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Quality management as a key for efficient building performance

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Abstract

The use of complex building services opens up many possibilities to gain an increase of energy efficiency in buildings. On the other hand there are also threats that ecologically and economically planned energy concepts for buildings do not work as proposed. To reduce this risk a procedure was developed, based on so-called "active functional specifications". It covers the time span from planning phase up to building operation and allows, by running a digital test to verify whether the building services work as planned and whether the building's owner received what he has ordered.

In this paper the procedure is explained and results for an energy plus multi-family home are shown. The building's energy supply is based on electricity only. A heat pump using an ice storage and solar thermal collectors as heat source provides the energy for heating and domestic hot water.

Keywords: *quality management, building services, test stand, monitoring, energy efficiency*

1. Introduction

The application of complex building services with integrated measurement technology holds the prospect of grand increase in energy efficiency. Securing the actual utilization of these potentials in the building's operation is therefore becoming a significant challenge. Discrepancies between energy demand and consumption can turn economical concepts originating from the planning phase into cost-pushers in operation.

Past research projects and experiences from building service operation show the importance of quality management for reaching the desired efficiency and complying with energetic specifications, stipulated in the planning, in practical application. One of the principal problems is based on the non-standardized specification of the systems' functionalities.

"Active functional specifications" (AFS) present an innovative technique for effective and economical quality management. The definition and review of system functions is executed in the form of so called operating rules, e.g. for mass flows or powers, on a digital test bench. These rules must be fulfilled during operation. They therefore can be used as setpoint states for the construction and are being monitored during operation.

Within the frame of the research project "Effizienzhaus Plus, FFM Riedberg – EnergiePLUS im Geschosswohnungsbau" the ordinary energetic monitoring is supplemented by the newly developed method for assuring quality – the "active functional specifications". The research project is part of the research initiative "Zukunft Bau" funded by the BBSR.

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2. Multi-family house Riedberg

A multi-family house (MFH) with 17 accommodation units from two to five rooms is located in Frankfurt am Main in the district of Riedberg. It has four full stories and an attic floor (Fig. 1). The building is in use since August 2015. The standard of "Effizienzhaus Plus" is to be achieved with the help of a high-quality thermal building shell and optimal utilization of renewable energies.

The "Effizienzhaus Plus" standard demands that both the building's primary and end energy production exceed the consumption in the annual balance. In contradiction to the EnEV certificate the users' electricity consumption is also included into the balance.

The essential building characteristics are summed up in Tab. 1.

Fig. 1: Front view multi-family house Riedberg (source: egs-plan)

Tab. 1: Characteristics of the building in Riedberg

Year of construction	2015
Living area	1.600 m²
Number of accommodation units	17
Heated building volume	8.517 m³
Heated usable floor area A_N	2.407 m²
Annual heating energy demand	19 kWh/($m^2_{A_N}$a)
End energy demand electricity incl. household	25 kWh/($m^2_{A_N}$a)
Electricity production through photovoltaics	36 kWh/($m^2_{A_N}$a)
Electricity surplus (annual balance)	ca. 25.000 kWh/a

3. Energy concept

The MFH in Riedberg is an “electricity only building”, meaning all energetic processes are driven by electricity.

The heat demand is supplied solely by an electrical brine/water heat pump with a thermal power of 50 kW. The building contains two distribution grids – a low-temperature grid of approximately 35 °C and a high-temperature grid of about 55 °C. The low-temperature grid serves the floor heating. The high-temperature grid is connected to the heating unit of the ventilation system, the bathroom radiators, and the preheating of the hot water in the fresh water stations of each flat. The additional heating of the hot water within the flats is realized electrically, too.

The building is ventilated mechanically. A heat recovery to reduce ventilation losses is implemented. Additional natural ventilation by opening of the windows is also possible.

The heat pump has two different heat sources, an earth-bound ice storage and solar thermal absorbers.

The solar thermal absorbers (11 modules, ca. 85 m²), which are located on the roof underneath PV panels, are used primarily to provide low-temperature environmental heat for the heat pump.

Additionally, an earth-bound ice storage of 98 m³ serves as an innovative heat source for the heat pump. The ice-storage uses the melting enthalpy (latent heat) of the phase change von liquid (water) to solid (ice). The latent heat per kg is nearly the same as the sensible heat provided by a temperature change of 80 K of a kg of water. When the amount of heat by the solar thermal absorbers is not sufficient, the heat source for the heat pump changes to the ice storage. The water in the storage cools down to 0°C and starts to freeze due to the heat extraction.

To maintain the functionality of the system the ice storage has to be regenerated, i.e. melting and heating up the water. The regeneration is done with natural heat from the surrounding soil and with the solar thermal absorbers when no heat is needed in the building and the temperature provided by the absorbers is higher than the temperature in the ice storage. The third option for regeneration of the ice storage is cooling of the building in summer.

The building is equipped with a cooling system. The floor heating system can be used for cooling in summer. The system works with free cooling and the ice storage is the heat sink, i.e. it provides the cooling energy.

PV modules on the roof (ca. 84 kW_p) and in the façade (ca. 15 kW_p) are planned to achieve a surplus of energy in the annual balance. The annual production of electricity exceeds the total electricity demand by approximately 40 % (ca. 25.000 kWh/a). The surplus is to be used for e-mobility. In addition to the electrical cars, a lithium-iron-phosphate battery (60 kWh) is used to increase the self-consumption of the produced electricity (Fig. 2).

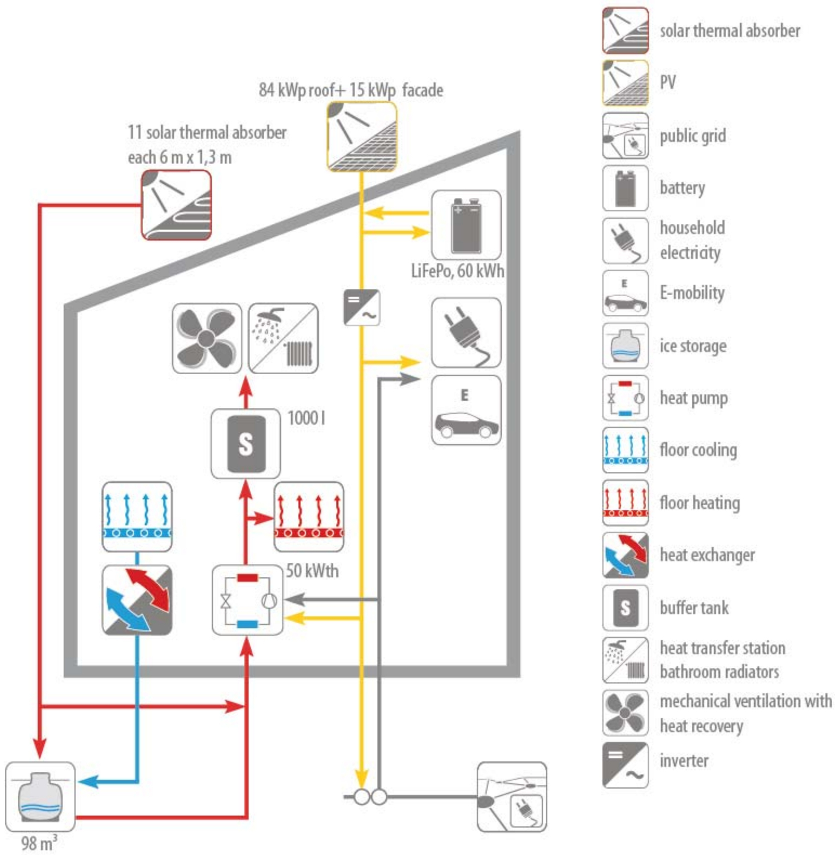

Fig. 2: energy concept multi-family house Riedberg

4. Active functional specifications

Within the scope of the active functional specifications operating modes and corresponding functions are already defined during the planning. These specifications, so called operation rules e.g. temperatures or valve positions, need to be fulfilled in the respecting operating mode.

Based on a simplified scheme the operating modes are being defined. Examples for different operating modes, rules, and definitions are presented in this paper. They are excerpts from the complex monitoring process.

The operating modes and rules are:

Operating mode BZ0 – OFF

All circulation pumps and the heat pump are inactive. All mass flows in the heat meters are equal to zero. The electrical power does not exceed standby needs.

Operating mode BZ1 – heating with heat pump - source ice storage

The heat pump (WP) is active due to a demand signal from the high- or low-temperature grid. The ice storage (ESp) serves the heat. The solar thermal absorber is inactive. The heat pump must be active for the correct operating mode 1. Heat meters WMZ3 and WMZ4 need to register mass flows, while the mass flows in WMZ1 and WMZ2 must be zero (Fig. 3, active circuits are coloured).

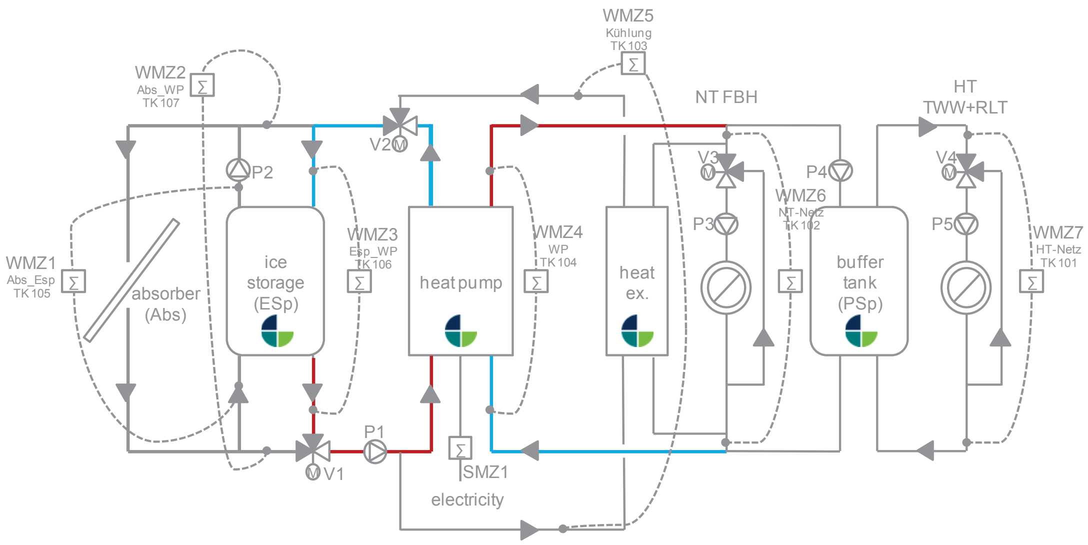

Fig. 3: operating mode BZ1 - source ice storage

Operating mode BZ2 – heating with heat pump - source absorber

In operating mode 2 the solar thermal absorber serves as the heat source. The ice storage is neither being charged nor discharged. For the correct execution operating mode 2 the mass flows at WMZ2 und WMZ4 are greater than zero and the heat pump is active (Fig. 4, active circuits are coloured).

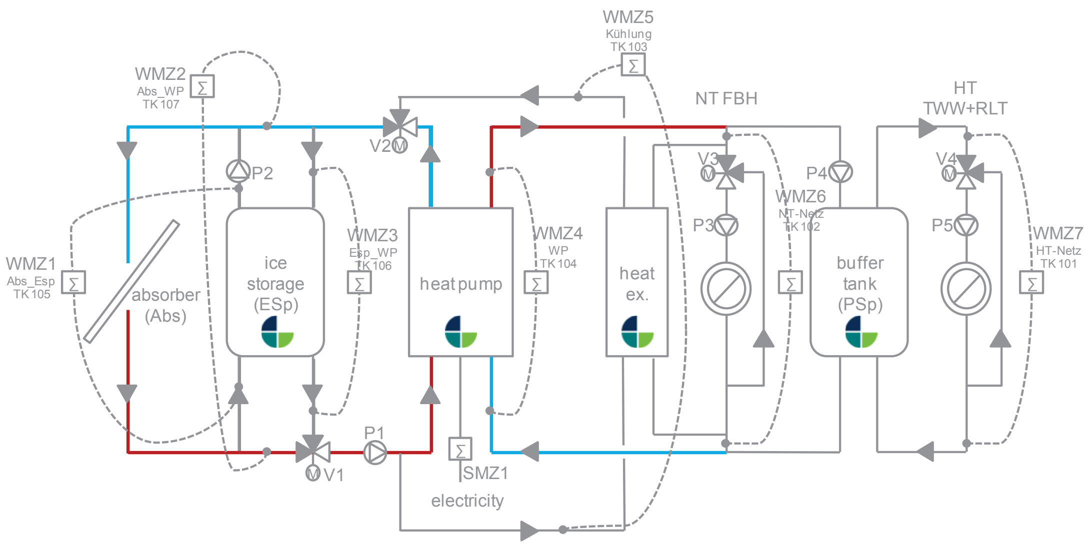

Fig. 4: operating mode BZ2 - source absorber

Operating mode BZ3 – regeneration of the ice storage

While the solar thermal absorber regenerates the ice storage, the WMZ1 must register a mass flow. The activity state of the heat pump can be either one, as it can operate during the ice storage regeneration, but does not need to (Fig. 5, active circuits are coloured).

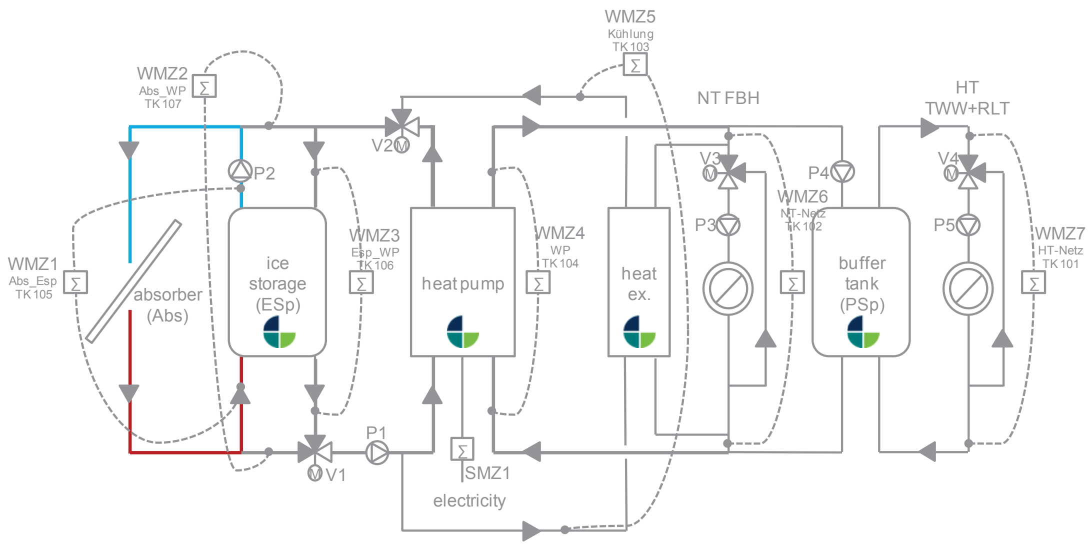

Fig. 5: Operating mode BZ3 – absorber to ice storage

Fig. 6 gives an overview about the operating rules that need to be fulfilled during the four operating modes. With all operating modes and rules defined, the monitoring and evaluation can be executed both during start-up and ordinary operation.

operating rule	BZ0 Off	BZ1 ice storage heat source	BZ2 absorber heat source	BZ3 absorber to ice storage
$\dot{m}_{WMZ1}$	0 kg/h	0 kg/h	0 kg/h	> 0 kg/h
$\dot{m}_{WMZ2}$	0 kg/h	0 kg/h	> 0 kg/h	0 kg/h
$\dot{m}_{WMZ3}$	0 kg/h	> 0 kg/h	0 kg/h	0 kg/h
$\dot{m}_{WMZ4}$	0 kg/h	> 0 kg/h	> 0 kg/h	0 kg/h
E_{SMZ1}	≤ 1,5 kWh	> 1,5 kWh	> 1,5 kWh	-

Fig. 6: overview operating rules

5. Operation and quality control

Only if all operating rules are satisfied, an operating mode (OPM) is being executed correctly. If not all rules are complied with, the operating mode is not active or incorrectly executed. Regulations like a set-point temperature comparison for the ice storage can be implemented to determine, whether an operating mode is supposed to be active.

The rate of correctly working OPM is transformed into the operating quality of the system. The operating quality describes the degree of conformity of the planned and the realised system. The automatic import of operating data from the building management system can be implemented to enable an automated control of the operating modes.

Fig. 7 displays the procedure for evaluating the operating quality. The monitoring data is assessed for every time step in the course of the year. The result of the analysis is stored as Boolean value (true/false, upper part of Fig. 7). The numbers of true and false values are compared to the overall number of assessment steps and form the operating quality (lower part of Fig. 7).

On the basis of a minimum ratio of true values the necessary conformity between planned and real operation can be defined.

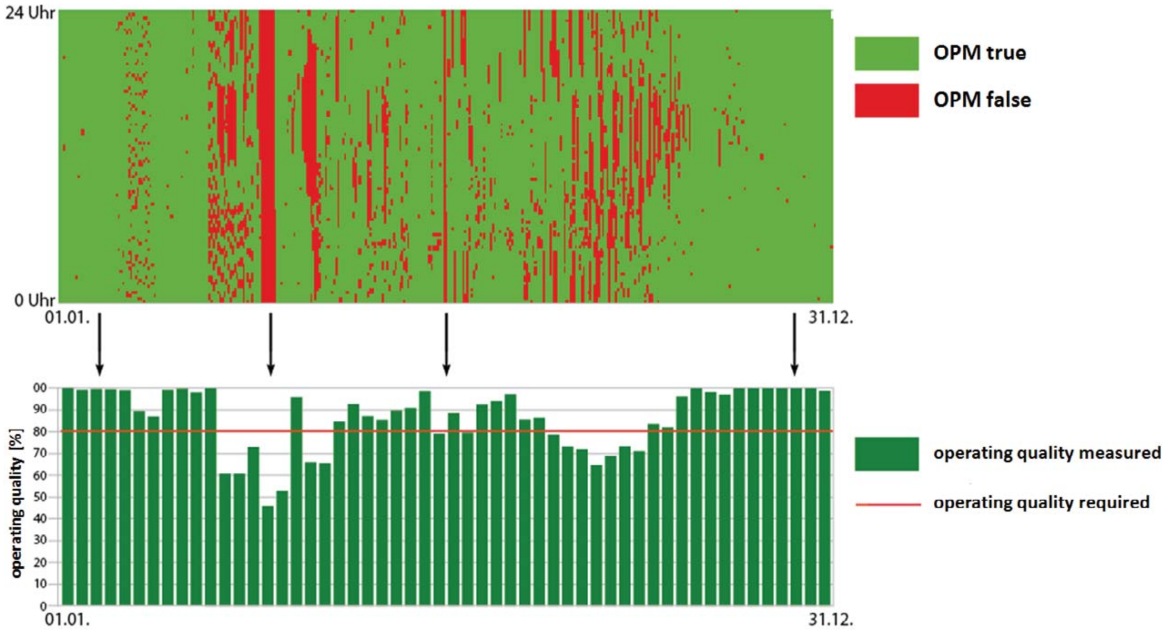

Fig. 7: Operating quality of the system (dummy values)

6. First monitoring results from MFH Riedberg

Measured data from the installed heat meters are available from November 2015 on. The analysis of the active functional specification (Fig. 8) shows that the system has been in OPM 1 (heating from ice storage) for most of the time. It is further visible that planning-conform operation has taken place in the beginning of the monitoring (green dots). From the middle of December on, the planned operation of the heat pump was not met (red dots). Where there is no point, the respective OPM was not active.

The problems in operation related to the heat source are easily visible in the operating quality (Fig. 9).

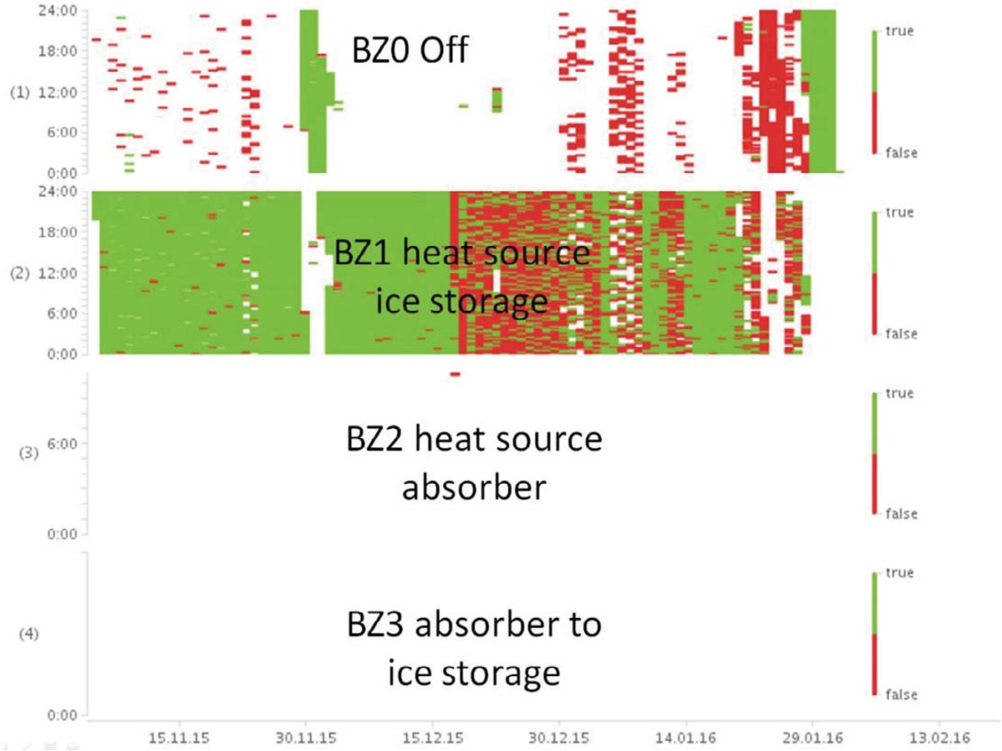

Fig. 8: Evaluation active functional specification - operating modes MFH Riedberg, November 2015 to January 2016

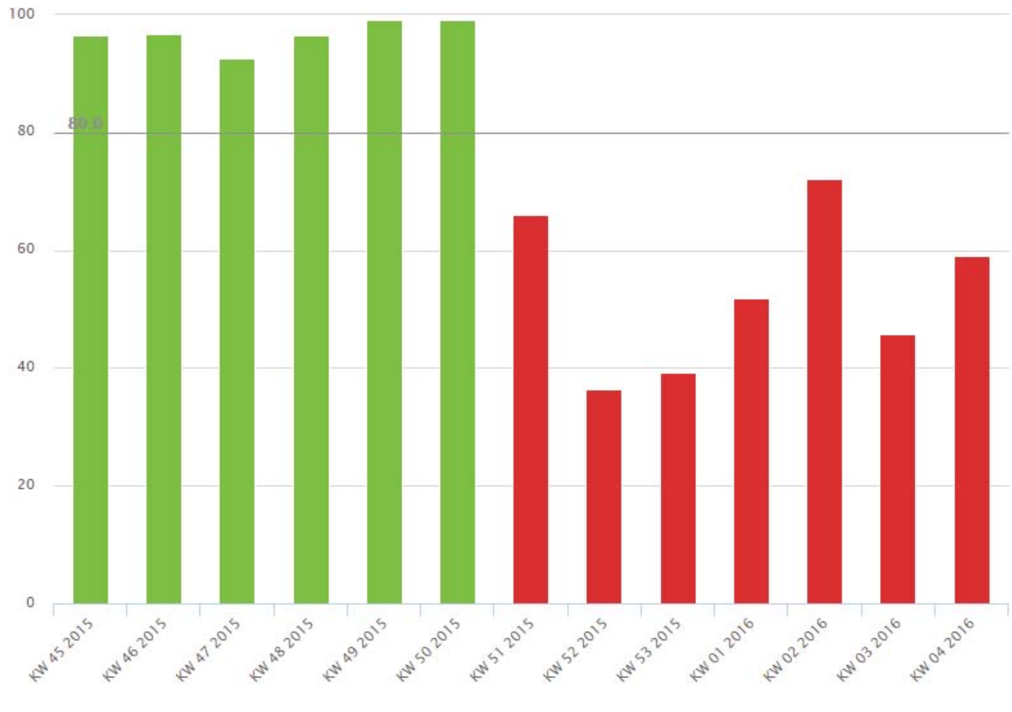

Fig. 9: Evaluation weekly operating quality MFH Riedberg, November 2015 to January 2016

Within the frame of the monitoring the inability of the absorber to deliver thermal power and the optimization need for the hydraulic system, especially regarding the control system, have been detected.

From February 2016 on, the system has been adjusted and altered to solve the problems of the hydraulic system. Among the solutions a buffer storage has been integrated into the low-temperature grid and the controls have been changed accordingly.

In the middle of June 2016 the last changes in the control system have been executed. The assessment of the operating quality shows planning-conformity since then (Fig. 10).

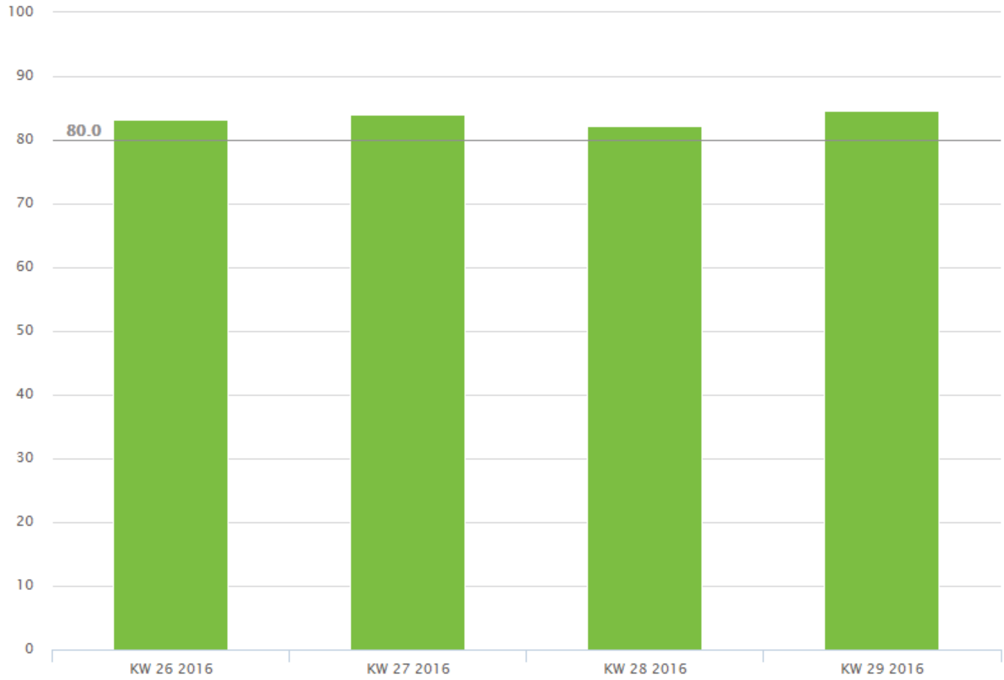

Fig. 10: Evaluation weekly operating quality MFH Riedberg, end of June 2016 end of July 2016

7. Conclusions and outlook

The assessment of the operating quality has made the early and easy detection of operating deviations from the planned design of the system possible. The active functional specification enables the efficient identification of errors. The scope of the detection goes from the broad view to the detail. In the first step the operating quality (Fig. 9) serves as an overview over the accordance to the planning. In case of deviations the operating modes are analyzed in detail. The singular operating rules are being evaluated and the source of trouble identified.

The combination of monitoring and the active functional specification have successfully detected the faulty operation of the heating system (absorber - ice storage - heat pump) and initiated the correction of the system.

First assessments after the reconstruction work show that the system has been in orderly operation since the beginning of the summer 2016. In the further course of the monitoring, the system functions are constantly being scrutinised and optimized.

A full evaluation of the system's performance is not yet possible because system was in irregular operation during the heating period 2015/16.

8. Acknowledgements

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Interested builders can receive further information and the possibility of participation under: https://www.tu-braunschweig.de/igs/forschung/specundchec