Practical experience of two small scale cooling plants and cost comparison to PV driven chillers

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Abstract

This work describes the measurement results and a cost analysis of two small scale solar thermal cooling plants located in Austria. All monitoring results refer to IEA SHC Task 38 level 3. The measurements were taken during the cooling period of summer 2009.

Most of the monitoring results are not as high as expected; especially the electrical coefficient of performance (COP) could not reach the estimated values. The highest total monthly electrical COP of plant 1 could only reach a value of 1.87. For plant 2 an average electrical COPs of 3.09 were measured between August and September 2009.

A cost comparison between the two solar thermal cooling plants and photovoltaic (PV) driven compression chillers was accomplished. The results show 4 to 7 times higher cold production costs (€/kWh) of the solar thermal plants compared to the PV driven systems and even 11 to 19 times higher production costs compared to the conventional compression chiller variant.

These facts show that the economical performances of these two solar thermal systems in Austria are currently not competitive to other cooling systems.

1. Introduction

The two solar thermal cooling plants are monitored and analyzed following the monitoring procedure of IEA SHC Task 38 level 3. Main results of this method are Energy fluxes, total electrical consumption, thermal and electrical COPs and Primary Energy Ratio.

The first system (plant 1) includes a 17.6 kW absorption cooling machine running with lithium-bromide, a 2'000 litre hot storage and 57.6 m^2 flat-plate collectors. Bypassing the absorption chiller and just using the cooling tower for free cooling can be realised. There is no backup for the cooling task installed. The cold water is distributed through radiant ceilings in order to cool the 573.5 m^2 office area.

Plant 2 is a retrofitting to an existing solar heating system and was realised in 2007. The cooling load is supplied to an office building. The solar cooling system has no conventional backup. It includes a 12 kW ammonia water absorption chiller and three 1'500 litre hot storage tanks. The flat-plate collectors (46m^2) are partly façade integrated partly mounted on the ground.

2. Practical Experience and Monitoring Results

During summer 2009 practical experience was made with these two small scale solar thermal cooling plants. Each component fulfils its function, but the assembled systems have significant technical difficulties to reach the expectations. The most important results are shown in Table 1.

Table 1: Calculated results of the solar thermal cooling plants

	electrical COP	thermal COP	time period
plant 1	1.8	0.6	Aug.2009-May2010
plant 2	3.2	0.55	Aug.2009-May2010

2.1. Plant 1

From July to September 2009 a thermal coefficient of performance of 0.6 was obtained. About 1/3 of the cooling demand was delivered by free cooling and 2/3 by solar thermal cooling. The electrical coefficient of performance for free cooling (COPelec) was 1.8 and for solar cooling 1.6. The entire coefficient of performance of the whole cooling period was approximately 1.8 and between Oct. 09 and April 10 about 8.2 for free cooling. No solar thermal cooling was obtained in winter time.
The whole system is running reliable but with a poor overall performance. Especially the electrical consumption is very high. The chiller was running very reliable throughout the whole summer. The chiller reaches the expected power level and an adequate COP. Free cooling mode is activated mainly in night times but runs with poor efficiency. The highest electrical loads, 75% of the whole electrical consumption, are needed by cooling tower and pump. A reduction in electrical consumption can be achieved by installation of a speed-regulated fan, improvements of the control system and by small changes of the hydraulics.

2.2. Plant 2

Between August, 21st and September, 30th a thermal COP of 0.565 could be reached. At the same time the electrical COP ranged from 0.5 to 5 and achieved an average value of 3.1. In the period between the 11th and 18th of September no results were monitored due to a data processing problem of the computer system.
When the plant was running, it worked as expected. Nevertheless the average values over a longer time period are still improvable. In the beginning of the cooling season cycling problems did occur due to the low volume flow of the solar cycle, therefore the mode was changed to maximum speed. Now the solar pumps are working in summer times without rpm-regulation.
During the monitoring period some problems with the measurement and control system occurred. The wet cooling tower worked very well. At a glance the PSC12 Pink chiller fulfilled the promised thermal COPs at the different driving, cooling and recooling temperatures. Considering the other parts of the system, such as the heating of the swimming pool, the hot storages or the district heat the complete hydraulic scheme seems to be overloaded and not clearly arranged.

Following suggestions are made to improve this solar thermal cooling plant:

- adapting the control system in order to make clear division between heating and cooling periods
- including the cooling cycle in the DHW priority rule to shut off the absorption chiller when DHW is tapped and avoid a short circuit in the cooling circuit
- to match the inertia system and to use the concrete core activation properly the control system should include a time delay or a dead band to shut off the cooling circuit
- rising the starting temperature in the control strategy to avoid a cycling behaviour of the chiller

2. Cost comparison

2.1. Structured boundary conditions and assumptions

PV driven solar cooling plants are compared to these two existing plants, where most of the data is known (e.g. investment- and operation costs). Therefore the PV solar cooling plant is dimensioned in a way, to produce the same cooling load as the two plants. Ongoing a sensitivity analysis will be shown in order to find crucial assumed parameters.

The price of photovoltaic systems decreased approximately 37% from the beginning of 2006 until the fourth quarter of 2009 with a strong downward trend in the last four quarters. Similar numbers are shown for Austria in [1]. The prices include the PV-modules, the inverter, miscellaneous components as well as the planning and installation on site.

The system boundary for the cost comparison is shown in Figure 1. Inside this boundary all components, which are related to the cold production, are taken into account. The distribution system is not included in the comparison. Neither costs of monitoring as installed in the current plants are included. All prices are overall gross prices including all taxes, dues, insurance, planning and installation costs.

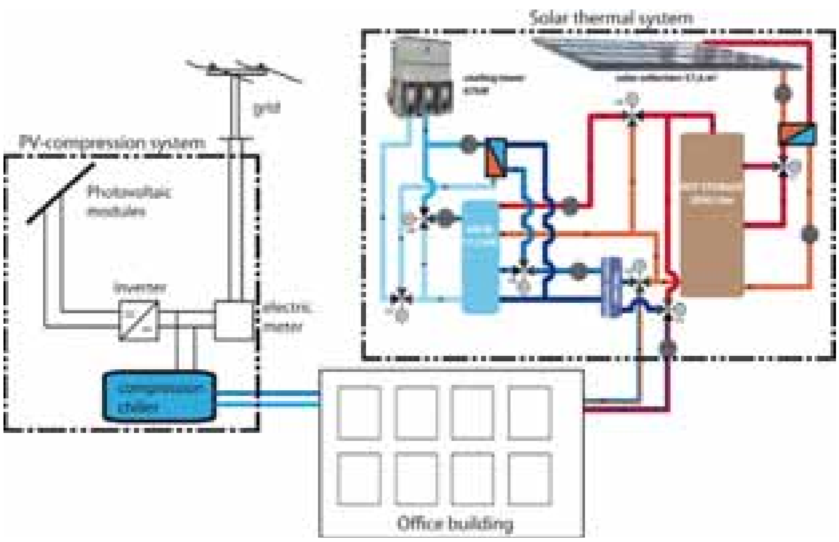

Fig. 1. System Boundary for thermal and PV driven plants

The analysis is based on the annuity method assuming that the plant is financed through a private loan. All the plant specific gaining such as extra produced electricity in the case of the PV driven system or the useful solar heat for space heating (SH) or domestic hot water (DHW) at the solar thermal plant are subtracted from the operating costs. No governmental subsidizes are included. The feed-in tariffs are equal to electricity costs, no investment subsidies are considered. Neither, needed roof area for the collectors nor installation spaces for the plants are taken into account but are compared and discussed.

The used values related to the solar thermal plants are taken out of the measurements from summer 2009. For the PV plant up-to-date costs and yield values were collected [1].

2.2. Solar thermal cooling plants

Table 2 summarizes the assumptions of the two solar thermal plants. The assumed thermal COPs are average expected values for the next summer after optimization of the system. Also the electrical COPs are expected values for the oncoming summer (2010). These values are linked to the existing plants and refer to the practically experiences of the Task 38 members [7].

Table 2. Boundary conditions and assumptions for the solar thermal systems

Solar thermal cooling	**Plant 1**	**Plant 2**	**Units**	**References**
Absorption chiller power	17.6	12	kW_{cold}	-
Solar collectors area	58	46	m²	-
Thermal COP	0.63	0.6	-	-
Electrical COP	5	5	-	-
Rate of interest	5	5	%	-
Term of the loan	15	15	a	-
Ø district heat prize	0.0918	0.0918	€	[2]
Maintenance costs	30	30	€/month	[1]
Electricity tariff	0.1507	0.1507	€	[3]

2.3. Photovoltaic solar cooling plants

Table 3 shows the assumptions and boundary conditions for the photovoltaic based system. The PV area and power values are calculated in order to reach at least the same cooling load as the solar thermal cooling plant. The rated COP of the compression chiller is assumed with 2.8 following the IEA Task 38 [4] taking part loads and practical conditions into consideration.

Table 3. Boundary conditions and assumptions of the PV-compression chiller systems

PV-compression cooling	Plant 1	Plant 2	Units	Reference
Compression chiller power	17	12	kW_{cold}	-
PV-panels area	58.5	40.5	m²	-
Power PV-panels	6.5	5	kW_{peak}	-
Chiller COP	2.8	2.8	-	[4]
Maintenance costs	22	17	€/month	[1]
Investment costs PV	3915.6		€/kW_{peak}	[1]
Investment costs Chiller	300		€/kW_{cold}	[5]

2.4 general assumptions

Measured results of the two small-scale solar cooling plants are implemented into the cost comparison. The calculation of the cost is done on a monthly basis, investment costs are calculated with the annuity method.

By definition the cooling system is working between May and September. In the heating season the solar plants are used either to support the SH and DHW production or to produce electricity in case of the photovoltaic panels. The monthly usable solar heat, which is not used for cooling, is calculated as heat revenue. Equally additionally produced electricity is calculated as electricity revenue. The auxiliary electricity costs of the solar thermal cooling plants are calculated through the electrical COP of the plant and the electricity tariff. In times were the cooling plant is not working an auxiliary electricity consumption of 5% of the produced usable heat was assumed for the solar plant.

3. Results and sensitivity analysis

For plant 1 cold production costs of 2.57 €/kWh_{cold} were calculated. Plant 2 has cold production costs of 1.48 €/kWh_{cold}. This difference results out of the diversity of initial investment costs. All results are compared and shown in Figure 2.

The specific average photovoltaic yield for Germany between 2004 and 2009 [6] was assumed as a pessimistic yield for the PV panels. The compression chiller was dimensioned for the same cooling power as the absorption chiller. For the PV driven compression cooling system at plant 1 cold production costs of 0.38 €/kWh were calculated. The PV variant at plant 2 reaches nearly the same price with the smaller plant. Figure 2 illustrates the annual cold production costs for the two monitored systems compared with PV-driven and conventional cooling systems.

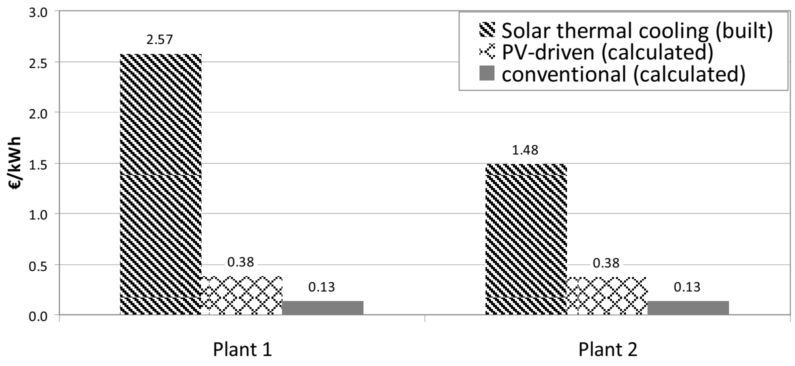

Fig. 2. Cold production costs for the two monitored systems compared with PV driven and conventional cooling systems

The results show huge cost differences between the solar thermal and the other two cooling systems. In case of plant 2 the solar thermal produced kWh_{cold} costs nearly 4 times more than the kWh_{cold} produced with the PV driven solar cooling system. The cold productions costs are approximately 11 times higher for solar thermal cooling system compared to the conventional compression cooling system. The conventional cooling costs in this figure were calculated with the same boundary conditions as the PV driven compression chiller, excluding the photovoltaic costs and revenues. Figure 2 shows that the first generation of small scale solar thermal cooling plants in Austria are not economically competitive to comparable renewable cooling technologies such as the PV driven compression chiller systems.

The next two figures (Figure 3 and 4) show a cost-sensitivity analysis of the solar thermal and the PV driven cooling plant for plant 2. Initial points of this sensitivity analysis are real variables including relatively high investment costs and poor specific solar gains including storage losses.

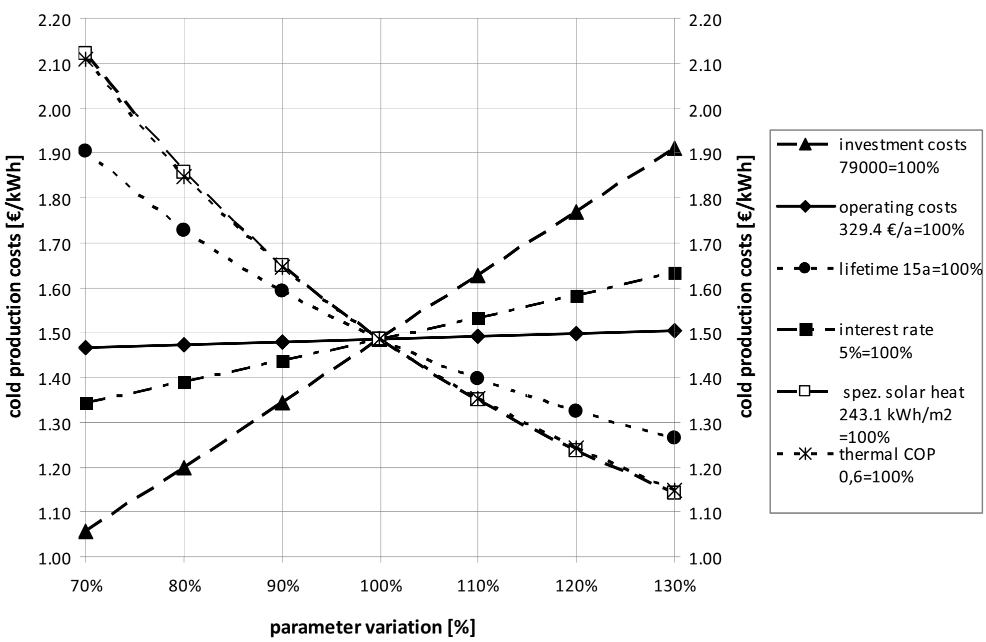

Fig. 3. Parameter variation analysis of the solar thermal cost calculation of plant 2

For the solar thermal part the specific usable solar heat, the thermal COP of the absorption chiller and the investment costs are the most important values. The operating costs and the interest rate have hardly any influence to the cold production costs. All sensitive parameters are measured or known values. Therefore the calculation can be rated as quite feasible.

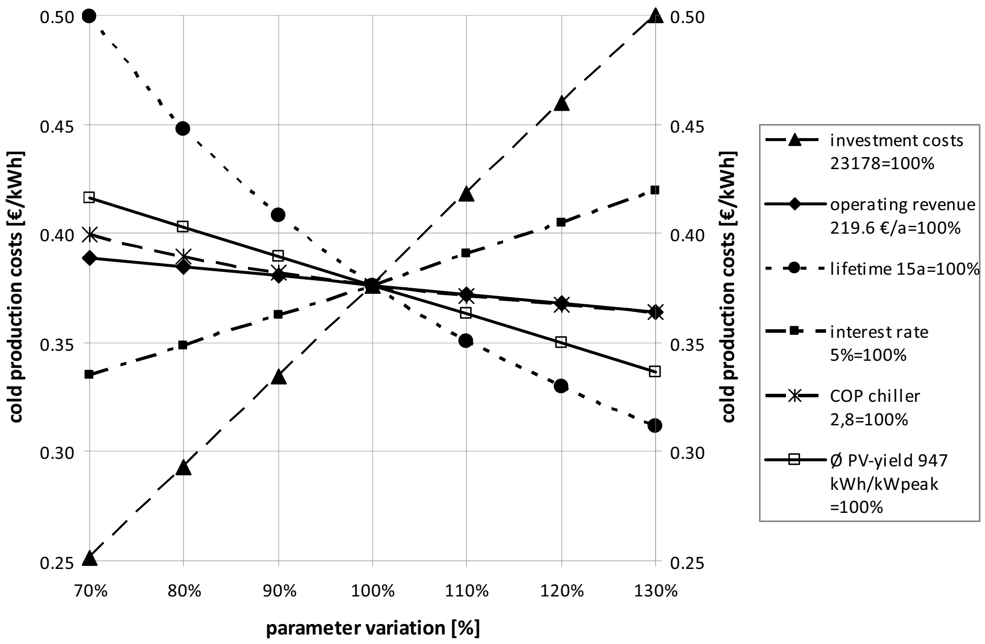

Fig. 4. Parameter variation analysis of the PV-driven cost calculation at plant 2

In case of the PV driven system the most influencing parameters are investment costs and lifetime. The same lifetime has been chosen for all variants so it has no influence to the comparison. The investment costs are assumed based on profound source values but should be taken with caution because of the extensive mounting system at plant 2.

The sensitivity analysis shows that low system losses and therefore higher specific usable solar heat, as well as higher thermal COPs, are crucial for solar thermal cooling plants. In this work only results of the parameter variation of plant 2 are shown. The variations of the plant 1 parameters show similar result.

5. Conclusion

Both plants were running reliable within the monitoring period started in August 2009 up to now. Nevertheless, the overall performance is quite poor mainly due to mistakes in hydraulics, design and control systems. The plants show a huge potential for optimization:

- coordinate design with focus on electrical consumption and high useable solar gains
- optimization of the hydraulic systems
- advanced control systems

The main assumptions for the cost comparison were not including any governmental subsidies, a lifetime of 15 years for both plants, a rate of interest of 5 %, a COP of the compression chiller of 2.8, an electricity tariff of 0.15 €/kWh, district heat cost of 0.09 €/kWh and assumed maintenance costs between 17 and 30 €/month. On the basis of the average consumer price the investment cost for the PV modules were calculated. The results show 4 to 7 times higher cold production costs (€/kWh) of the solar thermal plants compared to the PV driven systems and even 11 to 19 times higher production costs compared to the conventional compression chiller variant. In Figure 3 and 4 results of the parameter variation are shown for plant 2. The most important parameters are the investment costs, the solar yield as well as the thermal COP of the absorption chiller.

The cost comparison shows that the economical performances of these two solar thermal systems in Austria are not competitive to other cooling systems. Taking into account the high optimisation potential of both plants and the high investment costs general statements are only valid for the trends of the crucial parameters. For more general statements this cost comparison should be done with various and more advanced plants. . In case of bigger systems cost reduction and rising competitive capability can be expected.

The two plants will be monitored during this summer (2010). Therefore the implementation of the suggested changes, as well as the further monitoring of both plants, is important. Within a national Austrian Solar Cooling project (SolarCoolingMonitor), which started in November 2009, the two plants will be simulated in order to compute possible physical changes of the plants. A comparison and systematic analysis of the monitoring results measured last summer to the ones of this summer will bring more detailed results in order to estimate further improvement and optimization potentials.

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