OVERVIEW ON SOLAR THERMAL PLUS HEAT PUMP SYSTEMS AND REVIEW OF MONITORING RESULTS

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1. Introduction

In recent years several companies started offering Solar thermal And Heat Pump Systems (SAHPS) on the European Market; already in 2009 an overview was given for example by Zörner W. et al (2009). For single family houses the systems are offered as pre defined package (kit) solutions. The systems deliver thermal energy for heating, domestic hot water and eventually as well cooling to the building usually without any further back up burner. The hydraulic schemes of the single systems, especially the degree of integration of the solar thermal and electrical driven heat pump unit vary significantly. The same is true for the used low temperature heat source for the heat pump where ground heat exchangers (horizontal and vertical), ambient air, specific solar collectors, phase change material storages (e.g. ice/water) and exhaust air are implemented.

The objective of combining solar thermal and heat pump units is to enhance the overall share of renewable heat applied, by allowing a high Solar Fraction (SF) and an enhanced Seasonal Performance Factor (SPF) of the heat pump system. This second figure is claimed to be up to SPF ~ 5 in some commercial presentations. The practical experiences with such systems are still limited and the published monitoring results are only in part in line with the mentioned expectations. Within the Task 44/Annex 38 of the International Energy Agency (IEA) Solar Heating and Cooling Program / Heat Pump Program, such systems are analyzed in detail, including simulations, evaluation of monitoring results and development of test procedures.

The target of the present paper is to give an overview on commercially available Solar thermal And Heat Pump Systems (SAHPS) and a review on published monitoring results from realized installations.

2. Overview on commercial Solar thermal and Heat Pump Systems

Since the beginning of the IEA project Task 44/Annex 38 the partners collected information's of commercially available solar thermal and heat pump systems in order to get a possible complete overview of the actual market situation. By June 2011 a list of over 95 different commercially presented systems could be collected. These systems are of very different type including different heat sources. Therefore in order to structure the number of single systems a methodology was needed. Frank E. et al (2010) proposed in their publication a visualization and a notation scheme in order to analyze and classify the different solar thermal and heat pump systems.

The visualization scheme allows in a graphical simplified way to represent such systems. Within the scheme are shown the main components which are applied (e.g. solar collectors or heat pumps) which are represented by squares being placed in the centre of the scheme; the renewable energy sources included (e.g. solar energy or geothermal) which are represented by squares on the top row of the scheme; the additional energy needed (e.g. electricity) which is represented by squares in the left row of the scheme and finally the heat sinks served (e.g. heating and domestic hot water) which are represented by squares in the right row of the scheme. The energy flows are represented by different kind of arrows connecting the single squares. As the scheme is based on squares it was denominated “square view” of a SAHPS. The square view allows the reader in a short time to get a clear overview on the system components and energy flows. It does not give detailed information’s on hydraulic connections, neither are there included any information’s of sizing of the single components. The structure of the square view is shown in the following Figure 1:

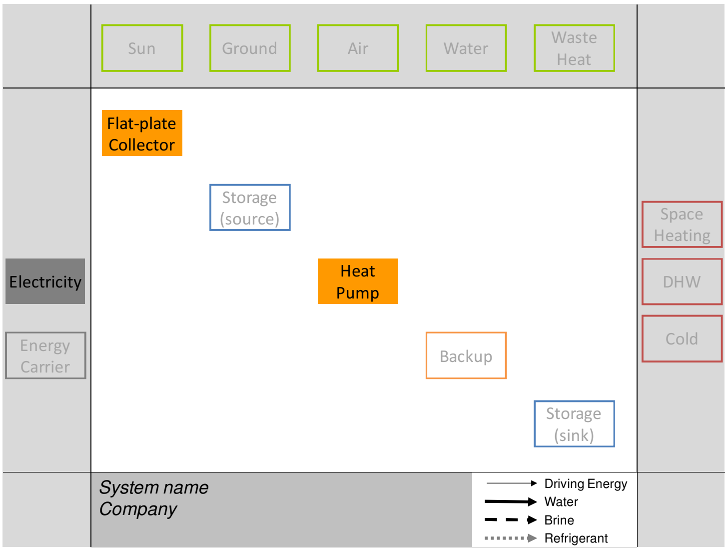

Figure 1: Structure of the “square view” diagram, showing the main components, heat sources, heat sinks and additional energy carriers implemented in a solar thermal and heat pump system.

In order to record as well information’s on the main hydraulic connections, within the list of systems next to a commercial diagram of the system and the square view, as well a unified hydraulic drawing scheme has been elaborated and was collected for each system. In the following Figure 2 the unified hydraulic scheme and the square view of a solar thermal and heat pump system is shown as example.

With the aim of structuring the list some primary properties have been collected allowing a classification of the systems. As explained by the notation scheme presented in Frank E. et al (2010) a subdivision based on the heat source used by the heat pump has been used as one characteristic aspect. In the following examples of systems applying a geothermal heat source, an aerothermal heat source and the solar thermal collector as only heat source will be shown. Examples could be recorded as well of systems using exhaust air of the air ventilation system and water (from e.g. ground, lakes, rivers) as heat source.

Next to a classification based on the heat source applied as well the degree of integration of the solar thermal and the heat pump system have been considered. Following Freeman T.L. et al (1978), Trinkl et al (2004) or Frank E. et al (2010) the subdivision in “parallel” and “serial” will be considered onwards:

- “Parallel” systems are characterized by the fact that the solar thermal collector field and the heat pump are delivering heat in parallel to the heat sinks, sometimes via a central heat storage.
- “Serial” systems are characterized by the fact that the heat delivered by the solar thermal collector is used as low temperature heat source directly or indirectly by the heat pump

It has to be noticed that these two groups are not exclusive, so one system can be of both types. Next to this two groups, in the mentioned publications a third type “regeneration” has been defined, including those systems where the solar thermal heat is used for the regeneration of the source, usually ground. Within the collected list as well the type “integrated” has been applied for the description of systems where solar thermal heat is integrated in several ways in the overall heating system. For simplification reasons in the present paper al this systems are collected under the type of “serial” systems.

In the following figures examples of the single system types are shown. In Figure 2 and Figure 3 solar thermal and heat pump systems using geothermal heat exchangers are shown. In the first case the interconnection is of “parallel” type only while in the second case of “serial” and “parallel” type.

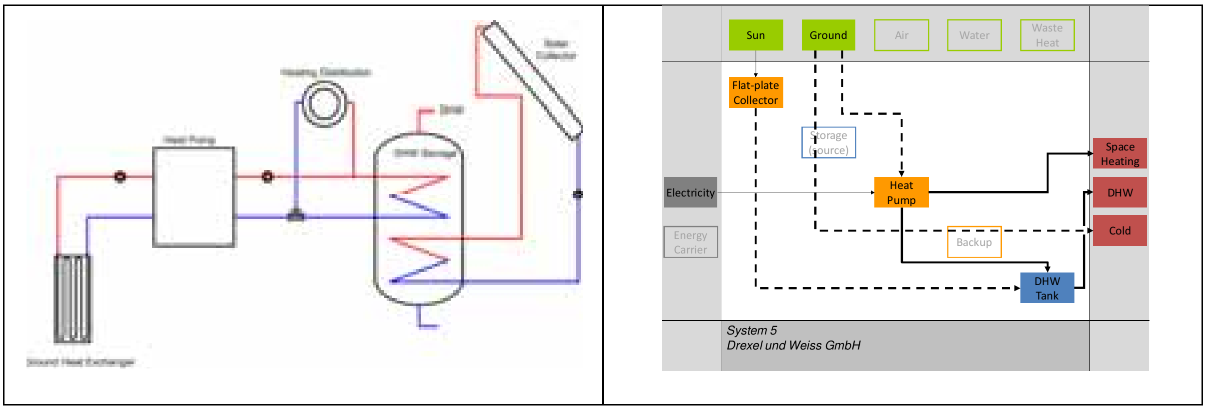

Figure 2: Unified hydraulic scheme (left) and the visualization scheme „square view“ (right) of a solar thermal and heat pump system. The system shown applies a geothermal heat exchanger as additional heat source and the solar thermal system and heat pump system are connected in a “parallel” way only.

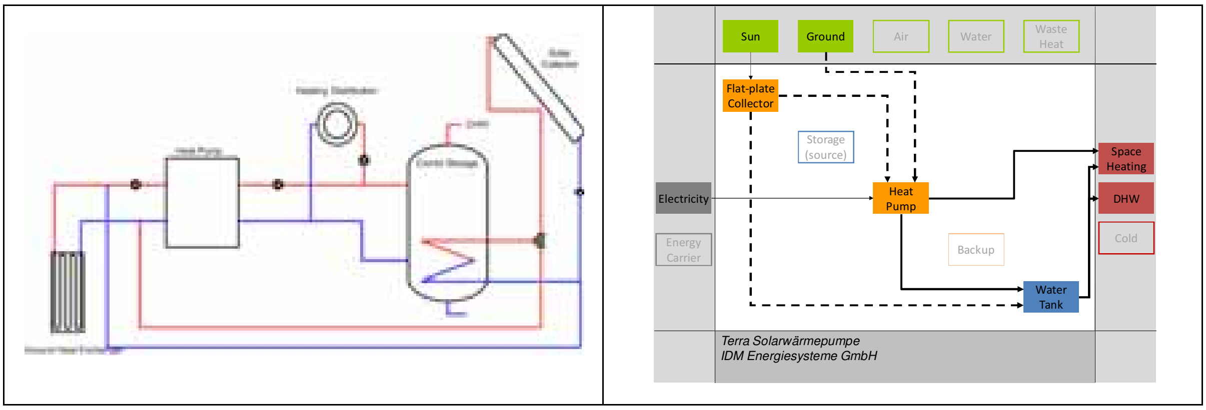

Figure 3: Unified hydraulic scheme (left) and square view (right) of a solar thermal and heat pump system. The system shown applies a geothermal heat exchanger as additional heat source and the two systems are connected in a “serial” and “parallel” way.

In Figure 4 and Figure 5 solar thermal and heat pump systems using aerothermal heat pumps are shown. In the first case the interconnection is of “parallel” type only while in the second case of “serial” and “parallel” type.

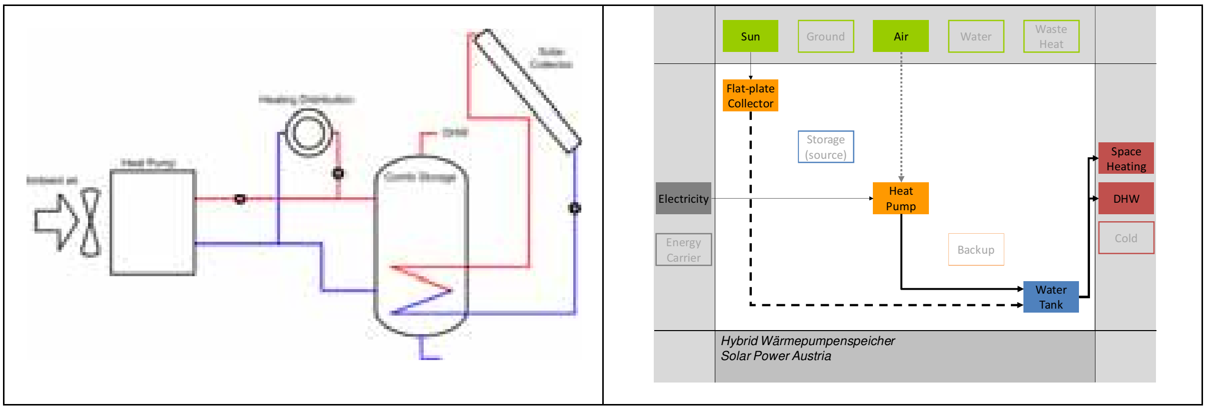

Figure 4: Unified hydraulic scheme (left) and square view (right) of a solar thermal and heat pump system. The system shown applies external air as additional heat source and the two systems are connected in a "parallel" way only.

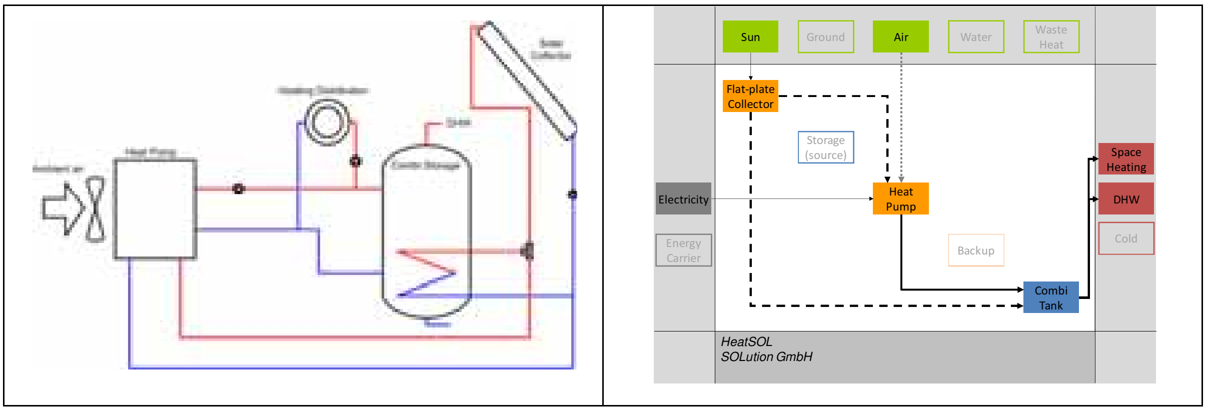

Figure 5: Unified hydraulic scheme (left) and square view (right) of a solar thermal and heat pump system. The system shown applies external air as additional heat source and the two systems are connected in a "serial" and "parallel" way.

The third typology of systems mentioned are those where the solar thermal collector represents the only heat source for the system. In these systems specific collectors have to be used which are able as well to work as efficient heat exchangers with the external air under conditions with no or reduced solar radiation.

In the following Figure 6 an example is shown of a solar thermal and heat pump system applying hybrid solar collectors which are connected to a combi storage for DHW and to a storage including phase change material (in the shown example water / ice) serving as low temperature heat storage. In Figure 7 an example is shown of a system applying unglazed solar collectors. In this case the solar collectors are directly connected to a heat pump.

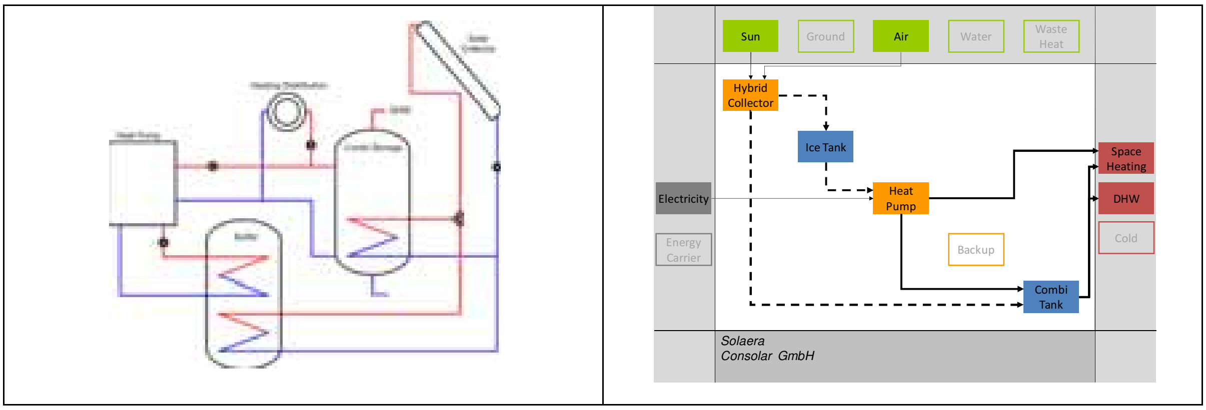

Figure 6: Unified hydraulic scheme (left) and square view (right) of a solar thermal and heat pump system. The system shown applies only the solar thermal collector as heat source. A hybrid collector is used feeding the DHW tank and an ice / water storage.

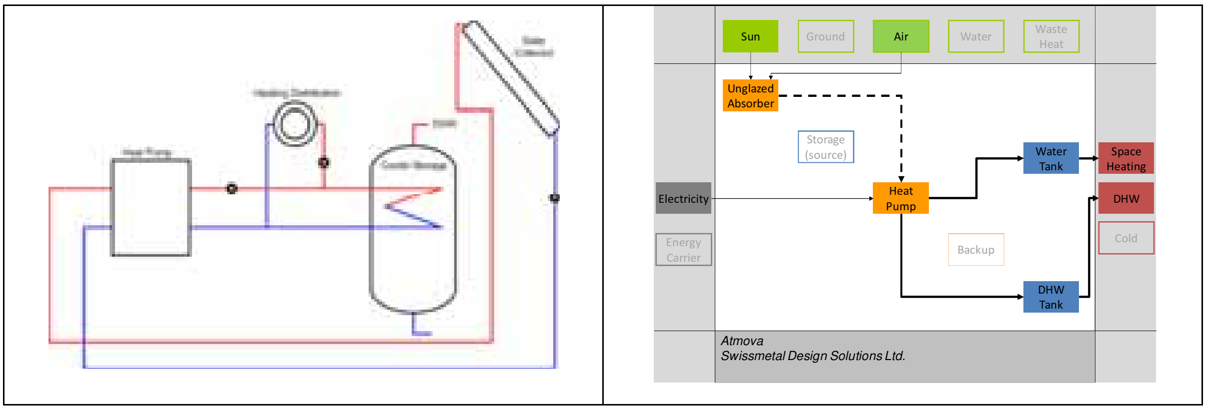

Figure 7: Unified hydraulic scheme (left) and square view (right) of a solar thermal and heat pump system. In the present system an unglazed collector is used serving directly as heat source for the heat pump.

Collecting the different solar thermal and heat pump systems, and classifying them the most typical typologies could be identified.

Out of 80 collected systems, 46 apply only a “parallel” scheme of interconnection between the solar thermal and the heat pump system.

With regard to the heat source applied it could be seen that the systems applying geothermal heat exchangers are the most common typology. In fact out of 80 systems 33 apply a geothermal heat source, 27 an aerothermal heat source and 12 systems use only the solar thermal collector as heat source. Within the rest of the systems water or exhaust air is used as low temperature heat source.

3. System performance evaluation methodology

Nomenclature:		Subscripts:	
Units and Symbols:		EH	Electric Heater
E	electrical energy	CP	Circulation Pump
$\dot{E}$	electrical power	cond	condenser
Q	thermal energy	comp	compressor
$\dot{Q}$	thermal power	DHW	Domestic Hot Water
		HP	Heat Pump
		HPS	Heat Pump System
		SAHPS	Solar thermal And Heat Pump System
		Sol	Solar
		tot	total
		Vent	Ventilator

The performance evaluation of a Solar thermal And Heat Pump System (SAHPS) can be done on the base of several figures. Possible key figures are Primary Energy Consumption, Final Energy Consumption, Electrical Energy Consumption, CO_2 emissions, Coefficient of Performance (COP) and Seasonal Performance Factors (SPF).

All these figures do depend not only from the SAHPS but are strongly dependent from the boundary conditions. These boundary conditions are in part directly related to the installed system and building, such as climatic zone, thermal energy efficiency of the building, thermal gains within the building or the heat distribution system. In part they are as well connected to the region, nation or macro area where the building is located. This is especially the case if the way of electricity production is considered in order to calculate figures such as the Primary Energy Consumption or CO_2 emissions.

In order to do a direct comparison of Energy Consumption Figures or CO2 emissions it would therefore be necessary to test the different SAHPS under unified boundary conditions. In order to do so unified test procedures would be necessary, which have not been developed yet. As already mentioned by Zörner W. et al (2009) or Bachmann S. et al (2008) the definition of such test procedures could enable a more transparent system description.

The central performance figure used in the present paper is the Coefficient of Performance (COP) and Seasonal Performance Factor (SPF) of the heat pump, the heat pump system and the solar thermal and heat pump system. This approach has been used as well by Miara M. et al (2010), Stojanovic B. et al (2010) or Ozgener O. et al (2007).

The Coefficient Of Performance is used to describe the performance power ratio of a single heat pump and considers only the heat power delivered by the condenser and the electrical power of the compressor. It is defined as follows:

$$COP_{HP} = \frac{\dot{Q}_{cond}}{\dot{E}_{comp}} \qquad \text{(eq. 1)}$$

The Seasonal Performance Factor describes the energy performance ratio of a unit in a defined period of time (e.g. one heating season). If the unit is the heat pump there is included the energy consumption of the compressor, but as well the stand by energy consumption or the energy consumption of an eventually installed electric back up heater. While the thermal energy produced by the condenser and as well the electric heater are considered. The SPF heat pump is defined as follows:

$$SPF_{HP} = \frac{\sum(Q_{HPtot}+Q_{EHtot})}{\sum(E_{HPtot}+E_{EH})} \qquad \text{(eq. 2)}$$

If the unit is enlarged not only the heat pump but as well the heat pump system is considered. In this case the electricity consumption of the pumps (for the geothermal heat exchanger or to the outdoor unit) and of the ventilators (in case of aerothermal systems) are included. The SPF heat pump system is defined as:

$$SPF_{HPS} = \frac{\sum(Q_{HPtot}+Q_{EHtot})}{\sum(E_{HPtot}+E_{CPHeatSource}+E_{Vent}+E_{EH})} \quad \text{(eq. 3)}$$

If the unit is further enlarged the whole solar thermal and heat pump system is considered. In this case the electricity consumption of the circulation pumps as well to the solar thermal collector field or between buffer storages is included; on the thermal side as well the thermal gains of the solar collector field are considered. The SPF solar thermal and heat pump system is defined as:

$$SPF_{SAHPS} = \frac{\sum(Q_{HPtot}+Q_{EHtot}+Q_{Soltot})}{\sum(E_{HPtot}+E_{CPHeatSource}+E_{Vent}+E_{EH}+E_{CPSol})} \quad \text{(eq. 4)}$$

The cited definitions are of general kind and intend to explain the concept of the performance figures shown in the following chapter. As the single SAHPS show very different hydraulic schemes as well the performance figures vary slightly in their definition in the single publications. In the explanations' of the single systems the authors mention eventual variations.

4. Review of published monitoring results of installed systems

In the following chapter an overview will be given on published monitoring results of solar thermal and heat pump systems.

Heat pumps as energy units satisfying the heating demand, the domestic hot water demand and / or the cooling demand of buildings are becoming increasingly popular in Europe. Forsén M. and Nowak T. (2010) report within the Annual Outlook 2010 of the European Heat Pump Association an increase of sold units in 9 European countries from 250.000 units in 2005 to over 520.000 units in 2009, with a sales peak of over 580.000 units in 2008.

The combination of heat pumps with solar thermal systems lead to an increase of cost, size and complexity of the system assuring comfortable indoor conditions and the provision of domestic hot water. On the other hand such systems should lead to enhanced Seasonal Performance Factors of the overall system and to a reduction of the electrical energy consumption.

In the following as starting point for this review and as reference for the Solar thermal And Heat Pump Systems (SAHPS) some results of a large scale monitoring campaign carried out by Fraunhofer ISE in Germany are presented. Miara M. et al (2010) evaluated about 112 heat pump systems installed in Germany and monitored them within the time frame from July 2007 to June 2010. The measurement campaign includes results of 18 aerothermal heat pump systems and 56 geothermal heat pump systems. Within this second category 41 systems apply vertical boreholes while within 15 systems horizontal geothermal collectors are applied.
The measured ground source heat pump systems showed an average Seasonal Performance Factor of the heat pump system (SPF_{HPS}) of 3.9 (including results in the range from 3.1 to 5.1) while the aerothermal heat pumps showed an average SPF_{HPS} of 2.9 (including results in the range from 2.3 to 3.4).
The systems provided in this time frame thermal energy in order to satisfy the heating demand (responsible in average for 82% of the provided energy) and domestic hot water demand (responsible in average for 18% of the provided energy).

Included in this report are as well measurement results of heat pump systems assisted by solar thermal. The monitoring results of 2 solar thermal and geothermal heat pump systems and 4 solar thermal and aerothermal heat pump systems are shown.
The measured seasonal performance factor of the whole system including the electrical energy consumption and thermal energy gain of the solar thermal system (SPF_{SAHPS}) is between 4.9 and 6 for the geothermal heat pump systems and between 2.8 and 3.4 for the aerothermal heat pump systems. Detailed comments and explanations to these results can be found in the report.

V. Trillat-Berdal et al (2006) (2007) describe in their studies an installation coupling a solar thermal system and a heat pump connected with two vertical boreholes in order to cover heating and DHW demand of a new single family building in the Savoy region in Southern France. The installation was carried out within the project GEOSOL and monitoring results of the first year of operation are described.
The building has a surface of 180 m² and the envelope shows a heat transfer coefficient of U= 0,63 W/(m²K), 154 m² of radiant floors were implemented in order to keep a set temperature of 19°C during the heating

season, the heat pump has a thermal output power of 15.8 kW and is connected to two bore holes of 90m depth each, the solar thermal collector field has a size of 12 m² and consists of flat plate collectors, the collector field is connected to a DHW tank with 500 l volume which is equipped with an electric heater. There is no connection between the geothermal heat pump and the DHW tank. With regard to the classification shown in the first chapter, the present system can be described as geothermal system of serial and parallel type.
The system is implemented in such a way that the solar collector field heats up as first priority the domestic hot water tank. If DHW temperature setting is reached but further thermal energy is available from the collector field, this energy is injected in the boreholes contributing to the thermal balance of the ground.

Within the study the monitoring results of the winter season 2004 / 2005 are presented. Within this time frame the system satisfies the thermal need of the building leading to an SPF_{HP} of 3.75 and an SPF_{HPS} of 3.2. In the present case the SPF_{HPS} does not include the provision of domestic hot water, therefore as well the electrical energy consumption of the electric heater is not included. The solar gains through the solar thermal collector field are considered in an indirect way. In fact the solar thermal energy not requested for domestic hot water is injected in the boreholes. This energy flux amounted within the measured time frame for 2121 kWh (34% of the heat extracted from the boreholes), allowing to balance the ground load after the summer season.

B. Stojanovic and J. Akander (2010) give in their study an overview of the monitoring results of an experimental SAHPS set up in a test building in Sandviken (Sweden) within the European Project "EndoHousing". Within this project research installations where set up in Italy, Cyprus, Germany and Sweden. The test building in Sweden is a single family house from 1920 with limited thermal insulation and a high temperature heating distribution system (radiators). The roof is oriented east / west.
The building has been equipped within the project with a commercial heat pump (thermal output 8.4 kW), a ground heat exchanger (~52 m² ground heat exchanger area, placed horizontally at a depth of 1.5 m in the ground) used as well as seasonal heat storage and 42.5 m² prototype solar collector placed on the east slope of the building. The roof integrated unglazed solar thermal collector (named Endopanel) consists of extruded aluminum profiles with welded in / outlet pipes underneath. With regard to the classification shown in the first chapter, the present system can be described as geothermal system of serial type. As the building was not used during testing phase the consumption (heating and domestic hot water) where emulated. DHW was drained twice a day to resemble a daily energy consumption of ~14 kWh, while the system had to provide the necessary thermal energy to keep an indoor temperature of above +20°C. Within the study monitoring results of a period from February 2006 till February 2008 are reported; the evaluation focuses on the second year.

The monitored performance figures for this period are SPF_{HP}=2.8 and SPF_{SAHPS}=2.1, where the difference between the two figures are mainly explained through the electric energy consumption of the circulation pumps (CPs). A further feature of this installation is the utilization of the ground as seasonal energy storage. It is reported that the applied Ground Heat Exchanger (GHE) design "was not capable of extensive seasonal heat storage". Considering the unfavorable framework conditions the authors assess this first results positive and propose several measures in order to enhance the SPF_{SAHPS}.

M. Heppelmann et al (2006) report about the set up and run in of the German EndoHousing test site. The test site has been installed in the city of Soest in Germany. An office building constructed in the year 1999 has been used, where for the project the heating of the office and workers room has been applied. On the roof facing west a 15 m² unglazed collector has been installed of similar type as applied in the EndoHousing project in Sweden (see above). A heat pump with a thermal output of 6 kW is applied in order to supply heating and DHW and a electric heater is installed as back up. Two thermal storages were implemented, a cold storage with a volume of 160 l filled with glycol and a hot storage filled with water respectively before and after the heat pump. The space heating has been realized by warm air convectors except of one room where a radiant floor heating system is used. In this system no ground heat exchanger has been implemented. With regard to the classification shown in the first chapter, the present system applies solar thermal collectors as only heat source connected to two storages.

In the study only monitoring data of a few month are reported. Within the period of March 2006 the measured COP_{HP} varied between 3.2 and 6.7. The authors report of major problems of the system in cold day's. In fact in February 2006 when outside temperature dropped below -5°C the, the temperature in the cold water tank dropped below -8°C leading to a safety switch off of the heat pump for a period of time of 3000 s. In order to avoid this switching the authors propose an improved control strategy loading the two storages during day time in order to avoid such situations.

Wang X. et al (2010) present in their study the monitoring results of a one year measurement campaign of an installed solar thermal and heat pump system including vertical boreholes in Harbin (China). Harbin is located in a cold climatic area, in the measured winter 2008 / 2009 the average outdoor temperature was -7.6°C.
The experimental set up was installed in a new detached house with three stories. The total heating area is of 500 m², the external walls and roof were externally insulated with 150 mm polystyrene insulation boards while 30 mm boards of the same material were laid on the ground. The building is equipped with a radiant floor for heating and cooling purpose. The SAHPS is composed by a 50 m² solar thermal collector field applying "independently developed high efficiency flat plat collectors". The collectors are south oriented and mounted with a tilted angle of 60°. The ground heat exchanger consists of 12 boreholes, which are 50 m deep each and arranged in three rows with a minimum distance of 3.4 m between the single bore holes. The applied heat pump had a rated electrical input power of 3.7 kW.
The hydraulic scheme is of such type that the solar thermal energy can be used for direct heating, for regeneration of the boreholes and can be connected to the evaporator of the heat pump. With regard to the classification shown in the first chapter, the present system can be described as geothermal system of serial and parallel type. The experimental set up has been used for heating and cooling but not for the provision of DHW. In fact during the measurement period of April 2008 to April 2009 the building was not used, the indoor temperature was set to be at least 18°C, no internal loads were emulated.

The set temperature was mostly reached, only in the coldest day's with average outdoor temperature of -18.1°C the average indoor temperature was with 16.5°C, slightly below the set value. For the heating season a SPF_{HP} = 4.29 has been measured, while the SPF_{SAHPS} was in the same timeframe 6.55; This is due the fact that 49.7% of the total heating output was supplied directly by the solar thermal collector field. In the measured year the soil temperature at 50 m rose from 4.2°C to 7.2°C in the period from April to October, it decreased again to 4°C in January of the following year and from then it rose to around 6°C in April. These temperature where measured in an observation well, placed with 2.5 m distance from one row of the boreholes.

Ochs F. et (2011) report in their study monitoring and simulation results of a SAHPS applied in order to satisfy the heating and domestic hot water demand of a thermally very energy efficient (passive house) two family building in Austria. The building has a calculated heating demand of 15 kWh/m²y and includes a mechanical ventilation. The heat is distributed via radiant floors, on the roof are placed 10,2 m² of glazed flat plate collectors. A heat pump with a rated electrical input power of 4.8 kW and an electric direct back up heater (for DHW only) is installed. Key component of the system is the ground heat exchanger placed horizontal below the building. In order to save cost and enhance the construction is has actually been included in the base construction, which is mainly set up of the ground heat exchanger, isolation layer and concrete layer.
The hydraulic scheme is of such type that the solar thermal energy can be used for direct heating of the central storage and for regeneration of the borehole. With regard to the classification shown in the first chapter, the present system can be described as geothermal system of parallel and serial type.

The measurement results show an actual heating demand of 23 kWh/m²y within the year 2009 / 2010 and an energy demand for the DHW of a similar order of magnitude. The overall electricity demand for the ventilation, heating and DHW system is given with 16.7 kWh/m²y. The specific solar yield of the solar thermal collector field was 485 kWh/m²y, while the SPF_{HP} is reported with 3.1. This limited SPF_{HP} is commented with not optimally suited single components and the low ground temperatures, in fact the ground below the building even after the summer month did not reach temperatures above 22°C, similar temperatures have been measured as well in the undisturbed ground next to the building in the same time period. The seasonal storage effect is therefore regarded by the authors as very limited and actually the system is described as geothermal system with solar ground regeneration. The primary energy consumption of the system is given with 44 kWh/m²y and through the carried out simulations and optimization potential down to 32 kWh/m²y is estimated. This value is regarded as interesting low value but the system as quite complex with a significant risk of failures / not optimized control situations. It is highlighted that such low values are only possible if a very energy efficient building envelope is applied.

Thissen B. (2011) reports about a test installation in Switzerland where the monitoring started in March 2010. Within this test installation unglazed solar thermal collectors have been coupled to a commercial solar thermal and heat pump system which uses only solar thermal collectors as heat source and includes a latent (ice / water) storage. This system is commercially offered with glazed hybrid collectors. The test installation has been done in an energetically renovated single family house with a ground gross surface of 230 m². The overall measured heating demand is given with 11 MWh/year and the DHW demand with 1.5 MWh/year. A radiant wall heating system is applied for the heat distribution and 30 m² of the mentioned unglazed collectors where installed on a roof facing east + 10°, with a tilted angle of 22°. With regard to the classification shown in the first chapter, the present system applies solar thermal collectors as only heat source connected to two storages.

Within the period of 18th March 2010 and 23rd February 2011 the installed system showed an SPF_{SAHP} of 4.3. In the timeframe from May to October the heating and DHW demand could be covered completely by the solar thermal system and the heat pump did not switch on. In single days during the winter time, it can clearly be seen that the collector works as well as heat exchangers with collector fluid temperatures being significantly below outside air temperature. For example in the night of the 13th March 2010 the outside air temperature was -4°C while the collector fluid temperature was below -12°C.

Bertram E. et al (2011) report on a pilot installation realized on a single family house near Frankfurt (Germany). The system consists of 39 m² unglazed solar thermal photovoltaic collectors, 3 vertical ground heat exchangers with a debt of 75 m and a heat pump with a rated input power of 12 kW. The application of solar thermal photovoltaic collectors (PVT) is expected to have a benefit for thermal energy production by enhancing the source temperature of the heat pump and for the electrical energy production by reducing the temperature of the PV modules. In order to measure this second effect at the pilot installation not thermally connected reference PV modules have been installed. The hydraulic scheme seems of such type that the solar thermal energy can be used for regeneration of the boreholes. With regard to the classification shown in the first chapter, the present system can be described as geothermal system of serial type.

Within the measured period from March 2009 till April 2010 an enhanced electrical energy production of the PVT collector by 4% in comparison to the reference PV module has been measured. The SPF_{HPS} is given with 4.3 while the SPF_{SAHPS} is given with 4.0, the average brine temperature from the ground heat exchanger is given with 5.7°C.
A TRNSYS model has been realized by the authors in order to research the effect of the PVT collector on the average brine temperature, using the measured data of the installed system. According to the given explanations the average brine temperature is expected to be 2.3 °C, if no PVT collector would have been coupled to the geothermal heat pump systems; this difference results according to the authors in an electrical energy saving of 10%. Further details as well to the simulated long term behavior are given in the publication.

5. Conclusions

The target of the present paper was to give an overview on commercially available Solar thermal And Heat Pump Systems (SAHPS) and a review on published monitoring results from realized installations.

Regarding the market overview within the IEA SHC Task44 / HPP Annex 38 a list of 95 commercially presented SAHPS could be collected. These systems were collected including the elaboration of the "square view" diagram and of a unified hydraulic scheme of each system. Within these systems different additional thermal energy sources are used (geothermal, aerothermal, …) and they vary strongly regarding the degree of integration of the solar thermal and the heat pump system. Not to all systems detailed information's were available to the authors. Out of 80 collected systems, 46 SAHPS apply a "parallel" scheme of interconnection between the solar thermal and heat pump system. Again out of 80 systems 33 apply a geothermal heat source, 27 an aerothermal heat source and 12 systems use only the solar thermal collector as heat source. Within the rest of the systems water or exhaust air is used as low temperature heat source.

Regarding the practical experiences a field test monitoring of installed heat pump systems in Germany served as reference. Within this field test geothermal heat pump systems showed an average SPF_{HPS} of 3.9, while aerothermal heat pump systems showed an average SPF_{HPS} of 2.9. In the presented review monitoring results of 6 commercially and 7 experimentally installed solar thermal and heat pump systems could be cited. For solar thermal and geothermal heat pump systems the installations showed SPF_{SAHPS} in the range from 2.1 to 6.55. For solar thermal and aerothermal heat pump systems (including those systems where the solar collector is applied as well as heat exchanger with external air and represents the only heat source) the SPF_{SAHPS} were in the range from 2.8 to 4.3.

In most cases the installations of which detailed monitoring results have been published are individual installation's realized within scientific projects. Therefore a direct comparison between the commercially on the market presented systems and the available monitoring results are not possible. Nevertheless the cited results show that an enhancement of the SPF factor of the SAHPS is not always given in comparison to heat pump systems without a solar thermal system. In fact complex hydraulic schemes, not optimized hardware components and limited control strategies can strongly limit the overall systems performance. On the other hand, specific systems do show promising performance figures.

Further simulations, monitoring results of installed systems and specific test procedures for solar thermal and heat pump systems can support the clarification of which systems can show high performance figures under specific framework conditions.

6. Acknowledgments

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