SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

SOLARCOOLING® SUNBELT REGIONS TASK65

IEA-SHC Task 65
Assessment and benchmarking of solar cooling systems

Dr. Daniel Neyer

neyerbrainworks

universität innsbruck
Unit of
Energy Efficient Buildings

IEA SHC Solar Academy
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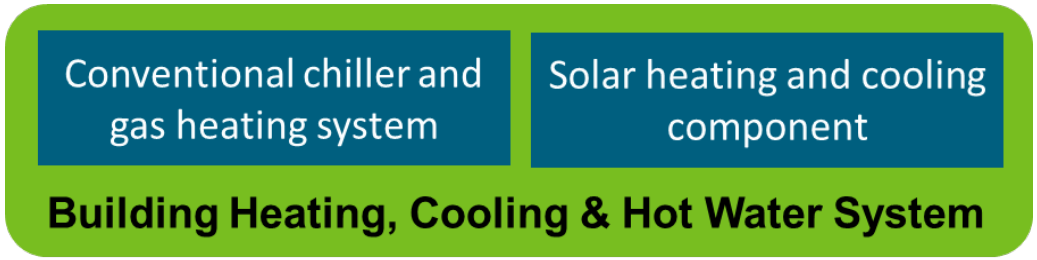
SOLAR ACADEMY SHC
FOR HEATING & COOLING IN BUILDINGS & INDUSTRY

ISES International Solar Energy Society

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

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

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

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

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

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

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

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

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

Subtask C:
ASSESSMENT and TOOLS

General Objectives

- Update / merging of **useful tools** for design & assessment
- Establishing / adapting of **assessment method** and benchmarking (incl. reference system in different locations)
- Create **common data base** for technical, environmental and economic assessment for the participating countries
- Analyses of **Subtask B results and benchmarking** against reference systems and different renewable and solar solutions
- **Sensitivity analyses** of high influencing parameters on the technical / economic / environmental assessment

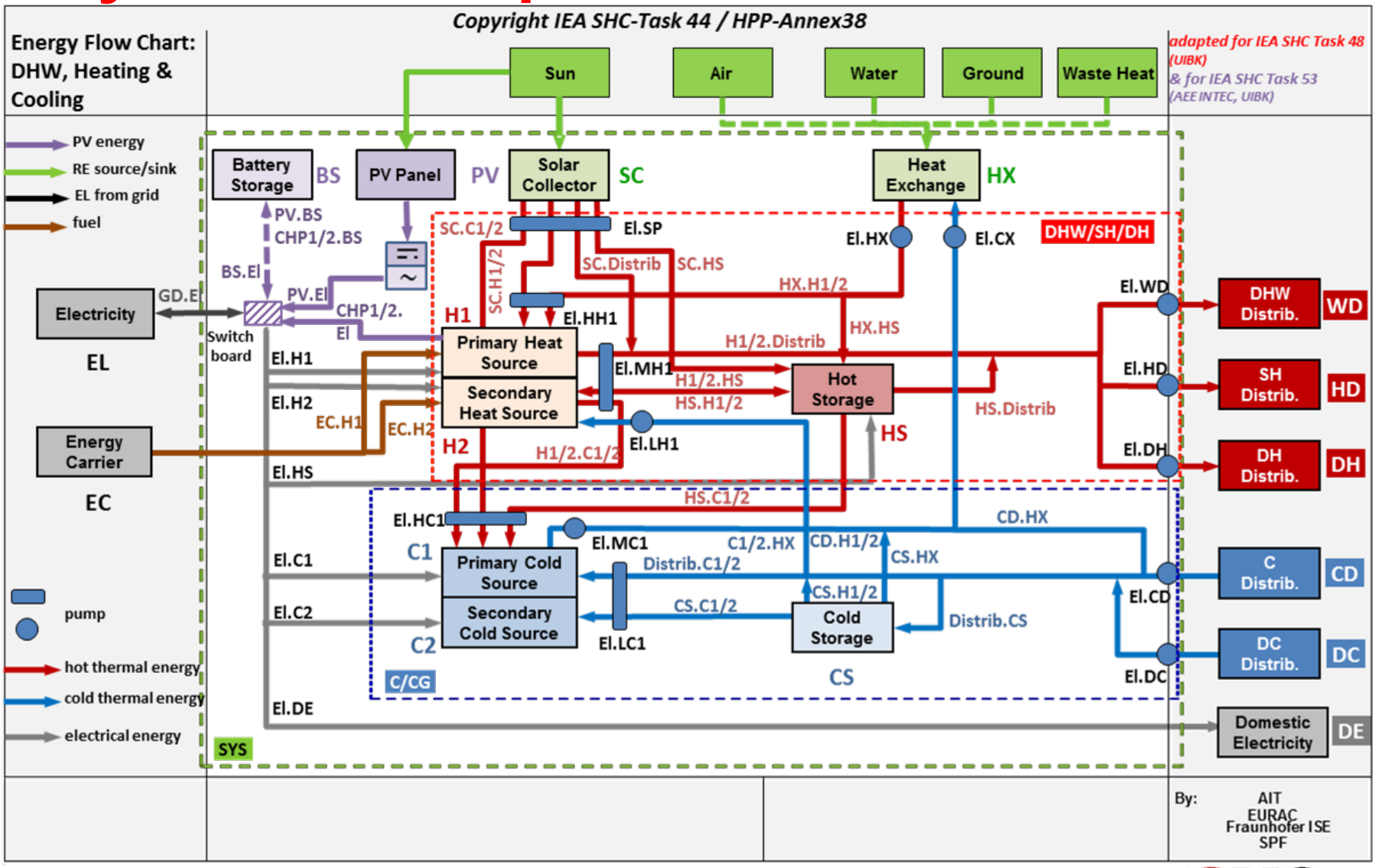
Task 53 - Tool

Assessment in a common comparable format

- Energetic, ecological, economic, evaluation

  → **T53E4 Assessment Tool**
- Assessment based on (monthly) **energy balances**
- Measured or simulated (sub-) systems
- **Data base** for technical and economic assessment

System & components

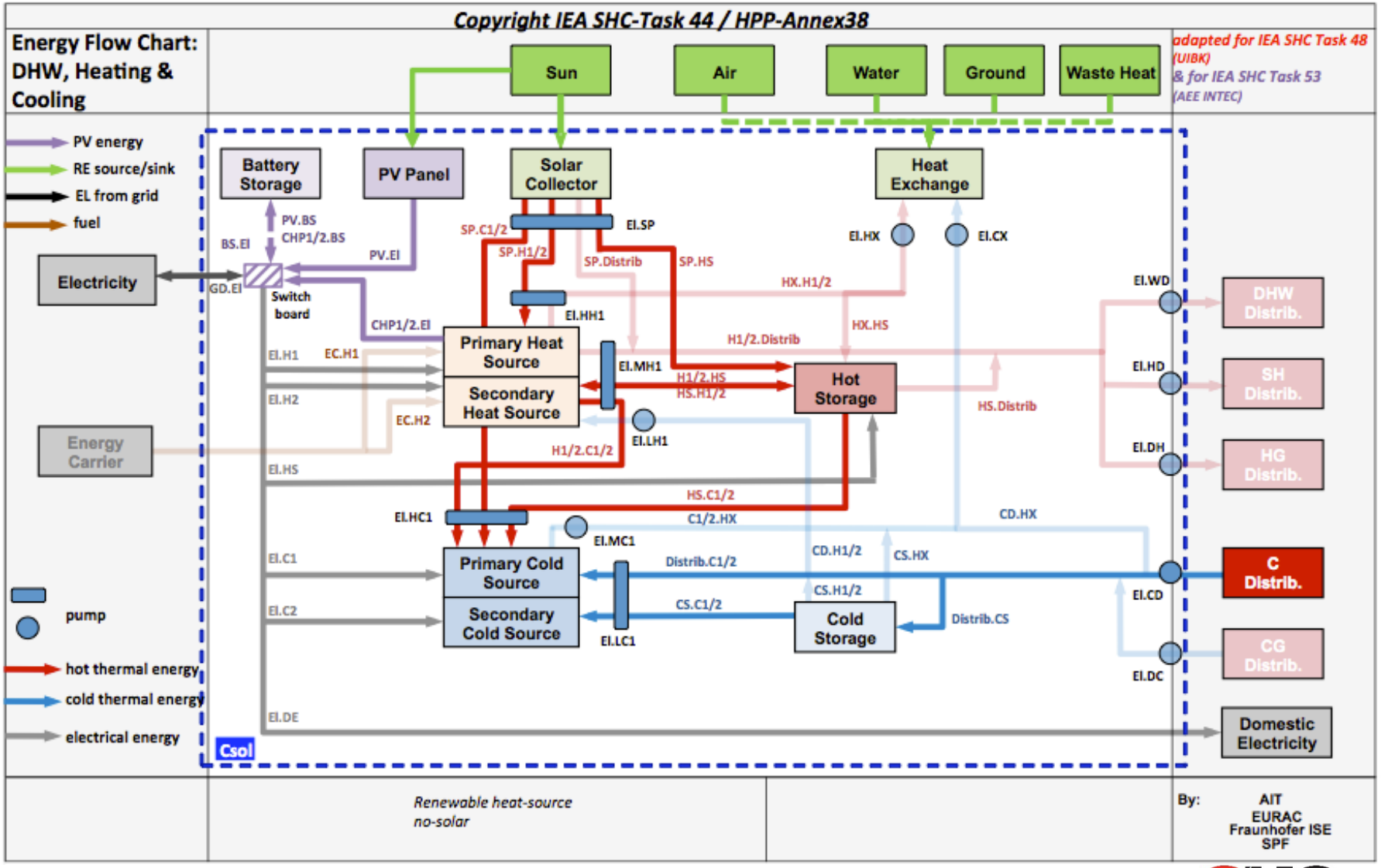


Systems & components

- 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 & double effect) • Adsorption chiller • District cooling (as cold source)
Storage (HS, CS, BS)	• Hot storage • Cold storage • Battery storage
Heat rejection (HX)	• Wet cooling tower • Dry cooling tower • Hybrid cooling tower

Boundary - solar cooling



Primary energy

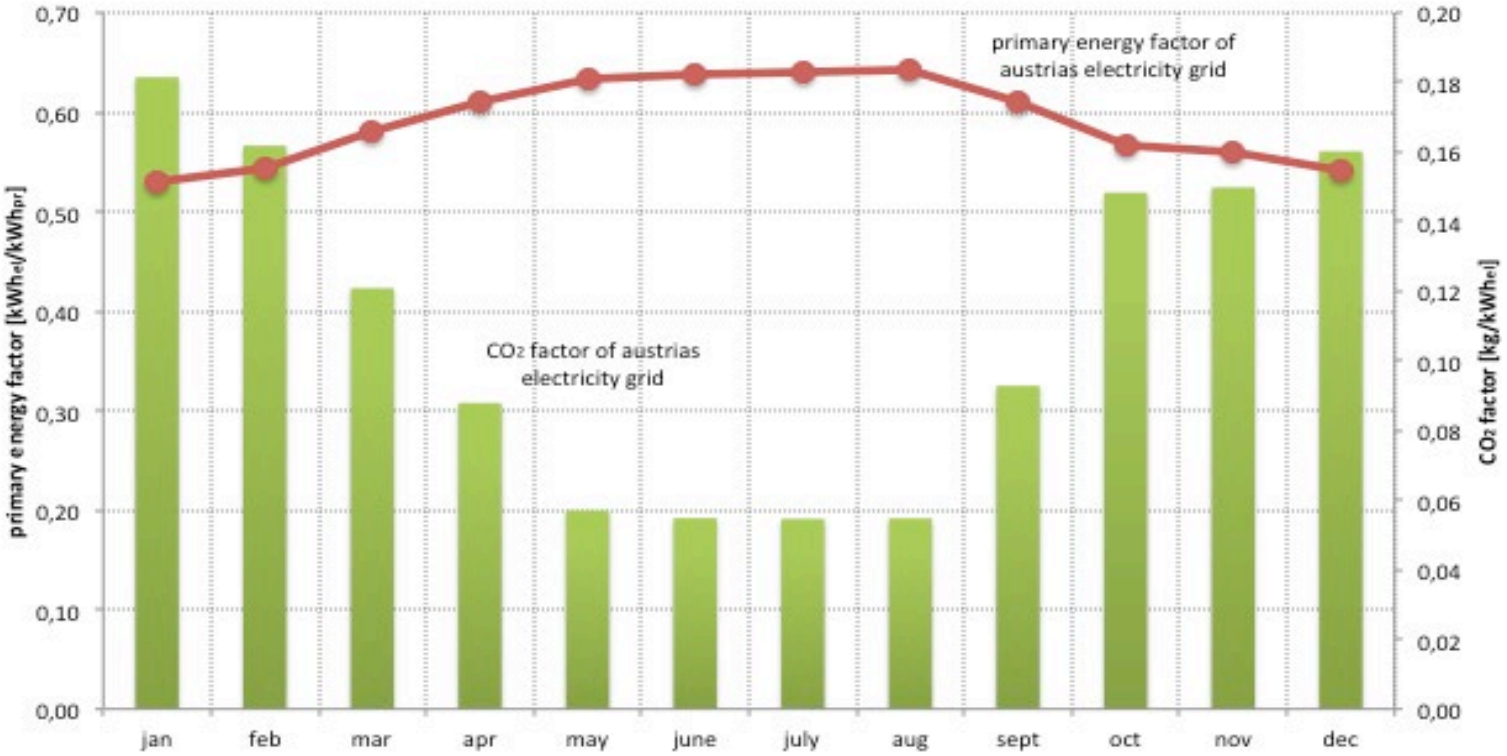
- Annual non-renewable primary energy conversion factors

	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

- Monthly T53 standard values for non-renewable primary energy and CO_2 emissions
- Example for Austria, based 2015



Technical key figures (I)

- Non-renewable primary energy ratio (PER_{NRE})
  - Similar to SPF but energy input (Q_{in}) converted in **non-renewable primary energy**
  - e.g. electricity: ε_{el} = 0.4 $kWh_{Use}/kWh_{PE.NRE}$, natural gas: ε_{in} = 0.9 $kWh_{Use}/kWh_{PE.NRE}$

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

- PER_{NRE} calculation for
  - SHC system
  - Standardized Task 53 reference system (Ref.)
    - Natural gas boiler & air-cooled vapor compression chiller

→ 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 (II)

SPF_{equ} = 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

Economic key figures

- **Annuity method** & input values based on **EN-standards** and **experiences** of IEA Task experts

- Standardized **data base** to calculate annualized costs
  - Investment, replacement & residual value
  - Maintenance & service,
  - Operational costs (energy, water)

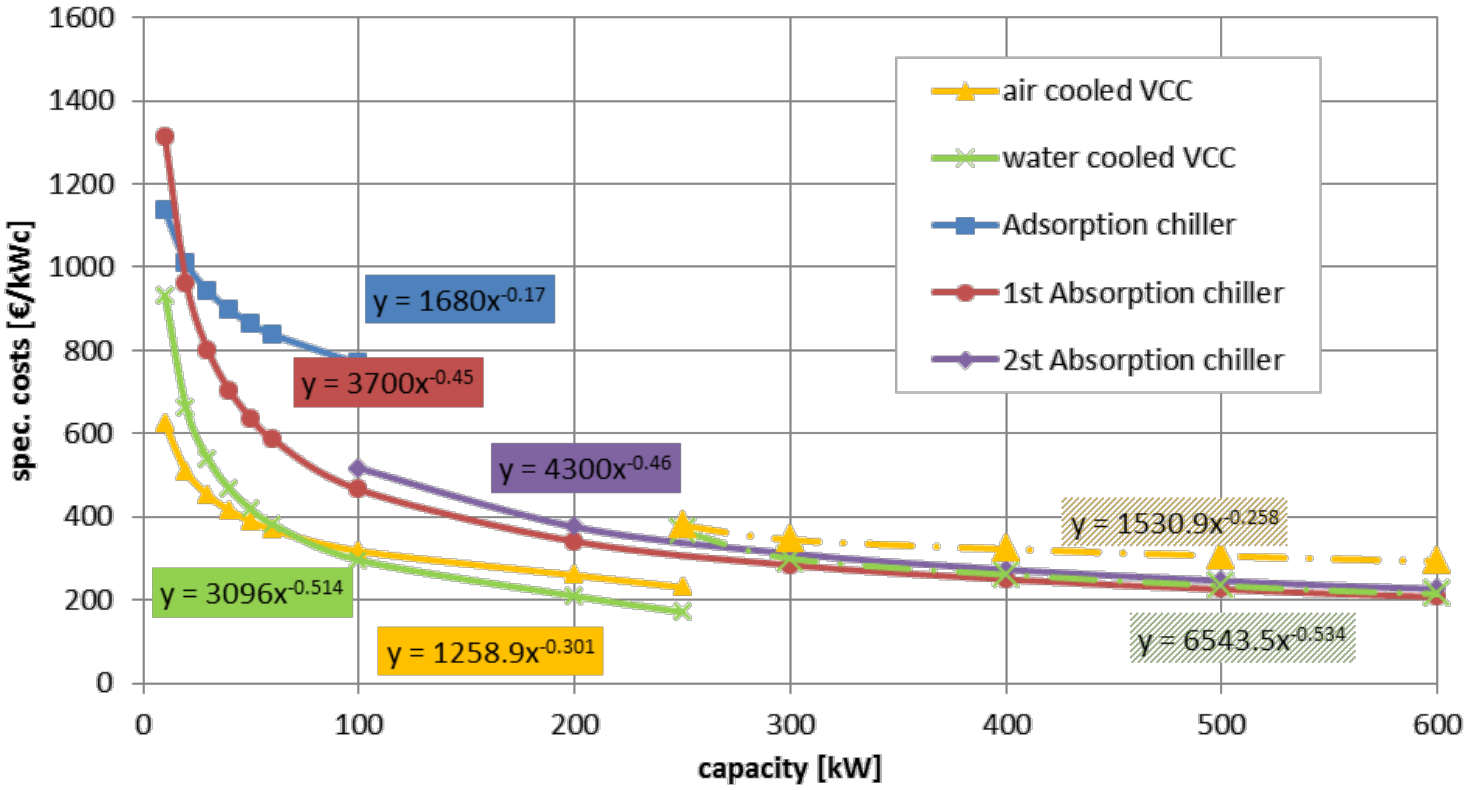
- Calculation of levelized cost of energy for
  - Solar Heating and Cooling
  - Standardized Task 53 Reference

→CostRatio (CR)

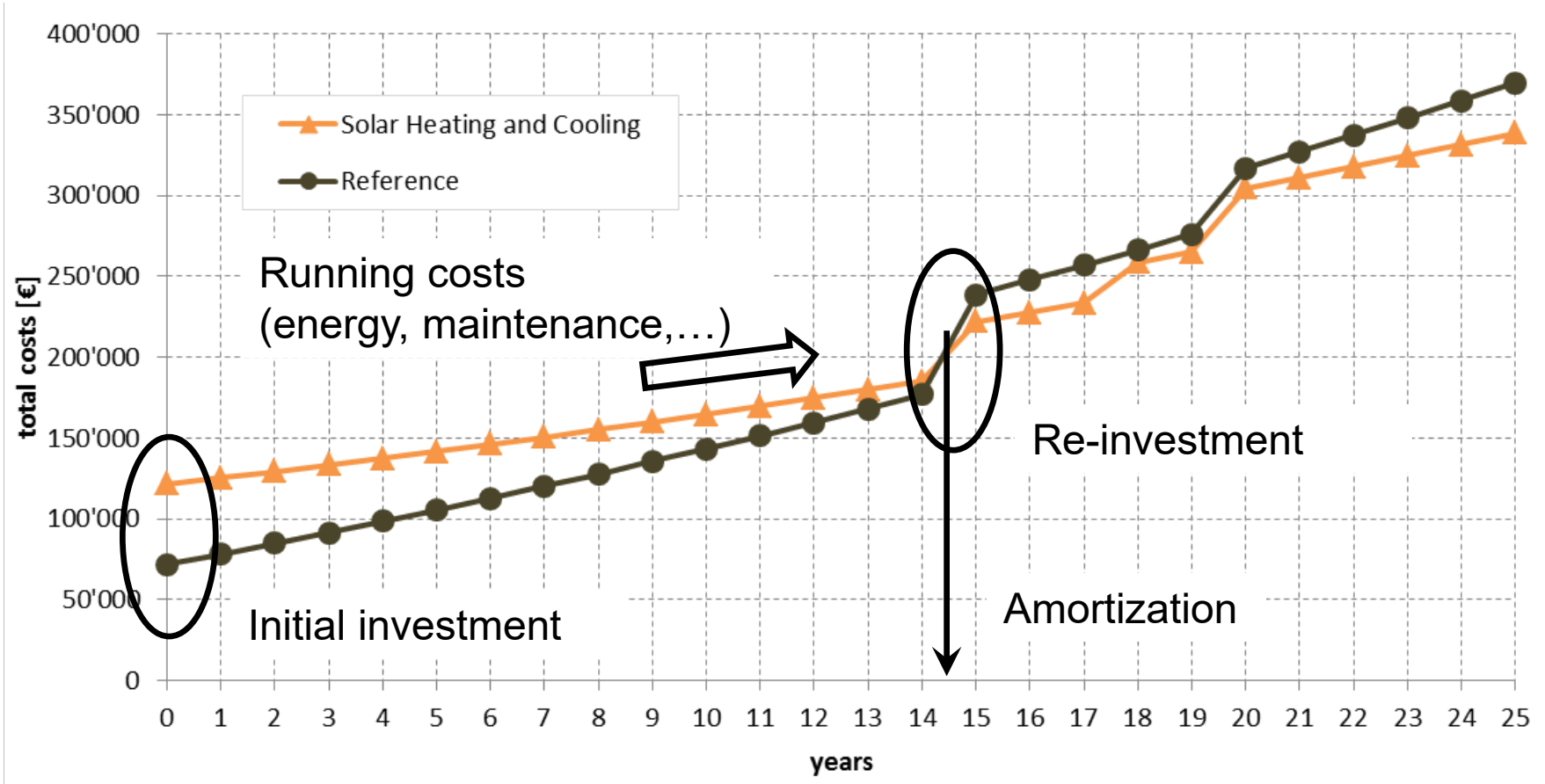
$$\text{CostRatio(CR)} = \frac{annualized\ costs\ SHC}{annualized\ costs\ REF}$$

Investment costs

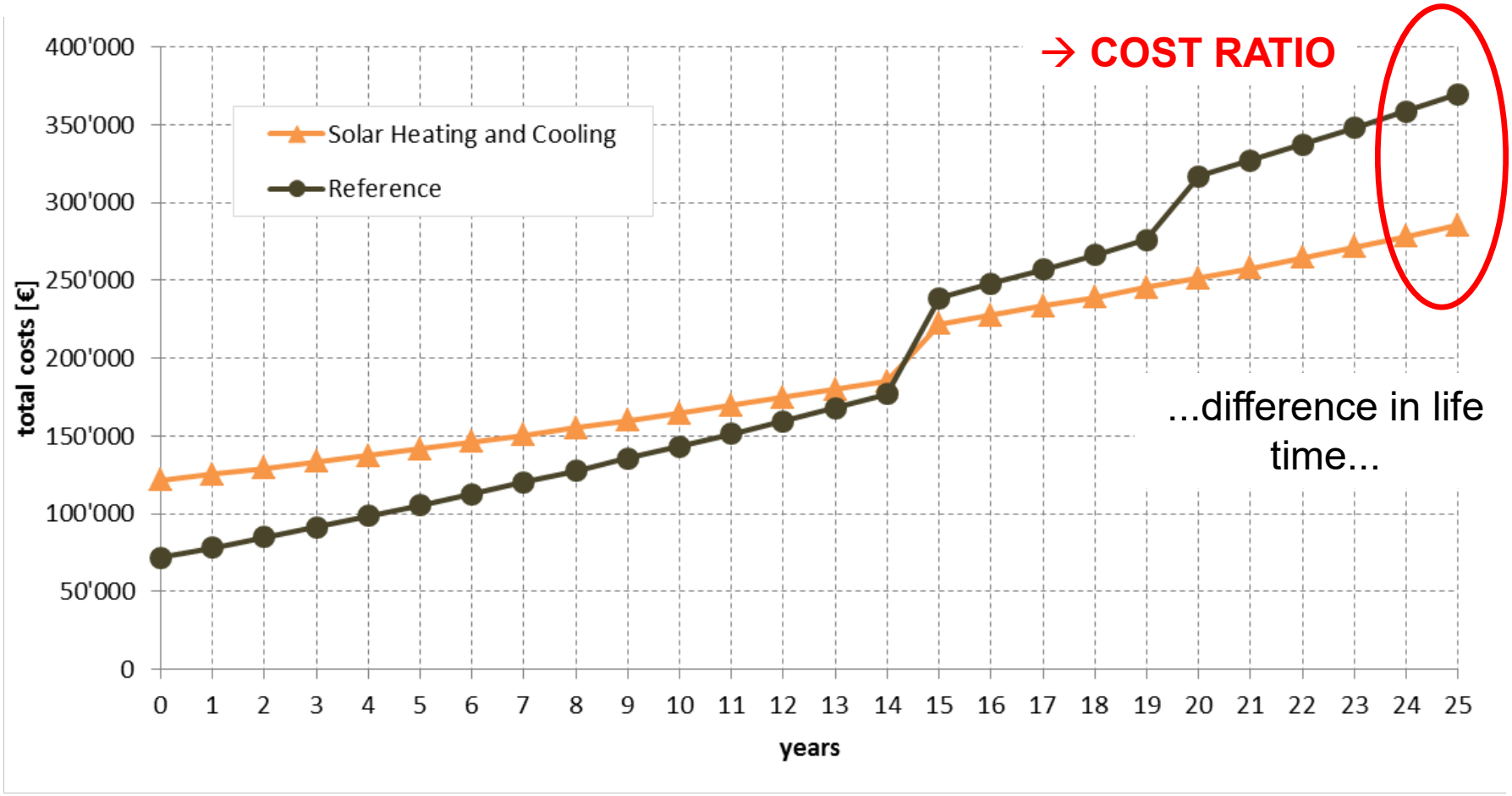
- For all main components
  - Size dependent incl. economy of scale
  - E.g. vapour compression / absorption chiller



Life cycle analyses (I)



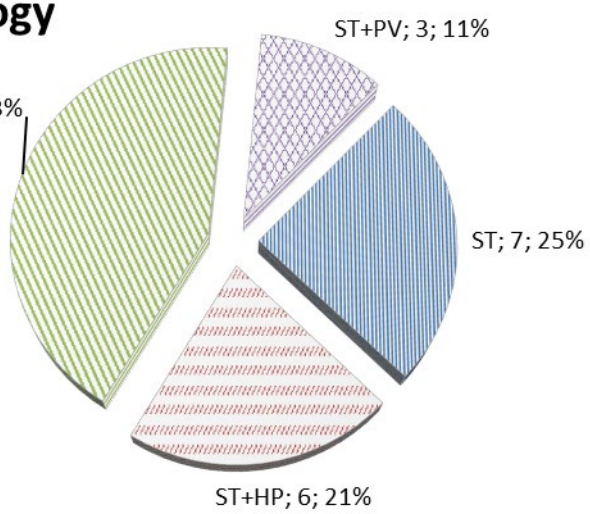
Life cycle analyses (II)



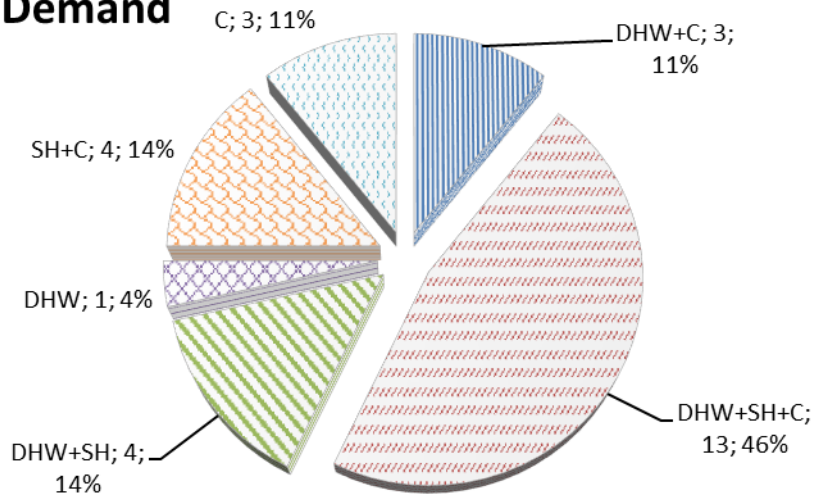
IEA SHC Task 53

- Assessment of 28 SHC configurations
  - **17 examples** (incl. simulation: 28 configurations)
  - System & subsystem analysis
  - Trend analysis
  - Sensitivity analysis

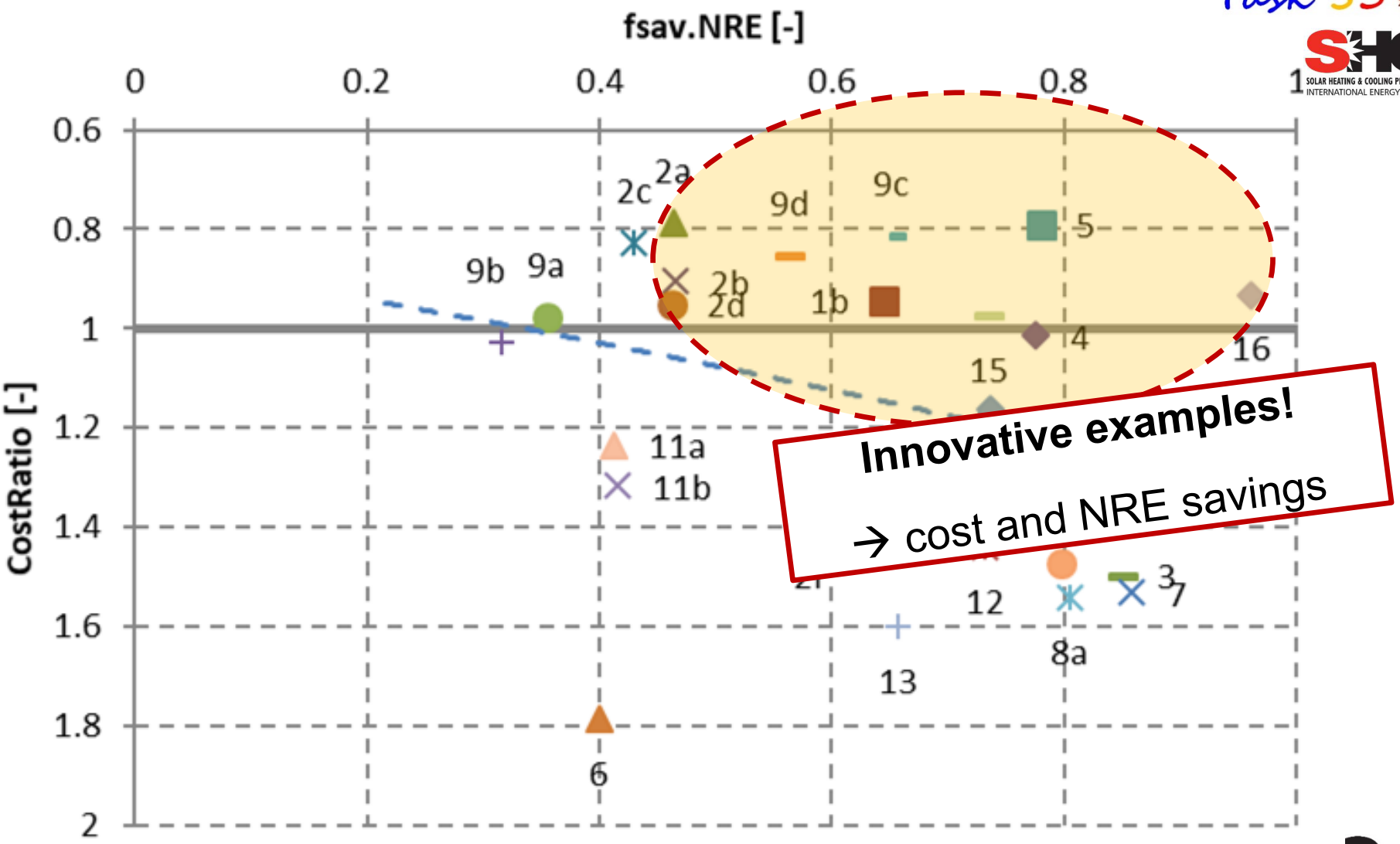
Technology



Demand



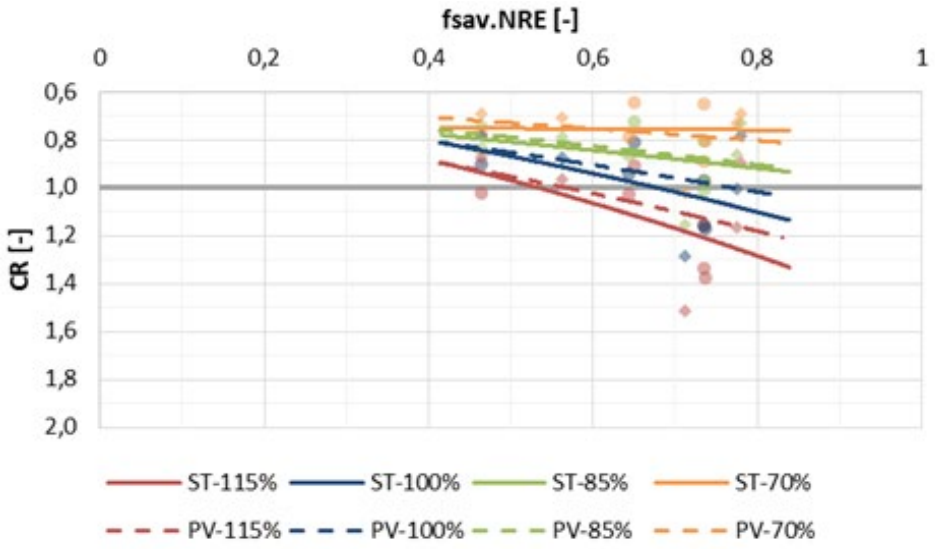
Result

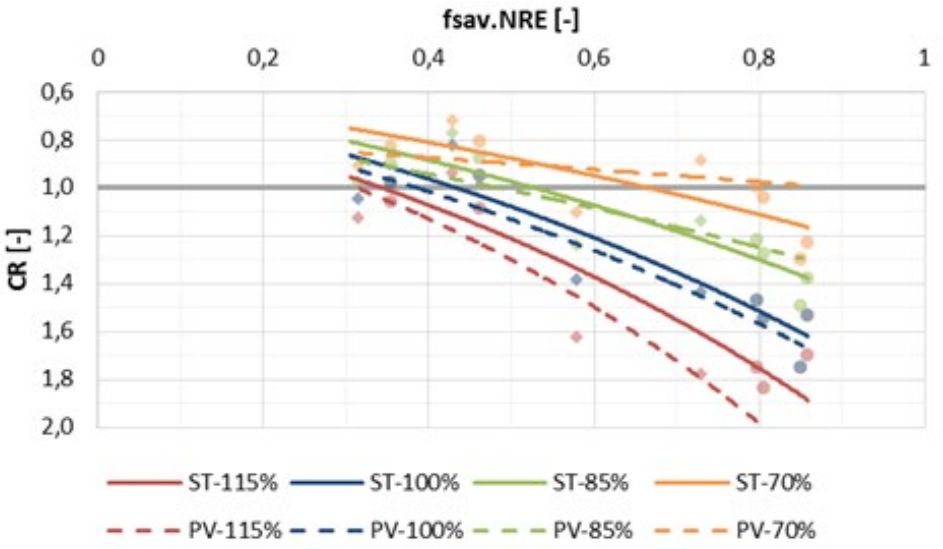

fsav.NRE [-]
0
0.2
0.4
0.6
0.8
1
CostRatio [-]
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2a
2c
9d
9c
5
9b
9a
2b
2d
1b
4
16
15
11a
11b
12
3
7
8a
13
6
Innovative examples!
→ cost and NRE savings

Sensitivity analyses

- Influence of chosen boundaries
  - Investment, electricity, natural gas price
  - Auxiliary demand, energy output,
  - Non-renewable primary energy conversion factors

→ Influence shown on trends





Summary

- Assessment
  - Based on a **common comparable system** view
  - including detailed **sub-system** knowledge is needed
  - Focus on
    - Non-renewable primary energy (fsav.NRE)
    - Cost Ratio

  → Adaptation of methods and data base in Task 65

- Outlook on **Task 65 contributions**
  - Comparison of different technologies (ST ACM, Hybrid, PV+VCC)
  - For different profiles & climates (public: hotel, hospitals, etc., residential)
  - With sensitivity analyses
  - …

Contact

Neyer Brainworks GmbH

Oberradin 50, 6700 Bludenz
Austria

+43 664 28 26 529

daniel@neyer-brainworks.at
www.neyer-brainworks.at

University of Innsbruck
Department of Structural Engineering and Material Sciences

Unit of Energy Efficient Building
Technikerstraße 13, 6020 Innsbruck
Austria

Telefon +43 512 507-63652
Fax +43 512 507-63698
E-Mail daniel.neyer@uibk.ac.at

www.iea-shc.org

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