SOLAR AND HEAT PUMP SYSTEMS

A new IEA SHC Task 44 & HPP Annex

And analysis of several combinations for a low energy house

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Abstract

Over the past few years, systems that combine solar thermal technology and heat pumps have been marketed to heat houses and produce domestic hot water. This new combination of technologies is a welcome advancement, but standards and norms are still required for its long term successful commercialization.

At this time, most of the manufacturers are developping systems without a clear framework of what could be the best combinations of the two worlds and customers are lacking comparative approaches. The result is that systems reaching today the market are far from being optimized and sometimes simple enough to guarantee a life time problem free and efficient operation both technically and economically.

What is needed is a systematic analysis of the different possible systems and their potential for application in different climates and under different boundary conditions. To begin to tackle this, the IEA Solar heating and cooling programme together with the Heat Pump Programme has initiated Task 44, "Solar and heat pump systems".

The scope of this new Task, which has begun in 2010, will be on the following items:

- Small-scale residential heating and cooling if needed and hot water systems that use heat pumps and any type of solar thermal collectors as the main components.
- Systems offered as one product from a system supplier/manufacturer and that are installed by an installer.
- Electrically driven heat pumps, but during the development of performance assessment methods thermally driven heat pumps will not be excluded.
- Market available solutions and advanced solutions (produced during the course of the Task).

The Task will work from 2010 to 2013 and will issue numerous publications and reports.

In this paper, we also compare several types of integration, from no integration to theoretical full integration. Theoretical seasonal performance factors and fraction of renewable energy are derived and compared for basic generic combinations of solar and heat pump.

Background

The solar thermal market is expanding since 2000 due to two factors: the near cost effectiveness of solar hot water preparation and the incentives and promotions in place in many European countries.

However reaching 100% solar is still a cost challenge. A good passive house in mid Europe can be almost 100% solar with about 30 m2 of collectors and 10 to 20 m3 of storage. The initial cost can reach 60 to 70’000 € for such a solution and it also deserves some space inside the house.

In most cases an auxiliary heating system will be needed.

It has become very popular to heat a house with a heat pump solution due to the promotion undertaken by electrical utilities since a few years and the willingness of consumers not to dependant upon fossil fuels. In some countries electricity is however produced by fossil fuels.

More and more customers are thus attracted by a heat pump solution combined with a solar installation at least for domestic hot water preparation.

Manufacturers have started to offer since a couple of years solution combining a heat pump and solar not only for hot water but also for heating purposes. Of course such combinations are more complex and need more control strategies and electronics. Therefore the optimisation of the combination is more complex and the cost effectiveness of the combination is not obvious.

Types of heat pumps can all kinds but the market is clearly oriented towards brine to water in ground coupled heat pumps and comes slowly more and more to air to water heat pumps since their performance, reliability and noise protection have improved over past years.

IEA Solar Heating and Cooling

The International Energy Agency has started the Solar Heating and Cooling programme since 1977. It has followed or lead the development of solar thermal market through a number of cooperative tasks that have confronted many new ideas within international groups of experts.

The SHC programme started its 44th Task at the beginning of 2010. The task is called “Solar and heat pump systems”.

IEA Heat pump programme

The IEA Heat pump programme has decided to jointly initiate the Task with the SHC programme. This gives the Task 44 group"annexe" status too, an a great opportunity to share solar knowledge with Heat pump experts and vice versa.

IEA Task 44 scope

The scope of this new Task, which will has begun in 2010, is on the following items:

- Small-scale residential heating and hot water systems that use heat pumps and any type of solar thermal collectors as the main components.
- Systems offered as one product from a system supplier/manufacturer and that are installed by an installer.
- Electrically driven heat pumps, but during the development of performance assessment methods thermally driven heat pumps will not be excluded.
- Market available solutions and advanced solutions (produced during the course of the Task).

To better focus on the current market demand, large scale systems i.e. systems using any type of district network or systems for large buildings are not directly included. Cooling of buildings is an important topic for south European countries and might be investigated with reversible heat pumps.

Large scale systems (more than 1 MW) are studied in another future IEA SHC Task.

IEA Task 44 organisation

Task 44 is divided into four Subtasks:

- Subtask A: Overview of solutions (existing, new) and generic systems, lead by Sebastian Herkel from Fraunhofer ISE of Stuttgart, Germany
- Subtask B: Performance assessment, lead by Ivan Malenkovic from the Austrian institute of technology (AIT), Vienna
- Subtask C: Modeling and simulation, lead by Chris Bales from the swedish energy research center of Borlange,
- Subtask D: Dissemination and market support, lead by Wolfram Sparber form the EURAC research center in Bolzano, Italy.

Like all IEA SHC Tasks, Task 44 meet twice a year during two days where experts report the status and progress of their work and discuss new method or tools for assessing and optimizing combinations of solar and heat pump.

Participants

The following countries have expressed interests in participating in the common work about solar and heat pump systems: Austria, Belgium. Canada, Denmark, France, Germany, Ireland, Italy, Spain, Sweden, Switzerland The Netherlands, USA.

From non integrated to full integrated systems

They are basically two kinds of systems that can be designed when having two heat producers which are depicted in figure 1.

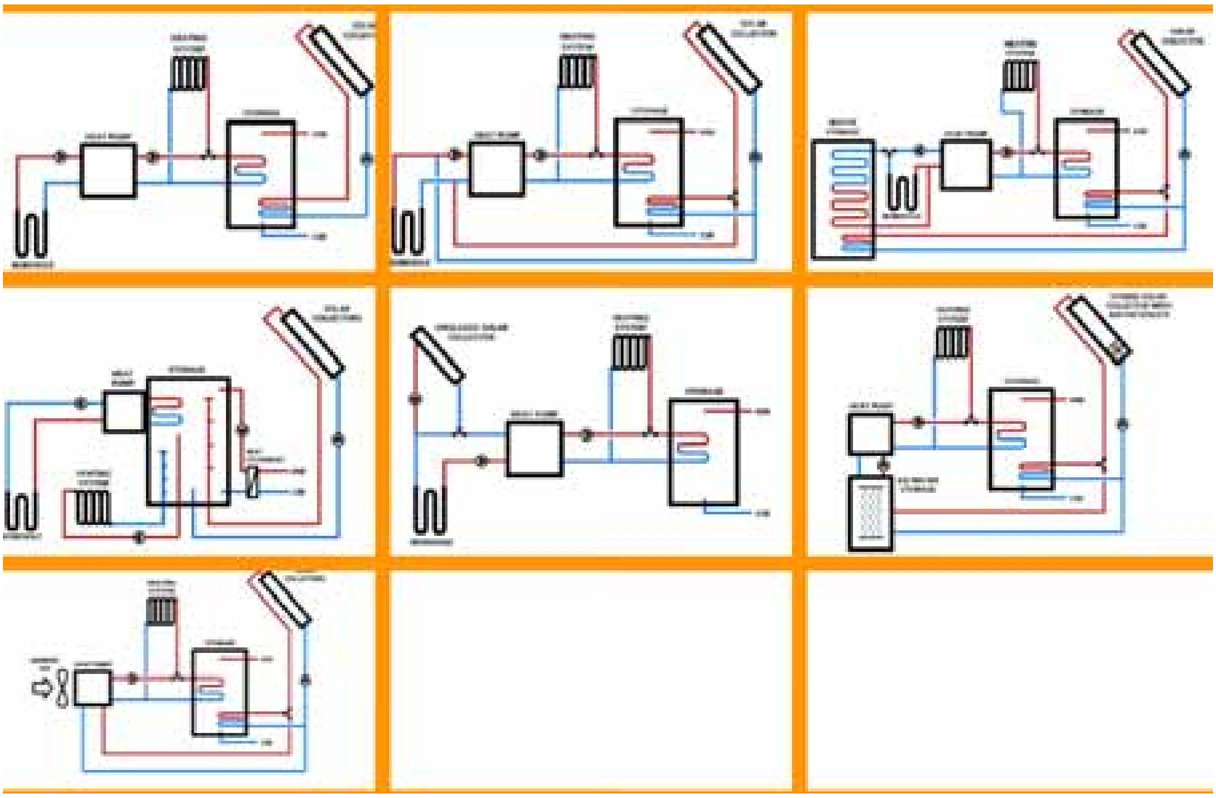

Figure 1: the seven generic systems identified by Task 44 (source: ISE 2010, 6)

A non integrated solution: basically the heat pump system does the heating and the back-up of the domestic hot water. The solar part is providing 60 to 70% of the hot water needs. The two producers interact only at the level of the DHW tank, the heat pump working for solar just as a gas or fuel boiler would as a back up.

A fully integrated system: the heart of the system is the heat pump but solar energy provides energy to the evaporator side of the heat pump, either through a storage tank or directly, and when possible to the DHW tank and/or to the heating distribution system.

Task 44 is working on a map of systems that represents the possible combinations between solar and a heat pump. Theses combinations have pros and cons that will be analyzed and they will be compared with a common framework (figure 1).

A Minergie house and several heating options

Apart from the common Task 44 work, let us compare 5 cases from non integrated to fully integrated to find out the limit of autonomy that could be reached. Please note than this analysis reflects the opinion of the author and was not issued by Task 44 experts. Task 44 will work on the chosen options and more to derive such an analysis for several climate.

We will consider a Minergie house having a floor area of 200 m2 . The total heat demand is at the most to be Minergie 38 kWh/m2 that is 7’600 kWh/a. DHW represents 17 kWh/m2 or 3’400 kWh/a. Notice that DHW is 45% of the heat demand and solar is a good solution for this reason.

<u>Option 1: a solar DHW small system and gas boiler</u>

A 6m2 solar installation with 400 l of storage tank will provide 80% of the DHW load in mid Europe with a productivity of 450 kWh/m2 a typical of a good flate plate collector (0.8, 3.0 W/m2 K).

The solar or “renewable” fraction is thus: 2’700 / 7’600 = 35%.

<u>Option 2: a heat pump only system</u>

Let us assume that the annual COP of the heat pump reaches 4.0, including the auxiliary pumps, which is claimed to be the case by many manufacturers leaflets but is not so often seen when a system is monitored !

The renewable fraction is thus: 3 / 4 = 75%, if we consider that the electricity for the heat pump is not produced by a renewable source.

<u>Option 3: Solar DHW and a heat pump, no integration</u>

With the same assumptions as before, solar will provide 2700 kWh/a and the rest will be covered by the heat pump that is 4’900 kWh with a COP of 4, or 1’225 kWh/a of electricity.

The “renewable” fraction is thus: (7600 – 1225) / 7600 = 83 %.

We can call it the SPF or seasonal performance factor, since it theoretically includes the auxiliary or parasitic energy for all 3 circulating pumps.

Option 4: Full integration

We will need more collectors say 12 m2 and 1000 l of storage which is a typical solar combisystem in mid Europe. Such a system can provide 300 kWh/m2 for DHW and heating, say in Geneva climate. Annual yield is thus 3'600 kWh from solar.

The heat pump still with a 4.0 annual COP will provide the remaining 4000 kWh and the SPF is thus: (3600 + 4000 * ¾) / 7600 = 87%

Option 5: Higher SPF ?

Is it possible to overtake this 87% ? 100% is not possible of course unless a PV installation is driving the heat pump. This is obvious but an expensive solution at present and this is not the scope of Task 44 that is looking for a generic solution. To do more that 87%, a bigger storage tank is presumably the solution, that could store some low temperature heat for the heat pump during cloudy days in winter. However more than 90% renewable will be hard to reach and in the cas of a ground coupled heat pump there will be a clear competition between the storage tank as the ground as "natural" storage. Therefore the cost might be a limiting factor.

What if a higher COP thanks to reloading the borehole ?

In the case of a ground coupled heat pump, there is some expectation that recharging the borehole with the solar collectors in summer or during sunny days in winter will bring higher SPF by providing a higher cold source temperature to the heat pump.

Table 1 (last column) shows that if COP (including auxiliary electricity for all circulation pumps) reaches 5.0 thanks to a global or more likely a local storage effect around the borehole due to a solar recharge, the SPF could reach 89%.

This COP of 5.0 might be reachable in theory, but our experience in several installations and many tests done in the 80s at Burgdorf on single borehole ground coupled heat pumps tells us that the recharge is likely to be marginal. Task 44 will bring more light on this question. It is of course not marginal for a group of boreholes where summer recharge might be mandatory. But these larger systems are not the main purpose of Task 44 which will focus primarily on family house solutions.

One step further is to compare the costs of each solution. This is done in Table 2 and it is shown that cost of delivered energy can reach 44.9 € cts/kWh according to our assumptions that are all visible in Table 1 and 2, compared to a 14.5 € cts/kWh for a current gas only solution. High SPF comes at a cost !

It can be concluded that probably either the air to water heat pump or a storage tank water or ice/water heat pump are the best solutions for an integrated combination with solar that definitively need a storage. But this of course has to be worked out in more details by Task 44.

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar DHW HP ground integration	Solar DHW HP ground enhanced COP
Solar								
Collector area	m2		6			6	12	12
Store volume	l		500			500	1'000	1'000
Productivity	kWh/m2 a		450			450	300	300
Heating contrib	kWh/a		0			0	900	900
DHW contrib	kWh/a		2'700			2'700	2'700	2'700
Total from solar	kWh/a		2'700			2'700	3'600	3'600
Heat pump								
Type			-	air/water	ground/water	ground/water	ground/water	ground/water
Power	kW			6	6	6	6	6
COP				3.5	4.0	4.0	4.0	5.0
Heating contrib	kWh/a		0	4'200	4'200	4'200	3'300	3'300
DHW contrib	kWh/a		0	3'400	3'400	700	700	700
Total from heat pump	kWh/a		0	7'600	7'600	4'900	4'000	4'000
Heating from source	kWh/a		0	3'000	3'150	3'150	2'475	2'640
DHW from source	kWh/a		0	2'429	2'550	525	525	560
Total from source	kWh/a		0	5'429	5'700	3'675	3'000	3'200
Auxiliary								
Power	kW	6	6					
Annual efficiency	%	80%	80%					
Heating contrib	kWh/a	4'200	4'200					
DHW contrib	kWh/a	3'400	700					
Total auxiliary	kWh/a	7'600	4'900					
Electricity								
Electricity for solar	kWh/a	0	72	0	0	72	144	144
Electricity for heat pump	kWh/a	-	-	2'171	1'900	1'225	1'000	800
Total electricity	kWh/a	0	72	2'171	1'900	1'297	1'144	944
Renewable energy performance								
SPF heating	%	0%	0%	71%	75%	75%	80%	84%
SPF DHW	%	0%	79%	71%	75%	95%	95%	96%
SPF overall	%	0%	36%	71%	75%	84%	87%	89%
Solar overall	%	0%	36%	0%	0%	36%	47%	47%

Table 1: Energy performances of several solutions “solar + heat pump” for a Minergie house

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar DHW HP ground integration	Solar DHW HP ground enhanced COP
Cost								
Solar	€		8'800			7'920	16'000	16'000
Auxiliary	€	6'000	6'000					
Heat pump	€	0	0	18'000	25'000	25'000	25'000	25'000
Total initial cost	€	6'000	14'800	18'000	25'000	32'920	41'000	41'000
Annuity	%/a	7.1%	7.1%	7.1%	7.1%	7.1%	7.1%	7.1%
Financial cost	€/a	426	1'051	1'278	1'775	2'337	2'911	2'911
Fuel	kWh/a	9'500	6'125					
Fuel cost	€ cts/kWh	5.0	5.0					
Cost of fuel	€/a	475	306					
Average cost of elect.	€ cts/kWh	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Electricity cost	€/a	0	8	239	209	143	126	104
Solar	€/a		100	0	0	80	120	120
Auxiliary	€/a	200	200	0	0	0	0	0
Heat pump	€/a			150	200	200	200	200
Total maintenance + insur.	€/a	200	300	150	200	280	320	320
Total annual cost	€/a	1'101	1'665	1'667	2'184	2'760	3'357	3'335
Cost of kWh heat	€ cts/a	14.5	21.9	21.9	28.7	36.3	44.2	43.9

Table 2: cost comparison of the options

Table 3 addresses the CO_2 emissions of the options. Of course the most “renewable” one produces the least CO_2 (755 kg/an vs 1957 kg for a 100% gas solution), which represents a 2.5 reduction factor. In other electricity production context with more renewables, this factor can be largely smaller.

System		Gas only	Solar DHW & gas boiler	Heat pump Air	Heat pump Ground	Solar DHW HP ground no integration	Solar DHW HP ground integration	Solar DHW HP ground enhanced COP
CO2 emissions								
from solar	kg/a	0	0	0	0	0	0	0
from auxiliary	kg/a	1'957	1'262					
from Heat pump UCPTE	kg/a	0	58	1'737	1'520	1'038	915	755
Total CO2	kg/a	1'957	1'319	1'737	1'520	1'038	915	755
in %		100%	67%	89%	78%	53%	47%	39%
Specific emission values								
gas	0.206	kg CO2/kWh						
UCPTE electricity	0.800	kg CO2/kWh						

Table 3: CO_2 emissions of the options in the framework of UCPTE electricity

Conclusion: Task 44 & Annex expectations

- The combination heat pump and solar will represent a large market share in future decades. In some regions, systems are already installed in 80% of new homes ! Task 44 will contribute to select best solutions either economically or in terms of best SPF.

- We have introduced in this paper one possible simple SPF definition. The Task 44 prenormative work will produce materials to define this SPF factor and to assess performances of combined systems. A common international definition of a SPF is currently lacking.

- An IEA framework provides a unique opportunity to meet and share with the experts from universities and industries working on thermal solar and heat pumps to exchange new ideas and to test them. We have at present 50 experts from 13 OECD countries part of the Task.

- Task 44 attracts top engineers and manufacturers of solar and/or heat pump solution for family houses and enhancements of existing systems can come out discussions.

- Models to simulate such any type of combination of solar and heat pumps will be available and the most common ones will probably appear in common tools like Polysun

- Future systems will be sketched and new ideas will emerge from the exchange of practice, knowledge and experience, as past IEA SHC Tasks did.

References

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