
Water	2.5 €/m³

Reference System - VCC

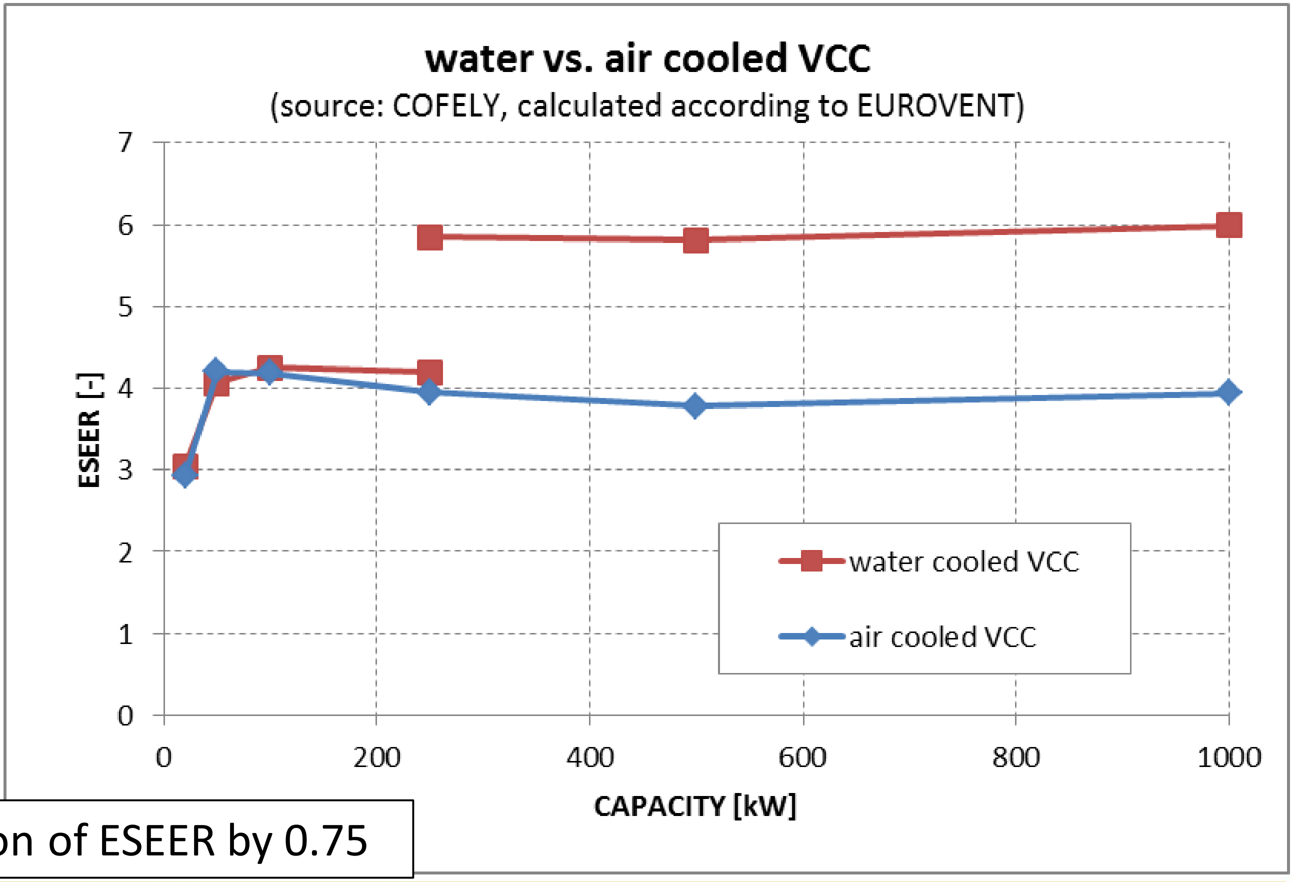
- Water cooled VCC
- Air cooled VCC

- Depending on capacity
  - Configuration (1/2 hydraulic circuits)
  - Technologies (comp.: scroll, screw, turbo; heat exchanger;…)

Capacity [kW]	Circuit	Water cooled	Air cooled
20	1	Scroll	Scroll
50	1	Scroll	Scroll
100	1	Scroll	Scroll
250	2	Scroll/Turbo	Scroll
500	2	Turbo	Screw
1000	2	Turbo	Screw

Reference - VCC

- European Seasonal Energy Efficiency Ratio (ESEER) of standard vapor compression chiller according to EUROVENT



→ SPF_{ref}: Multiplication of ESEER by 0.75

Summary

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- T53E4 Assessment Tool
  - Simplified analysis of system / subsystem
  - T53 Standard & specific calculation
  - Useful for benchmarking against reference and other RE
  - Focus on
    - non-renewable primary energy (fsav.NRE)
    - Cost Ratio

→ **need** of working group for **harmonizing** of calculation **methods** and technical and economic key **performance** indicators

Final reports of IEA SHC Task 53
to be expected soon
http://task53.iea-shc.org/

Tool download
http://task53.iea-shc.org/
Final Version to be expected in
Autumn 2018

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THE CYBERNETICS
OF RENEWABLE ENERGY
AND EFFICIENCY.

oberradin 50
6700 bludenz
austria
+43 664 28 26 529
daniel@neyer-brainworks.at
www.neyer-brainworks.at

Thank you for your attention!

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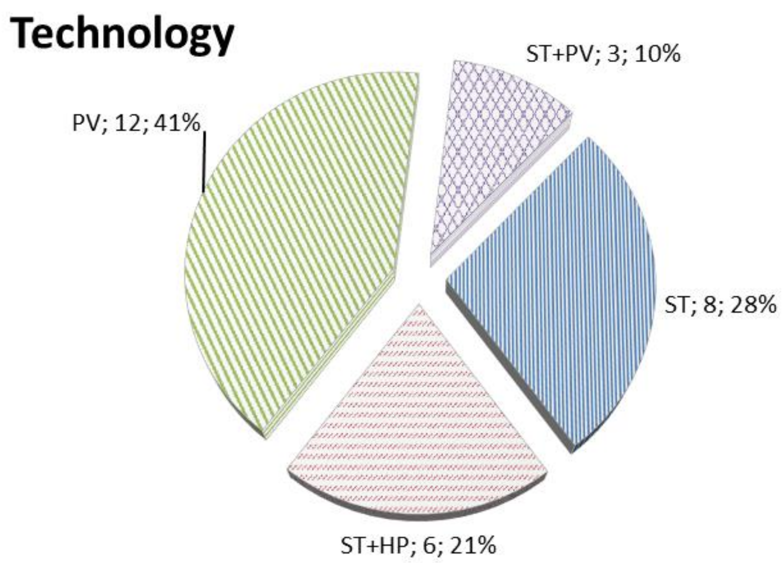
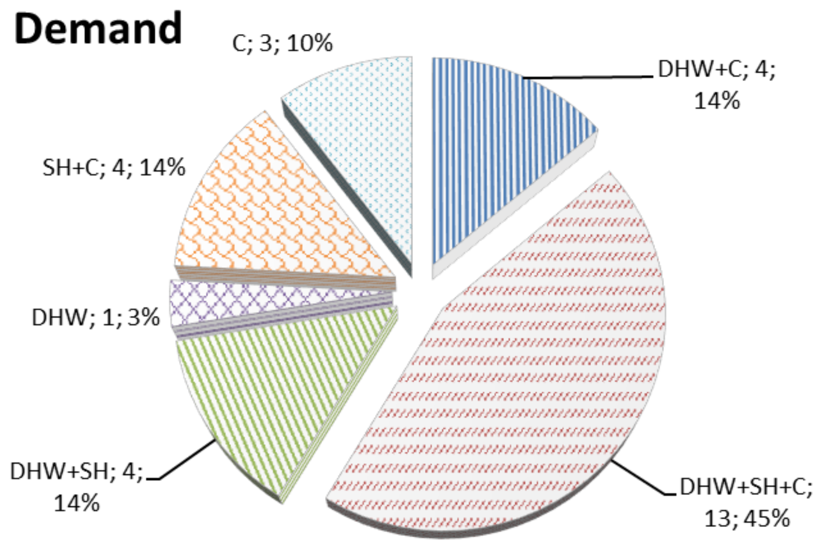
T53 Best practice examples

Introduction

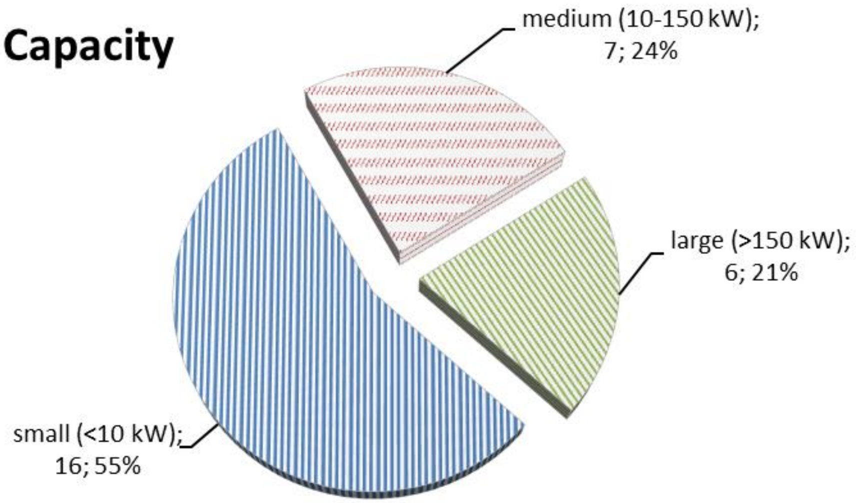
Overview Examples

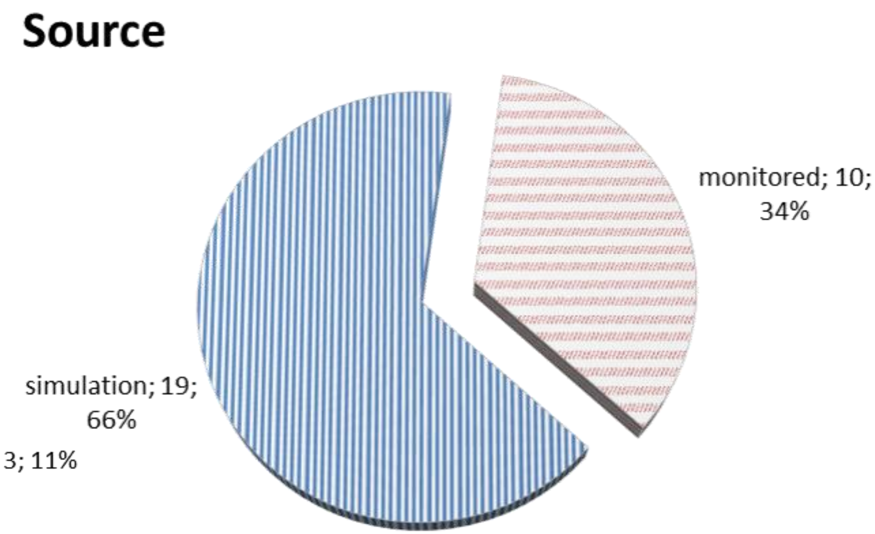
- Assessment of 28 SHC plants with T53E4 Tool
  - 17 examples (28 configurations)
  - System & Subsystem Analysis
  - Trend analysis
  - Sensitivity analysis

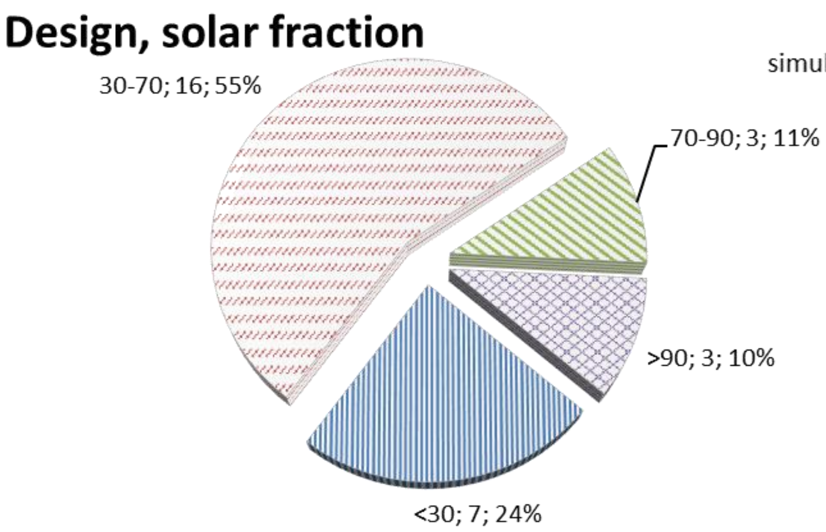




Overview Examples







Results obtained

- Assessment of 28 SHC plants with T53E4 Tool
  - Technical analysis
    - Energy balance check
    - Comparison to T53 Standard
    - System & Subsystem Analysis
    - PER_{NRE}, $PER_{NRE.ref}$, $f_{sav.NRE}$, SPF_{equ}
  - Economic analysis
    - Investment, Replacement & Residual
    - Maintenance, Energy (electricity, natural gas,…)
    - Comparison to T53 Standard
    - Spec. Invest, $LCOE_{SHC}$, $LCOE_{REF}$, CR
- Trend analysis
- Sensitivity analysis