Final Deliverable

Report for self-detection on monitoring procedure

Date: 06.05.2015

By Dr. Dirk Pietruschka

[1]Institution	Hochschule für Technik Stuttgart
	Center of Applied Research Sustainable Energy Technology – zafh.net
Address	Schellingstraße 24, 70174 Stuttgart, Germany
Phone	0711 / 8926 - 2674
e-mail	dirk.pietruschka@hft-stuttgart.de
Authors:	Dirk Pietruschka, Antoine Dalibard and Ilyes Ben Hassine HFT-Stuttgart
	Hilbert Focke; ASIC- Austria Solar Innovation Center, Wärmesysteme; Ringstraße 43a; 4600 Wels, Austria
	Florian Judex and Anita Preisler, AIT Wien, Austria
	Martin Helm, ZAE Bayern, Wärmetransformation / Heat Conversion Walther-Meißner-Str. 6, 85748 Garching
	Philip Ohnewein, AEE Intec - Institut für Nachhaltige Technologien 8200 Gleisdorf, Feldgasse 19, Austria
	A. Frein, M. Muscherà, Politecnico di Milano, Italy

IEA Solar Heating and Cooling Program

The Solar Heating and Cooling Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is *"to enhance collective knowledge and application of solar heating and cooling through international collaboration to reach the goal set in the vision of solar thermal energy meeting 50% of low temperature heating and cooling demand by 2050.*

The member countries of the Programme collaborate on projects (referred to as "Tasks") in the field of research, development, demonstration (RD&D), and test methods for solar thermal energy and solar buildings.

A total of 53 such projects have been initiated to-date, 39 of which have been completed. Research topics include:

- ⚲ Solar Space Heating and Water Heating (Tasks 14, 19, 26, 44)
- ⚲ Solar Cooling (Tasks 25, 38, 48, 53)
- ⚲ Solar Heat for Industrial or Agricultural Processes (Tasks 29, 33, 49)
- ⚲ Solar District Heating (Tasks 7, 45)
- ⚲ Solar Buildings/Architecture/Urban Planning (Tasks 8, 11, 12, 13, 20, 22, 23, 28, 37, 40, 41, 47, 51, 52)
- ⚲ Solar Thermal & PV (Tasks 16, 35)
- ⚲ Daylighting/Lighting (Tasks 21, 31, 50)
- ⚲ Materials/Components for Solar Heating and Cooling (Tasks 2, 3, 6, 10, 18, 27, 39)
- ⚲ Standards, Certification, and Test Methods (Tasks 14, 24, 34, 43)
- ⚲ Resource Assessment (Tasks 1, 4, 5, 9, 17, 36, 46)
- ⚲ Storage of Solar Heat (Tasks 7, 32, 42)

In addition to the project work, there are special activities:
- ➢ SHC International Conference on Solar Heating and Cooling for Buildings and Industry
- ➢ Solar Heat Worldwide – annual statistics publication
- ➢ Memorandum of Understanding with solar thermal trade organizations
- ➢ Workshops and conferences
- ➢

Country Members

Australia	Germany	Singapore
Austria	Finland	South Africa
Belgium	France	Spain
China	Italy	Sweden
Canada	Mexico	Switzerland
Denmark	Netherlands	Turkey
European Commission	Norway	United Kingdom
	Portugal	United States

Sponsor Members

European Copper Institute	Gulf Organization for Research and Development
ECREEE	RCREEE

Contents

1. Executive Summary

Starting from the statement of existing efficient system control (overview achieved in former IEA Task 38), a second generation of control system is needed to be developed which includes self-detection of faults and malfunctioning of the process based on a reduced monitoring. This new powerful functionality will be a key component assuring long term good reliability and performance of the system. This activity includes an update of good practice on the monitoring procedure starting from the experience and procedures developed during IEA SHC Task 38. However, possible system errors in solar cooling systems are diverse and reach from component defects over simple sensor faults to real control problems. Therefore, as a basic for new developments of automated fault detection systems within working group B6 first a categorization of typical system errors has been carried out. For each fault category typical errors have been collected and possible methods for error detection are discussed together with necessary monitoring equipment. In the last part of the document possible implementations of automated fault detection systems within local system controllers and within centralized internet based system observation systems are shown.

2. Introduction

For the development of a systematic error detection system, it is required that first of all the possible system errors are collected and sorted in logical error categories. Based on this error detection, methods can be developed for each category and type of error. To reach these goals the following steps were used within working group B6:

- Collection of the different typical system errors which occurred in different demonstration sites
- Characterization of these system errors for the different solar cooling systems
- Development and documentation of possible methods on how the most common system errors can be detected (sensor based and simulation based)
- Definition of minimum required additional sensors for the application of improved fault detection methods

The present document summarizes the work performed by and the information collected within working group B6. This includes experiences made in many different demonstration projects with solar thermal heating and cooling applications. Furthermore, ongoing developments in the field of automated fault detection methods for the different error categories are described. The main aim of the document is to give the reader an overview on the typical system errors and possibilities for a fast detection using automated system observation methods.

3. System definition

According to the results of Task 38 Generic Systems Characterization each SAC-system could be divided into subsystems. To ensure a good overall system performance the energy exchange between the subsystems has to be evaluated.
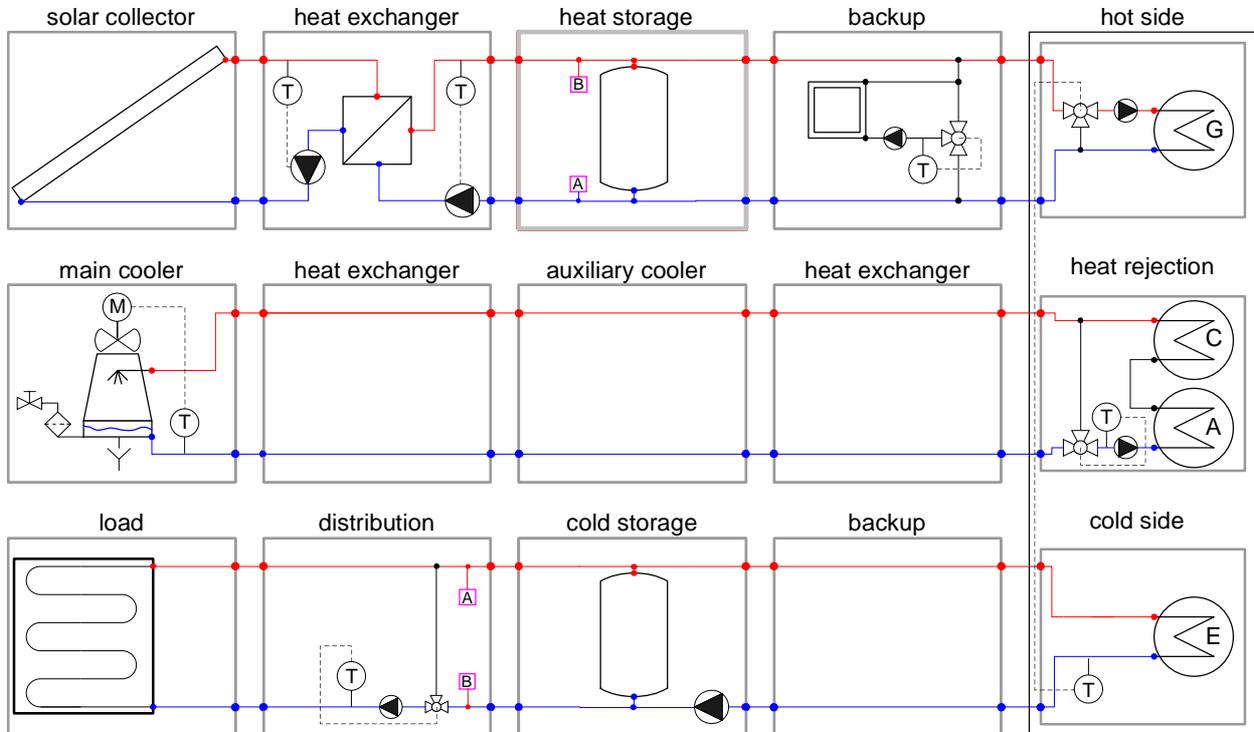
Figure 1: Generic scheme of a solar cooling system according to the IEA SHC Task 38, WP A2

According to Task 38 monitoring procedure can e.g. be carried out on the following 3 levels of detail with increasing the evaluation depth and requiring more detailed sensor equipment.

Level 1 – Overall system performance and renewable share of cooling provided to the building

Level 2 – Energy transfer between the subsystems

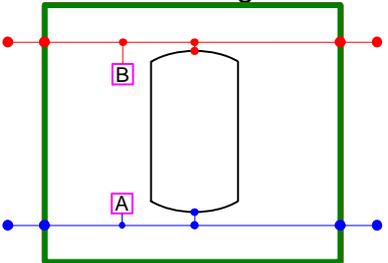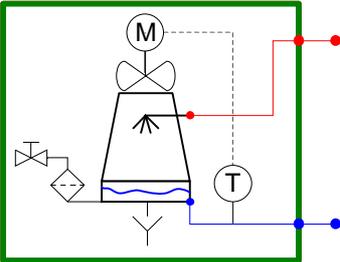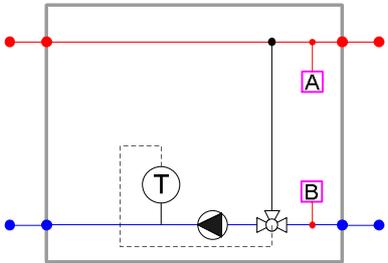Level 3 – Energy balance of each subsystem including the consideration of conversion factors to determine the efficiency and possible losses
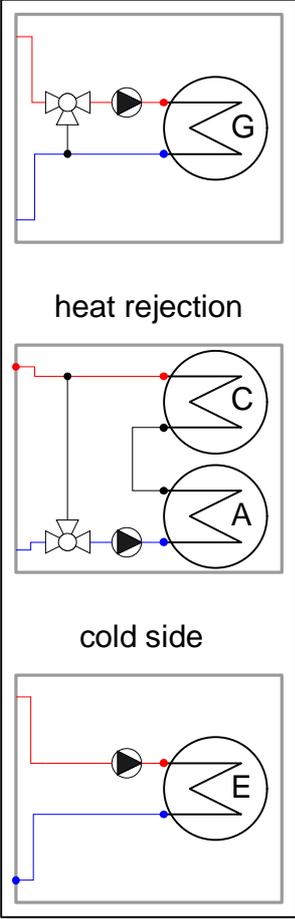
Required data related to each level:

Level 1 – long time (monthly or yearly) evaluation

- Electric energy meter to measure the overall electricity consumption
- Thermal energy meter on the chilled water side to measure the cold provided
- Solar radiation

Level 2 – daily evaluation

- Heat flux meters to measure the energy transfer between the components
- Metering of electricity consumption or a rough calculation by using control input parameters or operation and hours and average values of each component

Figure 2: Energy exchange between the subsystems (source: report of IEA SHC Task 38: Monitoring Procedure for Solar Cooling Systems - A joint technical report of subtask A and B (D-A3a / D-B3b))

Level 3 – thermodynamic analysis of subsystem performance using manufacturer data, excessive measuring equipment, and steady-state and dynamic simulation tools

Table 1: Required sensors and information for a detailed analysis and well known system errors

System components	Required information/measurement data	Well known mayor errors
solar collector	- T_amb, irradiation, wind speed - T_{in}, T_{out}, flow rate (Vdot), type of fluid (water or water/glycol) - Parameters from manufacturer data sheet: α_1, α_2, η_0, IAM, insulation, transmission rate of glass cover - Operation signal of solar pump	- Broken glass cover - Soiled glass cover - Scaling of tubing - Leakages of fittings - Vacuum leakage of evacuated tubes - Unbalanced flow regime between the collector subfields - Not sufficiently sized / wrongly installed gravity brakes - Undersized expansion tanks

heat exchanger	• T_prim_in, T_prim_out • T_sec_in, T_sec_out • Flow rates (Vdot_prim, Vdot_sec) and fluid properties (cp, rho) • Optionally: A_HX • UA-Value of data sheet	• Fouling, clogging, scaling • Mismatch of primary and secondary flow rate • Undersizing • Wrong connection of pipes (e.g. parallel flow instead of counter flow
heat storage	• T_ST_top, T_ST_mid, T_ST_bot • T_load_in, T_load_out, m_dot_load • T_charge_in, T_charge_out, m_dot_charge •	• Wrong connection of supply and return • Undersized internal heat exchangers • Undersized stratification / too high mass flow rates • Unfixed temperature sensors • High heat losses at connections
Heat rejection main cooler	• Ambient temperature (and humidity for hybrid/wet coolers) • Cooling fluid inlet/outlet temperature, mass flow and properties (cp, rho) • Operation signal of cooling tower fan • Operation signal of pump in heat rejection circuit • Auxiliary electricity consumption ➔ **Details see Subtask A3 final report chapter 5.4.1**	• Clogging of fins (dry cooler) or filling material (wet cooler) with dust, pollen, leaves etc. • Unfavorable positioning (e.g. exposed to direct sunlight, on black or metal surface, ... • Continuous full-load operation of fan(s) ➔ **Details see Subtask A3 final report chapter 5**
Interface to the building distribution	• T_in, T_out, flow rate (Vdot) • Insulation, T_amb • Pump • Time dependent operation signal • Electricity consumption • Cooling demand signals from building control (cold distribution circuit)	• Wrongly installed / connected three way valve /three way valve motor • Under / over dimensioned distribution pump • Missing return flow blockers • Bad insulation of tubes and components

Thermally driven chiller	Generator	
hot side	• Temperatures: T_EV_in, T_EV_out • Mass-Flow rates (m_dot_EV) and fluid properties (cp, rho) • Electricity consumption of evaporator pump • Position of three way valve	• Fouling, clogging, scaling of internal heat exchangers • Wrongly installed / connected three way valve /three way valve motor • Under / over dimensioned heat rejection pump
heat rejection	**Heat rejection from absorber and condenser** • Temperatures: T_AC_in, T_AC_out • Mass-Flow rates (m_dot_AC) and fluid properties (cp, rho) • Electricity consumption of evaporator pump • Position of three way valve	• Fouling, clogging, scaling of internal heat exchangers • Wrongly installed / connected three way valve /three way valve motor • Under / over dimensioned heat rejection pump
cold side	**Evaporator** • Temperatures: T_EV_in, T_EV_out • Mass-Flow rates (m_dot_EV) and fluid properties (cp, rho) • Electricity consumption of evaporator pump	• Fouling, clogging, scaling of internal heat exchangers • Wrongly installed / connected three way valve /three way valve motor • Under / over dimensioned evaporator pump
	General aspects of chillers • Electricity consumption chiller (solution pump) • Electricity consumption control system	• Vacuum leakages • Internal solution pump defect • Degradation of solution flow rate • Crystallization

4. Collection and Characterization of typical system errors

4.1 Error classification

Resulting from the discussion within working group B6 a classification of typical system errors found in solar thermal cooling system installations has been developed. This classification groups the typical errors in five categories: Systematic errors, sensor errors, control errors, component defects and component degradation.

Systematic errors are system failures or mall functions caused by a poor system design (wrong component dimensioning or/and poor hydraulic design) or by an unappropriated system installation. Sensor errors can be either caused by sensor or cabling defects or by more systematic errors like bad installation, wrong placement

9

or wrong parameterization. Errors which are related to the system control and the implemented control strategies can be caused by programming errors in the control code, a wrong / unappropriated control strategy or by sensor/cabling errors of the control system. Component defects are caused by defects of single components like pumps, valve motors, etc. which results in a complete shutdown of the system or in a system performance degradation. Component / system degradation means that the performance of system components decreases slowly by e.g. fouling effects, vacuum problems or other aging effects. Table 2 gives an overview on the defined error classification with some examples for each category and some possible error detection methods. In chapter 3.2 to 3.6 typical errors found in real installations are shown and discussed for each error class.

Table 2: Error classification, overview

Type of Error	Examples	Detection methods
Systematic System Errors	• Wrong or bad hydraulic design or installation • Wrongly installed three way valves • Missing return flow blockers • Wrong dimensioning of components like HX, pumps, under dimensioned return flow blockers, expansion tanks • Wrong placement of components • Valves closed • Etc.	Automated detection often difficult, in some cases systematic errors can be allocated to specific system components → Detailed system analysis required if performance is not as expected
Sensor Errors	• Sensors not fixed / cabling errors, • Sensor defects / sensor drift, offset • Wrong or missing calibration • Wrong parameterization etc. • Etc.	• Check sensor range, • Check possible plant specific range, • Plausibility check with other sensors, • Jump between two time steps, • Units, etc. …
Control Errors	• Bad PI od PID controller parameterization • Wrong placement of sensor/ sensor problems e.g. dirt on irradiation sensors used for mass flow control of collector (sensor error causing control error) • Control code with errors under specific conditions... etc. • Wrong control strategy e.g. missing fan speed control of heat rejection system, wrong set points, too short dead times, too small hysteresis, etc.	• Check with key performance indicators (PER, PFel, efficiency of solar system, etc.) • Rule/experience based check • Detailed analysis of measured performance data for typical days • comparison with simulation results → big effort • common step response test for PID during commissioning
Component defects	• Defect motors of valves, • Defect pumps, • HX turned off in maintenance mode • Blocked valves • Etc.	• Check pressure drops, • Check mass flow rates, • Check with efficiency curves of components, • Check with key performance indicators • Comparison with simulation results

		(efficient but high effort at the beginning) • Etc.
Component performance degradation	• Fouling etc. in heat exchanges or other components • Blocked or partly blocked valves or full filters • Blocked filters / (high pressure losses), • Aging of collector covers / foils, • Cavitation effects in pumps • Etc.	• Difficult to detect • Check with historic performance • Check pressure drop in the system (sensors required!) • Check with key performance indicators (PER, PFel, efficiency curves of components) • Rule based check, experience based, • comparison with simulation results • Etc.

4.2 Typical systematic system errors

Within this chapter some typical systematic errors found in real projects are shown and discussed together with possible detection methods. Systematic errors often result from design or installation errors of the hydraulic system including a wrong dimensioning of pumps, valves and return flow blockers. An automated detection of these types of error is difficult. In most cases only a bad performance can be recognized, for the detection of the error a detailed analysis of the hydraulic system is normally required.

4.2.1 Wrong dimensioned gravity break in solar loop at FESTO in Esslingen, Germany (Source: zafh.net)

The solar cooling system installed at the company FESTO in Esslingen consists of a pure water driven solar field with 1218 m² (aperture area) vacuum tubes collectors of Paradigma, 2 hot water storage tanks of 8.5 m³ each and 3 adsorption chillers of 350 kW cooling capacity each. Figure 3 shows a schematic diagram of the system design.
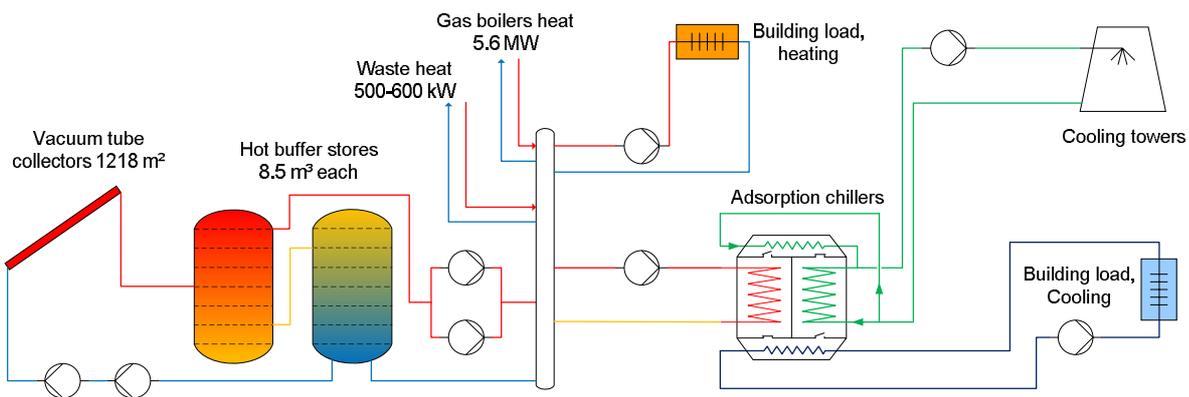

Figure 3: Hydraulic scheme of the FESTO solar cooling system (Source: (Dalibard & Eicker, Primary energy optimisation of a solar adsorption cooling plant through dynamic simulations, 2010))

Some problems occurred during the commissioning of this solar plant due to a wrong dimensioned gravity break of the solar loop. As the installed system is a pure water system, a specific control algorithm is required for frost prevention in the solar loop during the night. This control algorithm starts to operate the collector pump for some minutes if the temperature at specific places of the collector field decreases below a certain threshold. This control is clearly visible during the morning hours of 10th December 2007 (see Figure 4). This control leads to a faster decrease of the temperature in the hot water storage. However during day time the system operates normal and heating energy is transferred to the hot water storage. In the afternoon the temperature in the solar field decreases while the storage temperature decreases only slowly until 18:30 due to the frost protection algorithm. However, the collector temperature decreases very fast below the storage bottom temperature. At 18:30 a fast drop of the temperature at the bottom of the storage tank occurs and the temperature in the collector system starts to increase significantly. This is caused by a significant increase of the mass flow rate in the solar loop, which results not from system control but by gravity effects. More detailed analyses came to the conclusion, that the gravity break was not sufficiently dimensioned here.
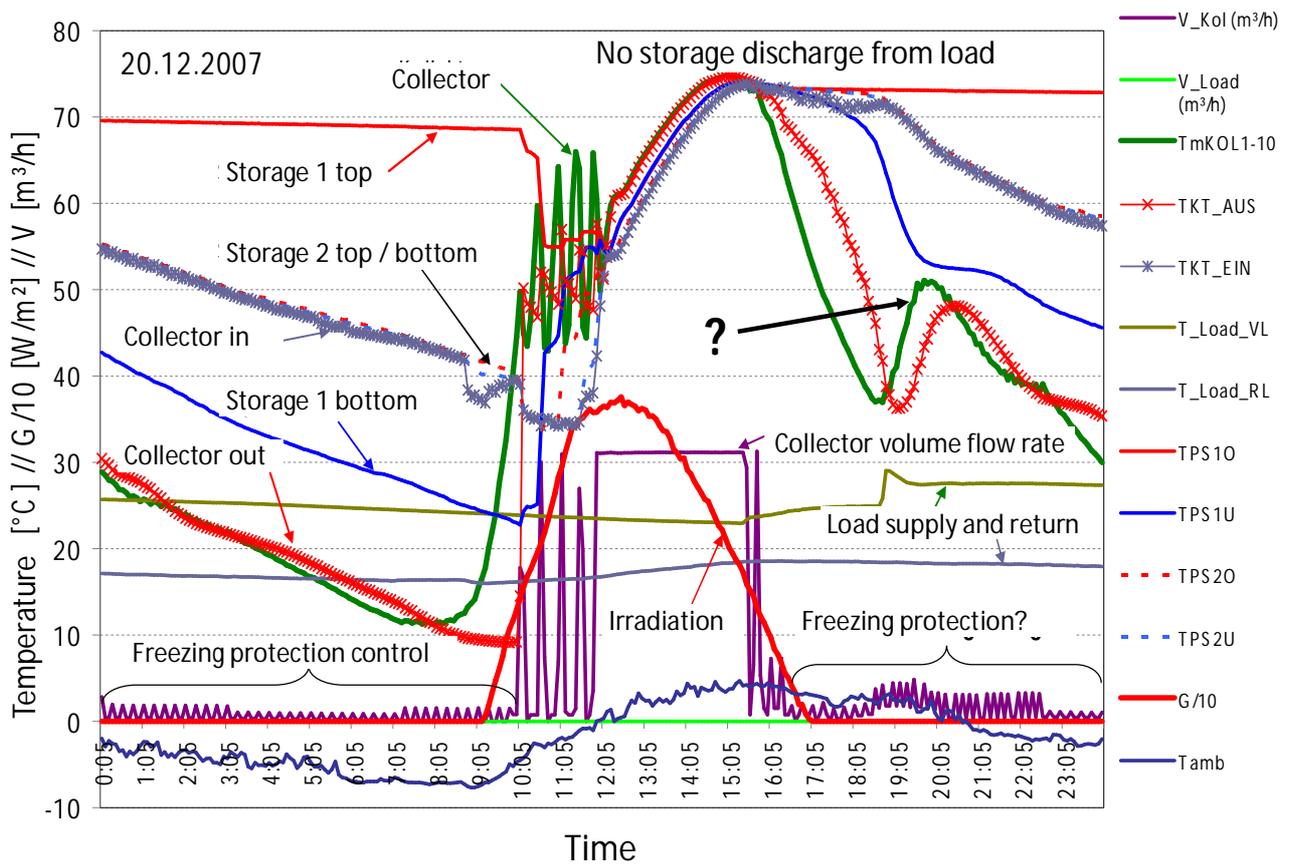

Figure 4: Hydraulic problem identified with measurement data analysis (source: zafh.net)

4.2.2 Insufficient cooling tower control at FESTO in Esslingen, Germany (Source, zafh.net)

Measurement data analysis shows that the batch operation of the adsorption chiller creates instability in the control of the fan speed of the cooling tower. Due to rapid temperature drop in the return water of the cooling tower, the lower set point temperature (around 19°C) is reached and both fan and spray pump are stopped. With the effect that due to the control hysteresis the fan and pumps start too late in order to reject the heat when the next "hot water" wave comes (see Figure 5). Due to the disturbances also the PID fan speed control of the cooling tower is not able to maintain a constant outlet temperature. All this results in an efficiency decrease of the chiller since the adsorber is actually heated instead of being cooled. To solve the problem a small buffer storage could be implemented in the heat rejection circuit before the warm water enters the cooling tower.
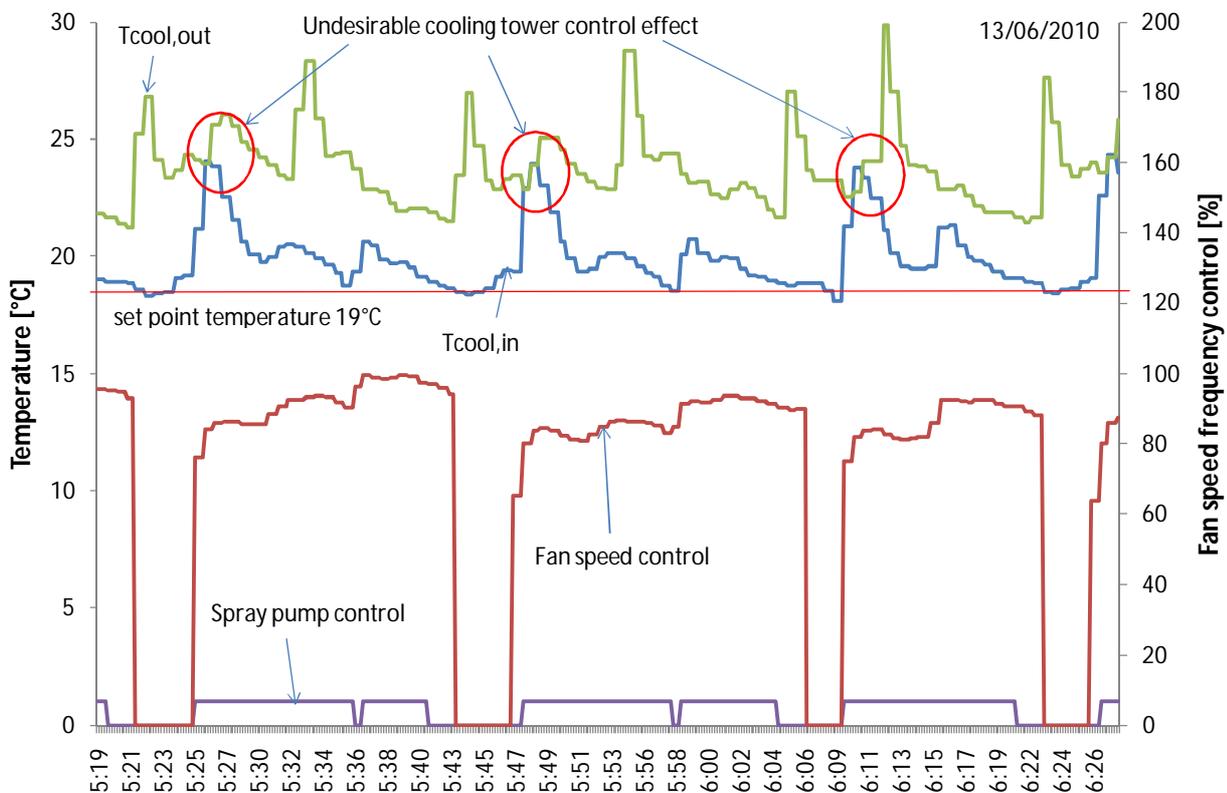

Figure 5: Undesirable cooling control effect due to adsorption/desorption cycle (Source: (Dalibard & Eicker, Primary energy optimisation of a solar adsorption cooling plant through dynamic simulations, 2010))

4.2.3 Wrong hydraulic design of a solar cooling system installed at a Bakery in Neckersulm, Germany (Source: zafh.net)

A solar heating and cooling system with heat recovery of the exhaust gas of the ovens has been installed in a Bakery in Neckersulm, Germany. The system consist of five storages, storage one is the cold water storage for cooling application and storage 2 to 5 are the hot water storages. Storage 3, 4 and 5 are used for hot water preparation used for cleaning tasks. Storage 2 is connected to an 18 kW Yazaki Typ WFC SC5 absorption chiller.

As heat source a solar collector system with 44 m² vacuum tube collectors has been installed. Further heat is delivered by a heat recovery system which extracts heat from the exhaust gases of the oven. However, when the system was set in operation the system never reached sufficiently high temperatures to operate the absorption chiller. A detailed analysis of the hydraulic system on site showed that all heat storages were installed in parallel instead of installing storage 2 in series (see Figure 6).
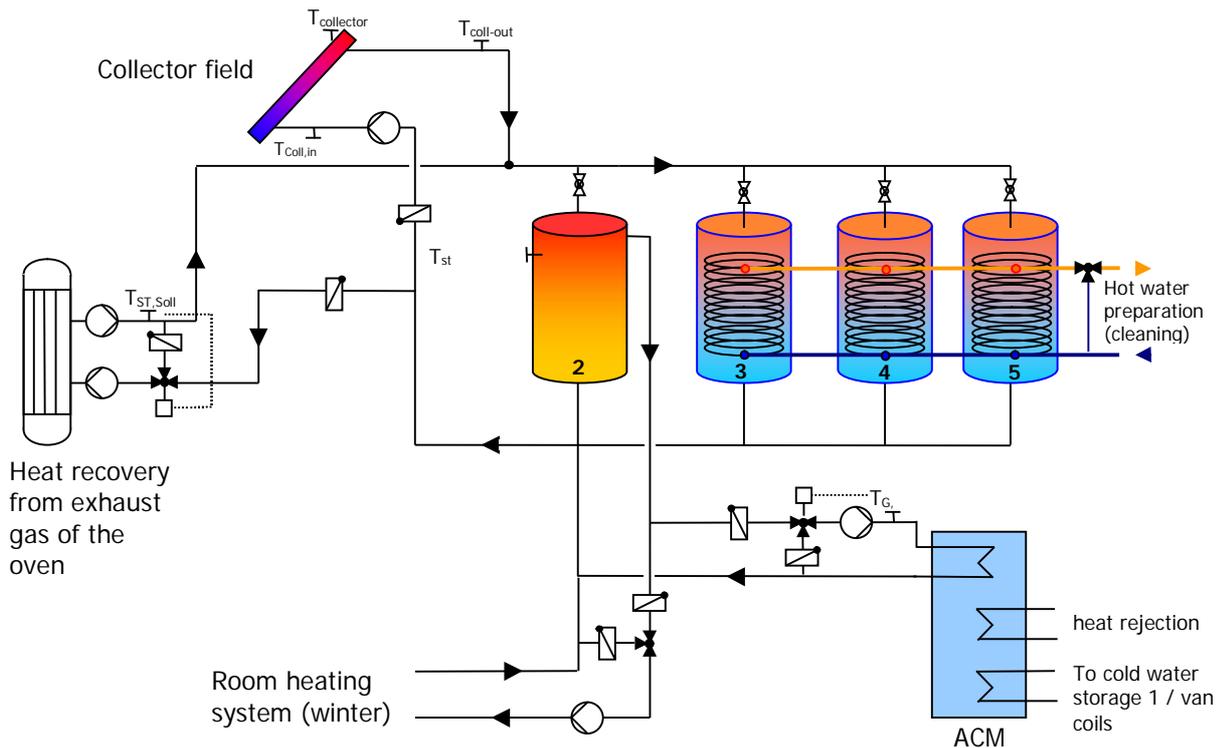

Figure 6: Wrongly installed hydraulic system found in the bakery in Neckarsulm, Germany with all storages in parallel

The developed improved system design connects storage 2 in series to the three storages for the hot water preparation. An additional three way valve allows to start mixing the hot water from bottom of storage 2 with cold water from the bottom of storage 3 to 5 until the full mass flow comes from storage 3 to 5. This control allows to keep a high temperature level in storage 2 and to slowly start charging the storages 3 to 5. For the correct system design with storage number 2 installed in series to storage 3 to 5 (see Figure 8) the control strategy was improved by dynamic system simulations. A proportional control for the three way mixing valve was implemented with a control characteristic as shown in Figure 7.
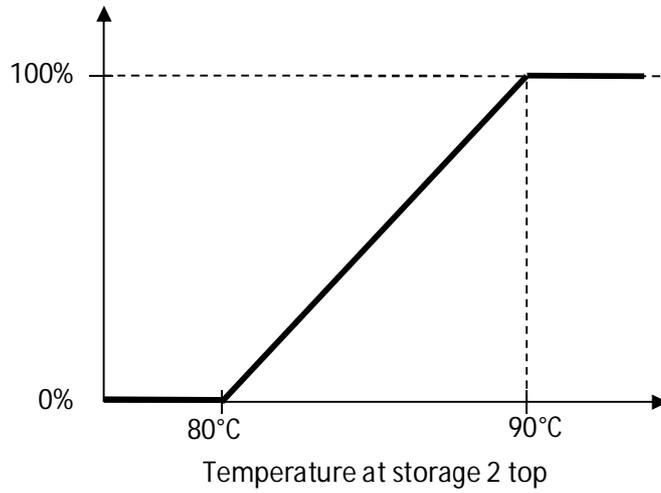
Figure 7: Proportional control for the new three-way valve
100 % open means full mass flow from storage 3 to 5,
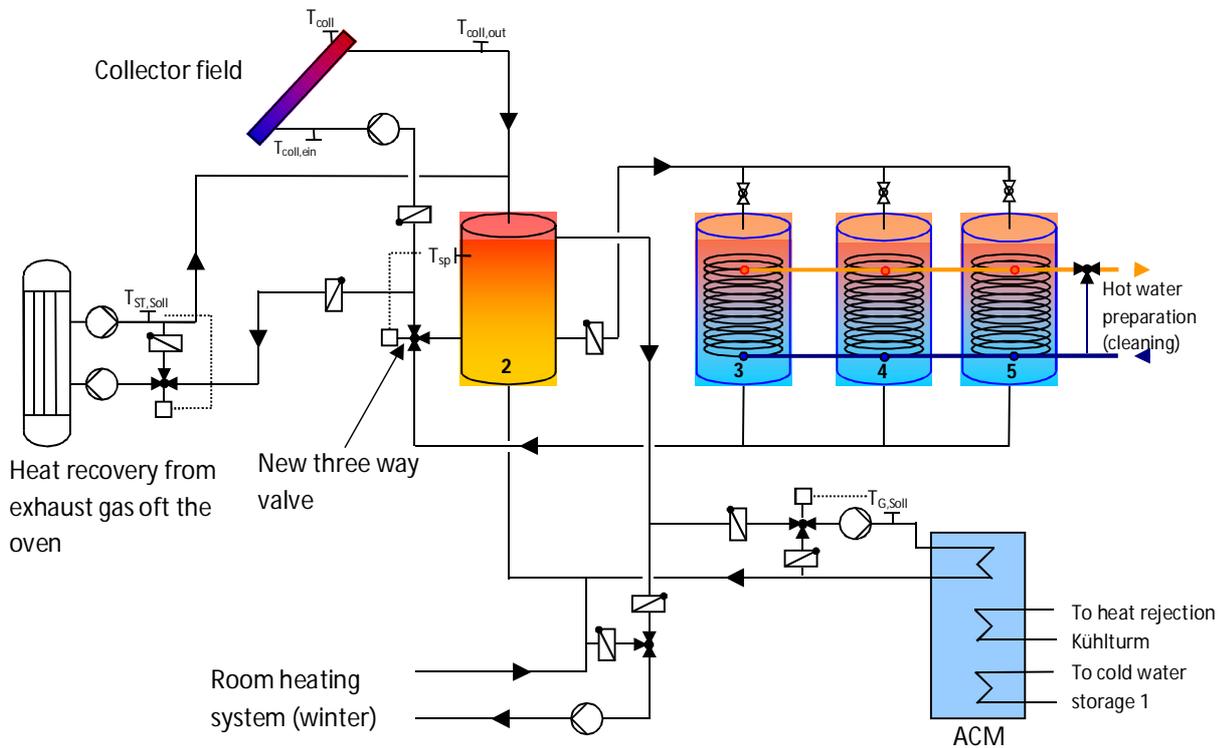*0% open means full massflow from bottom of storage 2*

Figure 8: Improved system hydraulic with storage 1 installed in series to storage 3 to 5

4.2.4   Wrong placement of the wet cooling tower and inactive safety blocking; Office Building in Rohrbach Austria (Source: Hilbert Focke, ASIC Austria)

The office building, owned by the regional government of Upper Austria was built up 2007, and settled in autumn 2008. The 120 m² flat plate solar thermal demonstration plant is used for generating the driving heat of the 30 kW absorption chiller and for supporting the low temperature heating system in order to maximize solar gains. The domestic hot water demand is rather marginal. The absorption chiller supports the substantially larger electric driven chiller (100 kW), minor cooling loads could be covered exclusively. When high cooling loads occur, the compression chiller is at least discharged, for saving electric energy. The air conditioning equipment consists of supply- air heat exchangers and fan coil systems. The minimization of the cooling load is done by exterior sunscreens and heat protection window glasses.

The building design causes very long distances between chiller and cooling tower. The thermal driven chiller is located in the HVAC room in the cellar of the building. The position of wet cooling tower was chosen on the flat roof of the building (best practise for electric chillers). Hence the power consumption for the heat rejection cycle is very high. Furthermore the included safety blocking of the chiller (crystallisation), done by the internal chiller controller, caused by cooling water return temperatures < 18°C was deactivated in order to prevent errors. This safety measure is transferred to the building control, which enables the chiller if cooling water return temperatures < 18°C with 10 minutes delay. This step allows the chiller to start, even if the temperature in the cellar is very low, and the temperature of the water in the heat rejection cycle is < 18°C.

The major effect on moderate thermal EERs is the relatively high water return temperature from the wet cooling tower into the chiller. The reason for this high temperature may be due to missing water treatment and the improper pump in the heat rejection cycle. The missing water treatment culminates in clogging the cooling tower basin and therefore an error because of no volume flow in the heat rejection circuit.

Figure 9: Clogging of the cooling tower basin, Office building in Rohrbach, Austria

Incomplete draining during wintertime, caused by wrong positioned vents in the heat rejection circuit, leads to a mechanically blocked heat rejection circuit pump in spring.

4.2.5 Wrong design of the collector hydraulics: stagnation problems

This part is taken directly from the lecture script of Wolfgang Streicher "Solar Thermal Heating systems", Graz University of Technology, Institute of Thermal Engineering March 2007.

Collector stagnation can be divided into several phases:

1. Heating of the collector fluid to the boiling temperature
2. Evaporation of the collector fluid
3. Superheating of steam in collector
4. Condensation of steam in tubes after the collector is near thermal equilibrium
5. Recondensation of fluid in the collector when the solar radiation decreases and the temperature in the collector drops below the boiling point of the fluid again.

Figure 10 shows two possible hydraulic schemes. In the left scheme (case 1) the increasing vapour pressure forces all liquid out of the collector as the increased pressure pushes the liquid down equally on both sides. No vapour occurs in the connecting tubes has only the liquid is transported through them during the emptying of the collector. In the right scheme (case 2), if the pressure is equal on both sides, all liquid in the "U" has to be evaporated because it is "trapped" in the collector. The steam is forced into the tubes and has to be condensed in the heat exchanger to the heat sink. Very high temperatures occur in the whole collector circuit. Additionally there is an increased degradation of the propylene glycol and the corrosion inhibitors, because of the high temperature in the collector. Therefore case 1 is recommended for the collector layout.
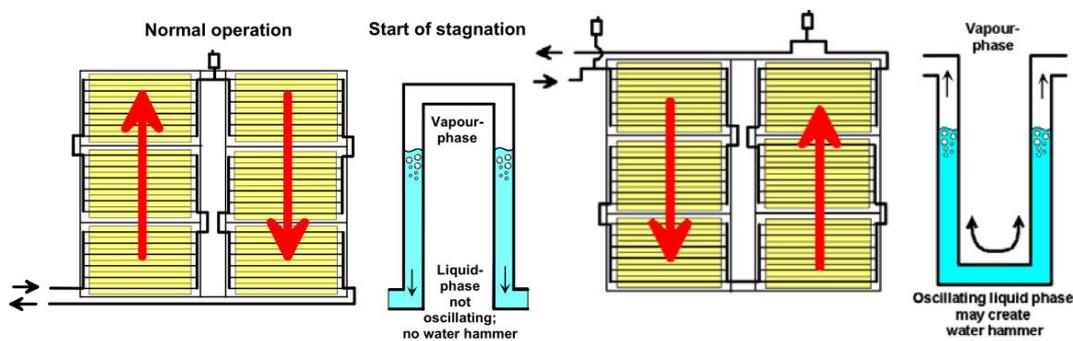

Figure 10: Hydraulic collector flow scheme pressing steam out of the collector during evaporation (case 1 left and case 2 right)

4.3 Typical sensor errors

Within this chapter some typical examples for sensor failures or defects are shown and discussed together with possible detection methods

The result of a perfect measurement would be the true value, but such a measurement doesn't exist. The result of a real measurement is afflicted with uncertainties due to systematic and random errors.

Systematic errors result in the same value under identical conditions and are caused for example by a defect measurement instrument. Identified systematic errors can be eliminated. But even if all systematic errors could

be quantified exactly and eliminated, the results of repeated measurements would not be the same. The results usually scatter randomly around the true value. These **random errors** are not correctable. The measurement result is an estimated value of the measured variable because of random errors and imperfect correction of the systematic errors (see Figure 11).
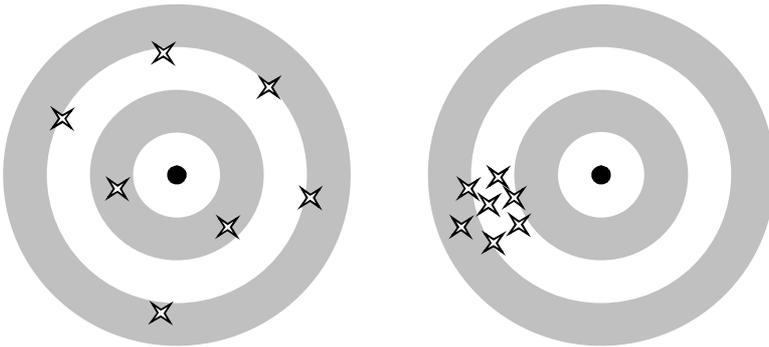

Figure 11: Random errors (left) and systematic errors (right) – Source: (Gamblin, Haller, & Ayadi, 2009)

4.3.1   Temperature sensors incl. wiring

Typical problems on site:

Error	Detection method
- sensor drift	matching modus during standby
- sensor offset	calibration, matching modus during standby
- sensor broken	=> max. min. values restriction
- sensor short cut	=> max. min. values restriction
- induction	=> use shielded wires and ground them!

Recommendation: Use 3 or 4 wire PT100 instead of 2 wires.

Suggested automated detection methods:

- Consistency check with physical limits
- Sensor check against other sensors
- Drift calculation via Kalman-filter

Example from Office Building in Rohrbach, Austria:

Figure 12: Broken temperature sensor of the collector, office building in Rohrbach, Austria

Damaged main temperature sensor in a solar collector caused by stagnation, no error message had been displayed.

➔ Possible automated detection method: Check collector temperature with temperatures in the collector circuit and with calculated collector temperature using the measured solar irradiation, ambient temperature and simple collector efficiency function.

4.3.2   Irradiation sensors

Typical problems on site:

- White frost on sensor
- Bird poo / dirt
- Partly or time dependant shading during the course of a day (check at installation!)
- Reflections from buildings collector etc.
- Condensed water in the sensor dome (partly shading)
- Condensed water on the sensor (electric. short)

Suggested automated detection method:

=> Matching measured irradiation with weather data from nearest weather station and additional sensor in the aperture area to avoid overheating or stagnation due to failures.

4.3.3   Flow meters

Typical problems on site

- fouling inside leads to decreasing flow detection
- null drift
- wrong parameterisation

Suggested automated detection method:

Synchronise with pump signal, null drift →check during, in general: check sensor range, check possible plant specific range, plausibility check with other sensors of the plant, check change of value, jump between two time steps, standby ...

4.3.4   Heat meters
- Inconsistent time stamps
- Drift of one temperature sensor!
- Summer and winter time problems
- Wrong parameterisation
- fouling inside leads to decreasing flow detection
- Missing data

Suggested automated detection method:

Check sensor range, check possible plant specific range, plausibility check with other sensors of the plant, check change of value, jump between two time steps, ...

4.4 Typical control problems:

4.4.1   Example: Solar collector system at BERGER Schinken Austria (FP 7 EU Project 'InSun')

Within the FP 7 InSun project a 1.067 m² big flat plate collector system has been installed at the ham producer BERGER in Sieghartskirchen, Austria, which supplies heat to the production process.
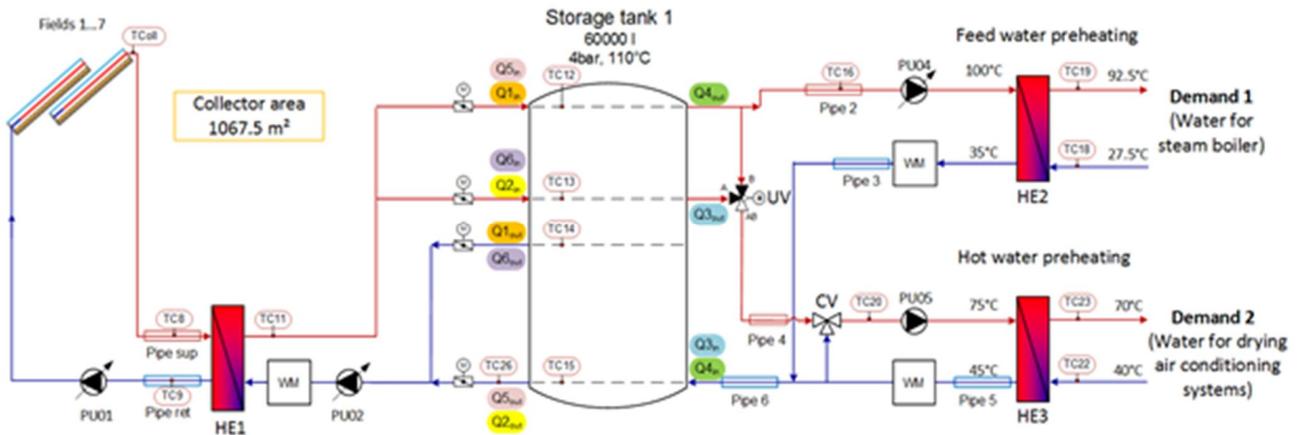

Figure 13: Simplified hydraulic scheme of the solar system integration at the company Berger within InSun

The produced thermal energy is mainly used to preheat feed water for steam boiler and the surplus heat is used to increase the supply temperature within the heating water system up to 70°C. The feed water (HE2) of the steam vessel shall be preheated from approx. 27.5°C up to 92.5°C. The steam is internally required for process heating – specifically for ham cooking. The hot water (HE3) is required for several heat sinks within the plant (cleaning, ageing etc.). First measurement data showed a strong fluctuation in the temperature of the solar loop.
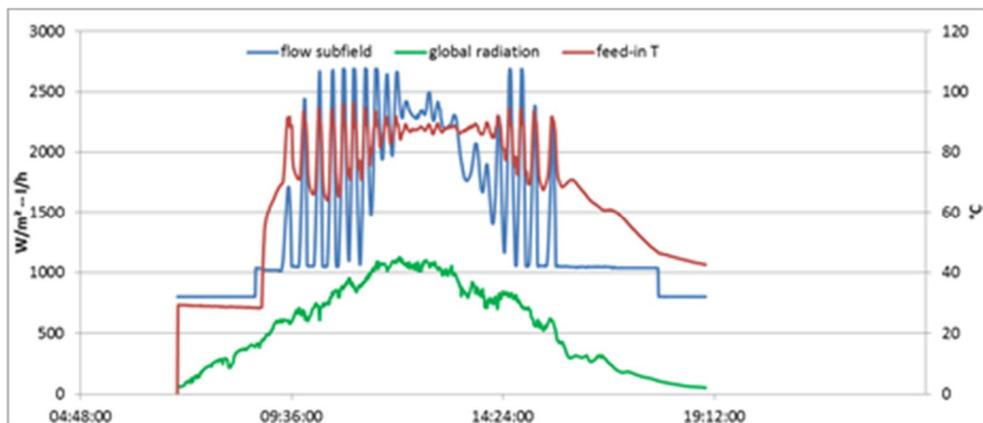

Figure 14: Measured data of the solar loop at the company Berger before improvement

Further detailed analyses showed that the problem was caused by the PID mass flow control of the collector pump. The main problem was the large distance between the sensor TC8 measuring the temperature of the return flow from the collectors and the collector field. This causes a quite high inertia for which the parameterization of the PID was not sufficient. To solve the problem the position of the sensor was moved closer to the collector field.
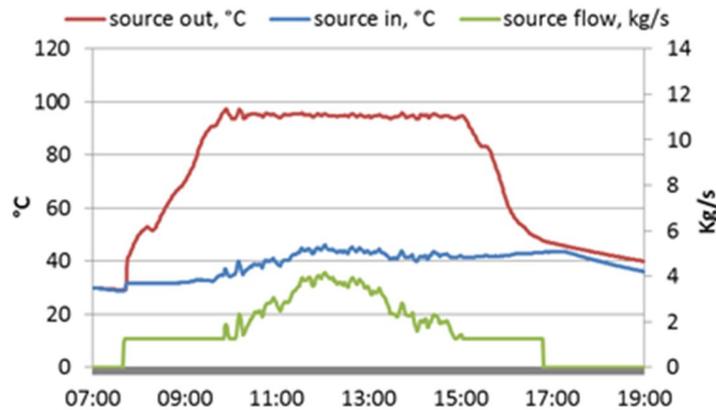

Figure 15: Measured data of the solar loop at the company Berger after improvement

4.4.2 Example from Office Building in Rohrbach, Austria (Source: Hilbert Focke, ASIC Austria)

Figure 16: Problems with three-way-valve, office building in Rohrbach, Austria

Several times problems arose regarding the three-way- mixing valve in the heat rejection cycle. The valve prevents invalid low return temperatures to the chiller, caused by ambient conditions, by admixing. The hydraulic design joint with the control strategy influences the water flow in the heat rejection device. The valve itself was often detected as cause of malfunction especially during recommissioning in spring.

➔ Possible automated detection method: Check of temperature values before and after three-way valve

4.4.3 Open wet cooling tower:

Such heat rejection devices should not be operated with too low flow rates since a certain pressure on the nozzle is necessary to achieve a good spraying and therefore a good use of the heat and mass transfer area. Figure 17 shows the example of an open wet cooling tower which should be operated at 7 m³/h in nominal conditions. Reducing too much the flow rate might lead to a not efficient spraying and therefore a significant reduced cooling tower performance. This can result in a nonlinear control behaviour which might cause problems with PID mass flow control or van speed control.

Figure 17: Water spraying at 1.5 m³/h (left) and 3 m³/h (right) (source: (Dalibard, 2014))

Possible automated detection method:

➔ Check of temperature values at cooling tower inlet and outlet and compare to calculated wet bulb temperature at ambient conditions multiplied with a cooling tower efficiency

➔ Check of temperature fluctuations between min. and max. outlet temperature values within a certain period e.g. 15 minutes.

4.5 Further sources for typical system errors:

- Appendix 1 of this document
- Sonne Wind & Wärme 2005: 10 wesentliche Fehler für Solaranlagen
- VDI 2169
- OPTISOL Endbericht – OPTISOL final report
- QAIST Projekt – QAIST Project

QAiST-Deliverables:

- "Recommendations For Further Needed Activities In The Field Of Function And Yield Control For Large Solar Thermal Systems"
- "Collection and Assessment of Available Function and Yield Control Concepts and Devices for Large Solar Thermal Systems"
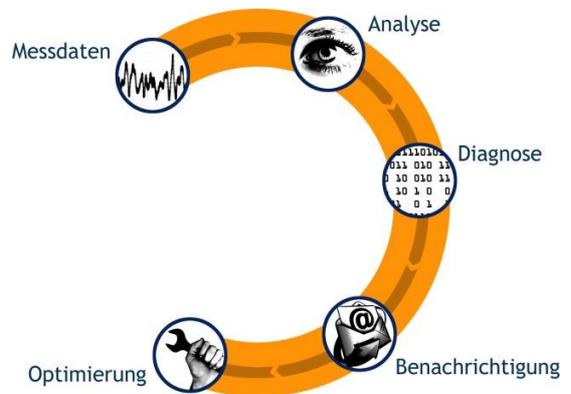
5. Existing error detection systems / ongoing development

5.1 METHODIQA (AEE INTEC, SOLID, Cerebra)

METHODIQA has been an Austrian R&D project from 2013 to end of 2014. The focus of METHODIQA is on **quality assurance for heat supply systems** that combine renewable and non-renewable energy sources. Main objective and result of the current project is the elaboration of the scientific and technical basis for a diagnostics system that aims at cost-effective but high-quality, computer-aided surveillance of system operation for large-scale applications. METHODIQA combines two important renewable heat technologies (solar thermal and biomass). Both renewable-only solutions as well as popular combinations of renewable and non-renewable technologies are investigated.

How does METHODIQA work?

METHODIQA uses the existing equipment (sensors, controllers) of biomass- or solar thermal systems; in general, it is not necessary to install new sensors or data loggers. METHODIQA evaluates different measurement data, such as temperatures, pressures, thermal power, energies, pump speed, valve position etc. The measured data are transferred, possibly in real time, from the controller or data logger to the **central METHODIQA database** which processes the data. The central storage of the operating data in the database also provides their long-term availability.

In the METHODIQA system, the operating data are prepared, filtered and checked for plausibility. The key of the system are   intelligent **algorithms** that analyze the operating data. These algorithms perform a comprehensive diagnosis of the data and calculate benchmarks that allow for a concise evaluation of the system operation. The intelligence of the system is capable of identifying malfunctions or unfavorable operating conditions.

Users will be able to control METHODIQA via a **web interface**: A web browser contains diagrams and shows current as well as historical operating data. In the browser, METHODIQA will also indicate information about malfunctions of the system. Other features will be available like data export, automated generation of reports etc.. Feedback from the system, alarm messages for example, will be available in the browser or via e-mail.

METHODIQA analyzes heat supply systems based on their operating data, but it does not influence the system control actively (it is a "passive system"). Hence, it is excluded that METHODIQA intervenes directly in the control or operation of the heat supply systems. The strength of METHODIQA is to provide clear and concise analyses of short or long term system data, so system operators have a straightforward means to take the right decisions about how to operate their plants.

METHODIQA is an ongoing research project. It is not yet possible to predict when METHODIQA will be commercially available as a tool or service. However, interested research institutes and plant operators are

24

invited to get in touch with the project coordinator in order to test evaluation algorithms or simply for information exchange.

Figure 18 to Figure 21 shows the actual vs. expected collector field thermal power output and efficiency for a particular plant for 1 year of operation. The presented graphs show the results from an algorithm-based evaluation of quasi-stationary operating conditions.
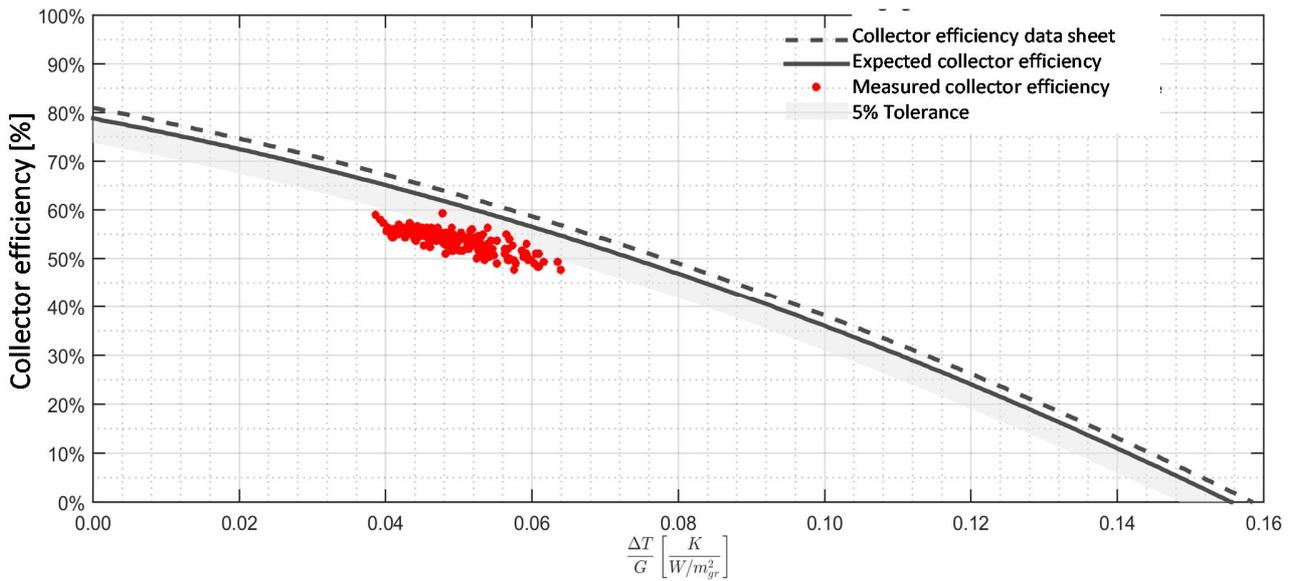

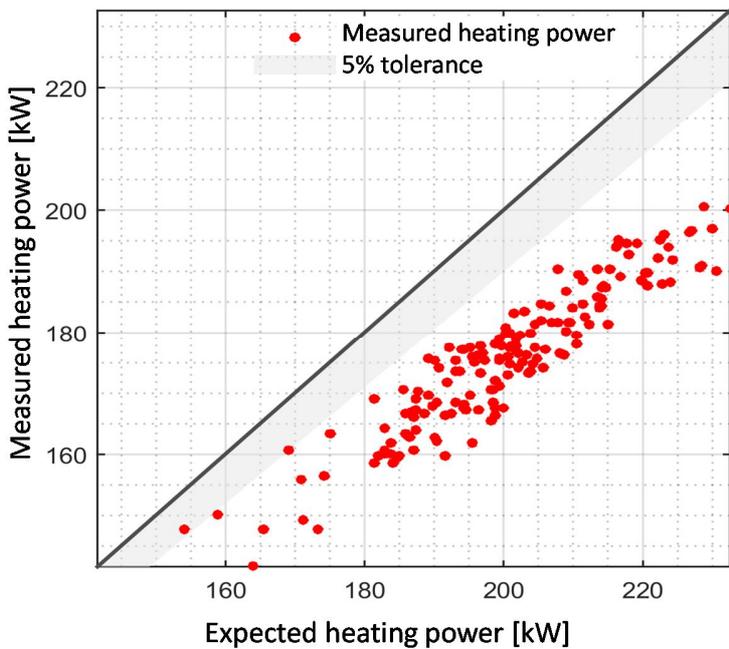*Figure 18: Measured versus expected collector efficiency*

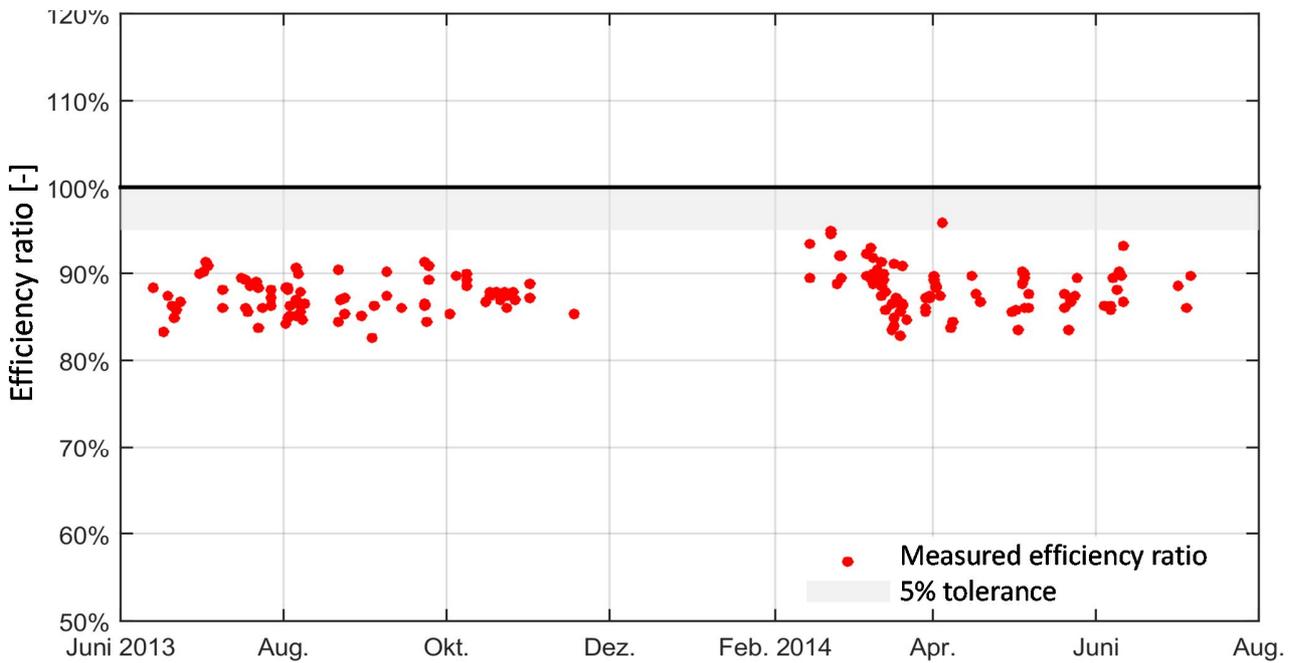*Figure 19: Measured versus expected collector heating power*

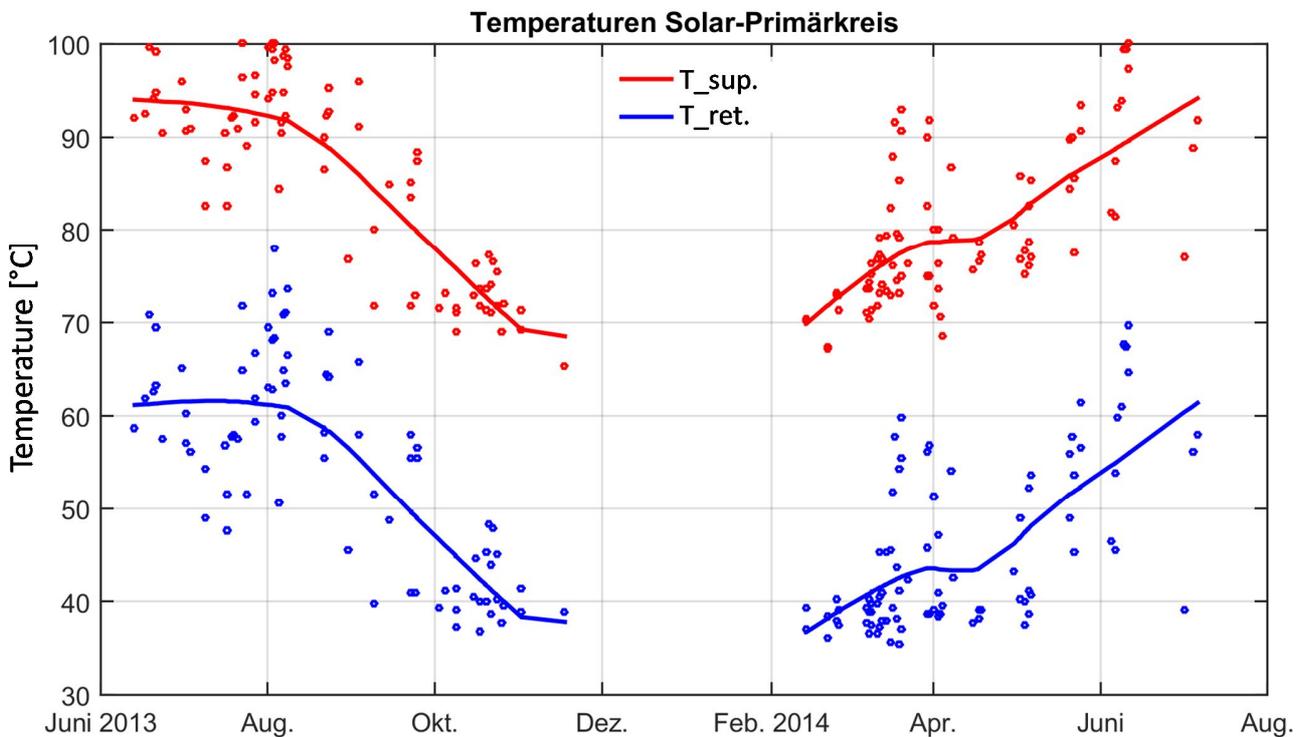Figure 20: Ratio between measured and expected collector field efficiency

Figure 21: Temperatures primary collector circuit

Contact details: Philip Ohnewein, AEE INTEC, p.ohnewein@aee.at, +43 3112 5886-255

5.2 FP7 InSun Project on solar process heat

Within the EU FP 7 InSun Project (solar process heat) zafh.net implements two error detection methods:

5.2.1 General fault detection method

An automatically started MATLAB routine loads daily data files and performs the following tasks:

a. it checks the quality of the data by finding out how much values are missing
b. it handles the measurements to fill in as much empty data sets as possible
c. it checks the consistency of the data to be in a physically acceptable range
d. it cross checks the sensor values of 'similar' sensors
e. it checks the steady-state performance of some sub-systems
f. it runs an external plant model and compares the main system performance indicators between measurement and simulation.

The output of the first task is a quality mark indicating how reliable the results of the following tasks are. The data are handled to fill in empty sets with interpolated values. The output of task c and d is a list of sensors being out of range. Two tolerance bands are applied in this level to find out 1) which sensors are totally unreliable and to be filtered out and 2) which ones have a slightly strange behavior and to be manually analyzed. In step e, the handled data are filtered and split into time frames with stationary behavior (for e.g. mass flow, temperature, radiation). Energy balances excluding -generally unknown- heat capacity terms are then applied to check the efficiency of some sub-systems like the piping, the storage and the collector filed and detect any deterioration over the time. The following figure presents the evolution of the data volume through the analysis steps described above. It corresponds to the temperature and flow data of an isolated piping system.

7165 raw data under which 6820 are numeric

7005 numeric data after handling

2590 data after filtering
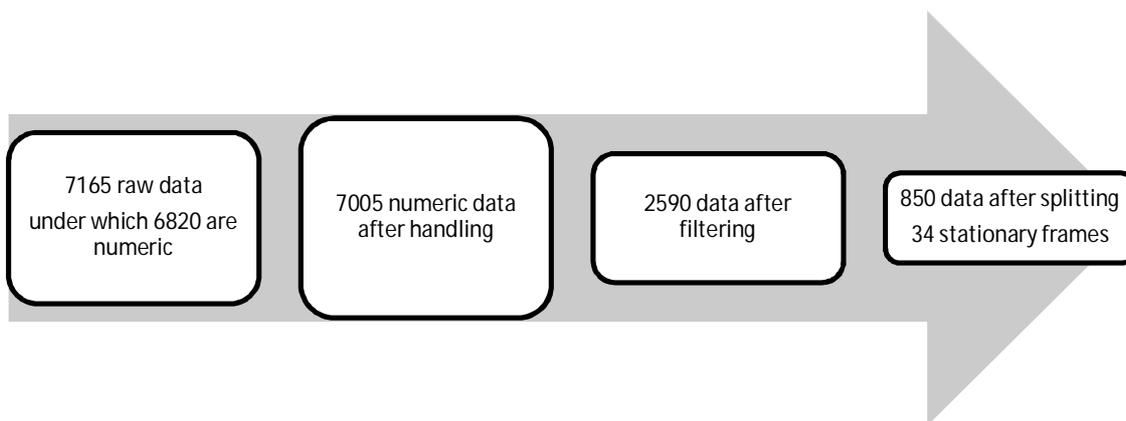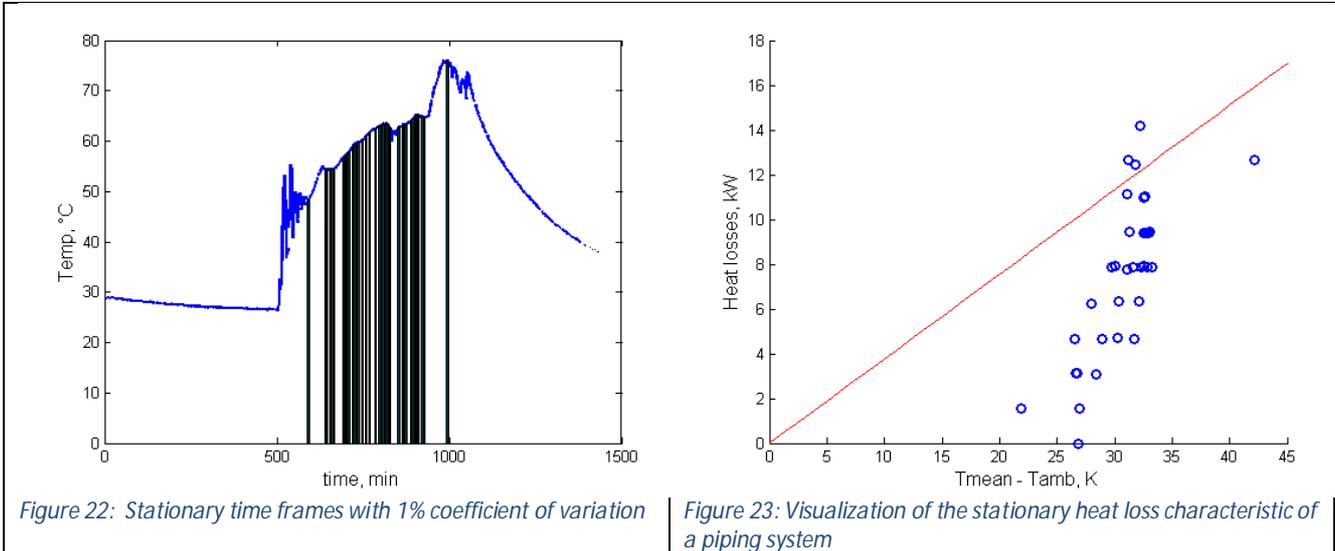
850 data after splitting 34 stationary frames

Fig. 1 Example of data volume evolution for a piping system

The figure below shows exemplarily the stationary time frames obtained when a coefficient of variation (relative standard deviation) of 1% is applied to the blue temperature profile. Each circle in the right hand side

figure corresponds to a time frame. during 3 of 34 time intervals the heat losses are beyond the expected value.

Figure 22: Stationary time frames with 1% coefficient of variation	Figure 23: Visualization of the stationary heat loss characteristic of a piping system

In the last task, zafh.net uses dynamic system simulation tools running in parallel to the real system to daily or weekly compare the measured performance with the simulated expected performance (see Figure 24). Contrarily to the last step, the models used consider heat capacity effects in the different parts of the system. This is very helpful to quickly check whether the installed system reaches the expected performance during commissioning and to detect performance degradations during long term operation.
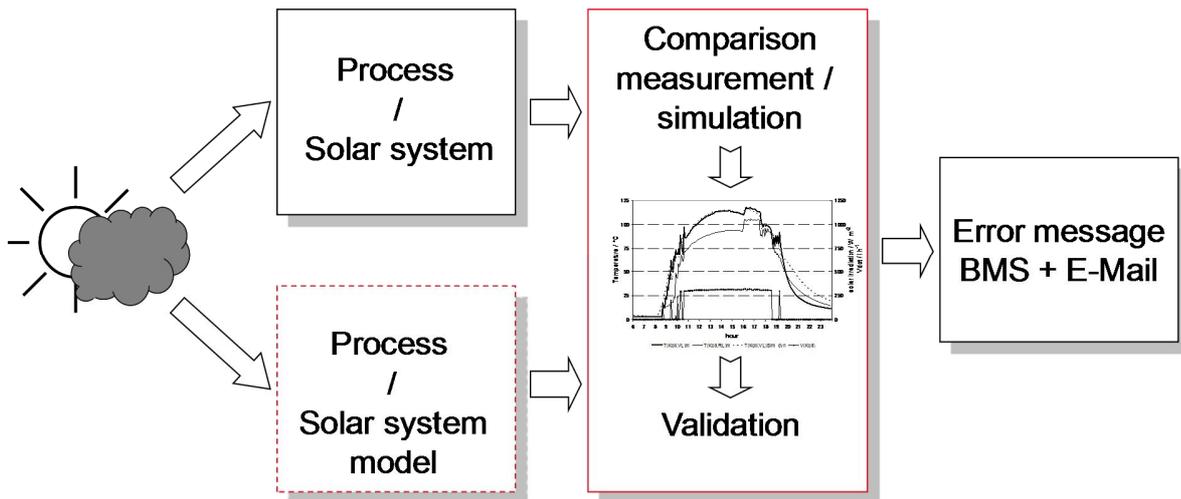

Figure 24: Simulation based system observation (source: Pietruschka)

5.2.2 Sensor drift detection method

Based on the work of Kumar (Kumar 2013), a two-step drift detection algorithm was implemented. For each sensor an estimated value is determined using the values of 'similar' sensors. Afterwards the drift of the sensor is calculated by means of a Calman filter. The method was applied for a set of humidity sensors, where similar sensors mean sensors in neighboring rooms. The application of the method for a solar thermal system is pending.

5.2.3 The spectral method

It is planned to implement this third detection method in the frame of the InSun project. The method builds upon the work of Räber (Räber 1997). Räber presented a spectral method, based on Fourier transformation of a temperature step response signal and a subsequent pattern comparison in the frequency domain. A frequency mode outside the previously defined safe range indicates a malfunction in the system.

This method, limited to the solar circuit, was tested for two small scale systems in Switzerland (Grossenbacher, 2003). Dirty glass, or a reduction of collector performance can be detected if the loss of power is large enough, e.g. 40% reduction of collector performance. Furthermore, air in the collector or in the heat exchanger could be easily detected. A reduction of at least 20% in volume flow was recognized. Also a change of DT-settings with about 20% can be recognized for the low flow system (De Keizer 2011).
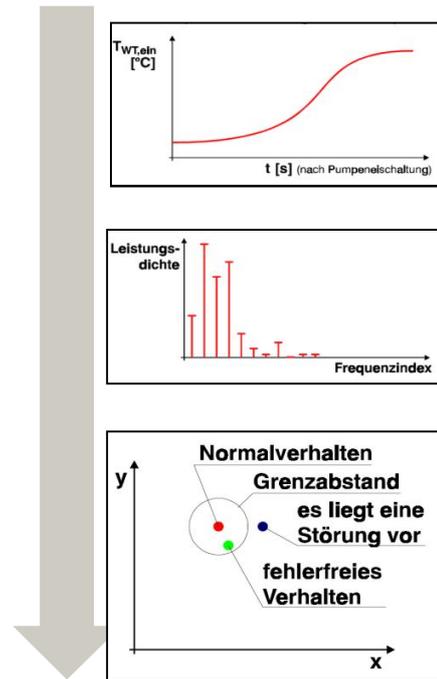
Figure 25: The spectral analysis steps (Grossenbacher, 2003)

![SHC Solar Heating & Cooling Programme - International Energy Agency]
Quality Assurance & Support Measures for Solar Cooling / www.iea-shc.org/task48

Task 48

5.3 New project of ZAE

ZAE has a new project which deals with self-detection procedures implemented in the controllers for fault detection of pumps. The idea is to use the auxiliary power consumption ratio according 'APCR' as indicator for the fault analysis and detection.

Specific Auxiliary Energy consumption for the total solar collector system (state of the art)

In the developed error detection method the ratio between transferred thermal energy from a heat source to a heat sink and the therefore required electricity consumption, caused by the circulators in a certain period of time e.g. 24h, is defined as Auxiliary Energy Consumption Ratio (AECR). Thus, even allows a direct comparison and validation of the hydraulic efficiency among different installations with different cooling capacities. Maximum, minimum and average limit values are defined in order to detect malfunctions of the components or control strategy. As shown in the following chart for the collector circuit the red line marks the design point AECR Solar of a 57m² collector field with a speed adjusted high efficiency pump (max.170 Watts at 100 %) for part load adoption in relation to the current insolation on the collector aperture area.
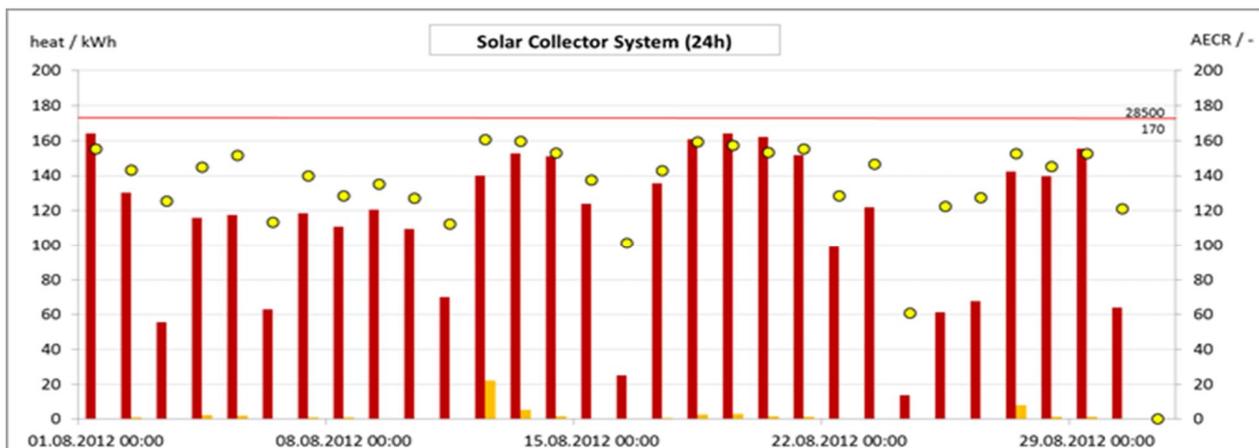

Figure 26:Transferred thermal energy from the solar system and AECR

While the AECR is below 120 when only a small amount of heat is generated, due to the heating-up process, a higher overall specific efficiency of about 150 is obtained at nominal conditions. In this case, comparable heat gains during a day show similar AECR values. In addition to that, it is possible to allocate the auxiliary energy consumption per kWh thermal energy to several heat consumers. In this way e.g. Seasonal Performance figures for solar cooling, heating and domestic hot water preparation can be calculated separately for each sub system. The following graph shows the same procedure for the cooling water circuit. Due to intelligent part load adaption the specific electricity consumption per transferred thermal energy from the chiller to the cooling tower is rather constant in a wide capacity range. Monitoring the daily AECR values over a longer period of time could assist by setting maintenance intervals or even to identify e.g. blocked filters or damaged pumps.
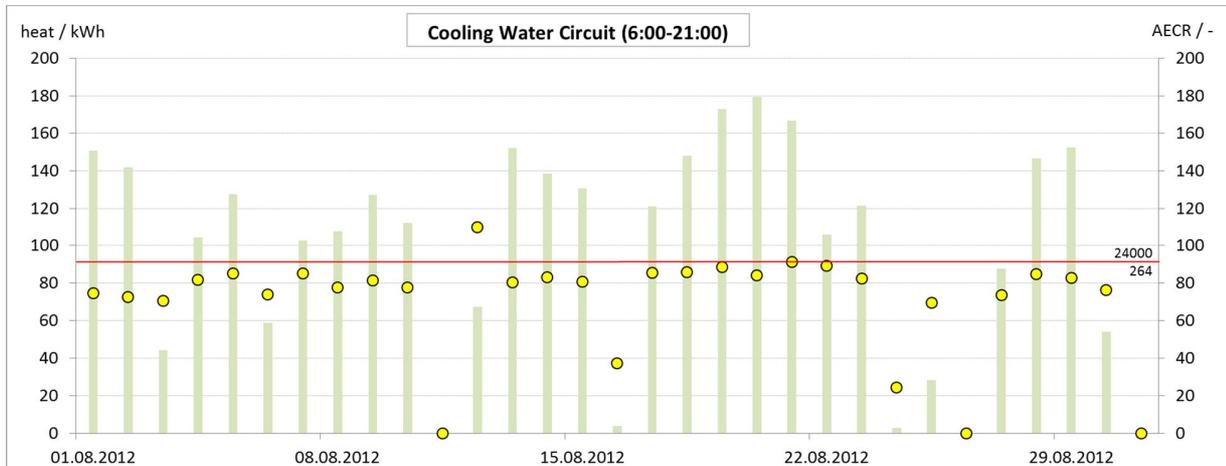
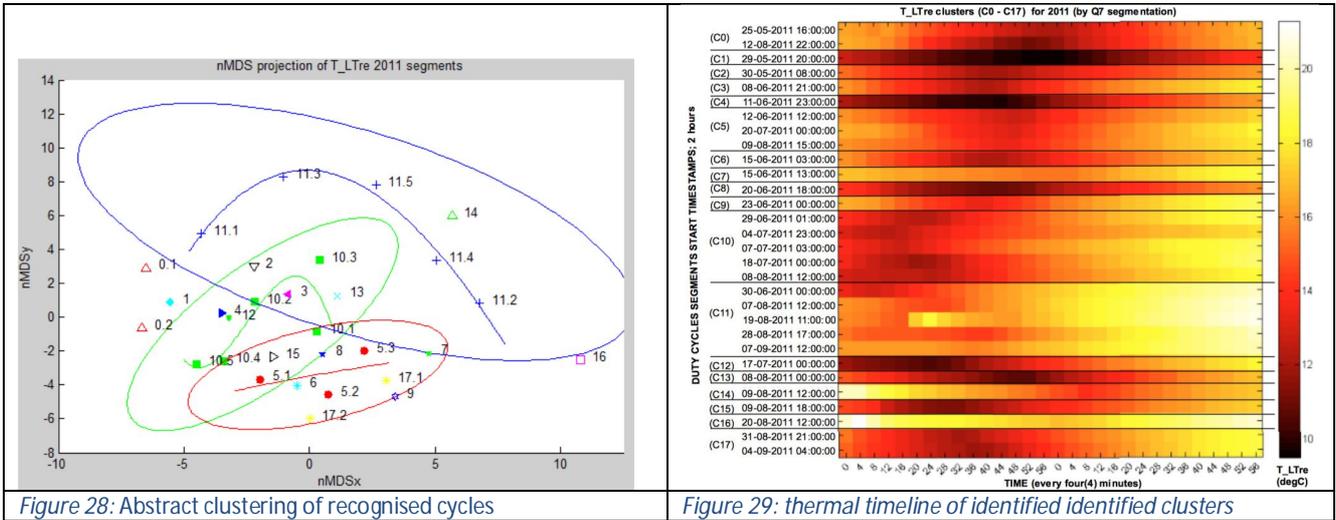*Figure 27: Transferred heating energy by the cooling circuit and AECR*

5.4 extrACT Project of AIT

The project extrACT[1] looks into the possibilities of detecting unusual behaviour in solar cooling devices automatically using tools from machine learning, and asses this behaviour energetically and provide input to the operator of the installation. The focuses in on absorption chillers, as nine installations are available as data sources. The approach op extract is a holistic one, trying to track the data from source to sink, and correct or mark data on the various steps to make sure the results are actually meaningful.

On the lowest level, the completeness of the data and its quality are checked, based on predefined values for physical ranges, intervals between measurements, possible physically plausible variation of a given sensor within the time between two measurements and so on. In the next step, violations of the conditions given above are subsumed for the operator, as well as corrected if possible. Single missing values for example can be interpolated either from the current behaviour, or from the overall behaviour of the system.

Once a reliable set of data is left, the tools of machine learning can be applied. As a first step, operations cycles are detected in the data set - operation cycles being defined as periods where there is a continuous operation of the thermally driven cooling engine, not he internal workings of the engine

---

| *Figure 28:* Abstract clustering of recognised cycles | *Figure 29: thermal timeline of identified identified clusters* |

These operations cycles are then clustered into cycles with similar using the x-means algorithm. Afterwards, they are assessed energetically. Interesting are mainly clusters with a low performance and a high amount of energy involved. These clusters can then be presented to the operator of the installation, along with corresponding data e.g. date and time (for unusual usage) or outside temperature (for levels outside the design conditions). Based on this information the significance of a cluster can be determined.
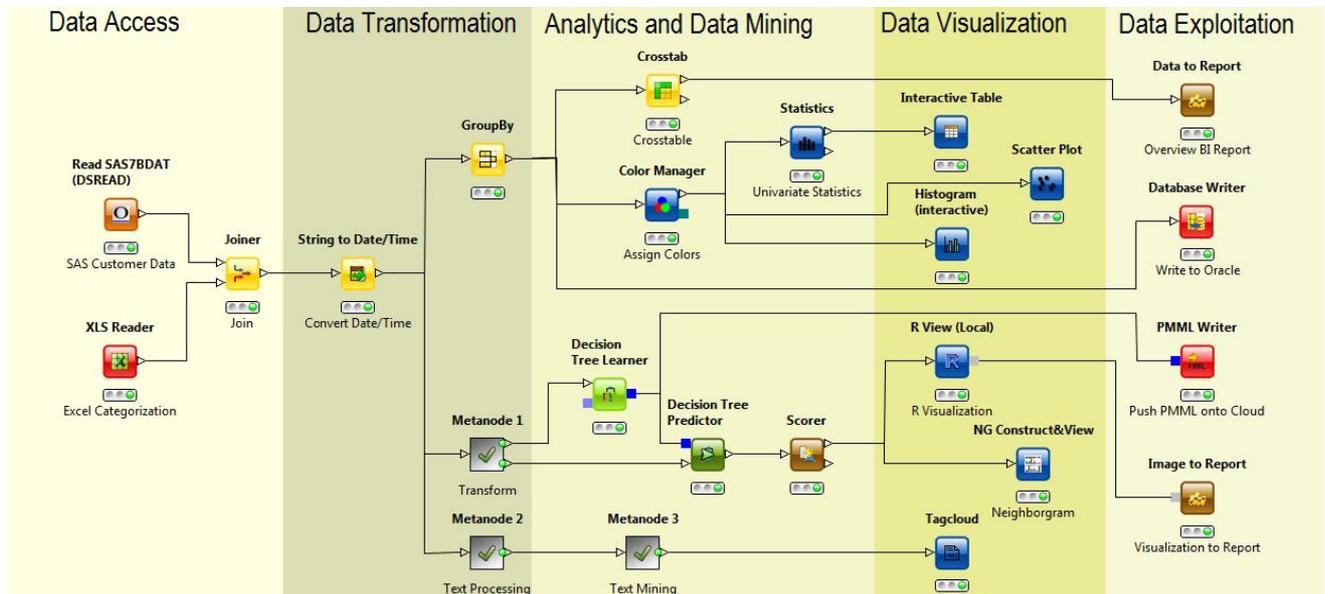

Figure 30: Screenshot of the KNIME

The overall approach is of curse recursive, with the assessment by the expert leading to new parameters to be incorporated into the analysis, allowing for more automatic diagnosis of clusters, and reducing the amount of

expert input needed. For advancing the method, also the KNIME[2] (formerly known as Konstanz Information Miner) is employed. This tools already has many features involved built in, and can be used to test the whole cycle of information retrieval from the installation to the operator can be realized in a single tool.

5.5 Fault detection and diagnosis (FDD) procedures for solar driven desiccant evaporative cooling systems (Politecnico di Milano: A. Frein, M. Muscherà)

In this chapter a developed fault detection and diagnosis system (FDD) developed at the Politecnico di Milano by A. Frein and M. Muschera for desiccant evaporative cooling systems (DEC) is presented and discussed.

5.5.1 Introduction

In a mechanical system, we can observe two possible problems:

- Breakdown: a component does not work
- Underperformance: a component behavior does not match the expected performances

In order to detect both types of fault, we decided to follow different approaches. A simple rule-based FDD tool was designed to detect the first type of problems, such as stuck valves, broken pumps, or other damaged components. The analysis is based on a set of logical rules each returning a true-false value. Verifying every single set of rules, it is possible to evaluate the correct components function, according to the control strategy statements. This is a daily analysis, performed by the maintenance staff, so the tool has to be very fast and simple. The software selected is Excel/VBA, with a macros set that enables the automatic reading of the system variables (from the data acquisition program) and pdf report generation.

The underperformances detection follows an alternative way. First, it is necessary to select the components that heavily effect overall plant performances. The analysis consists in the comparison between real components behavior and the expected one. The expected operations may be considered as the nominal situation that is the performance declared by the manufacturer on technical sheets. For this purpose, a model based FDD tool was implemented in Matlab, where a dynamic mathematical model reproduces the nominal behavior of the selected components, compared with the real one. If the observed difference exceeds the uncertainty limits, we can state that there is a faulty function.

	Level 1 FDD	Level 2 FDD
Fault	Breakdown	Underperformance
Approach	Rule based	Model based
User	Maintenance	Designers
Frequency	Daily	Seasonal
Software	Excel/VBA	Matlab

---

[2] www.knime.org

5.5.2 Rule-based FDD tool

The Excel tool designed for the daily FDD consists in a two level analysis: the first level investigates the supply air conditions, in order to assess the matching with the desired set point (temperature and humidity). The further analysis refers to each operation mode[3]. It is possible to identify three main elements composing this rule-based FDD:

- Logical condition: set of simple rules that have to be verified.
- Saturation time: time that has to elapse before the fault message generation. This is a necessary step, in order to take into account the components inertia and the actuators response delay.
- Answer: logical condition result (True or False).

In the following, a short description of the application on the POLIMI Solar DEC system is presented. For a brief example of the final automatic report, see the chapter 4.5.4.

5.5.2.1 Set point analysis

In this phase, the aim is to evaluate the inlet air conditions and to compare them with the predefined set points. We can define different levels of fault:

- Error: it is a serious fault, probably due to the breakdown of an important component. It has to cause the highest alert level, and the problem has to be fixed as soon as possible.
- Warning: it is a lighter problem, the system can operate and the inlet air conditions are considered acceptable, but it requires the maintenance staff investigation. The operation mode analysis will state if this response is caused by a problem occurred on a secondary component or if this is a temporary and normal operation behavior.

In the set point analysis, we can distinguish errors and warnings by the size of the difference between set point and measured supply air temperature and humidity, defining two different limit boundaries.

---

[3] The control strategy of the system is based on the "Finite State Machine" method, where only a predefined set of components is active according to the environmental conditions 0.
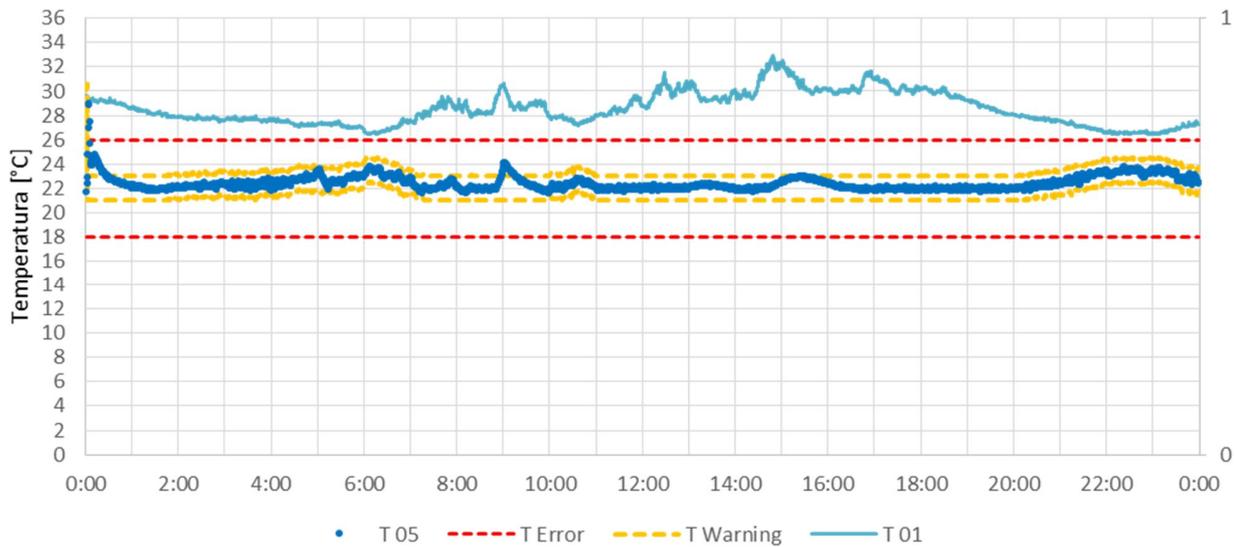
Figure 31: Temperature set point analysis. T01 is the external air, T05 is the supply air. The red boundaries represent the error limits, the orange lines the warning limits.

In this example, the supply air temperature is under investigation. It is possible to see short instabilities due to the response delay of the components to the variations of the external air (T01) temperature. This situation does not affect the internal comfort conditions, so a simple warning message is generated, but the maintenance staff has to investigate the reasons of this instability through the operation mode analysis.

5.5.2.2 Operation Mode Analysis

In order to investigate deeply the system behavior, we developed a detailed rule-based analysis applied to each operation mode. In this phase, the system is split into different subsystems. The number of components involved in each subsystem depends on the number and position of sensors. The more the sensors, the smaller the subsystems. The subsystem dimension implies the final response precision. With few sensors and large subsystems, we cannot state precisely the faulty component, but we can only indicate a set of various components that could be in trouble. The point is to find a compromise between number of sensors and the real diagnosis precision level needed.

The logical conditions of this analysis are based on the definition of trigger values: for every component or subsystem working in the operation mode under investigation, we can define a minimum or maximum value that represent the faulty behavior limit. For example, in the following we can see the humidifier and the heat exchanger operations during the IEC (Indirect Evaporative Cooling) mode (Aprile M., et al. 2012).

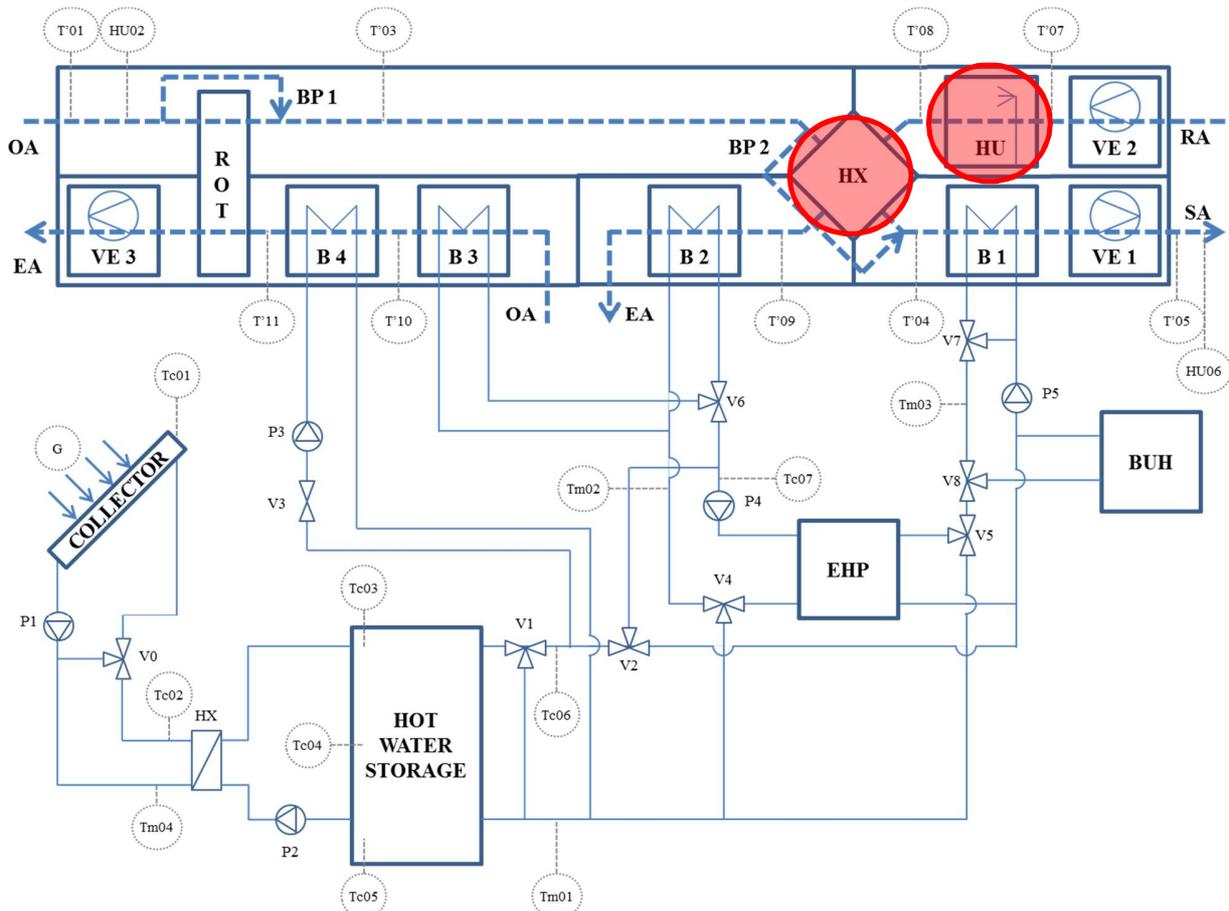*Figure 32: POLIMI SolarDEC scheme. Humidifier (HU) and heat exchanger (HX) are highlighted in red.*

Because of the complexity of the system and of the mutual influence between components, it is necessary to develop a logical conditions flow. The logical flow drives the conditions verification; otherwise, we could generate a fault of a specific element caused by another element faulty behavior.

Figure 33:: Logical scheme for the IEC mode fault detection and diagnosis.

During the humidifier regular operation, we expect a minimum cooling power of 2,5 kW; setting this value as a trigger, the error message is generated under this limit and after the defined saturation time. The humidifier fault is generated only if the VE02 fan is active and not in fault, otherwise we could see the humidifier error caused by the fan stop.

Figure 34: The cooling power provided by the HU is higher than the trigger limit, so no fault message is generated.

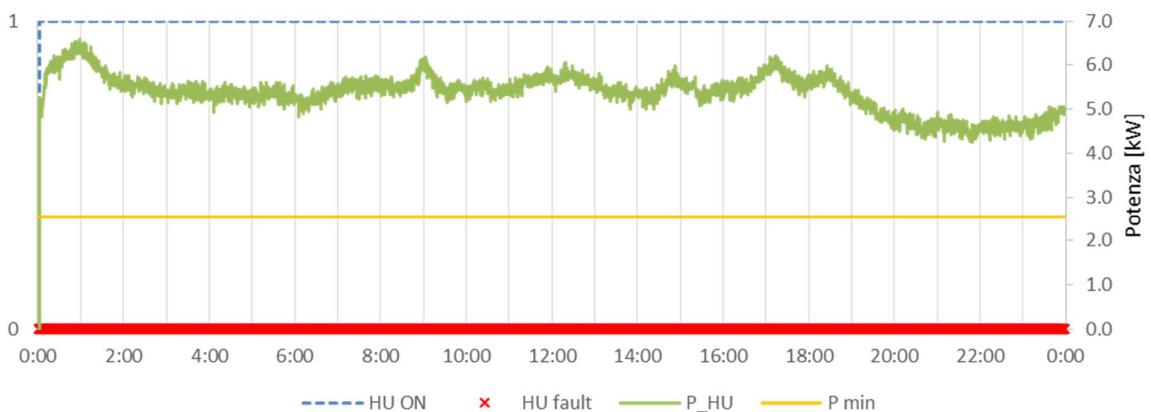Similarly, we set a trigger efficiency for the heat exchanger. We expect a minimum efficiency of 0,4. Under this limit and after the saturation time, the fault message is generated, but only if VE01 and VE02 fans are active and not in fault and if the control strategy closes the HX bypass duct (BP2).
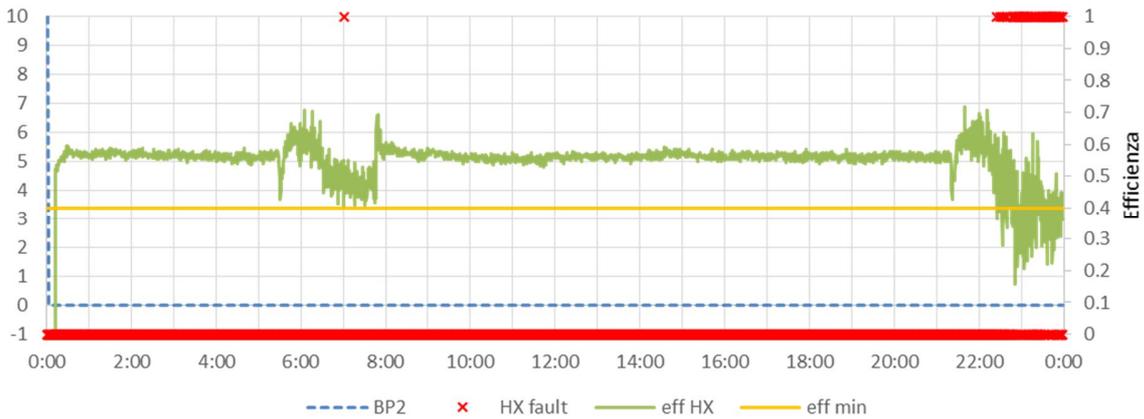

Figure 35: The exchange efficiency falls sometimes under the trigger limit. This is caused by the limited difference between the inlet air flows temperatures. This example is crucial to understand the importance of this procedure, that here gave us the possibility to recognize a control strategy problem: when the inlet T difference is too low, it is convenient to open the HX bypass. In fact, we could sacrifice the limited heat recovery in order to save electrical energy, because opening the bypass means to have less pressure drops in the supply air duct.

As a further example, the solar pump function (P1) is investigated. In correct function, when the P1 pump starts, the collector temperature (Tc01) raises and the inlet fluid temperature (Tc02) at the heat exchanger performs the same way (sensors in series). Taking into account the thermal losses between Tc01 and Tc02, the P1 fault is generated under the following conditions: if the P1 pump is active for 15 minutes (saturation time) & Tc01-Tc02 (see the plant scheme for the sensors position) is over 6℃, P1 fault = TRUE.

Figure 36: P1 pump operation. Regular behavior.

Figure 37: P1 pump operation. Faulty behavior. The control states the ON command, the collector temperature grows but the temperature at the heat exchanger does not grow.

5.5.3 Model-based FDD tool

When it is necessary to calculate and compare performances of crucial and complex components or subsystems, a model-based approach becomes more suitable.

Figure 38: model-based approach scheme.

First, because of the big efforts required, it is important to select the most influential and complex subsystems. In the POLIMI SolarDEC plant, we selected the solar thermal, the heat pump and the desiccant wheel.

For each subsystem, a dynamic mathematical model reproduces the theoretical behavior. Theoretical means based on the manufacturer performance data or on laboratory test results. The modeling approaches are

different, such as white, black or grey box. For the solar plant, we followed a white box method, for the desiccant wheel a pure black box approach, and for the heat pump a hybrid road (grey box). For further information, see (Frein, A. et al. 2014)0.

In order to keep into account the measurement and the simulation accuracy, an uncertainty analysis was built to draw the uncertainty cone on the x-y result graph, where on the x-axis we put the measured value and on the y-axis the simulated ones. If a point falls out of the uncertainty range, a possible fault is occurred on the investigated subsystem.

Where:

- Q_{theo}: theoretical simulated value.
- Q_{real}: real measured value.
- $\Delta Q_{theo,up}$ - $\Delta Q_{theo,low}$: maximum uncertainty width (upper and lower) of the theoretical simulated value.
- $\Delta Q_{real,up}$ – $\Delta Q_{real,low}$: maximum uncertainty width (upper and lower) of the real measured value.
- Q_{ideal}: the ideal condition, represented by the perfect correspondence between measured and simulated results.

Figure 39: Uncertainty cone definition and result representation.

For the detailed description of the uncertainty calculation methodology, please see (Frein, A. et al. 2014).

The analysis can be operated on different periods:

- Long period analysis: comparison of daily values.
- Daily analysis: comparison of values calculated every 10 minutes.

For example, the application of the procedure to the POLIMI SolarDEC solar system and to the heat pump gives the following results.

The performance figure selected for the solar plant is the solar gain, that is the energy transferred through the heat exchanger by the solar collector loop.

Figure 40: Solar system results: the daily analysis on the left and the periodic analysis on the right.

The results show the good matching of the measured performance with the theoretical one.

The electrical reversible heat pump presents acceptable results for the cooling energy, even if the real values are higher with one compressor.

Figure 41: Heat pump results, cooling power.

The electrical energy required is much higher in the real situation, compared to the technical sheet performance tables. The result points fall out of the uncertainty cone.

Figure 42: Heat pump results, electric power consumption.

These examples show the importance of an accurate analysis on this kind of components, allowing the detection of dangerous deviation from the correct behavior during the component life cycle. The descripted deviations, not easily detectable without a detailed investigation, drive considerably the whole system performances, in terms of thermal and electrical consumption, so this continuous monitoring procedure becomes crucial to understand the real system potential.

6. Conclusions

Within this work a classification has been develop to group typical system errors in Systematic-, Sensor- and control errors, component defects and component performance degradation. For each group typical error sources and possible detection method are described. Collected practical examples 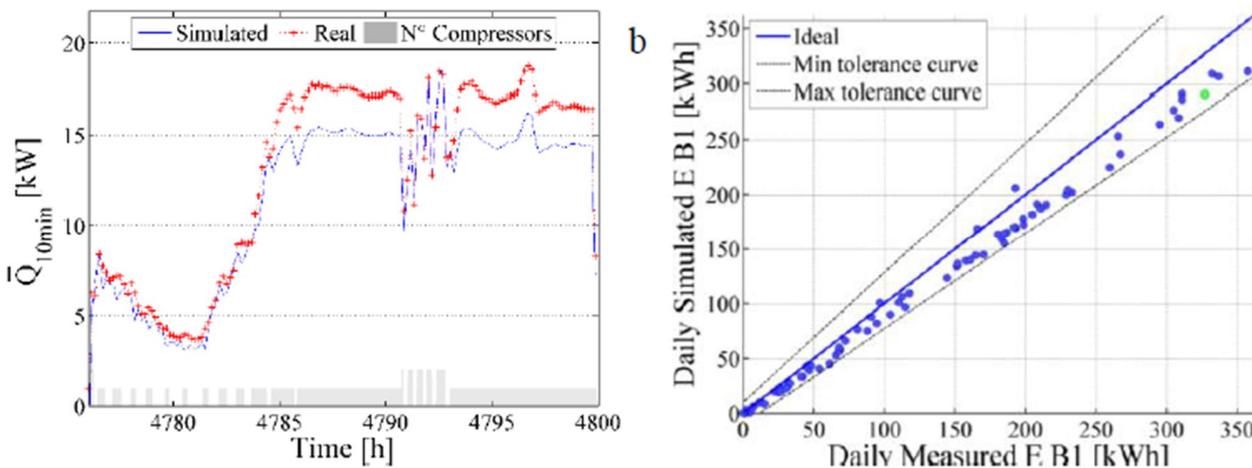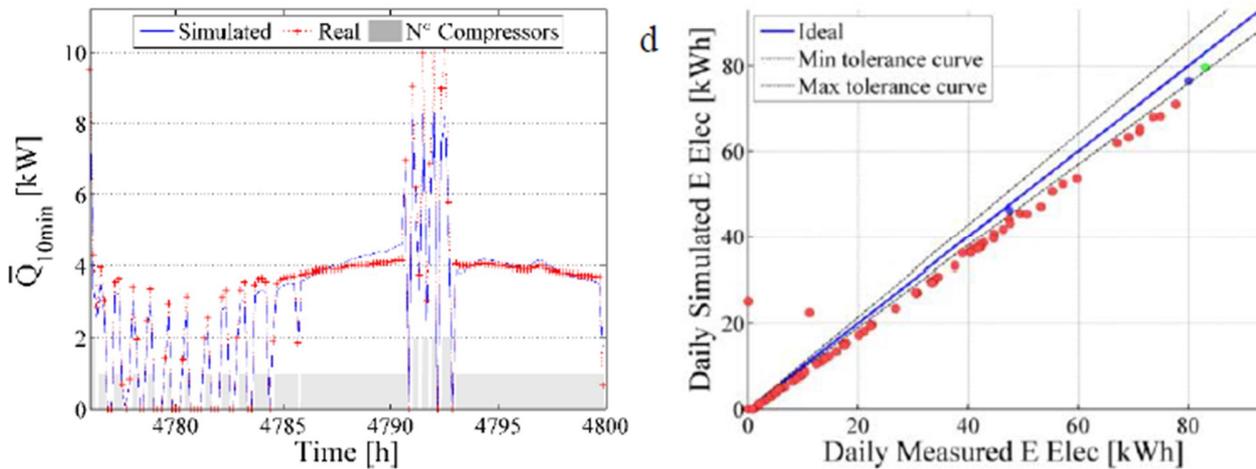from real projects are described, with the aim to help increasing the awareness of the presence of such system errors/malfunctions and to show possible detection methods. There are some research tasks ongoing which aim to atomize the error detection in practice. Four examples of currently ongoing research work are presented, to show different possible solutions and methods used. However, all the examples show, the automated error detection especially of not obvious mal functions and slow degradations can be a very useful tool with high potential to increase the energy efficiency and reliability of solar cooling systems over a long operational time. At present only some error checks and detection routines are used in some system controllers, but there are no advanced systems for automated error detection on the market, which highlights the need of further research and development in this important direction.

7. Bibliography

References

Dalibard, A. (2014). *Progress report of the research project Solarück - Efficient heat rejection for solar thermal cooling.*

Dalibard, A., & Eicker, U. (2010). Primary energy optimisation of a solar adsorption cooling plant through dynamic simulations. *Eurosun.* Graz, Austria.

Gamblin, J., Haller, M., & Ayadi, O. (2009). *Literature study on uncertainty in solar collector testing - Solnet Course.* Prague.

Holter C. et al. (2012) Development of the prototype IP-Solar: A web-based monitoring and diagnostics tool for solar thermal systems. Energy Procedia Volume 30, 2012, Pages 134–143 1st International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2012)

Kumar D. et al. (2013) Automatic Sensor drift detection and correction using Spatial Kriging and Kalman filtering. IEEE International Conference on Distributed Computing in Sensor Systems (DCOSS), Cambridge

Räber R. (1997) Spektralmethode zur Fehlerfrüherkennung in wärmetechnischen Anlagen. Dissertation. ETH Zürich; 1997.

Grossenbacher, U., 2003. Qualitätssicherungssystem für Solaranlagen; Methode zur permanenten Funktionskontrolle thermischer Solaranlagen. Energie Büro Grossenbacher, Murten, Switzerland.

De Keizer A.C. Review of long-term fault detection approaches in solar thermal systems. Solar Energy 01/2011; 85(7):1430-1439. DOI: 10.1016/j.solener.2011.03.025

Frein A., Aprile M., Muscherà M., Scoccia R., Motta M., A continuous commissioning analysis and its application to a new installed solar driven DEC system coupled with heat pump. International Conference on Solar Heating and Cooling for Buildings and Industry, SHC 2014.

Aprile M., Scoccia R., Motta M., Modelling and control optimization of a solar desiccant and evaporative cooling system using an electrical heat pump. Energy Procedia, Volume 30, 2012, p. 478–489.

APPENDIX 1: SUMMARY OF DETECTED ERRORS IN SOLAR THERMAL SYSTEMS AND HVAC SYSTEMS

Assignment of MA34 small scale solar adsorption cooling plant to detect listed errors

Authors: Anita Preisler, Benedikt Wanke, AIT

Date: 14.04.2014

Error detection – Performance

2006-12-27 - Funktionskontrollen bei kleinen Solaranlagen ohne Wärmemengenmessung - Horst Altgeld - 6p (short version)

Errors	Sensors
Swapped collector connection → pump is in on/off mode Detection: running time < 10 sec. (minimum pump running time)1	T_COLLre, T_COLLsu
Collector sensor wrongly positioned → pump is in on/off mode Detection: running time < 10 sec. (minimum pump running time)2	T_COLLre, T_COLLsu
leakage of the solar heat exchanger → System pressure too high Detection: (T_{Kol}=20°C) AND (p_{System}=$p_{System,soll}$ +2 bar)	T_COLL, PR1
solar heat exchanger calcified	-
inlet pressure in the expansion tank too low → system pressure temporarily to high	
inlet pressure in the expansion tank too high → system pressure temporarily too low	
Stop valve in the solar circuit closed → DeltaT too high Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Cable break between controller and pump → DeltaT too high Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Collector temperature sensor broken/imprecise → wrong DeltaT → Pump runs at incorrect times Detection: (R £ R$_{min}$) OR (R³ R$_{max}$) (resistance sensor)	T_COLLre, T_COLLsu,
Inputs of the controller broken → DeltaT too high, Pump runs at night Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Outputs of the controller broken → DeltaT too high, Pump runs at night Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Software of the controller broken → DeltaT too high Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Incorrect setting of the volume flow → DeltaT too high Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Wrong venting → DeltaT too high Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Check valve open → Pump runs at night Detection: (Pump „on") AND (time between 10 pm and 6 am)	PU1_%,
Check valve soiled → Pump runs at night Detection: (Pump „on") AND (time between 10 pm and 6 am)	PU1_%,

dT-setting inappropriate → DeltaT too high,operational instructions Detection: (Pump „on") AND (DeltaT=DeltaT$_{Soll}$+15K)	PU1_%, T_COLLre, T_COLLsu
Time programmed incorrectly → Pump runs at night Detection: (Pump „on") AND (time between 10 pm and 6 am)	PU1_%,
blackout→ System pressure too high Detection: (T$_{Kol}$=20°C) AND (p$_{System}$=p$_{System,soll}$ +2 bar)	T_COLL, PR1
current anode broken → storage tank corroded Detection: Current measurement implemented in new regulator	-
natural convection at night caused by a short pump run time in the evenings Solution: Usually the spring force of check valve (gravity break)is sufficient in order to suppress the short pump run time	-

Fa PHÖNIX - Montagetipps und Fehlervermeldung

T$_{coll}$ at the controller warmer than in reality → supply and return swapped	T_COLLsu, T_COLLre,
During filling via return flow connection: if T$_{coll}$ falls instantly and not after some minutes → sensor is situated at the supply flow connection	T_COLL
Collectors are connected at the bottom of the solar station → Pump runs in the supply and is exposed to high temperatures → System runs contrary and heat is extracted from the storage tank	T_COLLsu, T_COLLre, T_SOLsu_1, T_SOLsu_2, T_SOLre
Improper rinsing/filling → Air gets in the solar circuit Solution: Care; de-air at the highest point and mount a vent ; mount a permanent ventilator (Airstop) (no alternative but additional security)	-
Flow problems by soldering residues, scaling from the absorber/the heat exchanger, other materials (sand, insects, etc.) Solution: rinsing, dismount and manual cleaning (very laborious)	-
Pump connected to the wrong terminals→solar pump not operating or operating uncontrolled	PU2_%
Controller gets very wet (moisture damage) → Display broken, dysfunctions	-
Incorrect settings: • Collector-minimum temperature (CN): too high =System is not running or starting very late too low (< 4°C und lower) = storage tank is cooling in cold nights • Storage tank-maximum temperature (SX): too low (< 85°C) = frequent system shutdowns → lower gain • function number (FN): „should be 3 besides the user know exactly what he/she is doing" • manual starting (MM):	-

standard= 4; Change only for commissioning/maintenance	
Wrongly mounted diaphragm expansion tank: • Connection of the reinforced hose at the top of the solar station Reinforced hose should rise steadily from the diaphragm expansion tank to the solar station → Air can escape	-
Closed check valve to diaphragm expansion tank → diaphragm expansion tank gets separated from the solar circuit → strong pressure fluctuations	PR1, PR7, PR3a
The in the flow meter integrated flow controller is adjusted and thus hinders the flow Solution: The integrated flow controller should be always open because the flow is regulated by the rotation speed control	-
Incorrect power level set at the solar pump Flow would be either too strong or too weak Solution: adjust the step switch at the pump	E1, PU1_%
Closed ball valves in the supply/return	-
Location of the station is not in accordance with installation instructions Can only be mounted vertically	-
Crashed rubber gasket if using compression fitting → Leaky connection or constipation if the gasket is loose	-
Manometer sealed with hemp → manometer does not reach deep enough into the thread and remains separated from the solar circuit	-
Storage tank – sacrificial anode not connected = fatal → Pressure on Anode tester provides information	-
Storage tank – Hot and cold water connection sealed with hemp → Between the steel of the storage tank and the fitting there will be corrosion wherein the steel dissolves slowly → When fitting screwed too tightly, enamel may burst, which also leads to corrosion.	-
Water mixer is wrongly connected or is forgotten totally	-

Circulation connection
  • When the circulation connection is not connected to the cold water inlet of the water mixer, the circulation pump can be permanently damaged
  • If circulation exists, the pump should be switched on via timer only at the required times. (Better: circulation control)
	(Circulation connection)

Tightness of the connections (particularly: Plug for screw-in heaters and fittings of the flange cover)	-
Wrong material of the piping (has to be glycol and temperature stable)	-
Incorrect insulation material (no standard heating insulation but	-

high-temperature foam insulation or aluminium laminated mineral wool)	
Laying with high points (Avoid accumulation of air)	-

Short overview of possible system errors and functional problems

Collector sensors shaded → Control responds too late	Q_sol?, visual inspection
Collector shaded	Q_sol?, visual inspection
Pollution of the collector	Q_sol?, visual inspection
Lightning Protection/Earthing missing	-
Leaking roof entering	-
Excessive pump design	-
Too much antifreeze in the water-glycol mixture (> 50%)	Manual check
Pressure losses • Frost damage • Leaks • After a hot day by releasing steam → Perhaps the diaphragm expansion tank is too small	-
Condensation in the collectors • Insufficient ventilation • low tilt of the collectors • leakage	-
Declining system performance • Air in system • Increase of the shading • Pump is faulty • Condensation in the collectors	-
Reheating even on sunny days • Control defective • Solar pump defective • Time delay of reheating set incorrectly • Placement of the sensor is wrong • Pressure loss/air in the system • Circulation connection positioned incorrectly	-
Solar pump is running far less than the sunshine hours • Temperature difference is set incorrectly • control defective • Temperature sensor defective or shaded • Gravity brake defective	-
DeltaT is too high in the collector circuit • Air in the solar circuit • Volume flow too small	-

• Solar cycle clogged	
Too high temperature in the collector supply/Pump starts late • Switch-on temperature or DeltaT is too high • Dropped or misplaced collector sensor	-
Storage tank cools down too much • Too low starting and end values • Control defective • Insulation defective • Storage tank connections wrong • Re-cooling during the night (Gravity break open?) • Gravity circulation over reheating	-
High storage temperature • Storage temperature is set too high • Control defective	-
Pump-continuous operation • Sensor/Control defective	-
Pump switches on and off continuously • Hysteresis is too small • Placement of the sensor is wrong • Stopping time of the pump sufficiently?	-

Optisol final report - 144pp

Air in the system → Detection: Different heating of the collector fields → Ventilation	Massflow
Temperature difference between the primary and secondary circuit is too large (standard 5-6K) → Detection: temperature sensor → Either the external plate heat exchanger between the primary and secondary circuit is too small or the mass flows in the primary and secondary circuits are not tuned properly (due to suboptimal function of the speed control) Through data analysis not be elicited, therefore: • Set the speed control of the pumps out of service • Suitable speed set manually; the calculated nominal flow is set by the regulation valve • Recording the temperatures at 5-minute intervals • With the temperature gradients it could be shown that the heat exchanger could be excludes as a reason → Speed control works suboptimal, particularly during rapid changes of the solar irradiation	T_COLLsu, T_SOLsu_1, T_SOLsu_2,
Faulty solar heat exchanger: During the evaluation of the temperature profiles it was discovered that the temperature difference of the external heat exchanger of	T_COLLsu, T_SOLsu_1, T_SOLsu_2,

the solar system is too high. 2 possibilities for errors→ Either the heat exchanger is designed too small or a sub-optimal speed control is to blame Through data analysis not be elicited, therefore: • Set the speed control of the pumps out of service • Suitable speed set manually; the calculated nominal supply is set by the regulation valve • Recording the temperatures at 5-minute intervals • Because of the temperature gradients it could be shown that the heat exchanger is not capable of the required temperature difference of max. 6K. → it turned out that a production error was to blame	
Temperature of the Standby capacity in the energy storage tank too high: Since those high temperatures also appeared when the sun is not shining, the cause could be only defined in the conventional heat source. → Solution: The supply temperature is set on the pre-set minimum temperature in the regulation → the stand-by temperature dropped to 5K.	Not appropriate for solar cooling
High return temperatures from the heat distribution, if there is no space heating: • Remote analysis not successful → on-site visit • Hydraulic failure in the heat transfer station could be determined A two-way valve was missing and so a mass flow in the home station was possible although there was no heat usage in the rooms → Raise of the return temperature throughout the heat distribution	Not appropriate for solar cooling
Gas condensing boiler operating in an extreme intermittent mode After the boiler demand is activated the boiler starts operating at full power and the boiler heated → This operation led to frequent burner starts → high boiler losses Solution: modulating operation of the gas condensing boiler	Only in solar cooling systems with hotside backup appropriate
Regulation of the solar system and sensor positioning Measuring data analysis: A very large time difference between the temperature rise at the collector and the solar primary circuit can be detected→ System always turns on too late Solution: Incorrectly positioned collector sensor → Exchange of the sensor	T_COLL_1, T_COLL_2, T_COLLsu
Excessive Standby capacity in the energy storage tank Solution: After consultation with the regulation company it turned out that a wrong sensor was considered for the regulation → Programming has been fixed	Not appropriate for solar cooling
Strongly fluctuating supply temperatures	-

Problem was the use of a supply-temperature mixer, which in principle is not suitable for the requirements of a dual-pipe system. Solution: Replacement with a thermostatic mixing valve	
Faulty regulation of the network supply temperatures and too high network return flow temperatures: Network flow temperature is set too low from the regulation company Solution: Reprogramming of the regulation Network return flow temperature is too high because a sub-distributor in the ventilation station is constructed as a pressure-less distributor → there exists no differential pressure → The uncooled medium with flow temperature can be mixed with the return flow via sub-distributor. This leads to an increase of the network return flow temperature. Solution: Use of a return temperature limiter in the connection between return flow and flow distributor in the ventilation station	Not appropriate for solar cooling
Operation of the solar pump in the secondary circuit during the night: Problem: plant control system → The prevention of the secondary pump mode if the primary-circuit pump is not operating is programmed but not unlocked	PU2_%, PU1_%,

Overview of typical installation errors – small scale systems

Missing domestic hot water mixer: Caused by the transmission of knowledge from the conventional heat generation	Not appropriate for this solar cooling
Altered thermal transfer medium: For example, by improper refilling with water or when the water content of the heat carrier evaporates	Manual check
Missing documentation: Should be visible. Has to contain references to pressure drops, error messages, etc.	-
Missing blow-off pipe: In case of inadmissible overpressure there is a leakage of liquid or vapour, which may lead to a threat to life and limb if there is no blow-off pipe.	visual inspection
Inadequate circulation connection: By „usual" connection of the circulation-pipe to the storage-water-heater 40 degree drinking water is fed into the lower region of the storage tank, which significantly affects the thermal stratification.	(no circulation connection)
Lack of protective function of the regulation: In heating-assisted solar systems high temperatures and stagnation occur much more frequently → it must be ensured that the solar	Example: T_HST_1 maximum value

circuit isn´t starting at high system temperatures and "cooling functions" should not be overestimated but indeed activated when using high-performance collectors	
Incorrect position of the 3-way valve: The 3-way valve can only work effectively if it is mounted on the coldest return pipe of the heating circuits to allow a longer solar energy gain.	-

DA_Christian Mueller

Sensor error occurs when sensors, inlets, a measuring instrument or a measuring machine having a defect→ several possible effects: - If only one sensor is defective → visible in the measurement data is often an increase, decrease or a constant value - If a PT-100 temperature sensor (for example, by a cut through the sensor cable) the maximum resistance is measured	Sensors check: All sensors
Cable breaks, cold solder joints or loose contacts have similar effects in the measurement data as total failures	Sensors check: All sensors
Measured values which drift away slowly from usual measurement results because of a creeping defect are hard to see → no erratic behaviour → you need further information for example with the use of reference sensors because of which the data can be compared	Sensors check: All sensors
Measured values are overlaid by a noise → if the noise has strong characteristics it is easier to identify. Weak noise can be considered as normally occurring value fluctuation.	Sensors check: All sensors
Regulation errors: For example, when the solar system in summer is providing more hot water as needed, there should be a temperature rise in the storage tank. If you measure a high and rising temperature at the output of the solar circuit but the temperature at the input of the storage tank is constantly low than it can be assumed that there is a control error. For example the heat is then conducted in into the switched off heating circuit because the corresponding valve was not activated.	-
Incorrectly adjusted mixer valve→ unusual deviation of the measured values	-
Improperly operated pressure valve → if it quickly opens and closes it may cause a peak in the measured values	-