SOLAR HEATING AND COOLING FOR THE SOLAR CITY GLEISDORF

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Abstract: The „Solar City Gleisdorf“ decided to realize an innovative energy concept when renovating the old town hall and building a new Service Centre. In co-operation with the EU project HighCombi a system for „Solar Heating and Cooling“ was designed and finally constructed in 2008. In the new built Service Centre the technical room is situated to supply both buildings with domestic hot water, space heating energy and cold water for cooling. Cold water is produced by an absorption chiller which is powered by a solar thermal collector and a natural gas boiler. Additionally the new built Service Centre is equipped with a “Desiccant Evaporative Cooling” (DEC) system in combination with the air ventilation system. The main key figures of the solar heating and cooling system are:

Collector area: 304 m^2 (new developed high temperature collectors)
Heat store: 4600 Litre
Absorption chiller: 35 kW
DEC - Air flow rate: 6250 m^3/h; ca. 35 kW nominal cooling power

A detailed monitoring concept is integrated into the controller which allows to evaluate all heat flows, electricity flows, water consumption and of course all temperatures and relative humidity in the system and the building.

First year of monitoring shows good results of the solar heating part with electrical SPF_{el} (seasonal performance factor) of up to 82 kWh_{therm}/kWh_{el}, heat losses of the heat store between 4 and 25% and acceptable results of the single components like the absorption chiller and the DEC system during steady state conditions. Quite big potentials for improvements exist in optimizing the overall control strategy of the building in cooperation with the heat/cold delivery system and reduction of parasitic electricity consumption, especially for water treatment.

Keywords: Solar Cooling, Solar Heating, Absorption Chiller, DEC System

1. INTRODUCTION

The „Solar City Gleisdorf“ decided to renovate the old Town hall and to build a new Service Centre (Fig.) as a „light house project“ demonstrating the implementation of renewable energy sources by means of solar thermal driven heating and cooling technologies. This project finally was realized as part of the EC project „HighCombi“.

Both buildings are supplied with heat and cold for space heating, domestic hot water and cooling from a central technical room placed in the ground floor of the Service Centre. Additionally a “Desiccant Evaporative Cooling” (DEC) system in combination with the air ventilation system was installed for the Service Centre.

In fig.2 the energy concept is shown.

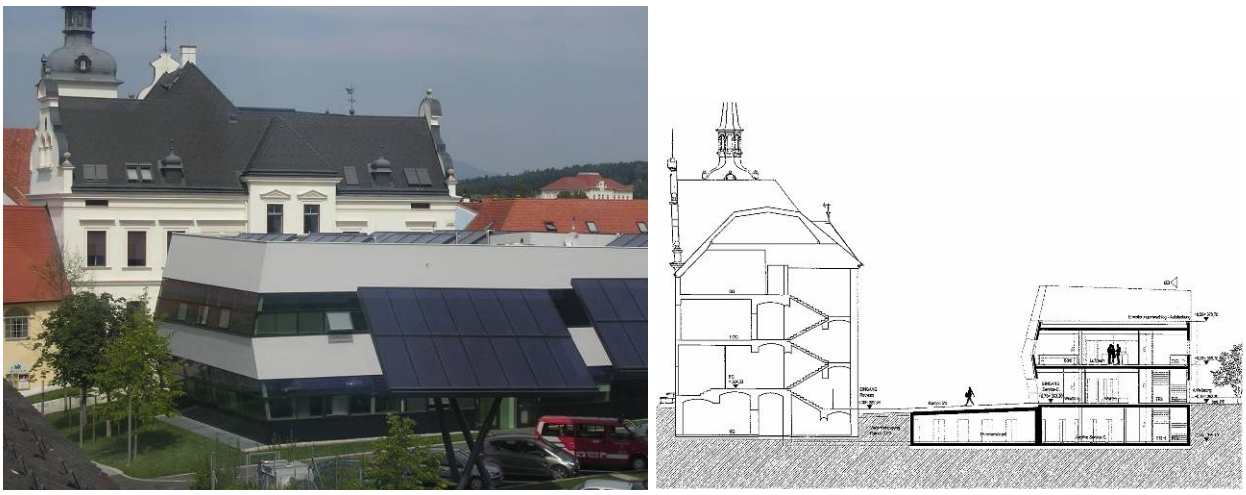

Fig. 1. Photo and section drawing of the old renovated Town Hall and the new built Service Centre

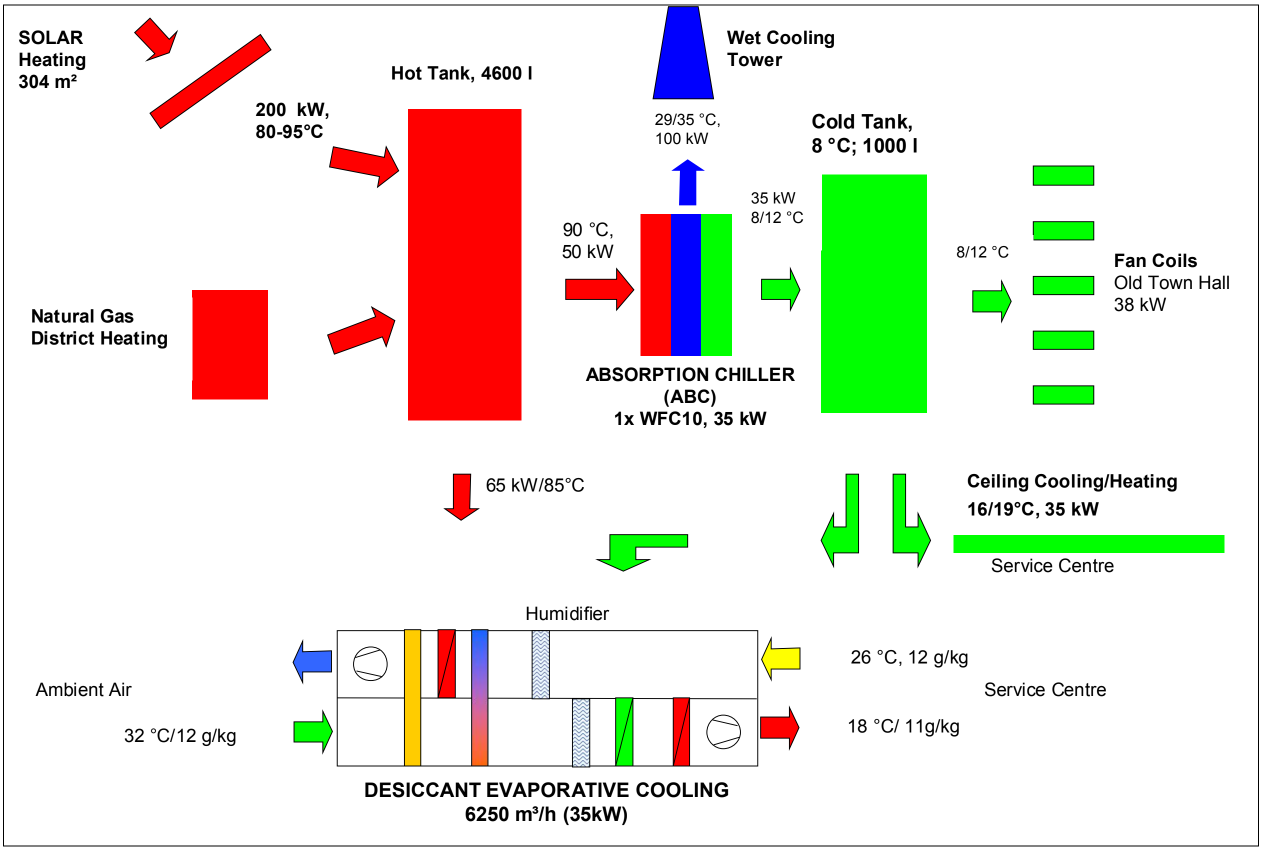

Fig. 2. Energy flow scheme of the entire system

Table 1. Key data of this project:

	Town Hall:	Service Centre:
Space:	1.321 m^2	1.212 m^2
Volume:	4.599 m^3	3.562 m^3
Persons:	ca. 25	ca. 25
Heating load:	94 kW	31 kW
Heating demand:	109.000 kWh/a	33.000 kWh/a
Cooling load:	38 kW	24 kW
Cooling demand:	29.000 kWh/a	42.000 kWh/a
Air ventilation:	windows	air handling unit (heat recovery=80%)

Table 2. Main components are dimensioned as following:

Collector area:	304 m^2 (gross collector area)
Stores:	4600 Litre (hot) and 1000 Litre (cold)
Absorption chiller:	35 kW nominal cooling power (Yazaki WFC-SC10)
Cooling tower:	Baltimore FXT 27, wet cooling tower; 100 kW nominal power
Air flow rate:	6250 m^3/h; ca. 35 kW nominal cooling power

The collectors installed on the roof of the Service Centre are 134 m^2 (Tilt angle: 20°, Azimuth: 30° W) of special high temperature flat plate collectors with integrated teflon foils. The remaining collectors were installed in August 2009 on extra designed "Solar Trees" (Tilt angle: 30°, Azimuth: 30° E), see fig.3. Due to the different orientation (30° E and 30° W) solar energy can be gained more equal during the day and in combination with an advanced control concept the quite small hot storage tank (4.6 m^3) hopefully will not be overheated.

The entire project (except the solar trees) was set in operation in July 2008. During summer 2008 the control system was adapted and the monitoring equipment was installed. Since October 2008 monitoring data are available, even though it was necessary to adapt and fine-tune the monitoring equipment until end of the year 2008.

Fig. 3. The entire project with solar thermal collectors mounted on „solar trees“ in front of the service center facing east and solar thermal collectors mounted on the roof facing west

2. SOLAR HEATING SYSTEM

The first part of the solar heating system with the special high temperature collectors could be evaluated during winter and summer operation as well. In fig.2 a typical winter day (February 2nd, 2009) is shown. At 13:20 solar irradiation was about 690 W/m^2, ambient temperature was 9°C, average collector temperature was 62°C (11 K temperature difference between flow (T_Solar_primär_VL) and return (T_Solar_primär_RL) flow) and the measured power was 47 kW (at secondary side in the water circuit). This results in an efficiency of about 53% of the complete solar thermal primary loop including all pipe losses and heat exchanger losses. According to the data sheet the collector efficiency itself at this operating point is 58%.

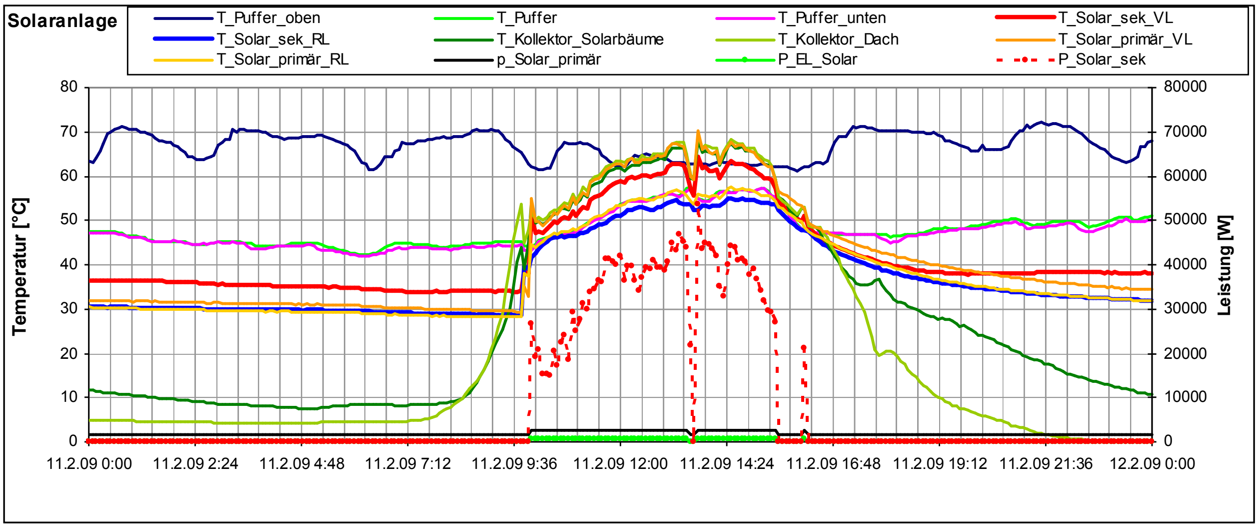

Fig. 4. Temperature and heat capacity (P_Solar_sek) of the solar thermal system on Feb 11th, 2009

In fig.5 an operating point on June 19th, 2009 at 13:00 (maximum irradiation) is evaluated. Solar irradiation was 950 W/m^2, ambient temperature was 32°C, average collector temperature was 80°C (15 K temperature difference between flow (T_Solar_primär_VL) and return (T_Solar_primär_RL) flow) and the measured power was 72 kW (at secondary side in the water circuit). This results in an efficiency of about 59% of the complete solar thermal primary loop including all pipe losses and heat exchanger losses. According to the data sheet the collector efficiency itself at this operating point is 65%.

For the electrical SPF_{el} of the solar circuit including the 2 pumps during the months October 2008 until September 2009 monthly values of 56, 36, 25, 29, 52, 62, 63, 71, 74, 82, 76 and 74 kWh_{th}/kWh_{el} and for the full year 67 were measured. The efficiency of the heat store within the same period was calculated based on the energy balance and resulted in monthly values between 75% and 96%, in average 91% for the full 12 month period.

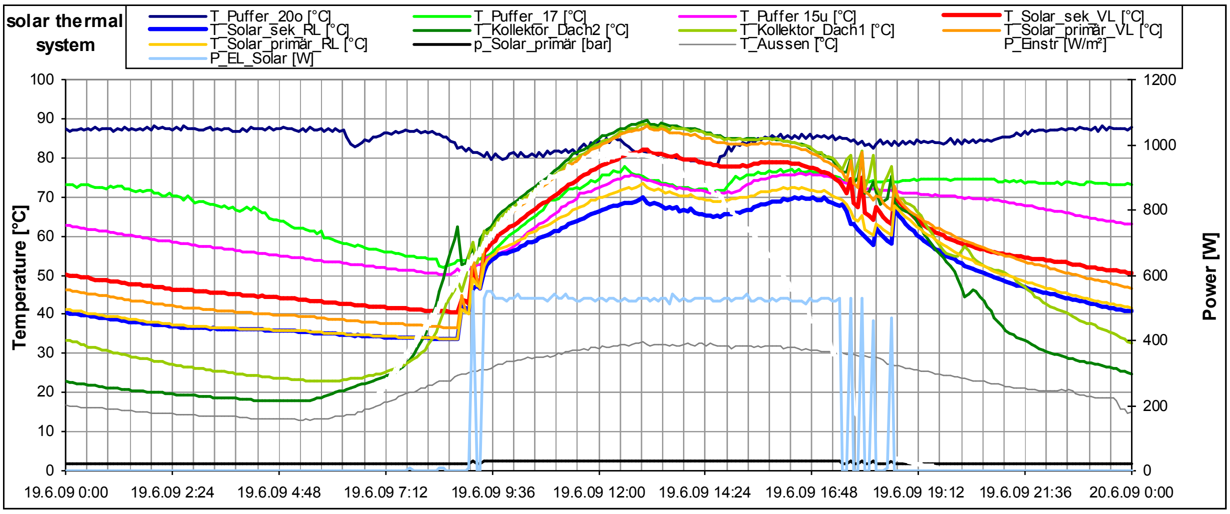

Fig. 5. Temperature and solar irradiation (P_Einstr) of the solar thermal system on June 19th, 2009

3. INTEGRATION OF AUXILIARY HEATER

The auxiliary heater in this project consists of three natural gas boilers, which are situated in a third building just beside the town hall. These boilers are connected to the heat storage with a short district heating network. One of those three boilers is a condensing natural gas boiler which should receive as low as possible return temperatures to be able to condensate. The auxiliary heater is able to charge the top 2000 Litre of the heat store.

Fig.6 shows the return temperature (T_FW_RL_prim) in the primary circuit of the auxiliary heater which is fluctuating at around 60°C, even though the temperature in the heat store below the height of the return pipe (T_Puffer and T_Puffer_unten) most of the time is around 45 to 50°C. A more advanced control strategy should be able to "hand over" this low temperature in the tank to the condensing natural gas boiler in order to allow condensation for which return temperatures far below 55°C are necessary.

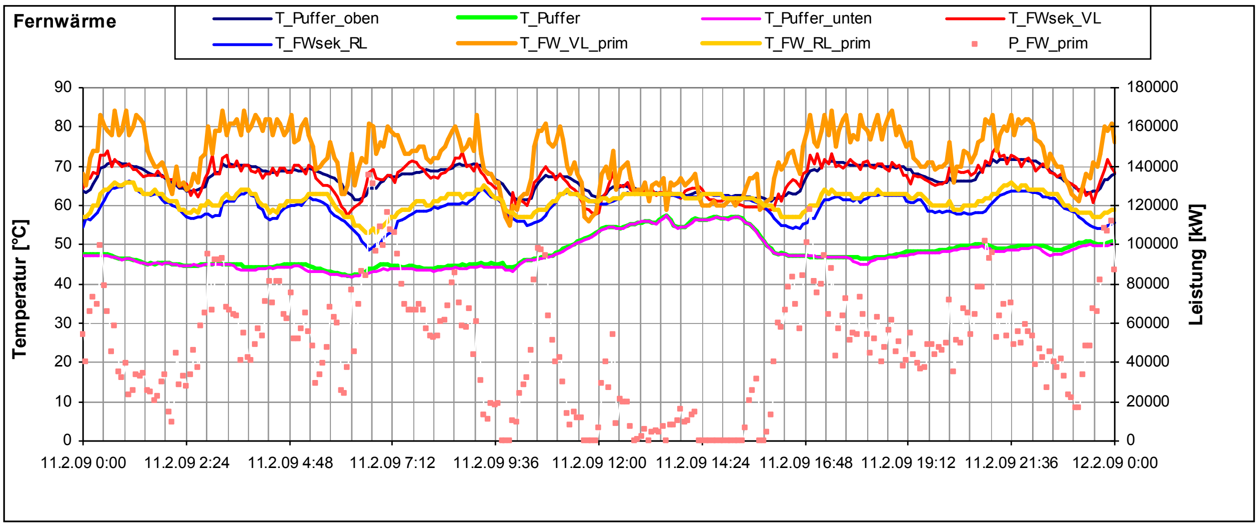

Fig. 6. Temperatures and heat capacity (P_FW_prim) of the hot store and the auxiliary heater on February 11th, 2009

4. HEAT DISTRIBUTION

In fig.7 the temperatures in the heat distribution net is shown. The ceiling heating elements (T_DHzg_VL/RL) have quite low return temperatures in the range of 35°C which is fine for solar thermal heating. Return temperatures of the radiators in the old Town Hall (T_Hzg_RH_RL) and of the radiators in the new Service Centre (T_HK_RL) are at a temperature level of acceptable 40 to 50°C.

In the new built Service Centre unfortunately some additional "high temperature" heating elements were installed directly below the windows in order to avoid condensation at the windows. These heating elements (T_Fenstertr_RL/VL) are operated at a temperature level between 50 and 60°C, which is much too high for efficient solar heating. Most likely this is caused by too low inlet air temperature of the air ventilation system and these window heating elements are used for compensation.

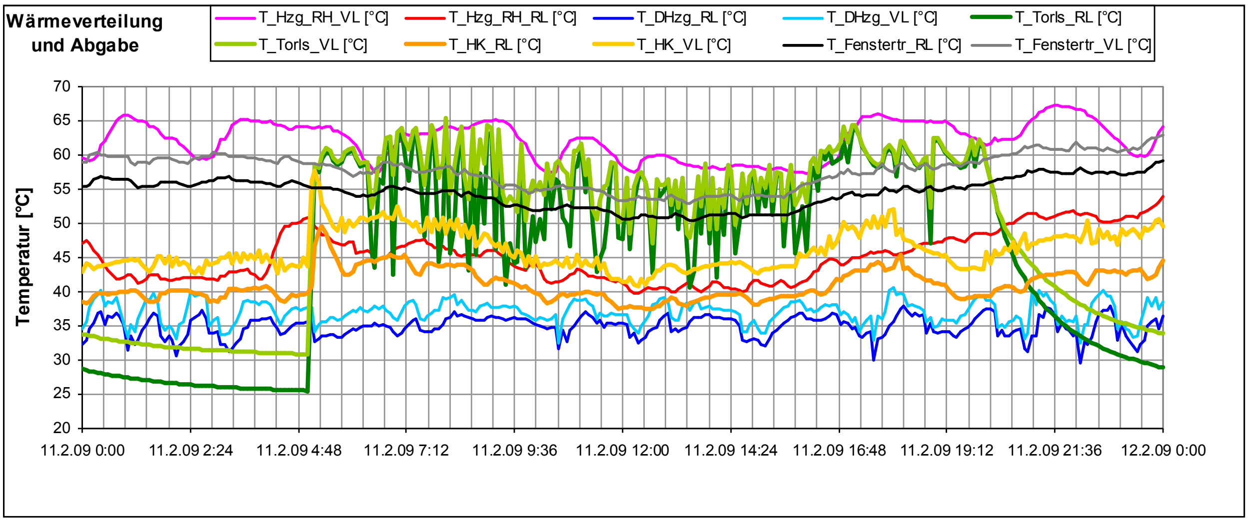

Fig. 7. Temperatures of the heat distribution system on February 11th, 2009

5. ABSORPTION CHILLER

In fig.8 a screenshot of the absorption chiller is shown during typical steady state operating conditions. Generator heating circuit is operated with relative low flow rate resulting in a temperature difference of about 9K (5K is recommended) but with the advantage of reduced electricity consumption for the pump. According to the Yazaki datasheet 60% of the nominal flow rate causes only a reduction of 10 to 15% of cooling power. Cooling water from the cooling tower is mixed up to about 29°C in order to avoid crystallization of the liquid lithium-chloride. Temperature difference in the cold water circuit is about 6K, which is according to the design data. As it can be seen in the screenshot all pumps are operated with fixed flow rates, just the fan of the wet cooling tower is speed controlled.

In fig.9 and fig.10 the evolution of temperatures, heat capacities, electricity consumption and water consumption of the absorption chiller is shown for June 18th, 2009. Most of the time the chiller is operating in a quite unstable "stop and go" mode. The reason for that is that if the minimum cold water temperature of 6.5°C is reached, the chiller itself is internally switching of for a while in order to avoid freezing of the water. After increasing of cold water temperature to more than 11°C, the chiller starts cooling again. At about 14:00 the chiller is switching off because the minimum generator temperature of 79°C (T_Hzg_VL_55) is not available anymore. After about 30 minutes the available temperature increased and the chiller started again.

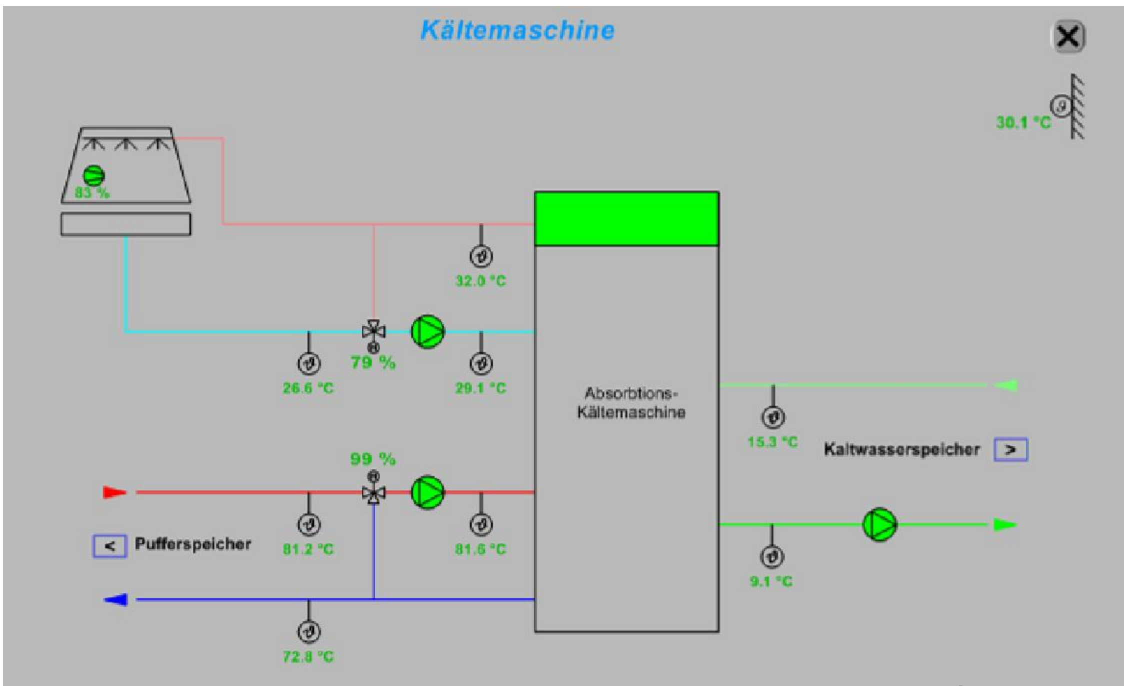

Fig. 8. Screenshot of the absorption chiller and wet cooling tower on July 30th, 2009

Steady state operation in fig.10 shows between 17:00 and 18:00 constant cooling power of the chiller (P_AKM_Kälte) of about 23 kW powered with about 50 kW (P_AKM_Austr) resulting in a thermal COP_{therm} (coefficient of performance) of about 0.46. According to the data sheet and the operating curves of this chiller the power under these operating conditions (generator: 84/74°C; back cooling: 29/32°C; cold water: 8/13°C; generator flow rate about 50% of nominal flow rate) should be about 25 to 27 kW. This shows that the chiller is working as it should, but the overall control strategy seems to have quite some potential for improvements.

Further analyzing the steady state operation at about 18:00 shows that the consumed electricity power of the absorption chiller including generator and cold water pump is about 0.72 kW (P_EL_AKM) and of the wet cooling tower including fan and pump is about 2.35 kW (P_EL_Kühlturm), in total 3.05 kW. This results in an electrical COP_{el} of 7.5 (=23/3.05) only for operating the chiller and producing cold water. The pumps of the primary and secondary solar circuits are consuming about 0.53 kW (not shown in fig.10) electricity. Including this electricity consumption results in an electrical COP_{el} of 6.4 (=23/3.58) for solar autonomous cooling in steady state operating conditions.

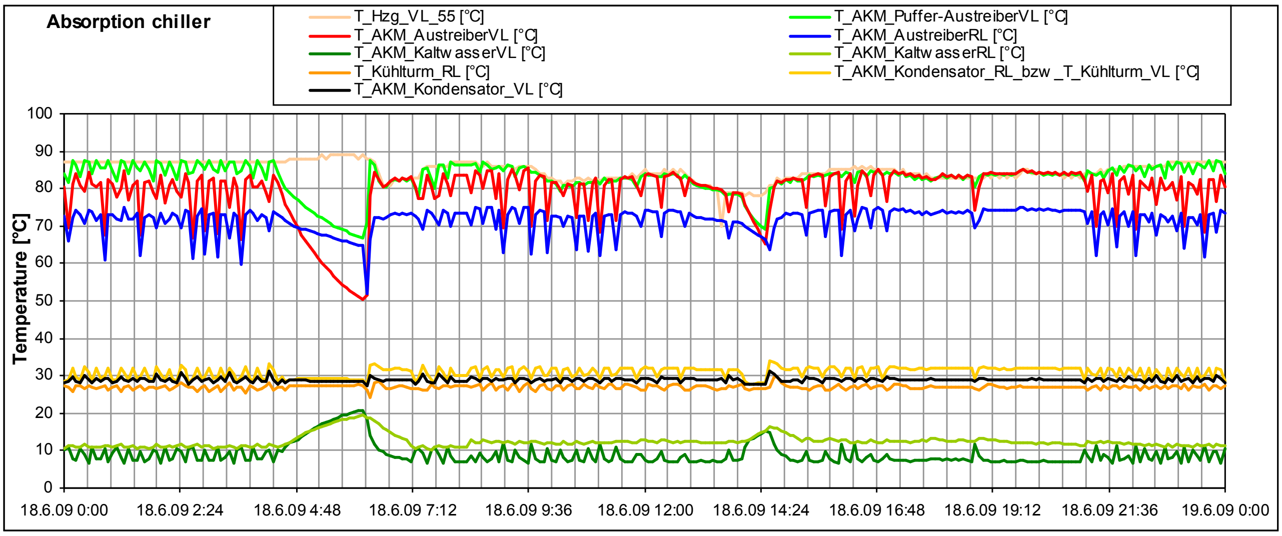

Fig. 9. Temperatures around the absorption chiller on June 18th,2009

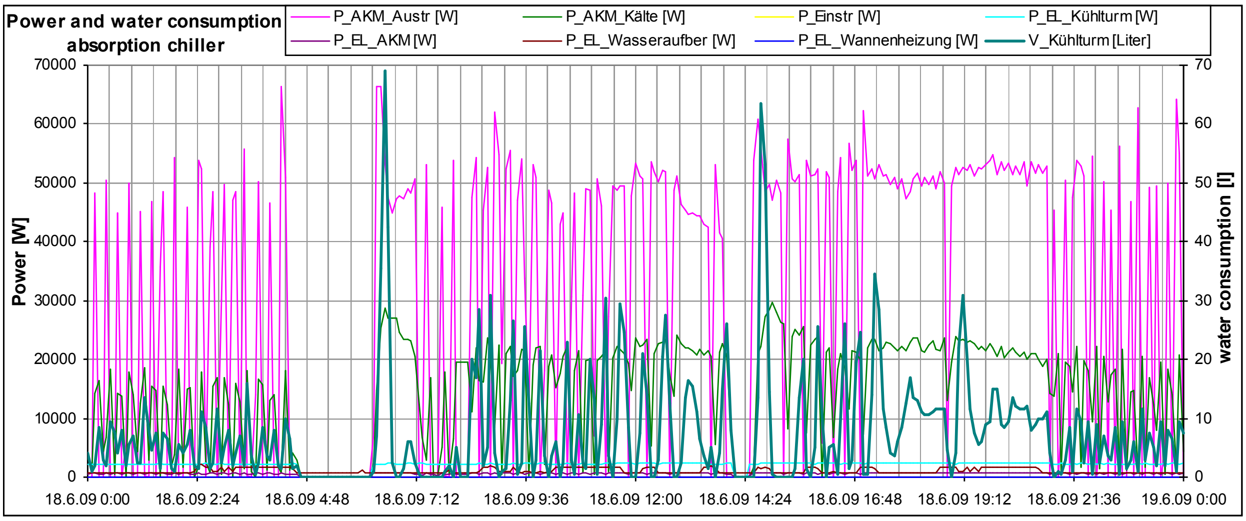

Fig. 10. Heat capacity and electrical consumption around the absorption chiller on June 18th, 2009

On long term for the period of the three months May, June and July 2009 the following average SPF's (seasonal performance factor) could be determined: $SPF_{therm} = 0.41$, $SPF_{el} = 4.2$ for chiller and cooling tower including the three pumps and $SPF_{el} = 3.9$, if additionally the solar circuit pumps are included. In this electrical SPF_{el} the electricity consumption of the auxiliary natural gas boiler and the two pumps, which are in operation to heat the hot tank, is not included. As it can be observed the chiller is operating in an extremely "stop and go" mode which does not support high values for SPF_{th} and SPF_{el}.

The reason for that was found in a mistake in the control program of the building itself. This mistake resulted in almost closed control valves of the chilled ceilings most of the time which naturally reduced dramatically the cold water flow and therefore only very reduced cooling of the office rooms was possible. If the cooling load is "artificially" reduced that much then of course there is no need for cold production of the chiller leading to this "stop and go" behavior. In Fig. 11 the average position of all control valves (Mittelwert Ventilstellungen) is shown. Since 0% means the valve is closed, it can be observed that most of the time the valves are in average in quite closed positions between 10% and peak values up to 60% for very short times. For the summer 2010 the control unit of the office building was reprogrammed and much better performance of the system and much higher comfort in the office rooms is expected.

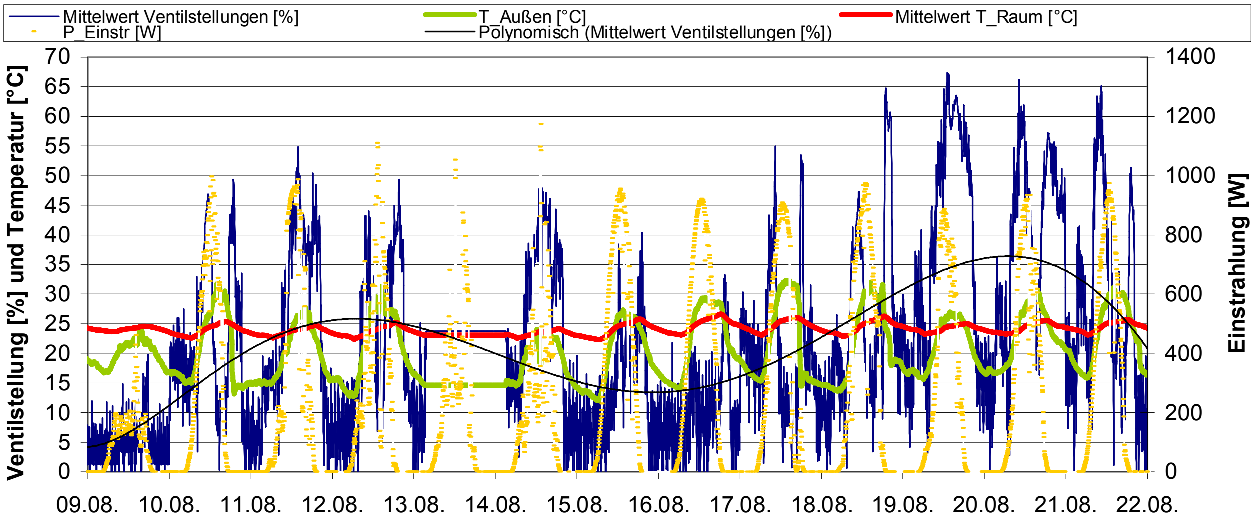

Fig. 11. Average control valve positions (Mittelwert Ventilstellungen) in relation to ambient temperature (T_Außen), solar irradiation (P_Einstr) and average of the 23 office room temperatures (Mittelwert T_Raum)

6. DESSICANT EVAPORATIVE COOLING UNIT

In fig.12 a screen shot of the air ventilation unit with Dessicant Evaporative Cooling (DEC) is shown. Accidentally this is a day with design ambient conditions for cooling in Austrian climate: 32°C ambient temperature and almost 40% relative humidity. Inlet conditions are 31.5°C and 38% relative humidity and supply air conditions, which are produced by the DEC system, are 19.1°C and 78% relative humidity. Outlet air of the building has 26.8°C and 48% relative humidity and exhaust air has 49.5°C and 20% relative humidity. Based on these data it can be stated that the DEC system is operating quite well in steady state conditions.

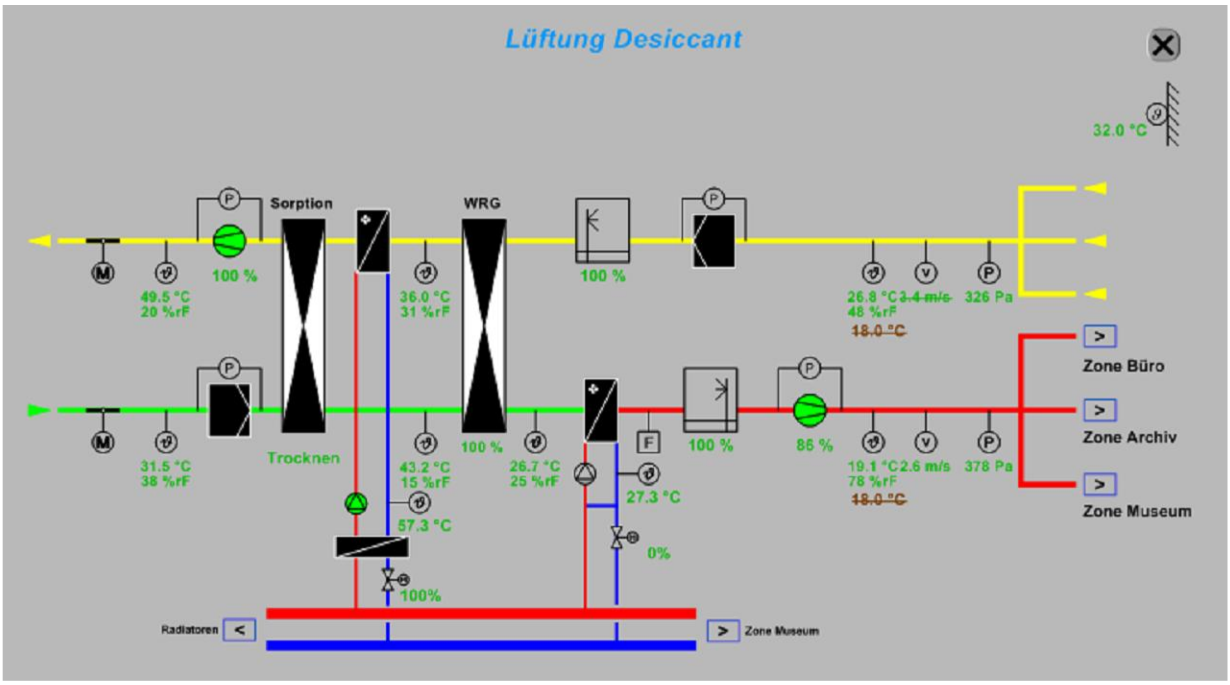

Fig. 12. Screenshot of the desiccant ventilation unit on June 19th, 2009

Temperatures and relative humidities are shown for June 18th, 2009 for the supply air stream in fig.13 and for the exhaust air stream in fig.14. At about 05:00 in the morning the air ventilation system starts exchanging air by sucking in ambient air and blowing it into the building. No heat recovery and no cooling is active. Due to several heat transfer effects (heat losses of motor of the fan and technical room temperature above 30°C) at about 05:30 the supply temperature (T_DEC_ZUL) finally is about 9K higher (around 19°C) than the ambient air temperature (T_Aussen) which is around 10°C at that time. For cooling down the building mass in order to keep lower room temperatures during the day it would be advantageous to "flush" the building with the ambient air directly. Therefore it would be a potential of optimization to switch off the supply ventilator and only to run the exhaust ventilator and to open the windows of the office rooms, what is possible since all windows are equipped with automatic actuators. Additionally the electricity consumption (about 2.7 kW nominal power) of the inlet air ventilation could be avoided.

At about 09:30 the DEC system starts active cooling and is active until 17:00. Supply air is cooled to around 19°C (T_DEC_ZUL) with relative humidity of about 78% (rH_DEC_ZUL). For drying the sorption wheel the water/air heat exchanger is supplied from the tank with hot water at around 80 to 85°C with heating power of about 45 kW. At about 16:30 the sorption wheel is able to dry the air from 30°C/40% rH (T_DEC_AUL / rH_DEC_AUL) to 44°C/14% rH (T_DEC_ZUL_nach SR / rH_DEC_ZUL_nach SR) which means a reduction of about 3g/kg absolute water content (from 10.6 g/kg to 7.6 g/kg)

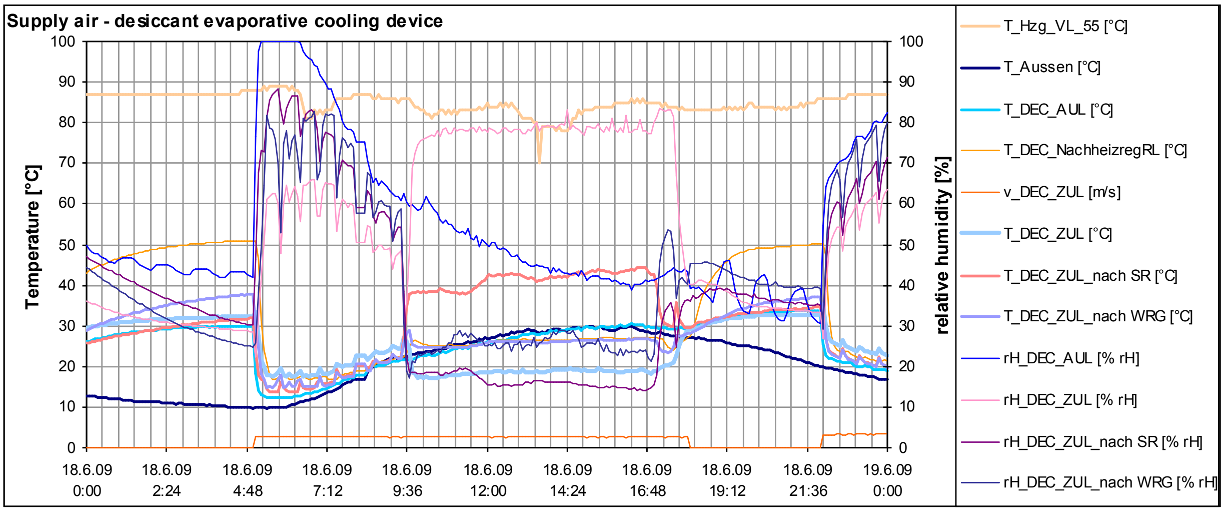

Fig. 13. DEC – supply air stream on June 18th, 2009

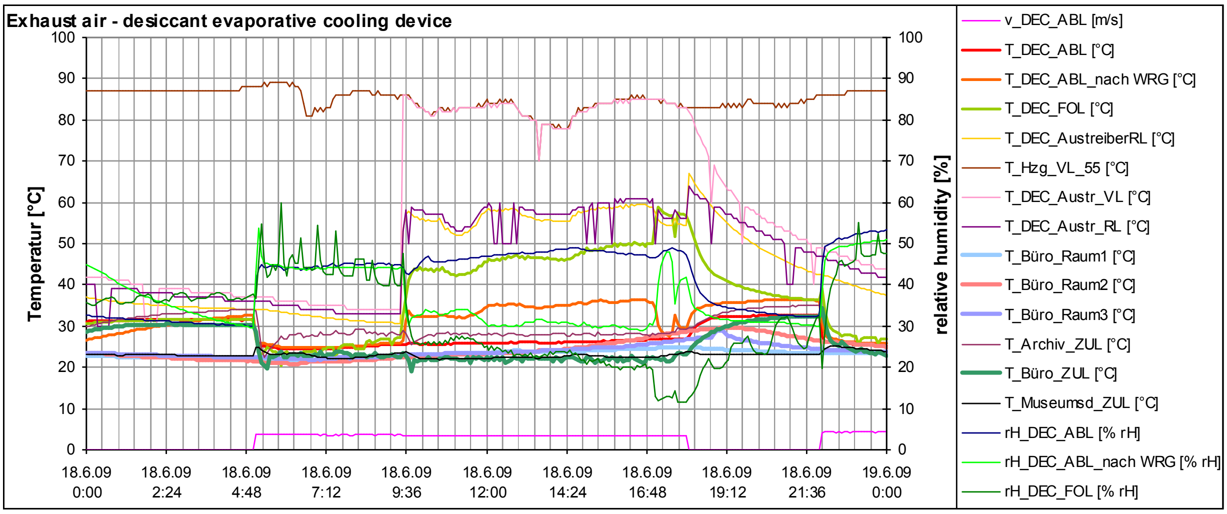

Fig. 14. DEC – exhaust air stream on June 18th, 2009

A quite big electricity consumer for this DEC system is the water treatment equipment with nominal power of about 0.8 kW stationary consumption for a circulation pump and the UV-lamp for disinfection and further 0.8 kW occasionally for the osmosis filter when fresh water is filled into the system. In June and July 2009 this resulted in average to electricity consumption just for water treatment of about 25 kWh per day, whereas running the DEC system itself consumed about 108 kWh per day. For comparison: thermal energy used for regeneration of the sorption wheel in average was 176 kWh per day in the two months June and July.

Even in winter time the water treatment unit was in operation despite the fact that no water was needed because the humidification unit in the air handling unit was switched off. This resulted during the period December 08 to February 09 in water consumption of about 81 m^3 and electricity consumption of about

1690 kWh. On November 20th, 2009 the controller of the water treatment unit was reprogrammed to minimum necessary activities, just to keep the components maintained as needed as shown in Fig. 15. Before the changes the electricity consumption was constant at around 800 W for running the UV-Lamp and the circulation pump for that. When the UV-Lamp got too warm the system cooled down by flushing the water to the drainage and refilling with fresh and cold water which caused the activity of the osmose filter with the intergrated high pressure pump resulting in a total power of up to about 1600 W electricity consumption.

After reprogramming in the months December 09 to February 2010 the water consumption reduced to about 6 m^3 and electricity consumption to about 41 kWh. This means a reduction of 93% water consumption and 98% electricity consumption.

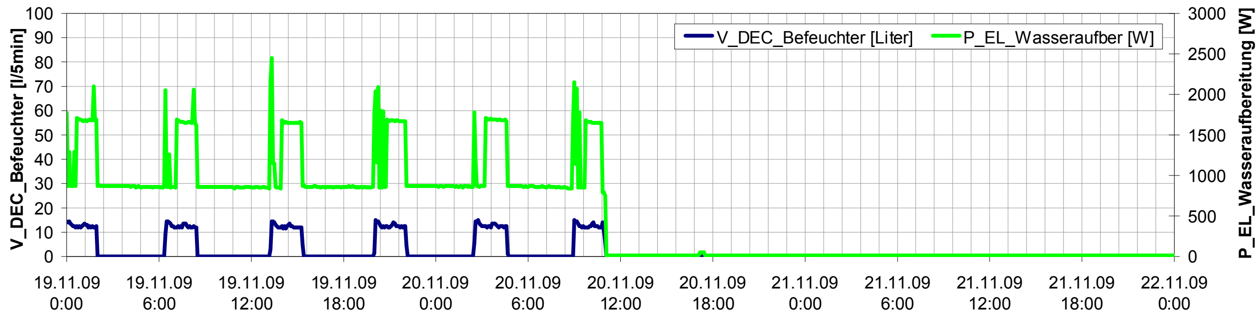

Fig. 15. Electricity consumption (P_EL_Wasseraufber) and water consumption (V_DEC_Befeuchter) of water treatment unit before and after reprogramming

7. CONCLUSIONS

For the solar heating and cooling plant of the town hall in Gleisdorf a detailed monitoring campaign is realized which allows to evaluate all heat flows, electricity flows, water consumption and of course all temperatures and relative humidity in the system and the building.

First year of monitoring shows good results of the solar heating part with annual electrical SPF_{el} of 67 kWh_{therm}/kWh_{el} and up to 82 kWh_{therm}/kWh_{el} as monthly peak values. Heat losses of the heat store are between 4 and 25% with in average 9% for a 12 month period. Acceptable results of the single components like the absorption chiller (COP_{el} of 7.5) and the DEC system (19°C supply air at 32°C ambient air temperature) during steady state conditions could be presented. When comparing COP`s and SPF`s (COP_{el} of 7.5 decreases to a SPF_{el} of 4.2), this shows that quite big potentials for improvements exist in optimizing the overall control strategy of the building in cooperation with the heat/cold delivery system and reduction of parasitic electricity consumption, especially for water treatment.

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