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Assessment of Solar Heating and Cooling – Comparison of Best Practice Thermal and PV Driven Systems

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Abstract

Assessing the performance of Solar Heating and Cooling (SHC) systems, especially cooling systems using solar thermal or PV driving energy, in a common comparable format, is complicated by the numerous, alternative energy sources and design possibilities. A generalized technical and economic assessment methodology was developed and tested in the course of IEA SHC Task 53.

At a glance seven best practice plants were analyzed and compared in a comprehensive format. All systems can achieve non-renewable primary energy savings greater than 50%, but none is reaching a cost ratio lower than 1 compared to a reference system. The results might not be representative but show interesting trends. There is almost no difference between solar thermal and PV driven systems. Both technologies can succeed the same magnitude of savings with similar cost ratios. Plants that are achieving or aiming higher primary energy savings turn out to be more expensive.

Finally the assessment shows that solar heating and cooling can achieve cost competitiveness with an appropriate design and solar fraction if investment costs can be decreased simultaneously.

Keywords: *assessment and benchmarking, new generation solar heating and cooling, IEA SHC Task 53*

1. Introduction

A tremendous increase in the global market for air-conditioning can be observed, especially in developing countries. The results of the past IEA SHC Tasks and the ongoing activities on solar cooling show the enormous potential of this technology for building air-conditioning, particularly in sunny regions. However, solar thermal cooling faces barriers to emerge as an economically competitive solution. Thus, there is a strong need to stimulate the solar cooling sector for efficient and cost effective small and medium sized systems.

IEA SHC Task 53, which builds up on earlier IEA SHC work in this field, is working to find solutions to make solar driven heating and cooling systems cost competitive and helps to build a strong and sustainable market for solar, photovoltaic and new innovative thermal cooling systems. These objectives are tackled through five activities:

1. Investigation of new small to medium size PV & solar thermal driven cooling and heating systems, as well as development of best suited cooling and heating systems technology with a focus on reliability, adaptability and quality.
2. Demonstration of cost effectiveness of the above mentioned solar cooling and heating systems.
3. Investigation on life cycle performances on energy and environmental terms (LCA) of different options.
4. Assistance with the market deployment of new SHC systems for buildings worldwide.

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5. Increasing energy supply safety and influencing the virtuous demand side management behaviors.

The Task's scope is technologies for the production of cold/hot water or conditioned air by means of solar heat or solar electricity. Therefore, the Task starts with the solar radiation reaching the collectors or the PV modules and ends with the chilled/hot water and/or conditioned air transferring to the application. It is focused on solar driven systems for both cooling (ambient and food conservation) and heating (ambient and domestic hot water).

The following work deals with the economic and technical (energetic) evaluation of different configurations and technologies of New Generation Solar Heating and Cooling.

Tab. 1: Nomenclature and Subscripts

Subscripts			
C	Cooling	out	Output
DHW	Domestic hot water	NRE	Non-renewable
EC	Energy Carrier	ref	reference system
el	Electrical	SH	Space heating
equ	equivalent	sys	Overall system (C & DHW & SH)
Nomenclature			
ACM SE	Absorption chiller, single effect	PER_{NRE}	Primary Energy Ratio (-)
CR	Cost ratio (-)	SEER	Seasonal Energy Efficiency Ratio (-)
ε	Primary Energy Factor (kWh/kWh_{PE})	SPF_{equ}	Seasonal Performance Factor (-)
$fsav_{\_NRE}$	Fractional savings (-)	VCC	Vapour compression chiller

Several studies in the past years show the competitiveness of solar thermal and PV driven systems. Depending on the boundary condition each system configuration shows appropriate advantages. Existing simplifying studies (e.g. Streicher (2010), but also more detailed studies (e.g. Henning (2010), Eicker (2012), Wiemken et al. (2013)) are evaluating both technologies under different boundary conditions.

The results of these studies depend on climatic conditions (ambient temperature, irradiation) as well as on the type of application (DHW, C, etc.), size and operation hours of the system, etc. Furthermore they show that reasonable system configurations (base or peak load design) and different control strategies have a crucial impact on reachable non-renewable primary energy savings. Even under various economic considerations the results can differ significantly. But in general in common controversy PV driven systems get more positive remarks than solar thermal driven systems. Often quoted arguments are regarding efficiency, costs and handling of surplus energy.

Selected performance indicators for evaluating technical and economic quality and cost effectiveness are fully discussed and defined in Neyer et al. (2015) during the course of IEA SHC Task 48 (http://task48.iea-shc.org/). The procedure is valid for thermal driven plants with vapor compression chillers (VCC) as cold backup. If a compression chiller is the main component and is supported by PV or other renewable electricity, the methodology has to be adapted.

This adaptation was performed under the course of IEA SHC Task 53 and is described in this paper. Furthermore numerous realized systems with in-situ monitoring or rather simulation studies of solar thermal (ST) driven and photovoltaic (PV) driven systems with different capacities and applications are shown. The plants are evaluated with the tool developed in Task 53 and are benchmarked among each other with technical and economic key figures. Sensitivity analysis of four plants show the impact of specific boundary conditions (primary energy factor, costs, etc.) on the performance and the difference between ST and PV driven systems.

2. Methodology

The assessment and evaluation tool of Task 48 was generalized and extended, with the focus on new generation of solar heating and cooling with either solar thermal or photovoltaic driven systems. It enables the assessment for a wide range of systems available on the global market. Systems can contain bivalent heating and/or cooling devices (boiler or chiller respectively). The component base information includes technical as well as economic data to evaluate and benchmark the systems. Multiple usage of each component in the entire system (energy flows) can be added and analyzed.

In Figure 1 the overview of all components and main energy flows is presented in an energy flow chart, invented in IEA SHC Task 44 based on work of Frank et al. (2010). Traded energies include electricity and other energy carriers and are arranged on the left (displayed in grey); free energy sources including solar and other ambient source/sinks on the top (in green); the application and its heating (in red), cooling (in blue) and electricity demand (in grey) on the right.

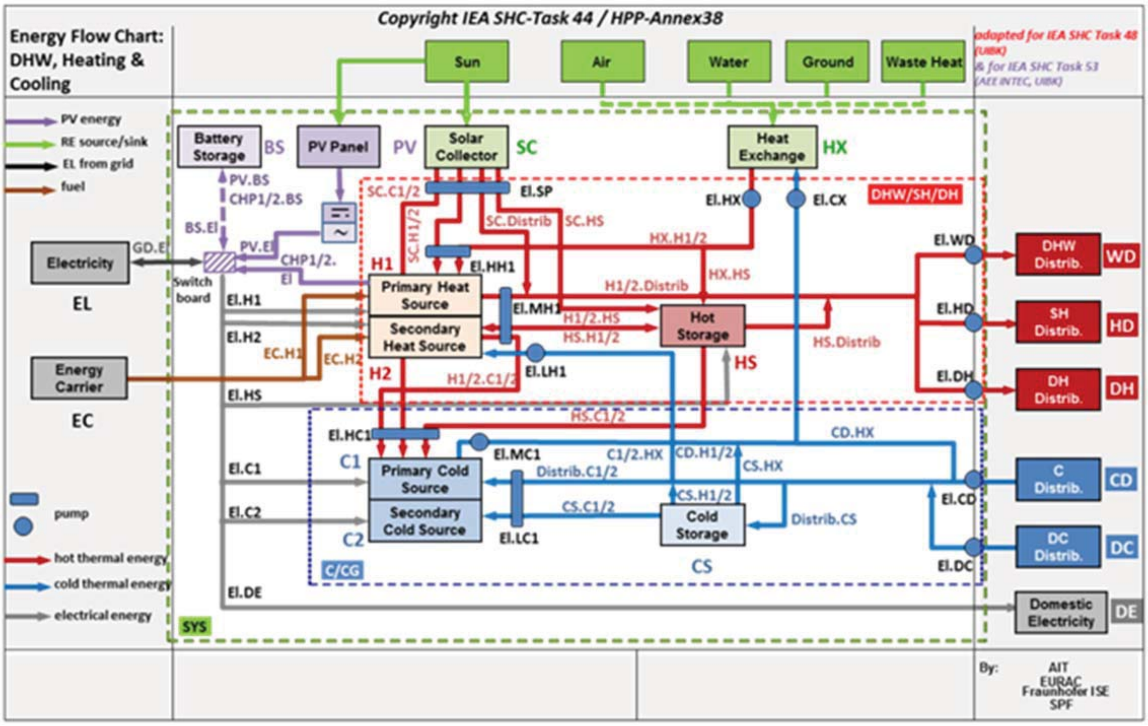

Fig. 1: Energy flow chart including all possible components for the technical and economic assessment of IEA SHC Task 53

Due to the dependency of the results on the system boundaries, it is obvious to display them in the energy flow chart. All components and auxiliary pumps can be identified easily. Within the Tool for each demand (DHW, SH, etc.) a separated assessment can be performed for the entire solar fraction and the overall performance; resulting in a maximum of five subsystems including further five solar sub boundaries and one overall system assessment.

The component selection includes reversible heat pumps (electric or thermal driven), chillers (air/water cooled VCC, SE/DE absorption, etc.), several boiler types (natural gas, CHP, oil, pellets, etc.) and storages (thermal, electrical). The database for the single components include either cut off or standardized (minimum) performance and cost indicators. For eight countries (Austria, Australia, France, Germany, Italy, P.R. China, Spain and Singapore) all input values, if applicable, were collected (primary energy factor, energy costs, etc.) and can be used for country specific assessments.

Nevertheless, these values are subjects of permanent changes, either driven by political decisions or technical issues. Furthermore the values depend on the choice of energy trading company or even on the territory. Therefore the tool enables the implementation/creation of self-calculated or investigated values, valid for a specific region or configuration / analysis. The assessment tool calculates and indicates regularly one set of

Task 53 (T53) standard Key Performance Indicators (KPI) and one set of specific (standard country or own choice) KPI's. The T53 Standard KPI's are based on a pre-defined reference system (natural gas boiler and air cooled vapor compression chiller) and the appropriate cost and primary energy factors. It allows the comparison of different plants under the same boundary conditions. In this study all KPI's are related to the T53 standard.

2.1. Technical assessment

The Seasonal Performance Factor (SPF), for a given system boundary, is generally defined as the ratio of useful energy (supplied to satisfy the needs of the application) to energy effort from any source. The SPF can include several auxiliary components within the defined boundary and is calculated over a defined period of time (e.g. annual or monthly). Well known SPFs are based upon thermal or electric energy inputs.

However, the electrical SPF_{el} can be misleading when a system with different energy inputs (thermal and electrical) is analysed. The SPF_{el} might show high results even when large amounts of fossil fuel (e.g. gas) back up is consumed with overall poor environmental performance. Therefore the Primary Energy Ratio (PER) and derivative key figures like the electrical equivalent SPF_{equ} and fsav are calculated and provide a better base for assessing different SHC systems.

- Non-renewable Primary Energy Ratio (PER_{NRE})

The non-renewable Primary Energy Ratio converts all non-renewable energy flows into primary energy equivalents. This provides appropriately comparable quality ratings for energy derived from alternative electricity, solar and fossil fuel heat energy sources. It is defined in eq. 1 as the ratio of useful energy (ΣQ_{out} supplied to satisfy the needs of the building) to non-renewable primary energy (electricity and other energy carriers). Certain primary energy conversion factors (ε) for each type of energy source have to be provided to calculate the PER_{NRE}. The primary energy factors depend on local conditions (e.g. the source from which local electricity is derived).

$$PER_{NRE} = \frac{\sum Q_{out}}{\sum\left(\frac{Q_{el}}{\varepsilon_{el}}+\frac{Q_{EC}}{\varepsilon_{EC}}\right)} \qquad \text{(eq. 1)}$$

A high value for PER indicates that the heating and cooling services can be obtained with a relatively small amount of fossil derived energy and is therefore an environmentally friendly system. However, values for PER_{NRE} (in a magnitude of ca. 1 to 2.5) are not directly comparable with any widely available industry figures of merit such as the EER or SEER of a vapor compression chiller.

- Fractional saving (f_{sav})

A further key performance indicator is the so called fractional saving (f_{sav}). This represents the percentage reduction in non-renewable primary energy for the application compared with a reference (business as usual) system. Thereby the reference system can also be another renewable system. The PER_{ref} uses the same calculation as PER but takes the standardized component information to calculate its non-renewable Primary Energy demand. The non-renewable primary energy savings ($f_{sav-NRE}$) in comparison to a reference system can be calculated as follows (eq. 2).

$$f_{sav-NRE} = 1 - \frac{PER_{ref}}{PER_{sys}} \qquad \text{(eq. 2)}$$

The f_{sav} cannot exceed a value of 1 but can be negative, depending on the choice of reference system (standard or renewable) and the performance of the SHC system (auxiliary electricity demand and fossil backup). A high f_{sav} indicates that a high solar fraction is given in the entire SHC system. The application's primary energy consumption has been eliminated by substitution with solar energies (solar thermal or photovoltaic).

These savings are used to generate a labeling to express the quality of the SHC systems. The labelling is based on the European energy labelling guideline 2010/30/EU (2010). The rating levels start from A+++ (best rating) to G (worst rating). If the considered SHC system has a lower primary energy demand than the reference system, the f_{sav} is greater than zero. The energy label is calculated for all subsystem (SH, DHW, C etc.) and the total system. The rating levels are kept in ten percent steps.

- Electrical Equivalent Seasonal Performance Factor (SPFequ)

Another technical key figure that is used to compare the systems is an "Electrical Equivalent SPF" (SPF_{equ}), which combines all non-renewable final energy sources (both electrical and energy carrier), by converting them into primary energy flows expressed in electrical equivalent units. This is achieved by using the relevant non-renewable primary energy factors for electricity (ε_{el}) and energy carrier (any kind of fuel) input (ε_{EC}). The SPF_{equ} is calculated following the unit conversion and ending up in eq. 3.

$$SPF_{equ} = \frac{PER_{NRE}}{\varepsilon_{el}} = \frac{\sum Q_{out}}{\sum\left(Q_{el}+\frac{Q_{EC}}{\varepsilon_{EC}}*\varepsilon_{el}\right)} \quad \text{(eq. 3)}$$

The electrical equivalent Seasonal Performance Factor for a subsystem (e.g. cooling $SPF_{equ\text{-}C}$) can thus be used to compare the application performance with a commonly used SEER value, even when hot backup is used as part of the heat supplied to a thermal chiller. The SEER declares the efficiency of a component under standardized testing conditions. The actual system performance is often much lower than these SEER values (cf. Wiemken et al. (2013), Nocke et al. (2014) and many more). Same SPF_{equ}'s indicates finally an equal primary energy demand, although the systems are supplied by different energy quantities.

However, when the building has a small solar cooling system relative to the size of a backup VCC system, the good performance of the solar cooling system may be undermined by the large fraction of cooling done by the conventional backup chiller. In this case, the SPF_{equ} of the solar subsystem can be used to represent the quality of SHC systems.

2.2. Economic assessment

Under the consideration of specific investment, replacement, operation and consumption based costs, the annualized costs for the entire system can be calculated by using the annuity method. Therefore derivative key figures (e.g. PE avoidance costs, etc.) are calculated easily.

All economically influencing parameters are pre-defined for the T53 Standard and country specific. Some of the values influencing the economical calculation are challenging and details could be discussed extensively. The aim of these calculations and definitions is to generate cut off values indicating a reasonable magnitude of economic effects. The results present best known averages and may differ from specific values.

If desired, own, project specific values can be implemented in the calculation. E.g. this is necessary if the application is serving domestic, commercial or industrial usage. Domestic prices are higher, but are mainly based on energy consumption. Commercial and industrial prices have low energy based costs, but can include capacity prices.

The economics that are defined prior for T53 and the eight countries are reaching from period under consideration, credit period, inflation rate, market discount rate, credit interest rate, inflation rate for energy prices electricity, inflation rate for energy prices, fraction of initial investment without financing up to the public funding's rate. Their main influence is visible when the different cost assets are discounted.

The consumption based costs are electricity and energy carrier prices for both energy and capacity or yearly costs. Water consumption costs are also defined as well as feed-in tariff for PV and for CHP with and without subsidies. The economic analysis is performed under the T53 standards. Main energy costs and economics are listed below. The prices are rather valid for commerce and industry and thus challenging for solar heating and cooling systems.

- Period under consideration (25 a), credit period rate (10 a)
- Inflation rate, market discount rate and inflation for energy prices (3%)
- Electricity energy prize (0.1 €/kWh) and electricity peak prize (80 €/kW)
- No subsidies, feed-in tariff for PV (0.03€/kWh)
- Natural gas energy prize (0.05€/kWh) and annual allowance (80 €/a)
- Water consumption (2.50 €/m²)

Not included are water treatment, distribution and heat / cold supply system costs.

Specific costs for each component include economy of scale prices. The greater the capacity of a certain component is the cheaper are the specific investment costs. Examples for different types of chillers are included in Figure 2. The investment curves indicate typical average and cut off values mainly valid for Central Europe. For each component the estimated lifetime, costs for maintenance, service and inspection is defined under consideration of VDI 2067. It has to be noted, that significant deviations to specific projects may occur. Therefore all values may be changed and user defined values can be implemented in the Excel Tool.

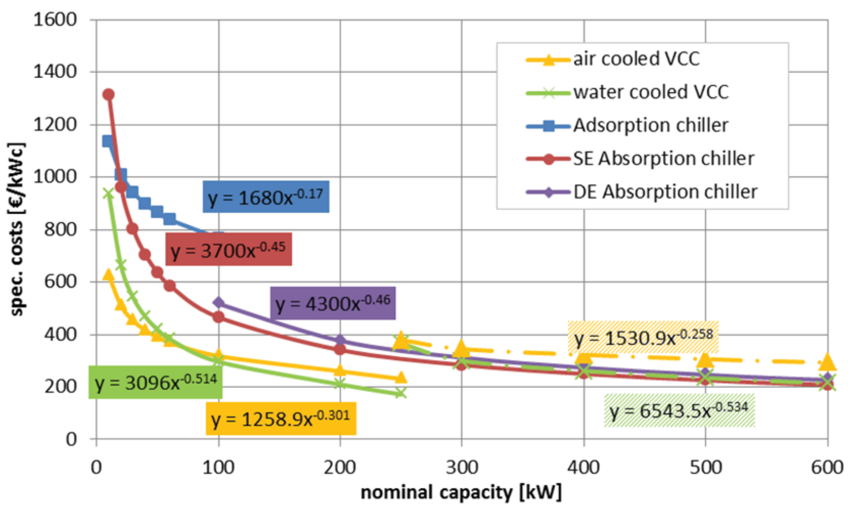

Fig. 2: Example of specific investment costs used for T53 standard calculation of investments for thermal and electrical driven chillers

The costs for each category are summed up and discounted to an annualized value according to the defined economics. The total annualized cost is the sum of yearly annualized investment, replacement and residual values, maintenance, electricity (auxiliary and if applicable domestic), energy carrier and water costs using the set of standard costs in the assessment tool. The Levelized costs of the SHC and also the one of the reference system are the ratio of annualized costs to the overall useful energy provided to the application.

Nevertheless, to avoid the discussion of absolute costs (e.g. when only taking sub systems into assessment) a cost ratio is calculated by comparing the Levelized costs of energy of the renewable systems with the Levelized costs of the reference systems.

$$CR = \frac{C_{tot.SHC}}{C_{tot.REF}} \qquad \text{(eq. 3)}$$

3. Analyzed best practice examples

The requirement for an annual cost analysis is the availability of annually measured or simulated data. There are many plants as demo- or research project in operation, but only a few were able to contribute with data. Therefore, the analyzed plants are a small selected group of photovoltaic driven and solar thermal driven systems.

Three PV and four ST systems, including some calculated derivatives, are presented and analyzed here. The most important facts are summarized in Table 2. The summary contains information of the status (monitored or simulated), the application (SH, DHW, C) and corresponding demand, solar technology used with capacity/size (ST in m², PV in kW_{peak}) and achieved solar fraction, the boiler and chiller type and its nominal capacity. The sizes vary from small scale (2 kW) up to large scale (1.5 MW). Main applications are domestic hot water combined with cooling

Regarding the design a differentiation between "full load" and "base load" is reasonable. In this sense the definition and explanation is as following.

- Base load: the solar heating and cooling system is design for assisting a larger auxiliary heating or cooling system, typically solar fraction appear between 20 to 60% appear in these bivalent systems.
- Full load: there is no backup for the solar heating and cooling system. Solar satisfies 100% of the energy demand of the according application.

None of the plants is intended for pure full load design. 6 of the example feature more than one application. The design often aims to satisfy one application by solar 100% whereas the second one runs in base load.

If there is no information available for the entire auxiliary heating / cooling system (no overall demands measured), the plants economic analysis appears to be a full load design. Two examples (#2, #3) are used to show the effect of full/base load design. A solar fraction is assumed for both and the key figures are recalculated. The derivations of these plants are marked with subscripts (3a, 5a).

Tab. 2: Fact sheet of examples

Plant	**Status**	**demand**		**Solar technology**			**Boiler**		**Chiller**		**Source**
	Monitored (MON) Simulated (SIM)	DHW/SH/C	Energy (MWh)	ST/PV	ST: Area (m^2) PV: peak capcaity (kWp)	Base or full load / magnitude SF [%]	Type	Capacity (kW)	Type	Capacity (kW)	
1	MON	SH C	175.2 15.5	ST	65	base / 20 full / 100	Pellets	300	ACM-SE	19	Nocke 2014
2	MON	DHW C	133.2 9.3	ST	240	full / 80 base / n.a.	Natural gas	70	ACM-SE	35	Mugnier 2015
2a						full / 80 base / 5			ACM-SE VCC	35 500	
3	MON	DHW C	143 949	ST	3800	full / 100 base / n.a.	-	-	ACM-SE	1500	Neyer 2013
3a						full / 100 base / 20			ACM-SE VCC	1500 5600	
4	SIM	DHW C	562.2 82.1	ST	720	base / 60 base / 30	Natural gas	270	ACM-SE VCC	20 70	Neyer 2016
5	SIM	DHW C	562.2 82.1	PV	70	base / 25	Heat pump	500	VCC	80	
5a				-	-	-					
6	MON	DHW	2.2	PV	0.47	base / 50	Split unit	2	-	-	Aquilar 2016
7	SIM	SH DHW	6.7 2.2	-	-	-	Brine heat pump	10	-	-	Thür 2016
7a				PV	2.5	base / 10					
7b				PV	2.5	base / 40					

4. Results

The assessment follows the above mentioned method of Task 53 and uses the standardized costs resulting in the following figures.

Figure 3 shows the breakdown of the total annualized cost of all plants and derivative calculations. Main cost driver are the investment cost; they aggregate between 40-60% of the overall costs. The ratio of investment cost is higher when the plants are smaller (#6, #7) or the information of the entire total system is missing (#2,#3). Second largest cost fraction are the energy cost (energy carrier or electricity). If PV surplus is feed in, the total costs reduce only slightly in #7a and #7b and up to 10% in #5. In the majority maintenance and replacement and residual value sums up to 20%.

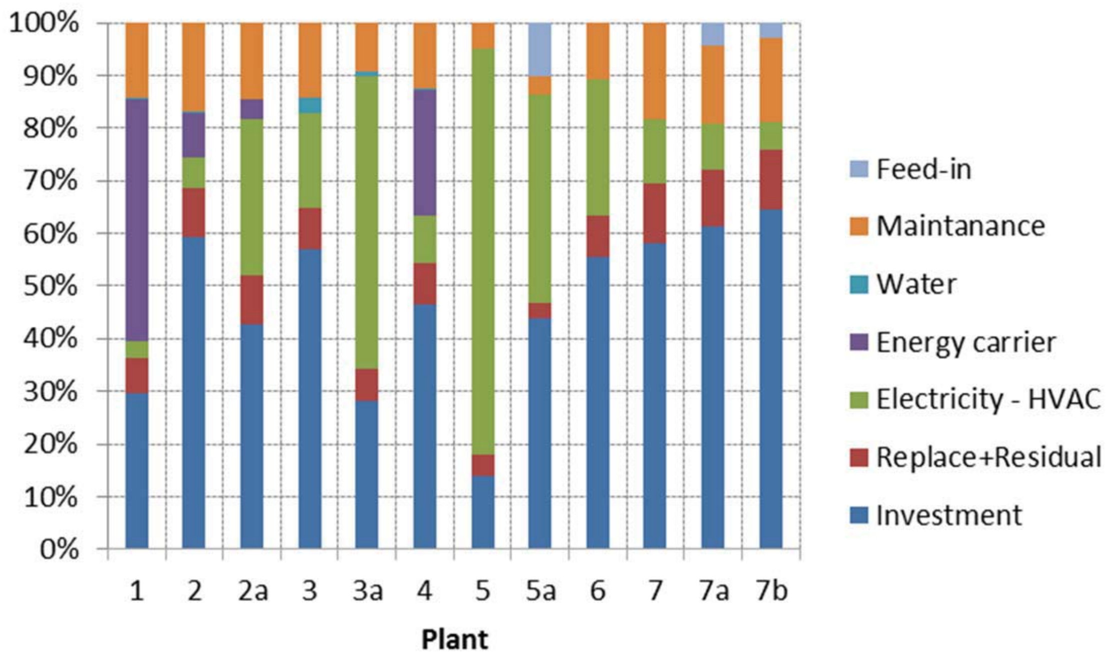

Fig. 3: break down of total annualized cost for al plants calculated with the T53 standard values.

The combined influence of non-renewable savings (f_{sav}) and the Cost Ratio (CR) is shown in Figure 4. The CR is displayed in reversed order on the y-axis in Fig. 4. A cost ratio of one is highlighted as bold line and is the value to be beaten by the solar driven heating and cooling systems. Values lower than 1 indicate that the entire SHC system is economical viable and thus cheaper than the T53 standard reference system (natural gas boiler, vapor compression chiller).

Each marker represents one plant. The target is a high non-renewable primary energy saving at affordable costs. The area in the upper right side represents that target. None of the analyzed plants can reach that area nor beat the CR of one. The trend shows, that more savings result in higher cost ratios and thus more expensive plants. Vice versa, the higher the investments are the more savings can be achieved – at least for these best practice examples.

All plants can achieve savings greater than 50% against the standard reference system. If another reference system would be chosen (e.g a heat pump system like #5a), the base is shifted accordingly (dashed lines). The average linear trend of PV and ST is displayed with a bold dotted line (PV) and a bold chain dotted line (ST).

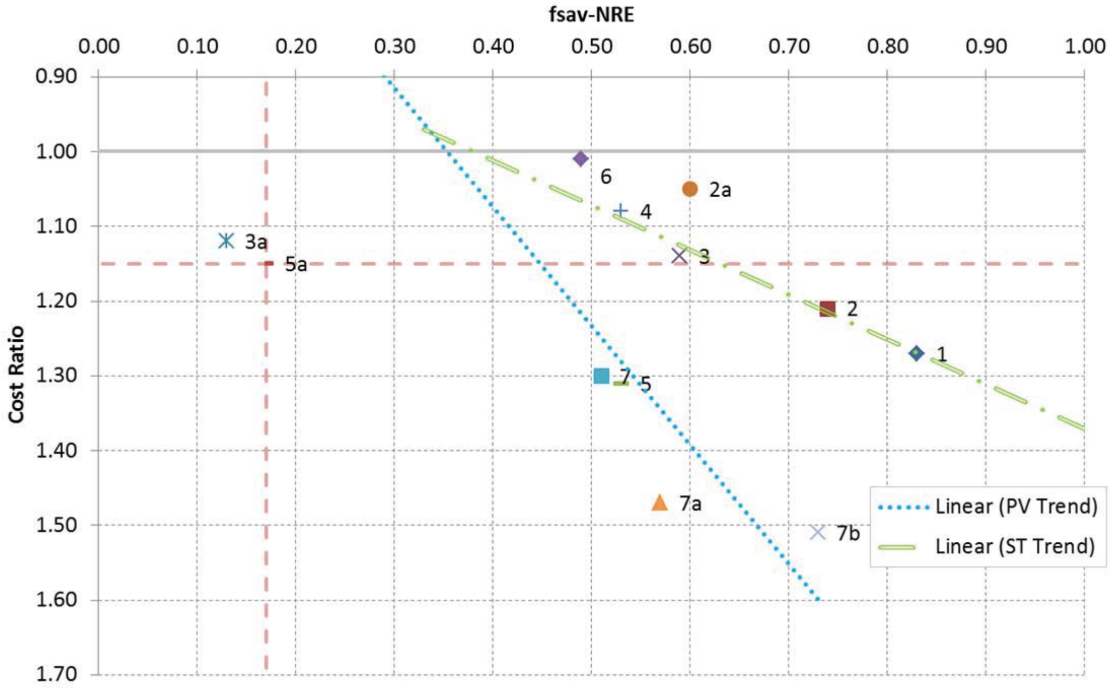

Fig. 4: Cost Ratio vs. non-renewable primary energy savings of the analyzed plants (1-7) and trends observed by PV and ST driven systems

Some findings of this line up are listed below. Including only 7 plants in the compilations, this is not representative, notwithstanding the trends are from interest and give a general view of solar heating and cooling.

- If 5a would be the reference (bold dashed lines), some examples would achieve cost competitiveness; one derivative example would decrease to negative savings.
- The plants with space heating (#1, #7a, 7b) are more expensive and can achieve higher savings.
- Heat pump systems (#5, #7) are more expensive than others.
- There is hardly any effect of the system size visible (cf. #6 – 2 kW & #3 1.5 MW).
- Type of heat pump system is shown clearly (#5 - DHW vs. #7 - SH)
- Climatic conditions are negligible.
- If gas back up is used, the f_{sav} is slightly smaller than the solar fraction (#3, #4)
- Against the common arguments the trend of PV and ST express that the sum of all solar thermal driven systems shows a smaller cost ratio with higher reachable savings than the PV driven systems.
- In this summary the economic parity of PV and ST can be reached below 40% savings.

After analyzing Figure 3 questions, especially regarding the boundary conditions of the comparison, are arising: What are the driving parameters for this constellation and how do they affect the results?

The sensitivity analysis was carried with four plants (ST: #1, #2 & PV: #5, #6). Following parameters were varied in the mentioned range.

- Primary energy factor (ε_{el}) — 70 – 160% of $\varepsilon_{el} = 0.4$ kWh_{el}/kWh_{prim}
- Investment costs (invest) — 50 – 130% for solar components
- Electricity costs (C_{el}) — 50 – 150% of C_{el}=0.10 €/kWh
- Electrical efficiency ($Q_{el.sys}$) — 70 – 130% of auxiliary electricity demand

The results are presented in Figure 5. The primary energy conversion factor for electricity is only affecting the non-renewable primary savings and results in horizontal lines. The investment cost and the electricity cost are only affecting the cost ratio, consequently resulting in vertical lines. An effect on both key figures is achieved by the change of the electricity demand of the entire system. This can be interpreted either as an improvement of the electrical efficiency of the heat pump or the reduction of the auxiliary electricity demand.

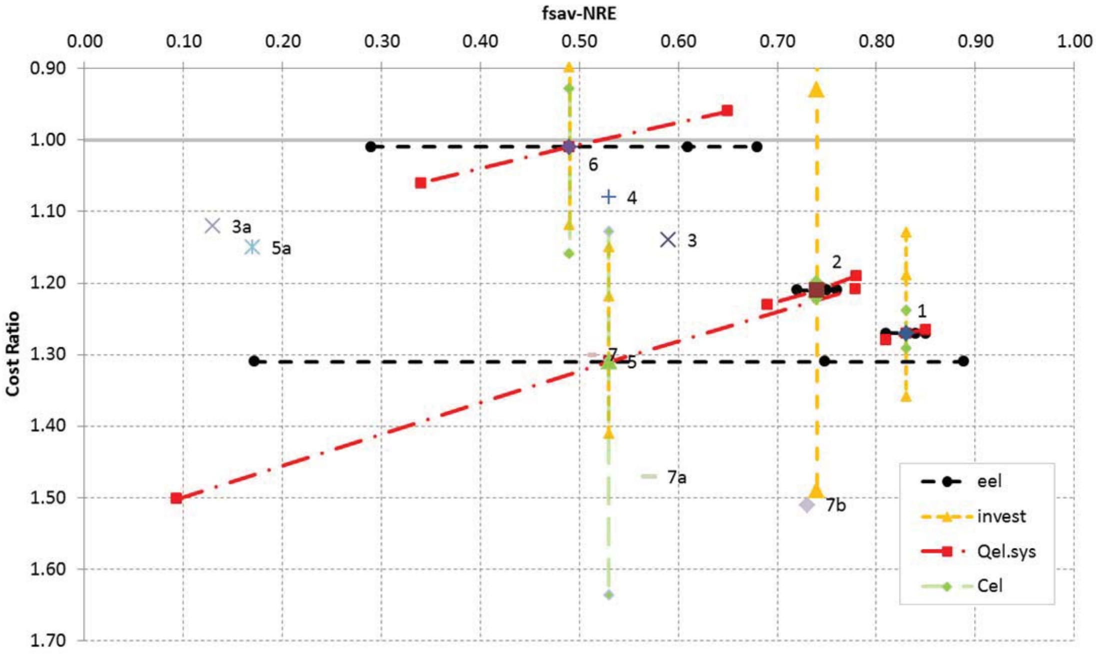

Fig. 5: Sensitivity analysis of two PV and two solar thermal driven plants

The two solar thermal plants (#1, #2) are less sensitive on the electric parameters (ε and SPF_{el}). Both thermal systems were designed and optimized regarding the auxiliary electricity demand. Thus the influence of changing input values is lower than for electrical driven systems.

The variation of ε_{el} results in a change of ±0.05 in the f_{sav} for the solar thermal plants but ±0.3 for the PV driven plants. The influence is less for ST because they are optimized towards low auxiliary electricity consumption. Thus electricity driven system are more sensitive the less the solar fraction.

Electrical efficiency is an important issue for PV supported systems. Only if the heat pump systems are optimized the systems get economical viable. Increasing the PV area increases the savings but also the cost ratio although the surplus energy rises and the revenues due to feed-in are increasing. If a system is optimized to a high standard, the less it can be influenced by varying input parameters.

Investment costs have a higher influence on the results of the solar thermal plant, due to the fact that the ratio of investment cost to all other costs is higher. Plant #6 and #2 could reach a cost ratio of 1 with lower investment costs. Plants #5 and #1 would reach affordable economics.

The sensitivity analysis shows that PV and ST are cutting across with the same trends (e.g. #2 and #5 if electricity demand is optimized). To reach cost competiveness lower investment costs have to be derived first, followed by the efficiency of the system. The chosen (or rather standardized) primary energy conversion factors have a great influence on the results and need to be stated clearly to interpreter correctly.

5. Conclusions

A comprehensive tool was developed in the course of IEA SHC Task 53 and is available for the analysis and assessment of new generation of solar heating and cooling systems. The key figures that are calculated allow a benchmarking and simplify the comparison of different system configurations. The Tool can be used to benchmark against a standardized reference systems or against other renewable heating and cooling technologies. Still, the comparability is challenging if applications and configurations are mixed. Nevertheless, a trend wise comparison of magnitudes can definitely be achieved. The tool can be downloaded at http://task53.iea-shc.org/.

One figure, that can be used to compare the application performance with a commonly used SEER value based on electricity, is the electrical equivalent Seasonal Performance Factor (SPF_{equ}). This key figure summarizes the performance even when both, electricity and heat is used to supply the entire system.

The presented plants show good performances resulting in non-renewable primary energy savings of more than 50%. None of the plants can reach a cost ratio below 1. The trend shows, that more savings result in higher cost ratios and thus more expensive plants. The four solar thermal plants show a lower gradient in the comparison than the three PV driven systems resulting in higher costs per saving.

The sensitivity analysis displays that PV and ST are cutting across with the same trends. Lower costs have to be derived first, followed by the efficiency of the system. Cost competiveness is achievable for both technologies! Change of conversion factors equals PV and ST driven systems even more, independently of the total system. Both technologies have their advantages and are desirable.

More comprehensive collection of annual data will be carried out in the ongoing Task 53 and will be presented within those activities.

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