Combined solar thermal and heat pump systems within the funding program of large-scale solar thermal systems in Austria – Status investigation and progress report

Franz Helminger[1], Bernd Windholz[1], Christian Fink[2] and Samuel Knabl[2]

[1] Center for Energy/AIT – Austrian Institute of Technology GmbH, Vienna (Austria)

[2] AEE Intec, Gleisdorf (Austria)

Abstract

The Austrian "Klima- und Energiefonds" started 2010 a funding program for the development and further market penetration of large-scale solar thermal systems. The most interesting projects in terms of innovation were selected for a system monitoring, analysis and optimization of about 12 months by a scientific partner. Since 2010 about 25 combined solar thermal and compression heat pump systems (STHP systems) were selected within this framework and for eleven of these systems monitoring data is available. In this paper the selected systems are categorized and findings from the monitored systems are presented. Therefore, the performance of the systems is assessed with technical, economic and ecological parameters. In principle, the compression heat pump suits well to the solar thermal system to generate low temperature heat for space heating purposes and hot water preparation. The compression heat pump acts flexible and generates heat whenever the solar energy is not available. STHP systems show also a very positive effect for reductions of environmental impacts. But lack of standards for planning and realization leads to higher effort, higher risk and costs. Up to now the knowledge transfer by the scientific partners to the market players is essential for the further development of this technology.

Keywords: large-scale solar thermal system, compression heat pump, monitoring

1. Introduction

The Austrian "Klima- und Energiefonds" introduced a funding program for large-scale solar thermal systems in 2010 for innovative solar thermal concepts of between 100 and 2000 m² collector area. In this funding program the implementation of following concepts is addressed:

- Solar process heat applications
- Solar district heating systems
- Solar cooling applications (until 2015)
- Solar combisystems with high solar fractions of above 20 %
- Novel technologies and innovative concepts (since 2013)

A scientific consultancy in the application phase for the funding program ensures the high quality of the addressed systems. For the most interesting projects a system monitoring is done for a period of about 12 months. Therefore operating data is continuously recorded and analyzed. Based on this analysis the heat generation systems (solar thermal, heat pump, biomass, oil, etc.) and their controls as well as the heat distribution systems are optimized. Any existing cold supply is analyzed, as well. Conclusions of the system monitoring and optimizations are published.

Since 2010 about 25 combined solar thermal and compression heat pump systems (STHP systems) have been funded and selected for the monitoring. For eleven of these systems monitoring data of the entire period is available. In this paper the selected STHP systems are categorized and findings from the monitored STHP systems are presented. In chapter 2 an overview and categorization is given. In chapter 3 an assessment of the STHP systems by means of following parameters is shown:

- Specific solar gains
- Mean collector temperature

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- Seasonal performance factor (SPF) of the heat pump system
- Operation time and number of operating cycles of the compression heat pump
- Greenhouse gas impact measured by CO_2 equivalents and primary energy consumption

In chapter 4 the results are summarized and a conclusion is given.

2. Overview and categorization

Solar thermal systems and compression heat pumps can be combined in many ways. The possibilities how to combine these systems were analyzed and described within the IEA SHC Task 44 documented by (Paula 2014) and (Ruschenburg and Herkel 2013). The main categories are “parallel”, “serial”, “regenerative” and “complex“ concepts. A short description of these four concepts is given in Tab. 1, Fig. 1 shows the energy flow schemes of the four concepts.

Tab. 1: Short description of different STHP concepts and their functionality

Concept	Short description
Parallel	Heat from the solar system and the heat pump is fed in one heat storage. The solar system and the heat pump work independent from each other, only coupled via the storage.
Serial	The solar system and the heat pump are hydraulically connected in a way, that the solar system delivers heat to the evaporator of the heat pump. This concept allows low temperatures in the solar system and the collectors act as air heat exchangers (ST+PV hybrid collectors and unglazed collectors).
Regenerative	The solar system delivers heat into ground heat exchangers to regenerate the ground. In that way heat from sunny periods is used in cold periods and the ground acts as seasonal storage.
Complex	Combination of parallel, serial and/or regenerative concepts.

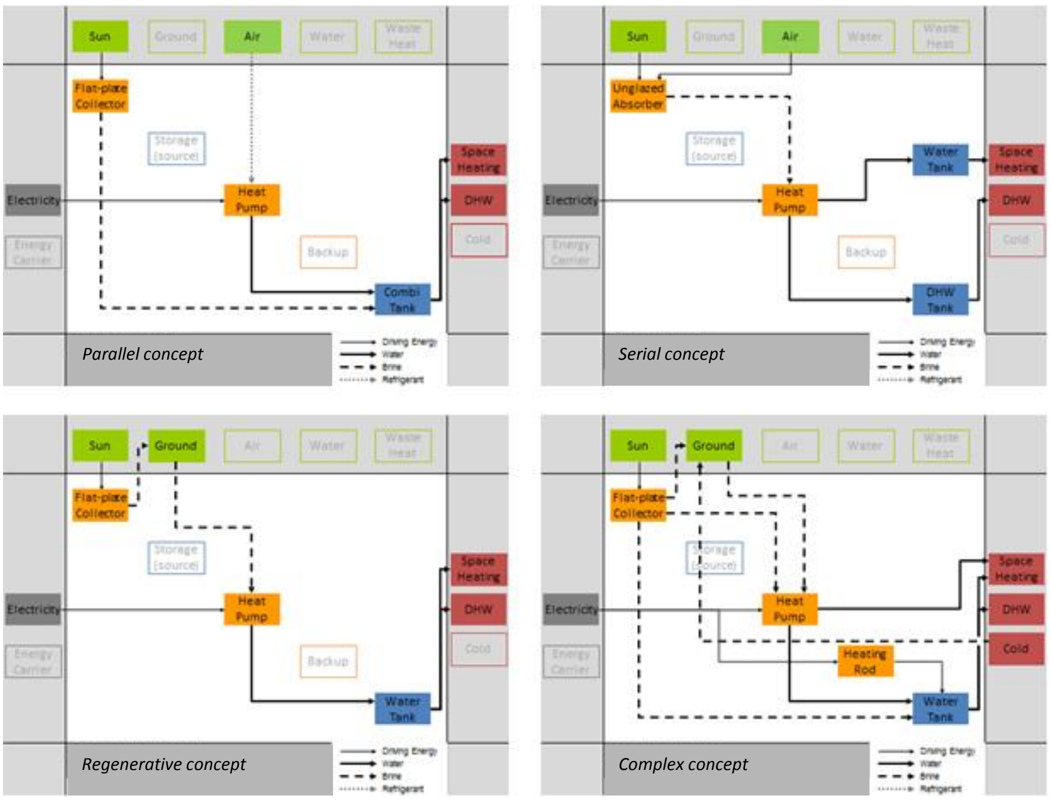

Fig. 1: Energy flow schemes of four STHP concepts by IEA SHC Task 44 (Paula 2014)

Of the 25 selected systems (sum of dark and light blue bars in Fig. 1), 19 (76%) STHP systems can be assigned as complex systems and six (24%) STHP systems as parallel systems. For eleven of the 25 selected STHP systems the monitoring is already finished and monitoring data of the entire period of 12 months is available (dark blue bars in Fig. 1). Ten of the monitored systems are complex systems and one system is a parallel system.

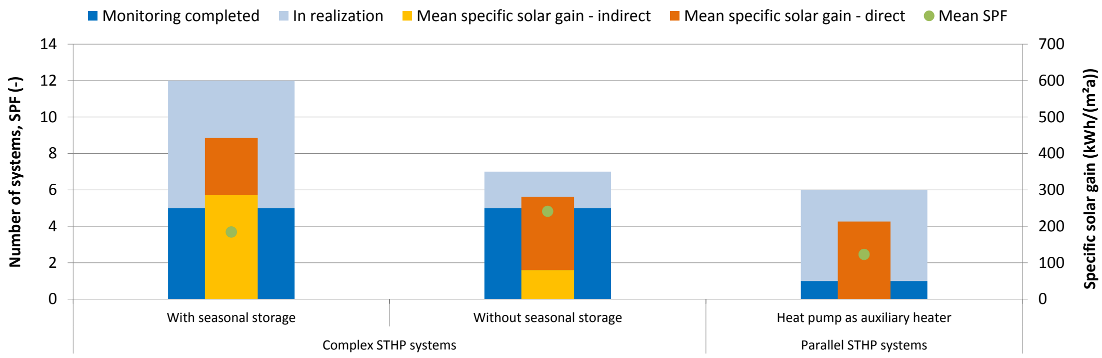

Fig. 2: Classification of selected STHP systems and overall results

For further distinction and better overview including the functionality following subcategories are established (see Fig. 1):

Complex STHP systems:

- Systems with seasonal storage
- Systems without seasonal storage

Parallel STHP systems:

- Systems with heat pump as auxiliary heater

The subcategory „systems with seasonal storage“ covers systems with horizontal ground collectors and depth probes. Heat from the solar system can be delivered to the ground and used by the heat pump. In “systems without a seasonal storage” systems are summarized where the combination of solar thermal and compression heat pump enables solar heat at the evaporator of the compression heat pump without a seasonal storage. Within the category “parallel systems” a (brine-to-water or air-to-water) heat pump acts as auxiliary heater to the solar system. 14 systems are in implementation (light blue bars in Fig. 1), seven of these systems are covered by the category “systems with seasonal storage”, two belong to “systems without seasonal storage” and five systems are “systems with heat pumps as auxiliary heater”. In three of five “systems with seasonal storage” with finished monitoring, the heat pump is used for heating and cooling and the seasonal storage is partly regenerated by the heat pump. The following assessment covers only heating mode of the systems.

3. Assessment

For the assessment of the specific solar gains and the mean collector temperature two different operating modes of the solar system are distinguished. The operating mode “direct” considers the solar gains and collector temperatures in periods where the heat is directly delivered to the respective use (e. g. space heating or hot water preparation) or to a short-term storage (i.e. buffer tank). The operating mode “indirect” includes solar gains and collector temperatures in periods where the heat is given to the evaporator of the compression heat pump or to a seasonal storage. The solar gains in the two operating modes are shown in Fig. 2, which also shows the mean seasonal performance factor (SPF) of the heat pump. The SPF is the ratio of the useful heat taken from the condenser of the compression heat pump divided by the electrical energy consumption of the compression heat pump. It is typically analyzed to assess the efficiency of a heat pump and gives also a value for the assessment of the economical operation. It was analyzed only for heating mode and not taking into account auxiliary devices like circulation pumps due to the fact that auxiliary devices need not to be measured regarding the funding scheme.

All STHP systems with completed monitoring are analyzed and the results are given at Fig. 3 to Fig. 5 for each subcategory. This graphs show the specific solar gains (direct and indirect operating mode), the mean collector temperature (direct and indirect operating mode) and the SPF as most significant parameter of the heat pump.

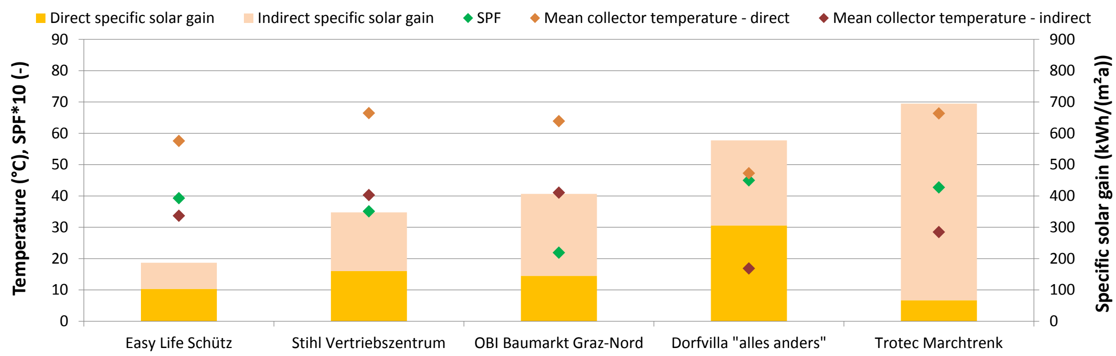

Fig. 3: Results of complex systems with seasonal storage

By means of the specific solar gains in ”direct” and ”indirect” operating mode different behavior of each STHP system is presented. In all STHP systems heat from the solar system in ”direct” operating mode is generated at a higher temperature level than in ”indirect” operating mode. The average of the mean collector temperature in ”indirect” operating mode is about 25 K lower than in ”direct” operating mode. With lower collector temperatures the efficiency of the solar collector and the solar gain increases. In many cases heat at lower temperature cannot be used directly and needs to be lifted by the compression heat pump. This operating mode causes an electrical energy demand. The higher the difference of the temperature of the heat source to the heat sink of the heat pump, the higher the electrical energy demand and lower the SPF.

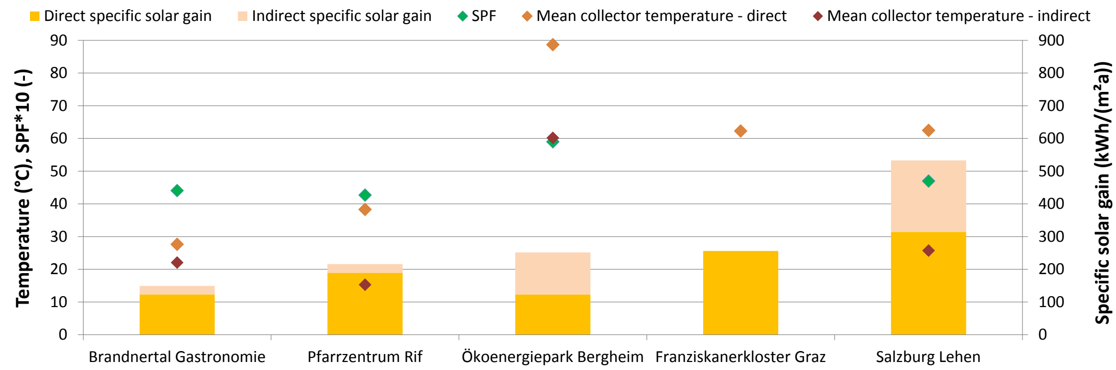

Fig. 4: Results of complex systems without seasonal storage

An optimization of the respective STHP system in consideration of diametrical optimization criteria (minimum electrical energy costs, maximum reduction of CO_2 emissions, etc.) is a sophisticated task and done by the operators with different optimization targets and different framework conditions (e.g. storage sizes, collector area, energy prices, etc.).

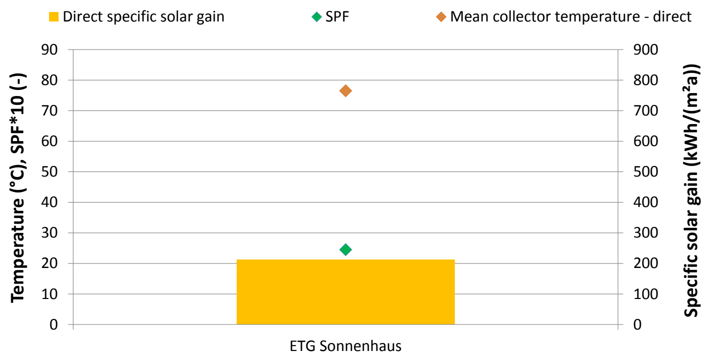

Fig. 5: Results of parallel systems with heat pump as auxiliary heater. In this specific case an air-to-water heat pump is used.

The specific solar gain differs significantly within each category. Even if the configuration of the STHP systems is similar within one category, each STHP system is planned, realized and operated individually (collector area, storage size, orientation of solar collectors, heat demand, temperature level of consumers, etc.). Therefore, it is not possible to give clear conclusions and generally applicable recommendations.

The monitoring results of the compression heat pumps are very good for almost all STHP systems, only at „OBI Baumarkt Graz-Nord“ and „ETG Sonnenhaus“ the SPF is low. At these two STHP systems, the operating conditions for the compression heat pumps are very unfavorable and therefore, a higher SPF cannot be reached. At the STHP system „OBI Baumarkt Graz-Nord“ the ground collectors are placed below a parking area and are not sufficiently insulated against outside air. The operating temperature of these ground collectors is very close to the outside temperature and especially in winter lower than expected. At the STHP system „ETG Sonnenhaus“ the air-to-water heat pump is operated only in December and January with a very high temperature lift from outside temperature to the heat delivery system.

The compression heat pump at the STHP system „Franziskanerkloster Graz“ was not operated during the monitoring period and therefore, the SPF can not be calculated.

A continuous operation of the heat pump is generally an advantage for an economical use. To assess the continuity of the heat pump operation of the STHP systems the yearly operation period, the mean operation period per activation in the monitoring year, the mean operation period per activation in the month with longest operation period and the number of activations per year are compared in Tab. 2. The mean operation period per activation in the monitoring year is between ten minutes and about ten hours. Very short operation periods per activation have negative consequences for the lifetime of the compressor(s) of the heat pump (lubrication gap has to be built up), and for the SPF, because on start up (takes at least one minute) the efficiency is lower than in steady state operation. Mean operation periods below 30 minutes are disadvantageous, but can not be avoided due to varying energy demands.

Tab. 2: Analysis of activation periods and number of activations of the compression heat pump

		Yearly operation period (h)	**Mean operation period per activation in the monitoring year (min)**	**Mean operation period per activation in the month with longest operation period (min)**	**Number of activations per year**
Systems with seasonal storage	Easy Life Schütz	2790	90	62	1868
	Stihl Vertriebszentrum	790	44	63	1074
	OBI Baumarkt Graz-Nord	313	14	21	1349
	Dorfvilla "alles anders"	1887	176	206	644
	Trotec Marchtrenk	1113	43	69	1536
Systems without seasonal storage	Brandnertal Gastronomie	570	10	10	3552
	Pfarrzentrum Rif	1067	24	32	2721
	Ökoenergiepark Bergheim	3055	114	371	1609
	Franziskanerkloster Graz	No heat pump operation during monitoring period			
	Salzburg Lehen	3744	567	781	396
Heat pump as auxiliary heater	ETG Sonnenhaus	146	194	182	45

Fig. 6 shows the results given in Tab. 2 and emphasises that due to different applications of the STHP systems and different share of energy from the solar system and the compression heat pump, a wide range of operation periods occured in the monitored systems. An example with continuous operation of the heat pump is given in

”Salzburg Lehen”, where the yearly operation period is long (3750 hours, about 5 month). The main reason for this behavior is that the capacity of the STHP system is very low compared to the energy demand. The STHP system covers a part of the base load, therefore, it is activated continuously.

During monitoring periods numerous improvement measures were implemented in the considered STHP systems. In some cases, due to planning mistakes (e.g. dimensioning of storage), just small improvements were possible. High effort would be necessary to correct such planning mistakes. In some STHP systems the heating capacity of the compression heat pump is too high compared to the energy demand or the storage size. This leads to short activation periods of the compression heat pump, because the compression heat pump is deactivated when the storage is loaded and no heat is needed. The dimensioning of the compression heat pump has to be done according to standards and is calculated to cover the energy demand at the coldest day of the year. To compare STHP systems the mean operation period per activation is assessed, on the one hand for the monitoring year and on the other hand for the month with the longest operation period. The mean operation period of the month with the longest operation period is normally longer than the mean operation period of the monitoring year. Only for the STHP systems „Easy Life Schütz“ and „ETG Sonnenhaus“ the mean operation period of the monitoring year is longer than the mean operation period of the month with the longest operation period. At both STHP systems the reason is the specific use of the buildings. The mean operation period should be longer than about 45 to 60 minutes. Otherwise, a compression heat pump with less capacity would be sufficient to cover the energy demand. Looking at the past years, the lowest outside temperature of each year was rising. Therefore, the nominal capacity of the overall heating system is rarely needed, the heating system is operated in partial load, and operating periods are shorter. A bigger but more expensive energy storage could improve the situation and lead to lower electrical energy demand of the heat pump.

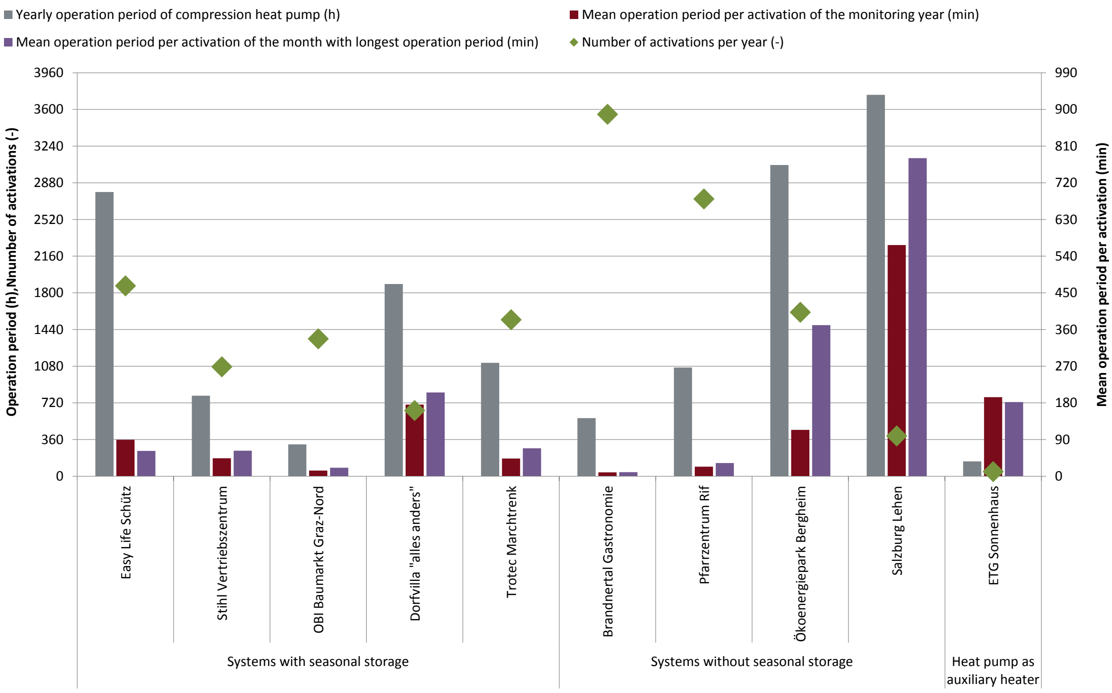

Fig. 6: Operation periods and activations of compression heat pump

STHP systems enable a reduction of negative environmental impacts (CO_2 emissions, primary energy consumption, etc.) compared to heating systems operated with fossil fuels. An ecological assessment of the yearly reduction of CO_2 equivalents and primary energy consumption was done by comparing the monitoring results to a reference scenario. Therefore, following assumptions were made:

- As reference scenario a gas boiler with 96 % efficiency was chosen.
- At STHP systems without any additional heating system (listed below) it was assumed that the gas boiler delivers the overall energy demand without storage losses.

Easy Life Schütz	Stihl Vertriebszentrum	OBI Baumarkt Graz-Nord
Dorfvilla "alles anders"	Trotec Marchtrenk	Pfarrzentrum Rif
ETG Sonnenhaus		

- At STHP systems with additional heating systems (listed below) it was assumed that just the energy delivered from the solar system and the heat pump is compared to the reference.

  Brandnertal Gastronomie   Ökoenergiepark Bergheim   Salzburg Lehen

  This assumption neglects that the behavior of the additional heating systems is affected by the operation of the STHP system and the reference. At these STHP systems the heat pump operates as a booster and lifts low temperature heat to heat at temperature levels used by the heat consumers. It is neglected that the additional heating systems have an influence to the ecological emissions. As this paper wants to present the effect of the STHP systems, all these neglections cause a simplification of the analysis.
- The electrical energy consumption of auxiliary devices of the STHP systems was estimated out of the monitoring results as it was not measured. The electrical energy consumption of the auxiliary devices was assumed to be 3.5 % of the electrical energy consumption of the compression heat pump of each STHP system.
- At the STHP system “Franziskanerkloster Graz” the heat pump was not activated during the monitoring period. As there is an additional heating system, just the solar heat delivered to the entire system is compared to the reference. The electrical energy consumption of the auxiliary devices was assumed to be 3.5 % of the solar heat delivered to the entire system.

The CO_2 equivalents and primary energy consumptions for Austria and EU-25 (abbreviated EU) were determined for the reference scenario and the monitored STHP systems (see Tab. 3 and Tab. 4). Following factors from (Öko-Institut Freiburg) were used:

- Greenhouse gas emissions to air – CO_2 equivalent for natural gas in Austria
- Greenhouse gas emissions to air – CO_2 equivalent for natural gas in EU
- Greenhouse gas emissions to air – CO_2 equivalent for electrical energy in Austria
- Greenhouse gas emissions to air – CO_2 equivalent for electrical energy in EU
- Resource requirements – primary energy consumption ratio for natural gas in Austria
- Resource requirements – primary energy consumption ratio for natural gas in EU
- Resource requirements – primary energy consumption ratio for electrical energy in Austria
- Resource requirements – primary energy consumption ratio for electrical energy in EU

Tab. 3: Yearly reduction of CO_2 equivalents using emission factors for Austria and EU, respectively

		Yearly reduction of CO_2 equivalents (t)	
		Austrian energy mix	EU energy mix
Systems with seasonal storage	Easy Life Schütz	7.58	6.59
	Stihl Vertriebszentrum	44.05	38.34
	OBI Baumarkt Graz-Nord	91.01	73.94
	Dorfvilla "alles anders"	14.30	14.55
	Trotec Marchtrenk	38.14	40.47
Systems without seasonal storage	Brandnertal Gastronomie	4.07	3.65
	Pfarrzentrum Rif	9.71	9.83
	Ökoenergiepark Bergheim	312.18	311.55
	Franziskanerkloster Graz	20.10	21.27
	Salzburg Lehen	239.60	242.02
Heat pump as auxiliary heater	ETG Sonnenhaus	3.93	4.05

Tab. 4: Yearly reduction of primary energy consumption using consumption factors for Austria and EU, respectively

		Yearly reduction of primary energy consumption (MWh)	
		Austrian energy mix	EU energy mix
Systems with seasonal storage	Easy Life Schütz	29.82	19.46
	Stihl Vertriebszentrum	173.35	113.07
	OBI Baumarkt Graz-Nord	336.16	165.41
	Dorfvilla "alles anders"	65.06	63.91
	Trotec Marchtrenk	180.44	191.94
Systems without seasonal storage	Brandnertal Gastronomie	16.47	11.81
	Pfarrzentrum Rif	43.95	42.70
	Ökoenergiepark Bergheim	1394.78	1316.76
	Franziskanerkloster Graz	94.84	100.40
	Salzburg Lehen	1082.62	1048.22
Heat pump as auxiliary heater	ETG Sonnenhaus	18.09	18.22

The results of the assessment shown in Tab. 3 and Tab. 4 vary in a wide range due to the fact that the heat demands of the STHP systems are very different. The ecological improvement was additionally analysed by a comparison of relative improvements of each STHP system. Therefore, the ratio of the yearly reduction of emissions and primary energy consumption of the monitored STHP systems to the CO_2 emissions and primary energy consumption of the reference scenario was determined and is shown in Fig. 7 for CO_2 equivalents and in Fig. 8 for primary energy consumption. In both graphs the grey bars represent the reduction, if the STHP system was powered by the EU energy mix and the dark red bars represent the reduction, if the STHP system was powered by the Austrian energy mix. The reduction of CO_2 equivalents is between 40 % and 96 % for the EU energy mix, and between 53 % and 97 % for the Austrian energy mix. The reduction of primary energy consumption is between 19 % and 95 % for the EU energy mix, and 41 % and 96 % for the Austrian energy mix.

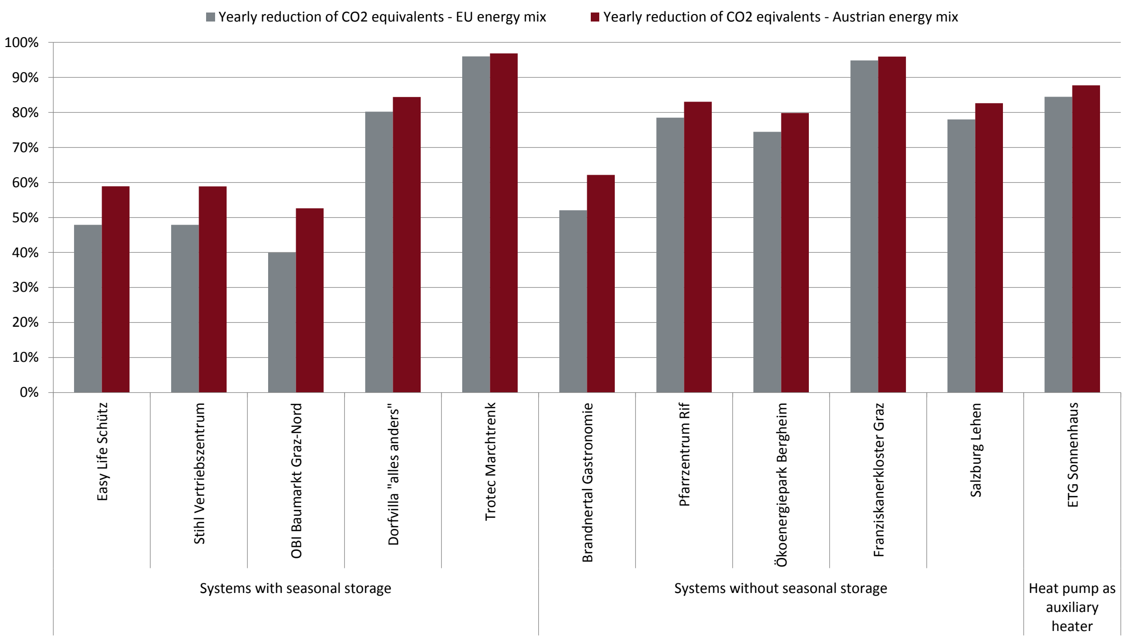

Fig. 7: Yearly reduction of CO_2 equivalents (Austrian and EU energy mix, respectively) by use of STHP systems compared to a gas boiler

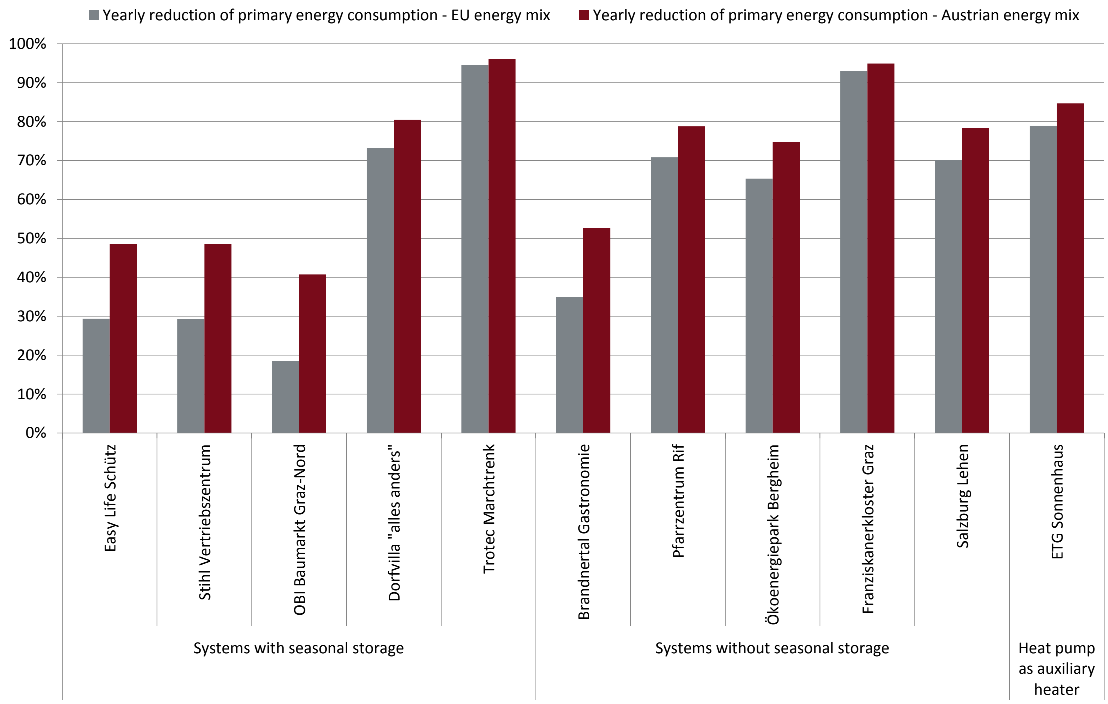

Fig. 8: Yearly reduction of primary energy consumption (Austrian and EU energy mix, respectively) by use of STHP systems compared to a gas boiler

4. Conclusion

The number of STHP systems within the framework of the funding program for large-scale solar thermal systems was increasing in recent years. Eleven systems are realized and monitoring results are available, additional 14 systems are selected and should be realized within coming years.

In principle, the compression heat pump suits well to the solar thermal system to generate low temperature heat for space heating purposes and hot water preparation. The compression heat pump acts flexible and generates heat whenever the solar energy is not available. STHP systems show also a very positive impact for reductions of environmental impacts.

Although experience in STHP systems is available for planers, installers, operators, and owners, the lack of standards for planning and realization leads to higher effort, higher risk and costs. Up to now the knowledge transfer from the scientific partners to the market players is essential for the further development of this technology. Within the framework of the funding program some planers with long-time experience apply for funding, but also planers with no or nearly no experience take part. For both groups tools, standards and guidelines for STHP systems would lower costs and risks. As the STHP systems are mainly composed for the individual situation, a detailed simulation is advantageous. Some of the planers do not take care of this and therefore the risk for mistakes and dissatisfaction occurs.

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