Grant Agreement: 768936

TEMPO

D3.2: REPORT - INTEGRATED INNOVATIONS IN ENERPIPE NETWORK

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768936.

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SUMMARY

This deliverable "Report integrated innovations in Enerpipe network" is developed within WP3 of the H2020 TEMPO project. TEMPO is the acronym for: Temperature Optimisation for Low Temperature District Heating and focusses on the development, demonstration and deployment of innovations for low temperature district heating (DH) networks across Europe. TEMPO aims at reducing DH network system temperatures to achieve improved network efficiency, costs competitiveness and capability of integrating sustainable energy sources like renewable and residual heat.

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GLOSSARY / LIST OF ACRONYMS

ACRONYM	DEFINITION
DHS	District Heating System
DHN	District Heating Network
DH	District Heating
DHW-station	Domestic Hot Water - station

1 INTRODUCTION

The ENERPIPE demo is located in the town of Windsbach, 35 km south west of Nuremberg (Germany). The municipality of Windsbach is developing a new residential housing project in a rural area. The houses will be heated by means of a District Heating System (DHS). The project consists of 3 phases:

- Phase 1
  - 59 single family houses
  - 3 multi family houses
- Phase 2
  - Additional 57 single family houses
- Phase 3
  - Additional 20 single family houses

In this demo only Phase 1 and 2 are included. The innovations described in [1] will be implemented on site to analyse their impact while operating on a real DHS. This document will give a brief description of the different innovations together with a detailed explanation of the technical and economic aspects of implementing them at the demo site. Furthermore we will also discuss the quality control measures that were put into place and the commissioning and initial operation of the demo site.

2 THE ENERPIPE DEMONSTRATION SITE

2.1 OVERVIEW OF THE SITE

The municipality of Windsbach (6000 inhabitants, located 35 km south west of Nuremberg, Germany) has planned a new residential housing project, developed in rural area and heated by district heating (DH). In phase 1, 3 multi-family-houses and 59 single family houses will be built and most of them will be connected to the district heating network. In phase 2, 57 single family houses will additionally be added to the network. The design for the network allows an additional connection of 20 single family houses (phase 3). In the meantime some housing owners of existing houses in the surroundings have confirmed to connect on separate DH-scheme, which will also be supplied from the same plant room. However this network has no impact on the real demo-site, because it has its own heating circuit with pumps, valves, heat meter and controlling system.. This allows to operate the network of the demo site maintaining a low temperature.

Figure 1: The Enerpipe demo in the municipality of Windsbach.

The network has an estimated total heat demand of 1000 MWh (800 kW peak load), if every new house will be connected on the district heating scheme. In other regions there is an obligation to connect on a DH scheme, however not in this project. The local authority in Windsbach is inclined to develop new residential areas with "sustainable" heat sources. Therefore no gas pipe will be installed. However the use of air-water heat pumps is also allowed in this area.

However Wärme.natürlich GbR, the owner and operator of the DH network, received positive feedback and the people who have bought a building plot also intend to connect on the network. The total package which will be delivered is favourable: in fact, compared with the different heating options in the area, district heating has the cheapest overall costs and also a primary factor of 0, which is quite attractive for the new housing builders. The primary factor describes the energy amount of an energy source (gas, oil,

current) from the production, transformation and distribution to the plant. In Germany home builders have to prove that they do not exceed a specific heat consumption (according to the Energy Saving Ordinance). To ensure this, they must build their house with a good insulation and using heating technology with a low primary factor. If the primary factor is low, the building fulfils the requirements of the decree and, furthermore, home builders have the opportunity to get funding from the government.

The heat to the network will be delivered from an existing biogas plant (850m from the plant room). This biogas plant was built years ago to produce biogas in a biogas fermenter. CHP's produces electricity and heat. The plant supplies a small number of houses with heat. Extra waste heat is available and fed into the DHS, in summer about 200 kW and in winter about 100 kW. The waste heat will be utilized to cover the base load in the new built DH network. The rest of the heat is supplied by two new bio methane CHP plants together with a bio methane peak load boiler.

The network will be operated by Wärme.natürlich GbR, the owner of the biogas plant. They also operate an existing DHS, which is also supplied by the biogas plant. Enerpipe has developed the total concept, the design and has done the project management. Wärme.natürlich GbR has a maintenance contract with ENERPIPE for supporting the operation and maintenance of the DHS. The first heat was delivered in March/April 2018.

2.1.1 DISTRICT HEATING NETWORK

The demo only focuses on phase 1 and 2 of the Windsbach project. The existing DHS, which provides the existing houses with heat, is not connected to the demo site but has the same plant room. This DHS is not under consideration in the TEMPO project.

Designing the DHS was challenging because at the start of the housing project the number of connected buildings was not clear, as not even all building plots were sold. Therefore ENERPIPE made some assumptions on heat load of the individual houses, percentage of the connected buildings and the simultaneity factor.

- Single family houses
    - Small houses – up to 10 kW
    - Big houses – more than 10 kW
- Multifamily houses – 40 kW
- Simultaneity factor (overall peak load / sum of all peak loads) - 75%

Taking into account the above assumptions the total peak heat demand of the DHS would be 1100 kW at the end of phase 3. However, because not all houses will connect to the DHS a peak load of 800 kW is assumed at the end of phase 2 which increases to 1000 kW at the end of phase 3.

The DHS is designed to operate with a temperature difference, delta T, of 30 K. ENERPIPE has already realized other projects in which this network regime is applied. The main difference is that in this demo the absolute temperatures will be lower. The reduction of the return temperature is one of the main goals of the development and implementation of the new decentralized buffer concept. The maximum flow rate will be about 30.000l/h and a pressure drop about 4,0 bar.

Installation of the pipes going from the biogas plant to the plant room started in March 2017. The rest of the piping was installed as follows:

- Phase 1 (May 2017 – November 2017)

    - 1550 m
- Phase 2 (October 2019 - December 2019)
    - 1400 m

At each building plot a T-junction is already installed to facilitate the DHS connection of the not yet existing houses. *Figure* ***2*** shows the DHS in the different phases together with the location of the plant room.

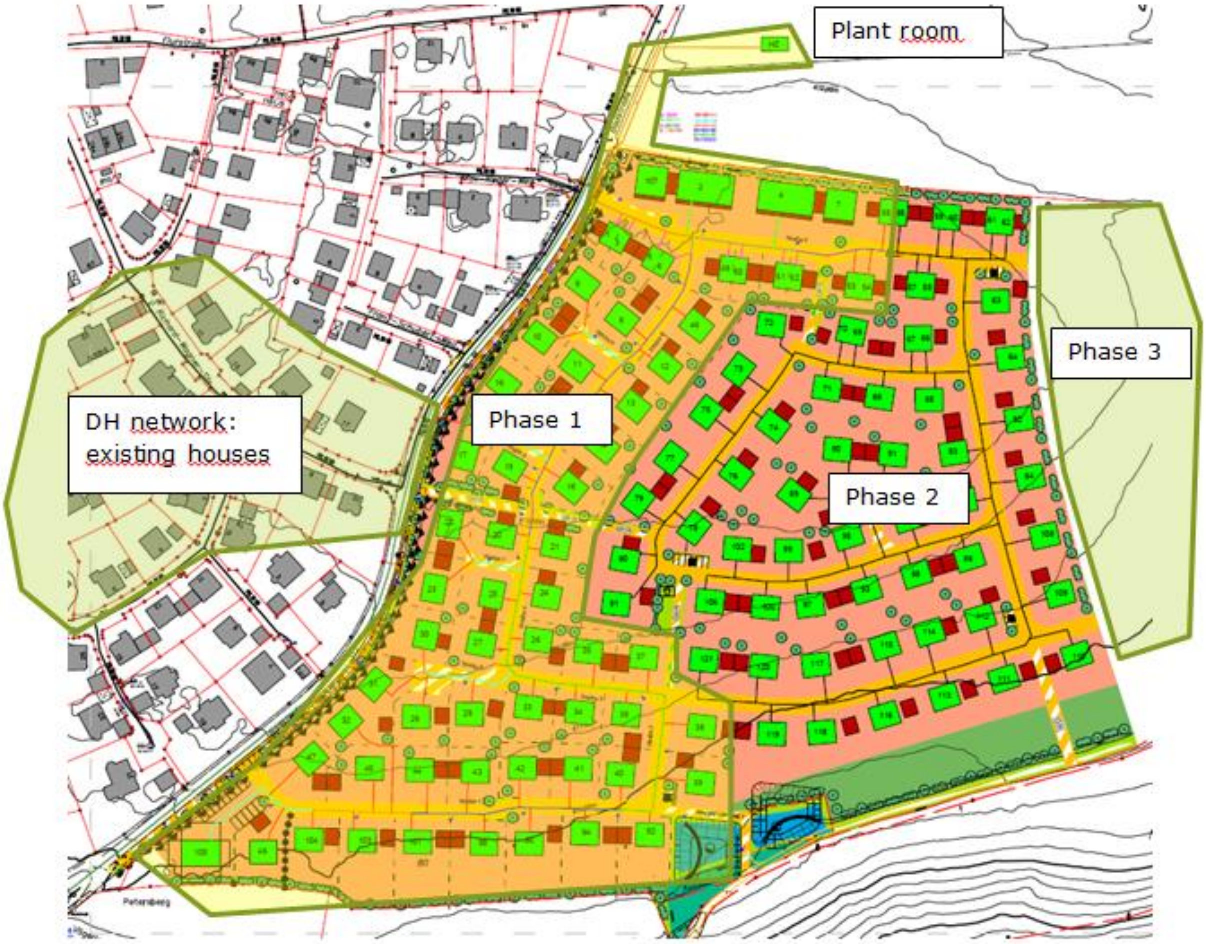


Figure 2: District heating scheme of the Windsbach project (Source: ENERPIPE)

The following list gives an overview of the key numbers of the DHS:

- Phase 1 and Phase 2: Trench length 3000 m
- Largest pipe dimension: 110 x 10 mm, Single
- Pipe-Type: CaldoPEX PN6
- Max Heat load: 1000 kW
- Primary Temperatures: 75°C / 45°C
- Max Volume flow: 30.000 l/h
- Max Pressure drop:4 bar
- Max heat load buildings Standard:6-20 kW
- Heat load Multi-family houses: up to 40 kW
- Annual heat consumption 1.300.000 kWh/a
- Annual heat losses pipes 300.000 kWh/a
- Heat occupation density 433 kWh/(m a)

2.1.2 HEAT SOURCES

The demo site will be supplied with 100% of renewable energy coming from different heat sources (waste heat and biomethane). First an existing biogas plant, 850 m from the plant room, provides its waste heat to the DHS. In winter this adds up to around 100 kW of injected heat while in summer it increases to around 200 kW. In 2019 it provided 491820 kWh of heat to the Windsbach DHS. A twin 75+75/202 FibreFLEX pre-insulated pipe is installed to transport this heat to the plant room. The waste heat from the biogas plant will cover the base heat load of the project. The plant room itself, see *Figure 3*, consists of the following extra heat production and storage units:

- 1 bio methane CHP (2G / KWK-140 EG)
    - 207 kW_{th} - 140 kW_{el}
    - Heat production 2019 = 269360 kWh
- 1 bio methane CHP (2G / patruus 400 EG)
    - 505 kW_{th} - 400 kW_{el}
    - Heat production 2019 = 0 kWh
- Peak load biomethan boiler
    - 560 kW
    - Heat production 2019 = 7980 kWh
- 2 buffer tanks
    - 2 x 20000 l

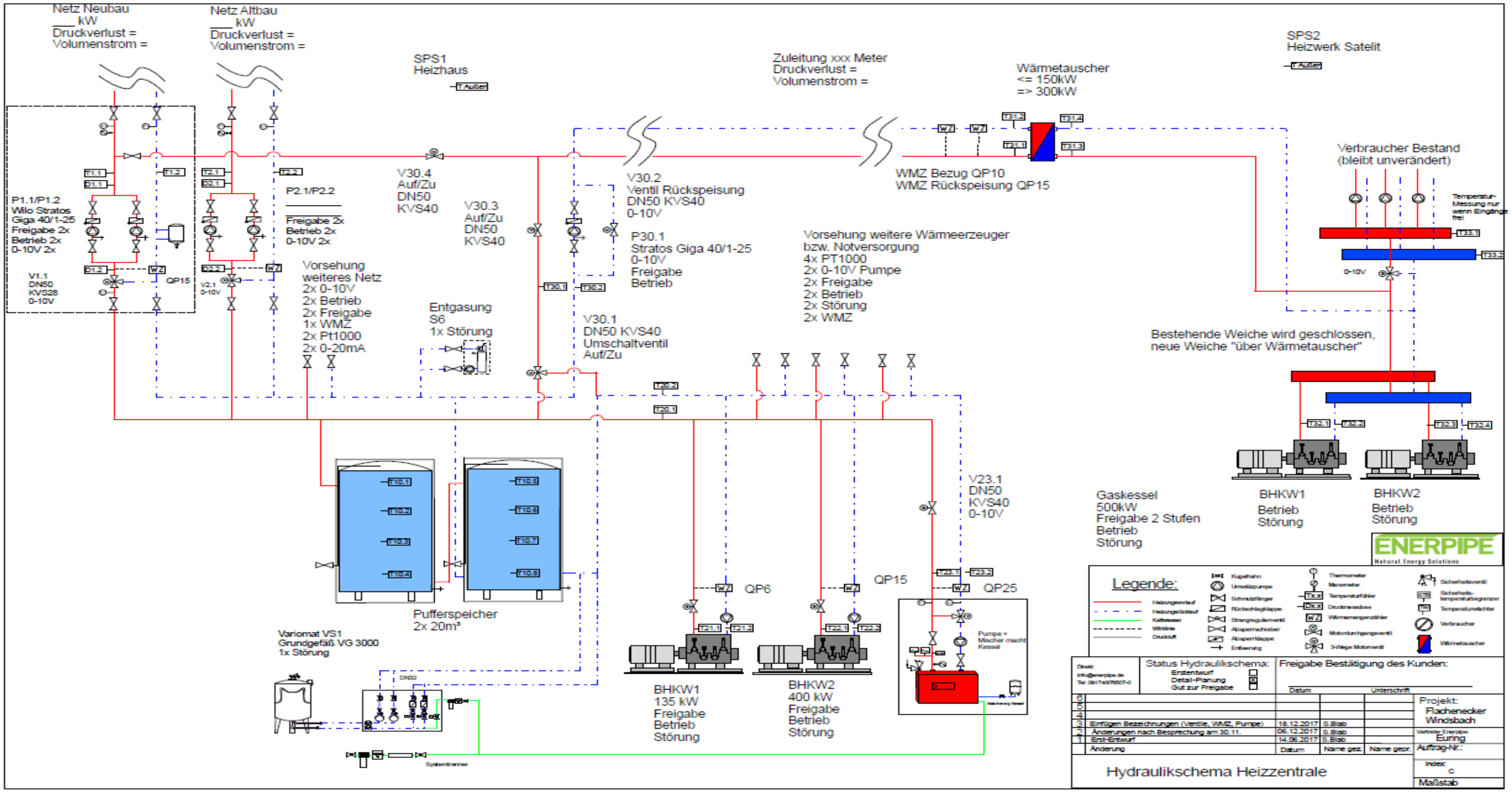


Figure 3: Hydraulic scheme of the plant room (Source: ENERPIPE)

2.2 DETAILS OF THE DEMONSTRATION SITE

2.2.1 HEAT TRANSFER CONCEPT

As described in [1] the following innovations and technical solutions were installed in Windsbach:

- Decentralized buffers
  - Reduction of peak demand
  - In previous, existing Enerpipe DH-networks with decentralised buffer solution the primary water flows through a coil heat exchanger in the buffer and heats up the stored secondary water. The stored secondary water (600-1000 litre) was used directly for the radiators or the floor heating system. The DHW preparation was realised with secondary water, too. The new primary concept uses the stored buffer water directly. So the buffer volume belongs to the primary side. The coil heat exchanger in the buffer heats up the water for the connected heating systems. This concept allows to operate the storage in a way reducing the primary return temperature. Another benefit is the possibility to use the high primary temperature directly for the DHW-station. Consequently, lower primary side T are needed for DHW preparation than in the previous concept.
- Piping optimization
  - Lower peak demands allow smaller pipes
- Heat loss reduction
  - Smaller pipes have less heat losses
- Smart buffer charging
  - CHP production optimization
  - Cost minimization through reduced heat losses and pump costs. Maximise switch off times of the central DHS pump: enforced buffer loading to maximise switch off times during summer saves DHS pump costs and reduces heat losses
- Primary storage concept
  - 2x20m^3 storage buffers are installed in the heating plant
- Reduction of substation size
  - The aim was to develop a substation which requires less space, optimised buffer volume and to integrate as much components (expansion vessel, speed pump, pressure gauge, safety valve, DHW-station) as possible in the unit to minimise installation times.

2.2.2 TRENCH PLAN

Figure 4 shows the installation of the pipes. Between customer 37 und 121 a second pipe connection is installed between construction site phase 1 and phase 2. In this connection a valve is built-in. In normal operation the valve is closed to ensure trench-wise loading.

Figure 4: Trench plan phase 1 and phase 2

2.2.3 PIPE TYPE

For the heat trasmission from plant room to the substations Enerpipe chose a pre-insulated flexible pipe system (CaldoPEX). The pipe consists of Polyethylene PE-Xa SDR11. *Figure 5* shows the construction of the pipe.

Figure 5: CaldoPEX pipe

Figure 6 shows the technical specification and the limits of use.

Technical Specification:	
Max continuous operating temperature:	+80°C
Max variable operating temperature:	+95°C
Max operating pressure:	6 bar at +80°C
Insulation thermal conductivity:	≤ 0.021 W/mK
Service pipe:	PEX-a
Thermal insulation:	PUR, CFC-free, cyclopenthane-based
Jacket pipe:	corrugated PE-LD

Figure 6: CaldoPEX technical specification

2.2.4 STANDARD SUBSTATION WITH BUFFER

Figure 7 shows how a standard substation with buffer, as it was constructed before in TEMPO project. This solution is used for multi-family-houses. The substation separates the primary from the secondary side with a plate heat exchanger. The buffer stores secondary water. The circulation pump supplies the connected apartments. In the apartments decentral substations with a heat exchanger for heating (with tertiary heating circuit in each apartment) and DHW are installed. This requires a continuous operation of the circulation pump.

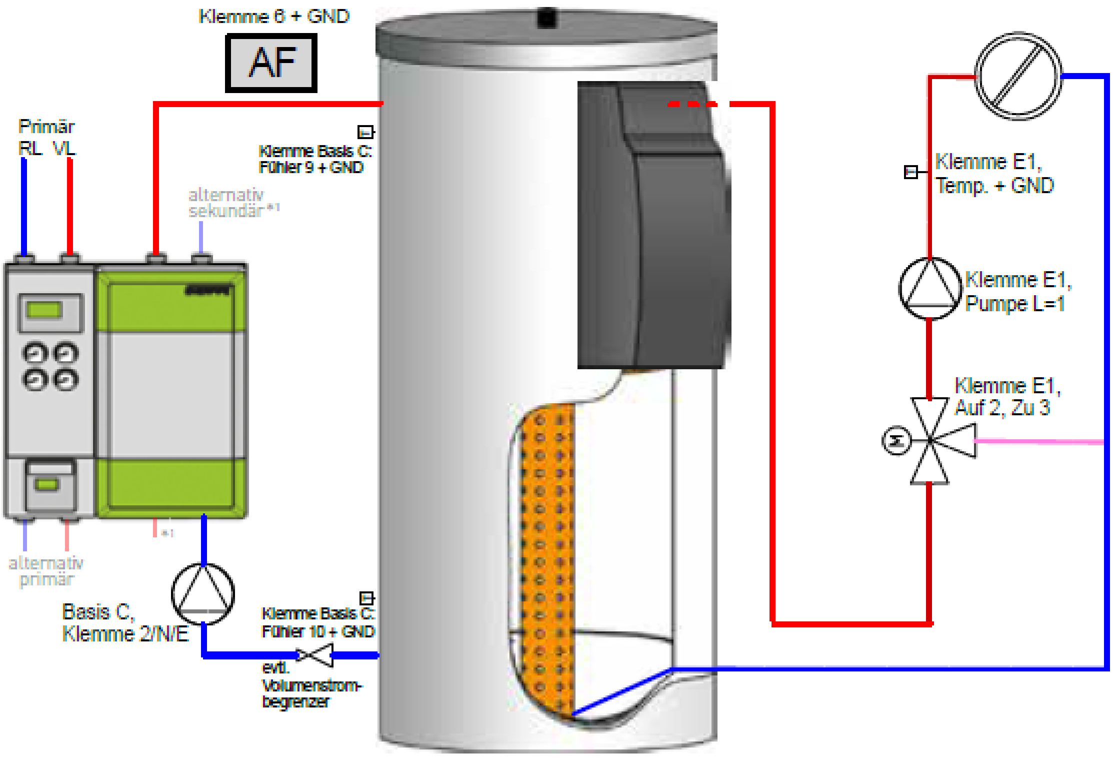


Figure 7: standard substation with buffer

There is also a possibility for end-users to install individual solutions. For example integrating solar heat or a wood fired heater into the heating concept. For this case ENERPIPE plans new hydraulic concepts to match with the requirements and wishes of the customers.

2.2.5 INNOVATIVE TYPES OF SUBSTATIONS

DECENTRALISED BUFFER 250 L

For the specific requirements in Windsbach and in accordance to the TEMPO-project Enerpipe designed and developed a new buffer storage concept. The solution is a decentralized buffer unit of 250 l , see *Figure 8*.

Figure 8: Decentralized buffer unit of 250 l

The substation is optimised for new build low energy houses with a maximum heat load of 10 kW (surface heating systems) or 6 kW (radiators). The Domestic Hot Water (DHW) station is sufficient for a family of 4 persons with a normal hot water consumption (40 l/day/person). The maximum tap hot water volume flow is limited to 30 l/min (depending on the desired temperatures).

DECENTRALISED BUFFER 600 L TO 1000 L

As different types of buildings are present in the site, also larger decentralized buffer units (of 600 l up to 1000 l, see *Figure 9*) were developed. These larger buffers take up more space and the necessary components for the secondary side such as expansion vessel, safety valve, drain tap and pressure gauge are not pre-installed or in scope of service contrarily to the decentralised buffer 250l. These components have to be installed separately from the installer.

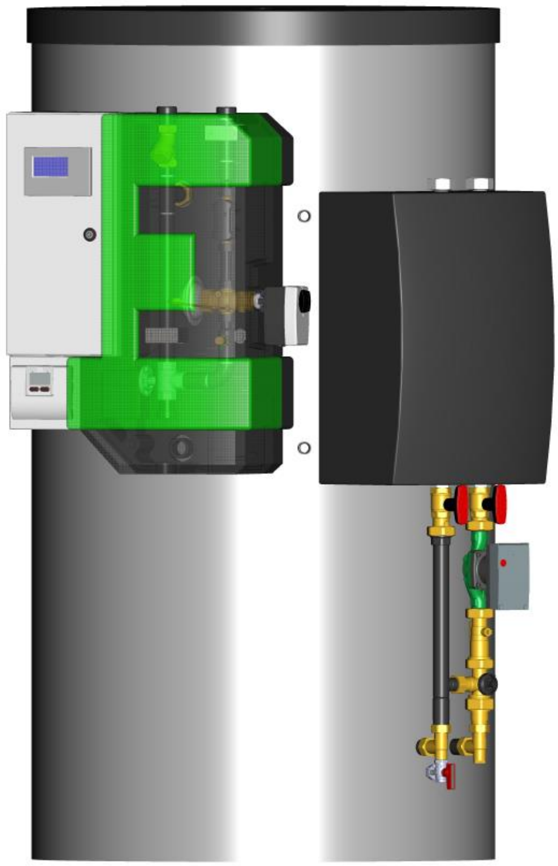


Figure 9: Decentralized buffer unit of 600 l to 1000 l

Table 1 gives an overview of the maximum heat load of the different buffers.

Table 1: Maximum heat load buffers

Buffer unit	Litre	600	800	1000
Max. heat load 35/30°C (surface heating system)	kW	14	19	24
Max. heat load 50/35°C (Radiator)	kW	10	14	18

The required space for all sizes are:

600l decentralised buffer unit 1,60 m x 1,80 m x 2,0 m (BxTxH)

800l decentralised buffer unit 1,70 m x 1,90 m x 2,0 m (BxTxH)

1000l decentralised buffer unit 1,70 m x 1,90 m x 2,2 m (BxTxH)

2.2.6 DEFAULT SUBSTATION CONTROL

The default behaviour of the substations (buffer units) depends on the primary water temperature inside the buffer. Three temperature sensors are installed in the buffers, one at the top, one in the middle and one at the bottom of the buffer, see *Figure 9*. The top and bottom sensor are used for controlling the buffer while the middle sensor is only used for visualisation. The default control scheme is as follows:

- **Start buffer charging**
  - T9 and T10 are under their respective setpoints minus the hysteresis. The primary valve opens and starts charging.
- **Stop Buffer charging:**
  - T10 is above or equal to its the setpoint. The primary valve closes. (T9 is not relevant once charging has started).

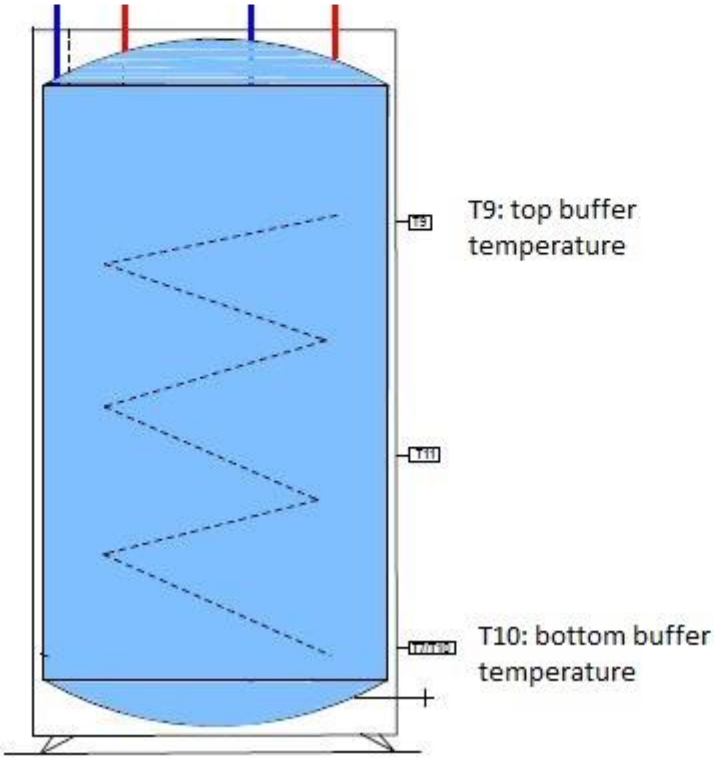


Figure 9: temperature sensors buffer

This is the default control strategy of the buffers, without smart control. When the smart control features developed in TEMPO are enabled, this operation mode is used as a fall back scenario in case the communication between the buffers and the cloud control system fails.

2.2.7 COMMUNICATION AND VISUALISATION

Figure 10 shows the communication scheme which is running in Windsbach. The visualisation- and management software Winmiocs is located in the plant room. Access to Winmiocs is possible with the remote software TeamViewer.

Winmiocs offers the opportunity to visualise, control and manage the complete DH-network. This includes all components in the plant room and with exceptions the biogas

plant. Every connected customers and its substations in the DH network are visible and controllable.

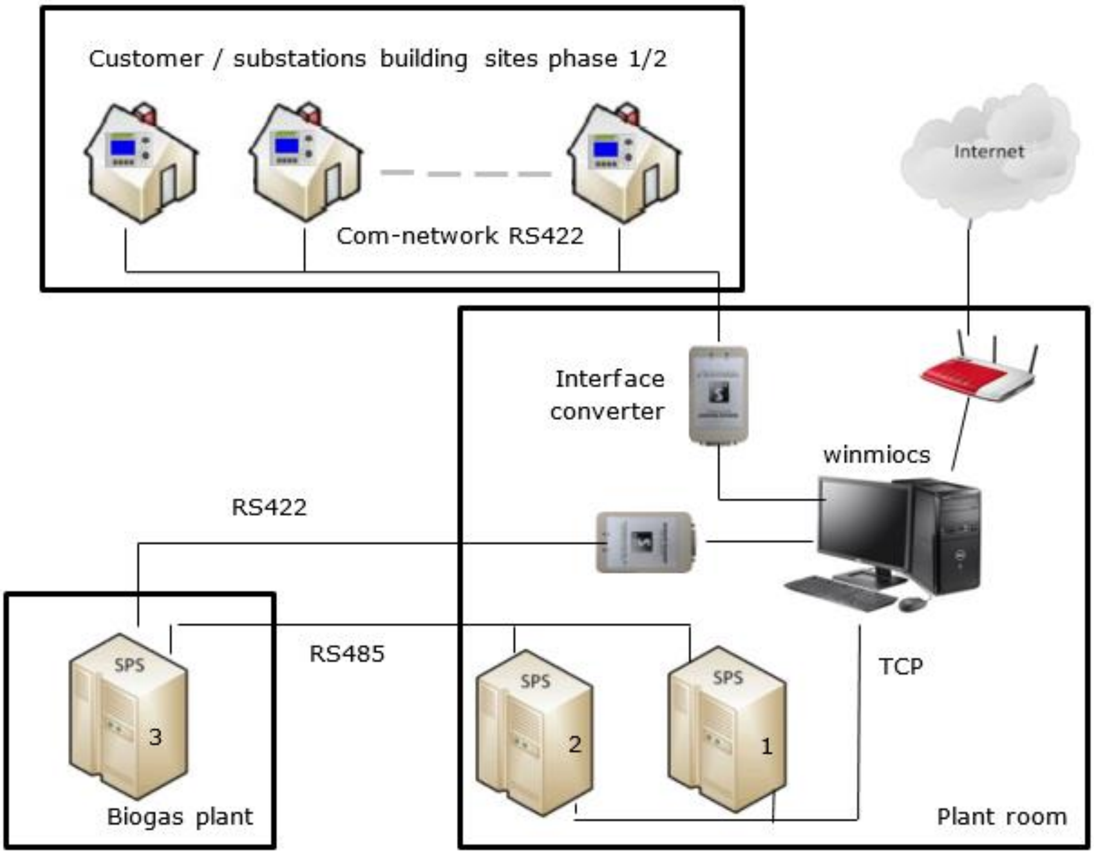


Figure 10: Communication scheme Windsbach

The communication with the substations operates with RS422; a 4-wire connection. The communication protocol is a Schneid-specific solution. The communication with the central controller in the plant room operates with TCP.

2.2.8 VISUALISATION WINMIOCS

Figure 11 shows the main visualisation page in Winmiocs. The status and operation behaviour of all installed components can be controlled and if necessary changed.

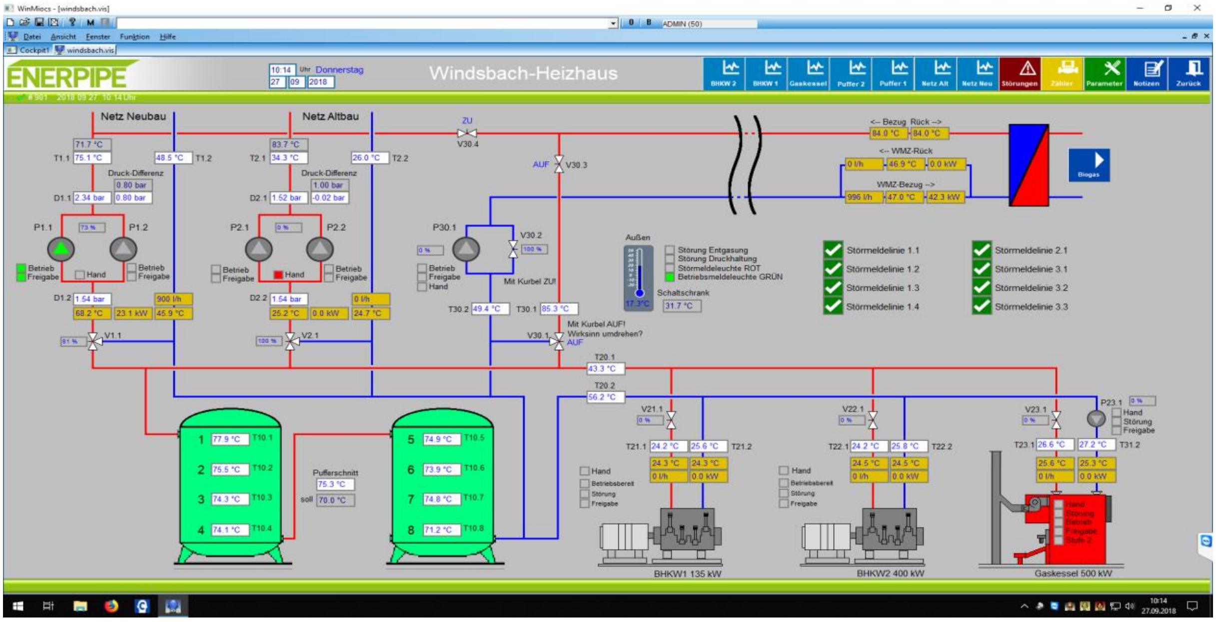
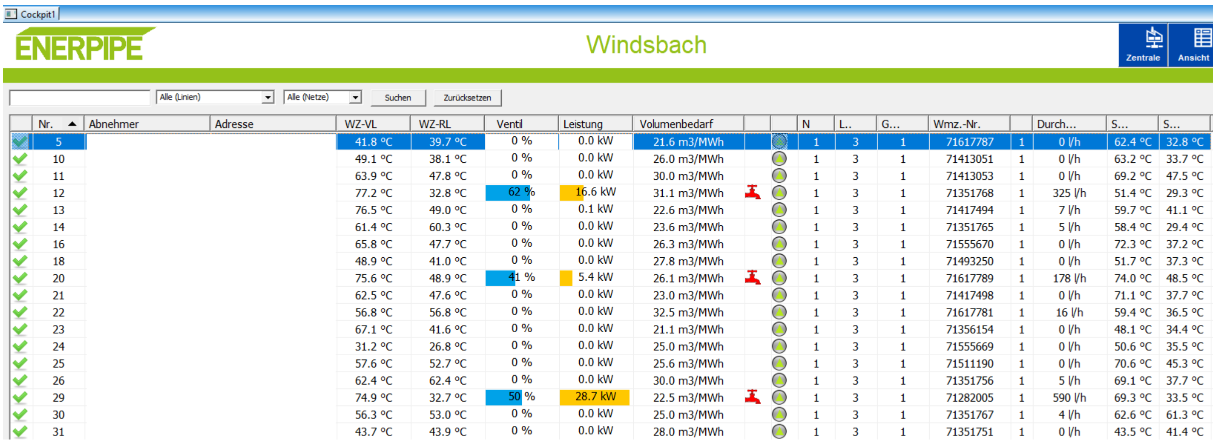


Figure 11: Plant room visualisation in Winmiocs

The cockpit as shown below gives a short overview of all connected substations. The following values can be checked:

- heat meter values (primary supply and return temperature, volume flow rate, power
- status of the primary valve
- top and bottom buffer temperature
- volume requirement (how many heating water volume (m³) is necessary for every transported heat consumption (MWh))



Nr.	Abnehmer	Adresse	WZ-VL	WZ-RL	Ventil	Leistung	Volumenbedarf	N	L..	G...	Wmz.-Nr.		Durch...	S...	S...
5			41.8 °C	39.7 °C	0 %	0.0 kW	21.6 m3/MWh	1	3	1	71617787	1	0 l/h	62.4 °C	32.8 °C
10			49.1 °C	38.1 °C	0 %	0.0 kW	26.0 m3/MWh	1	3	1	71413051	1	0 l/h	63.2 °C	33.7 °C
11			63.9 °C	47.8 °C	0 %	0.0 kW	30.0 m3/MWh	1	3	1	71413053	1	0 l/h	69.2 °C	47.5 °C
12			77.2 °C	32.8 °C	62 %	16.6 kW	31.1 m3/MWh	1	3	1	71351768	1	325 l/h	51.4 °C	29.3 °C
13			76.5 °C	49.0 °C	0 %	0.1 kW	22.6 m3/MWh	1	3	1	71417494	1	7 l/h	59.7 °C	41.1 °C
14			61.4 °C	60.3 °C	0 %	0.0 kW	23.6 m3/MWh	1	3	1	71351765	1	5 l/h	58.4 °C	29.4 °C
16			65.8 °C	47.7 °C	0 %	0.0 kW	26.3 m3/MWh	1	3	1	71555670	1	0 l/h	72.3 °C	37.2 °C
18			48.9 °C	41.0 °C	0 %	0.0 kW	27.8 m3/MWh	1	3	1	71493250	1	0 l/h	51.7 °C	37.3 °C
20			75.6 °C	48.9 °C	41 %	5.4 kW	26.1 m3/MWh	1	3	1	71617789	1	178 l/h	74.0 °C	48.5 °C
21			62.5 °C	47.6 °C	0 %	0.0 kW	23.0 m3/MWh	1	3	1	71417498	1	0 l/h	71.1 °C	37.7 °C
22			56.8 °C	56.8 °C	0 %	0.0 kW	32.5 m3/MWh	1	3	1	71617781	1	16 l/h	59.4 °C	36.5 °C
23			67.1 °C	41.6 °C	0 %	0.0 kW	21.1 m3/MWh	1	3	1	71356154	1	0 l/h	48.1 °C	34.4 °C
24			31.2 °C	26.8 °C	0 %	0.0 kW	25.0 m3/MWh	1	3	1	71555669	1	0 l/h	50.6 °C	35.5 °C
25			57.6 °C	52.7 °C	0 %	0.0 kW	25.6 m3/MWh	1	3	1	71511190	1	0 l/h	70.6 °C	45.3 °C
26			62.4 °C	62.4 °C	0 %	0.0 kW	30.0 m3/MWh	1	3	1	71351756	1	5 l/h	69.1 °C	37.7 °C
29			74.9 °C	32.7 °C	50 %	28.7 kW	22.5 m3/MWh	1	3	1	71282005	1	590 l/h	69.3 °C	33.5 °C
30			56.3 °C	53.0 °C	0 %	0.0 kW	25.0 m3/MWh	1	3	1	71351767	1	4 l/h	62.6 °C	61.3 °C
31			43.7 °C	43.9 °C	0 %	0.0 kW	28.0 m3/MWh	1	3	1	71351751	1	0 l/h	43.5 °C	41.4 °C

Figure 12: Winmiocs cockpit

*Figure 13*4 shows the new developed visualisation page for the decentralised buffer units (CaldoTHERM). Every substation can be examined and if required the settings can be adjusted.

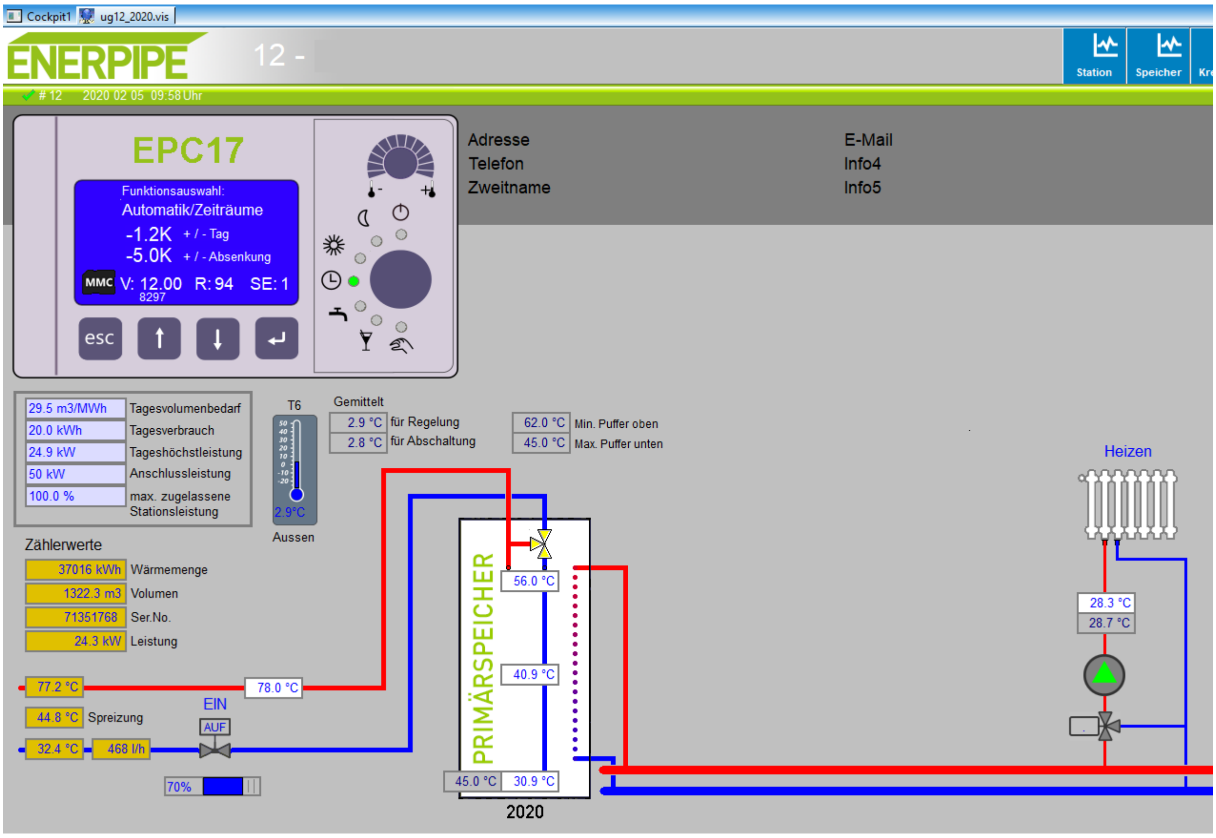


Figure 13: Winmiocs CaldoTHERM

2.2.9 HEAT GENERATION AND CONSUMPTION BALANCING

Figure 14 gives a schematic overview of the different heat meters available in the system

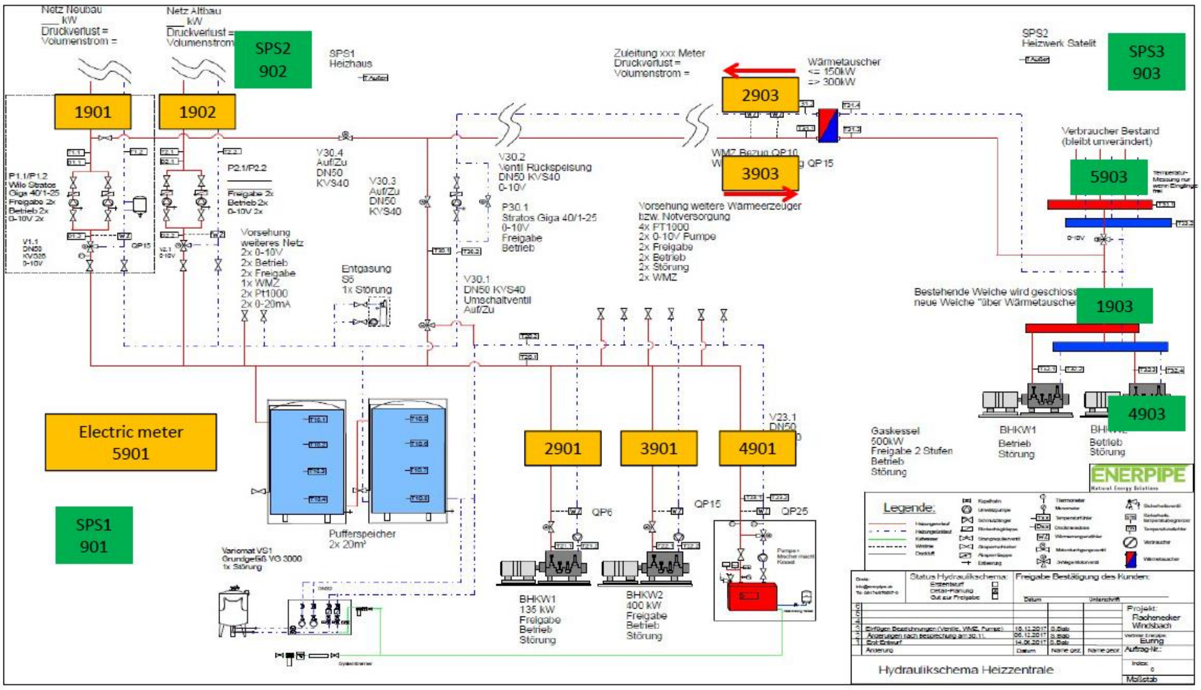


Figure 14: Scheme of the heat meter numbering

- 1901 (consumption)
  - Building site phase 1 and 2
- 1902 (consumption)
  - Building site (not yet in operation)
- 2903 (generation)
  - Heat from biogas plant
- 3903 (consumption)
  - Heat transfer to biogas plant
- 2901 (generation)
  - CHP1
- 3901 (generation)
  - CHP2
- 4901 (generation)
  - Peak boiler

2.2.10 DATA LOGGING SUBSTATIONS

The controller EPC17 from Schneid is installed in every substation. The complete controlling process will be managed independent from the status of the central visualisation. Every datapoint from the controller will be logged and saved in Winmiocs.

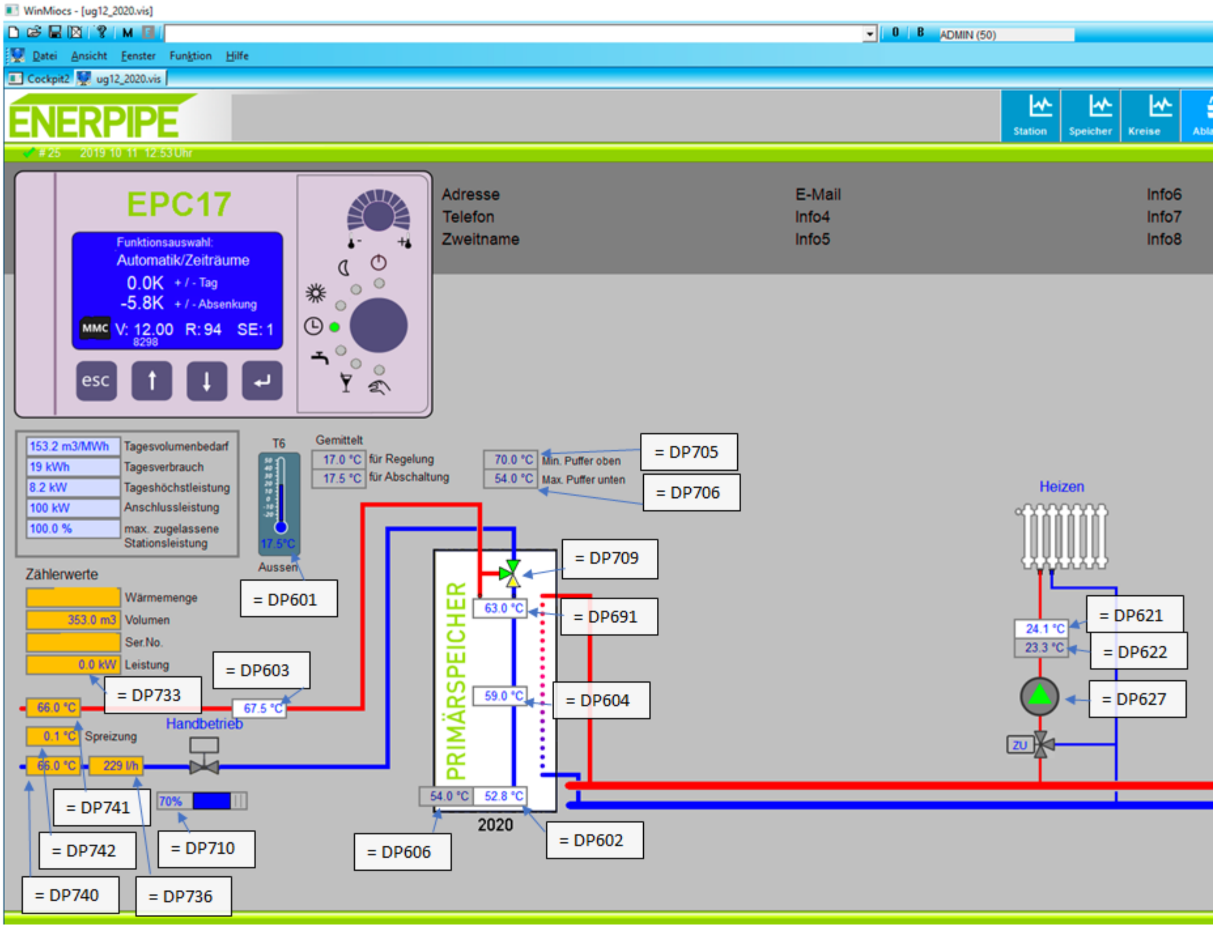


Figure 16: Substation datapoints

2.2.11 CURRENT STATUS CONSTRUCTION SITES

Table 2 shows the current status of the building site phase 1.

To date (beginning of Feb. 2020) 60% of the possible connections are realised (37 of 62). Few building sites are still vacant. After response from the DH Network owner a maximum number of 42 connections should be possible. This would be a share of 68%.

So far the TEMPO innovation decentral buffer unit (CaldoTHERM 250l) is installed in 32 houses.

Table 2: status building site phase 1

description	number	share	date: 05.02.2020
sum building sites phase 1	62	100%	
CaldoTherm 250 l	32		
Buffer unit 600 l	4		
Standard Substation with buffer	1		
Substations connected	**37**	**60%**	
vacant connections	5		
max. possible connections	**42**	**68%**	

For phase 2 no houses have been built yet but the installation of the pipes is completed. It is estimated that the first buffer units have to be delivered in March 2020

3 IMPLEMENTED TEMPO INNOVATIONS

The TEMPO solution package of the Enerpipe demonstrator consists of the following innovations:

- Supervision ICT platform [Noda, VITO]
- Visualization tools for expert and non-expert users
- Smart DH controller
- Decentralised buffers
- Optimization of the building installations

The deliverable [1] gives a general description of these innovations. The following paragraphs illustrate how the innovations are implemented in this specific demonstration site.

3.1 SUPERVISION ICT PLATFORM

3.1.1 DESCRIPTION

The on-site control systems installed in the ENERPIPE demonstration site is connected to the NODA data management platform (Figure 5). This platform handles the data collection and storage, as well as supportive system tools such as an application programming interface (API) and a web-based front-end user interface (EnergyView). The automated analysis and control functionality developed in TEMPO will use the API to read and write data accordingly. All collected data is available through the API, which makes it possible to access for all relevant partners in the project.

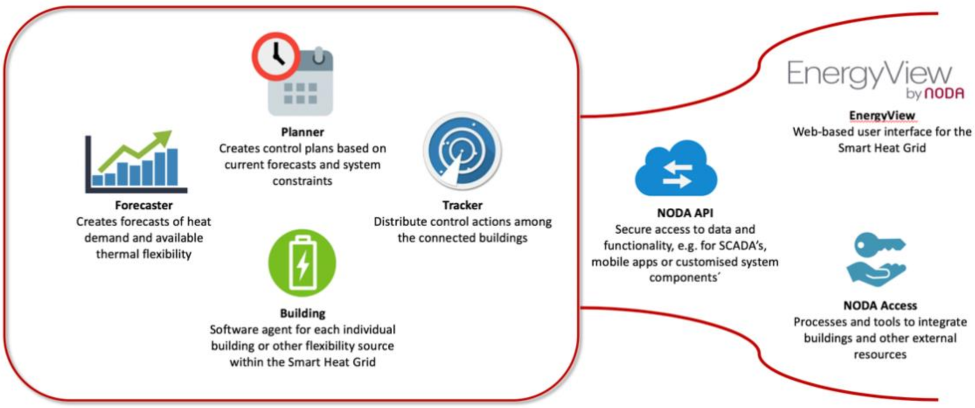


Figure 17: a conceptual overview of the ICT platform used in the ENERPIPE demonstrator

The data collected is used to calculate the performance metrics as defined in the project. These performance metrics are then used either by themselves or in combination as input for further ranking and analysis. The performance metrics used in version 1 are:

- Primary differential temperature
- Volume weigthed primary differential temperature
- Primary return temperature (PrT)
- Volume weighted primary return temperature (PrTv)
- Volume per energy (VpE)
- Overflow (OF)

Each performance metric is calculated on the time step relevant for each specific application.

3.1.2 INSTALLATION

Considered as a supervision ICT platform, NODA EnergyView is readily available as a Chrome web application to anyone with the proper login credentials. When made available as a commercial product, the solution also comes configured with a dashboard of standard reports. However, the unique nature of the Windsbach site prevents the use of standard reports, though tailor made reports can and will be added throughout the project.

3.2 VISUALIZATION TOOLS FOR EXPERT AND NON-EXPERT USERS

3.2.1 DESCRIPTION

The NODA EnergyView web application makes it easy to create dashboards and specialized reports for monitoring the data feeds integrated with the ICT platform. The tool is suitable for expert as well as non-expert users, though when provided as a commercial product the latter case is combined with a standard set of ready-made reports for the front page/dashboard. The unique nature of the Windsbach site prevents the use of standard reports, though tailor made reports can and will be added throughout the project. The screenshot in *Figure 18* shows an example report demonstrating one of the many features in this case to display measurement (and control) values of different units of measure in the same graph. However, for more efficient use, it is often more productive to target one feature per report and utilize the possibility of switching between browser tabs to cover a wide range of features.

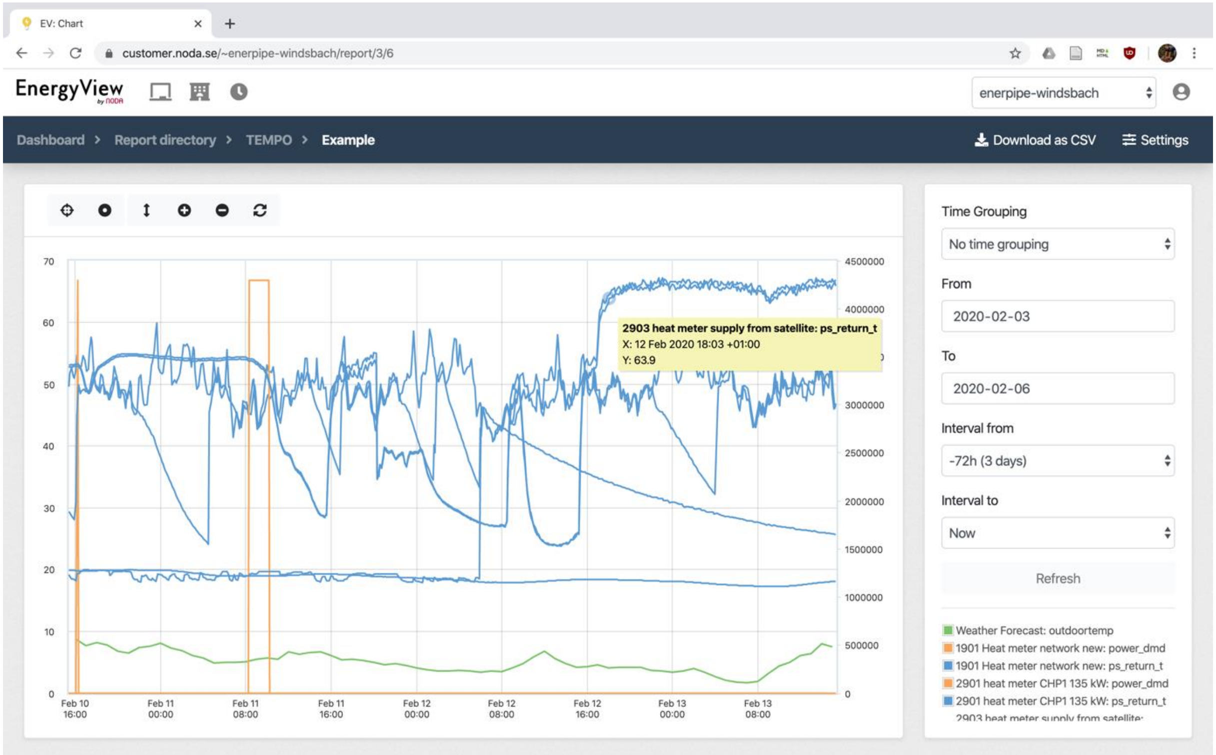


Figure 18: EnergyView screenshot

EnergyView also comes with a REST API for reading measurement (and control) values as well as writing control values. This makes it possible for the expert user to extend the ICT platform with analytics solutions targeting features beyond what's readily available. The API documentation is available to anyone logged in to EnergyView, see the screenshot in *Figure 19*. However, to use the API, additional credentials are needed.

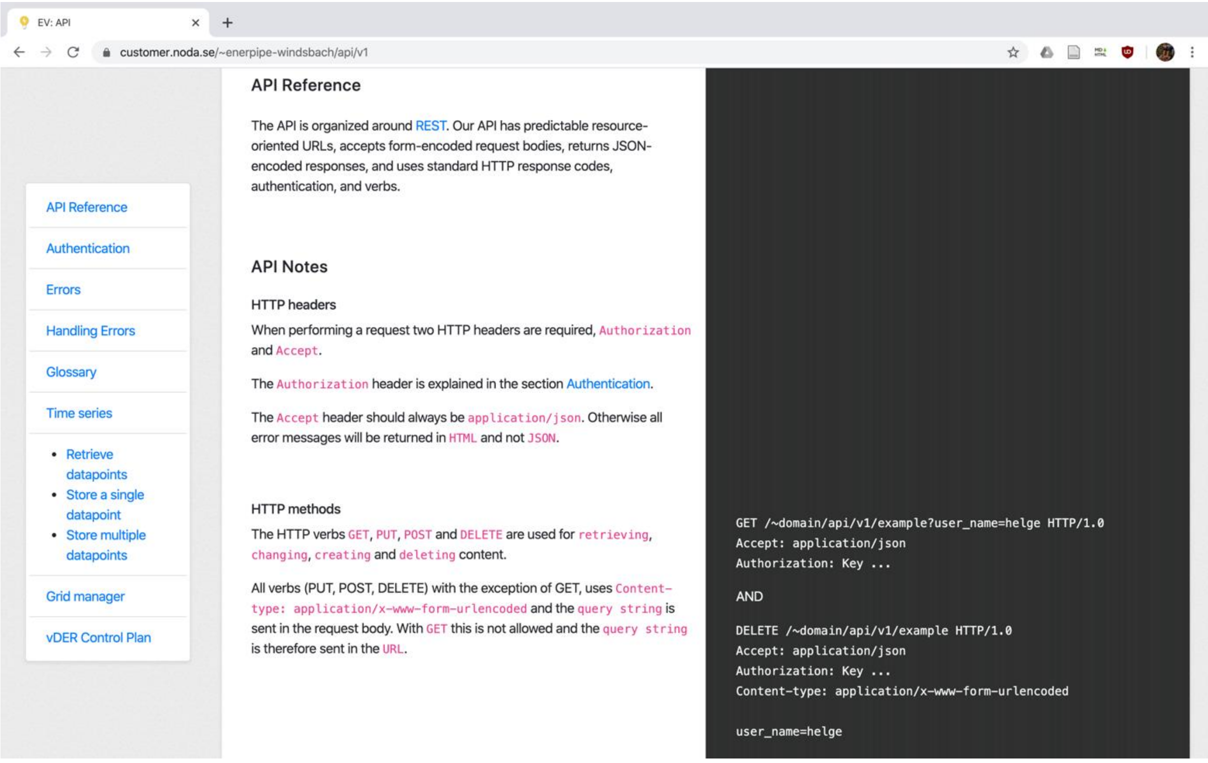


Figure 19: Screenshot of the EnergyView API documentation

Among the different metrics outlined in the project proposal, the overflow method and related metrics provides a starting point for monitoring large numbers of substations. Linking substation performance with the monetary gain of substation maintenance, the method constitutes a natural starting point for further in-depth analysis. And while the method and related metrics can be evaluated in a purely numerical fashion, they can also be presented visually. *Figure* ***15*** and *Figure* ***16*** illustrate the situation for an [anonymized] commercial situation with thousands of substations, the first image depicting certain metrics underpinning the overflow method and the second image the actual overflow metric plotted against the temperature difference. The benefits of visualization are twofold, firstly, it builds on the strengths of the human visual system for selecting substations of interest and, secondly, for judging the validity of the data set and building trust in the metric.

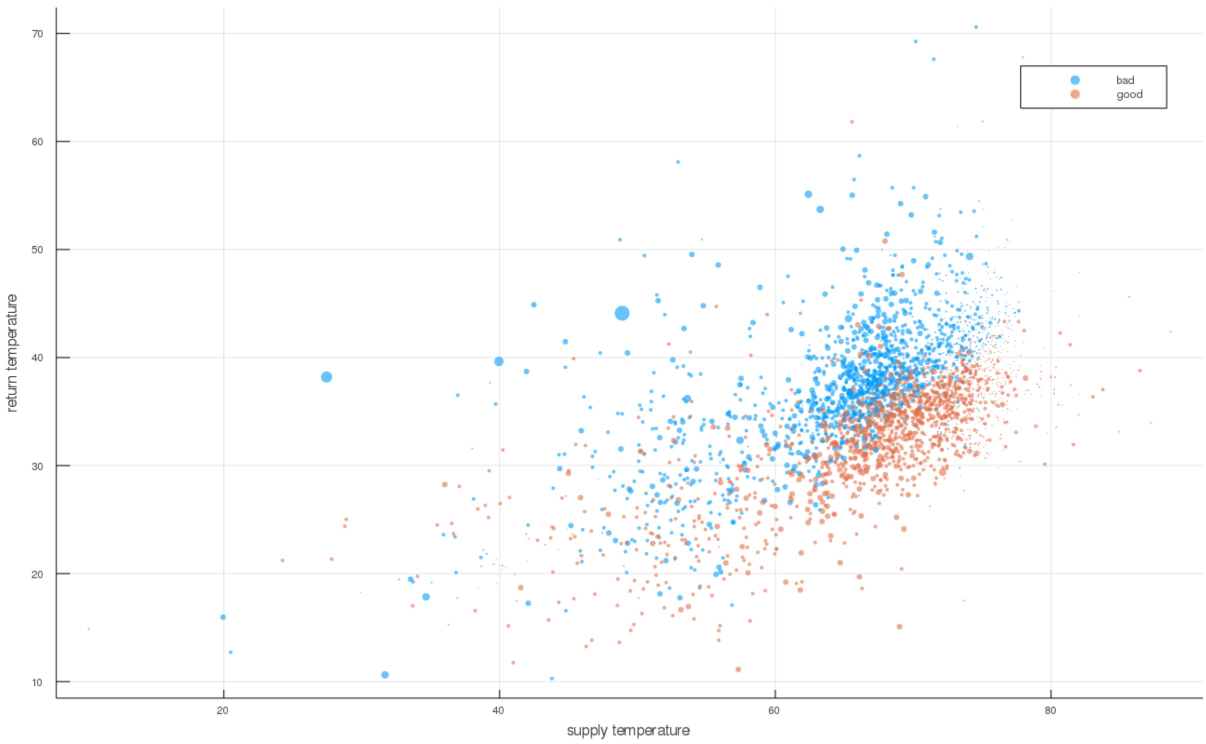


Figure 15: Overflow method

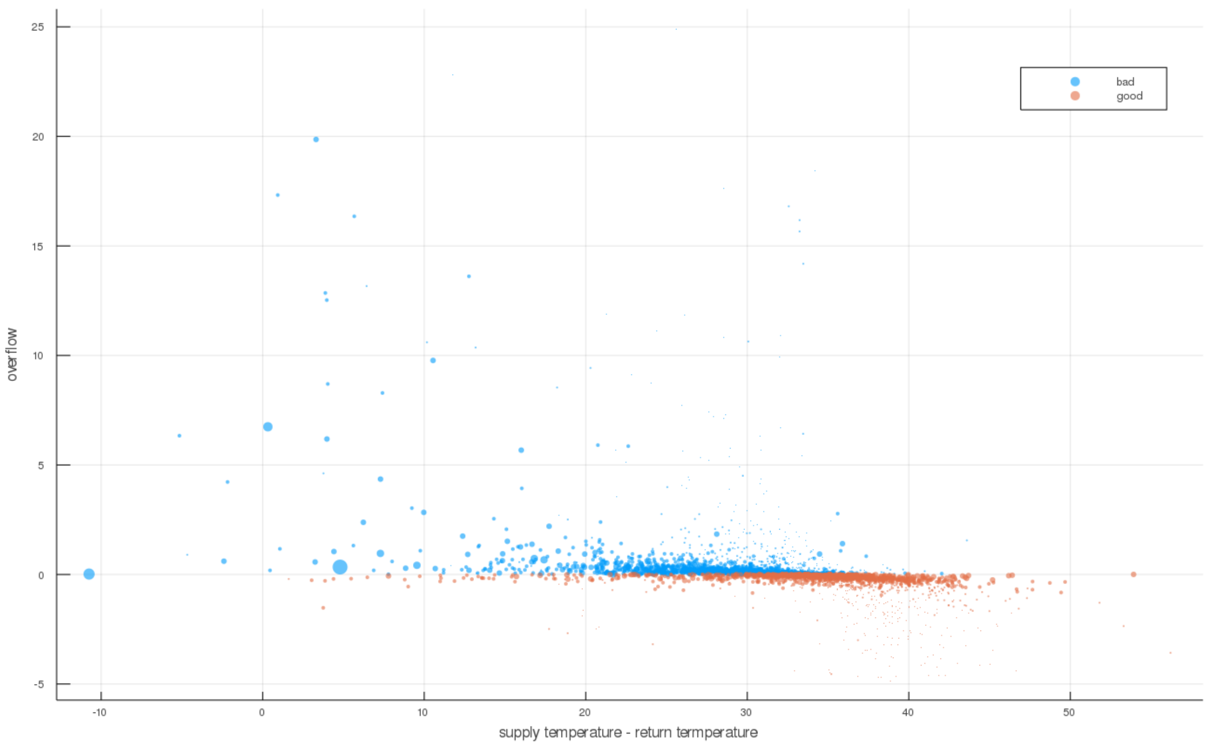


Figure 16: Overflow method against supply and return temperature difference

3.2.2 INSTALLATION

NODA uses the CoCalc web platform to make analytics tools available for expert users in the form of Jupyter notebooks. The solution requires proper credentials but no

installation, and solves the challenge of making programmatic tools available to for the expert user while isolating the ICT platform from human errors.

3.3 SMART DH CONTROLLER

3.3.1 DESCRIPTION

The purpose of the smart DH controller is to control the heat load in the network in order to optimize the temperature levels in the network. Three different control strategies were identified and will be tested in the demonstration sites:

- **Return temperature optimization**
  - By sending heat demand control signals to the buildings, it is possible to lower the return temperature to the network. By doing this in a coordinated way, the average return temperature can be decreased, or the temperature reduction can be concentrated so that the low temperature front hit the production unit on appropriate moments (such as times when the electricity price is high in case of CHP).
- **Coordinated buffer charging**
  - The objective is to optimize the charging of the centralized and decentralized buffers according to a specific business case. This control strategy has been specifically developed for the Enerpipe demonstrator and three business cases have been identified:
    - Optimisation of CHP operation
      - Maximization of the CHP operating revenues by generating electricity when electricity prices are high
    - Minimization of heat losses and pumping costs
      - Maximise off time of the central DH pump: group charging of buffers in order to maximize the total off time of the DH network
- **Supply temperature optimization**
  - Use the water in the network as a virtual storage buffer: by increasing the temperature of the water in the supply pipes when excess heat is available, heat can be stored for a limited time.

Extra hardware and software is needed to apply the above control strategies, both for monitoring/measuring data as well as controlling purposes. The next subsections will give a detailed overview of the extra hardware and software that is used in the Enerpipe demonstrator

3.3.2 INSTALLATION

The smart DH controller algorithm as described in Chapter 4 of [1] runs on the following setup which is hosted in the local VITO network:

- Virtual windows server 2016 (64 bit)
- 4 GB RAM
- 2 Intel64 Family 6 Model 79 2.6 Ghz processors

The controller gets it input by calling the API provided by NODA which is able to access the EnergyView system. It also calls the same API to send the output of the controller.

The large-scale global architecture is outlined in *Figure 17*. It relies on Azure and AWS cloud solutions for the backbone, CoCalc to host Jupyter notebooks for expert users, and the Schneid solution in Windsbach for the collection of measurement values and the execution of control. Communication over the backbine is by JSON over a REST and JSON over MQTT. The other communication links are owned and managed by VITO, NODA, and Enerpipe/Schneid/Windsbach , with the communication links between NODA CoCalc and NODA using the same AWS REST API as between VITO Azure and NODA AWS.

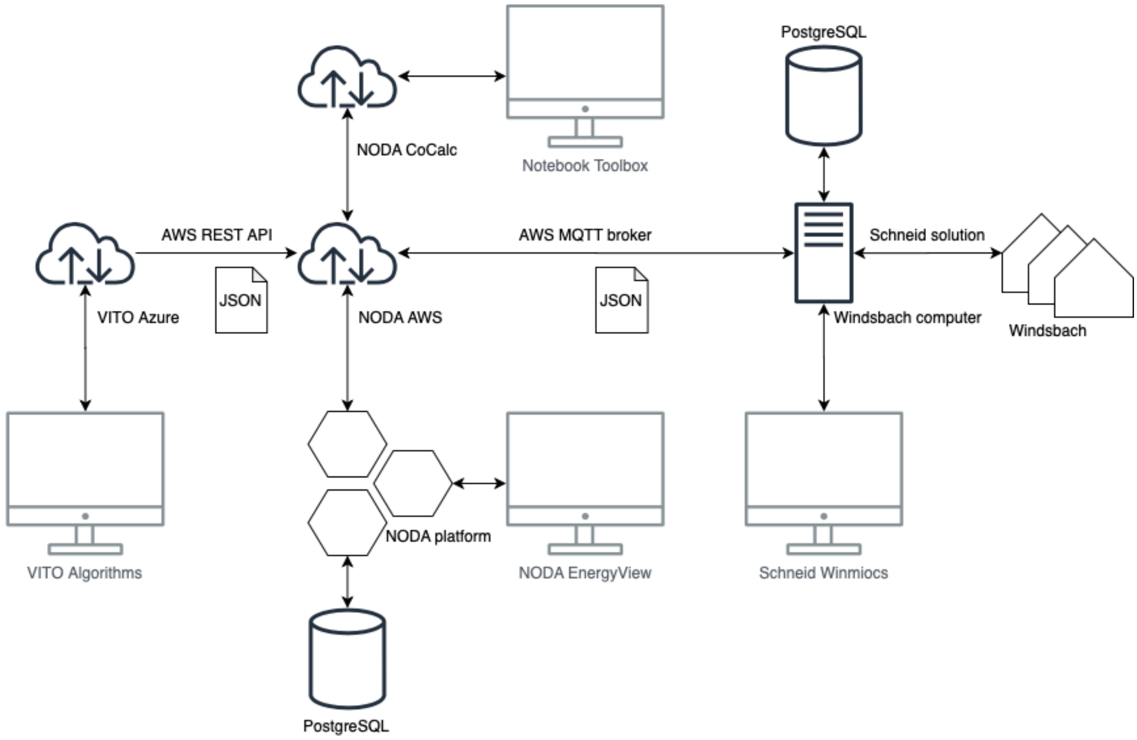


Figure 17: System overview

The two PostgreSQL databases are managed by NODA and Schneid, and integrates with the corresponding monitoring and visualization systems, NODA EnergyView and Schneid Winmiocs respectively. The computer running the Schneid solution in Windsback also runs a Java program/the NODA bridge (not in picture), which connects the Schneid solution to the NODA solution through the AWS MQTT broker.

3.3.3 COST AND TIME EFFORTS

The integration with the ICT platform has been performed by Beck & Partner KG (BEP) in collaboration with NODA Intelligent Systems AB. The work carried out can be structured into research of technical constraints, negotiation of communication solutions, and implementation and configuration of the agreed solutions followed by verification and validation of the solution, and followed the normal process for commercial projects closely. However, the I/O-list for the communications solution involved about 30 types of values as compared to the normal 10 types of values, causing administrative overhead. For an outline of the integration effort, see *Table 3*.

Table 3: Effort timeline

Topic	Time	Content	involved
Planning Meeting	2019-10-01	defining tasks	project team + BEP
Work out of details		selecting and identifying sensors (datapoints), stations publishing details of existing solution to build on	project team + BEP
Review and confirmation of datapoints	2019-10-01 to 2019-11-15	carried out by project team	project team + Schneid
Selected stations and datapoints	2019-12-1 to 2019-12-27	• 37 buildings selected, 35 operative, 2 still in (building) construction • 20 datapoints for each builing • 3 heat producers (2x biogas CHP, 1x natural gas) (heat meter data) • 2 heat exchange meters (in / out to old grid) (heat meter data) • 1 heat meter total grid (heat meter data) • 1 location with 2 central storage tanks (temperature data) Total of ca. 750 datapoints communicated to NODA each 1-5 minutes (interval variable)	BEP, NODA, Enerpipe, Schneid
Preparation of start- and endpoints of data traffic	2019-11-15 to 2020-01-15	administrative preparation setup of NODA database (client, buildings, sensors, data access) checkup of installed controllers and software (latest versions?)	NODA NODA Schneid Schneid

		installation of Postges database in Windsbach setup of interface Postgres/Winmiocs	Schneid Schneid
Setup of data exchange Windsbach / NODA	2020-01-02 to 2020-01-31	install Java Runtime install NODA Bridge software Schneid to NODA select datapoints map stations / buildings to NODA IDs map sensors/datapoints to NODA IDs map units to NODA unit codes	BEP
Test of data exchange	2020-01-02 to 2020-01-31 partly completed, pending	test data out (JSON format) review data content for validity test control data in (simulation of NODA switching commands towards the Schneid database verify the data trail from database in Windsbach to Schneid Winmiocs system and then down to the buildings	BEP NODA BEP BEP + Enerpipe

Table 4: technical products and software

Component / Software	Description	Source / Producer
Building controllers	MR12 district heating controllers (advanced microcontrollers), software partially modified for Enerpipe / Windsbach	Schneid (commercial prodct)
Visualization Server	PC	commercial standard product
Central visualization software for grid Windsbach	Winmiocs, layout customized for Enerpipe / Windsbach	Schneid (commercial product)
PostgreSQL database Windsbach	basis for exchange Winmiocs / NODA	PostgreSQL
NODA-Bridge	mapping and coding/decoding software, picks data from PostgreSQL database and wraps it into JSON messages for NODA uses MQTT protocol to communicate with NODA (AWS Server)	BEP, Java-based (inhouse)
Java Runtime	Runtime license for using NODA Bridge	Oracle
MQTT broker	connection to NODA's AWS database	AWS Amazon
AWS database	used for hosting the data for NODA's operative and analytic purposes	AWS Amazon Database PostgreSQL

3.4 DECENTRALISED BUFFERS

3.4.1 DESCRIPTION

Different improvements and innovations are implemented in the decentralised buffer units (CaldoTHERM). The current unit is version 3 of the buffer. The following list is a short description of the included buffer innovations:

- Primary storage concept
  - The buffer volume belongs to the primary side. The coil heat exchanger in the buffer heats up the water for the connected heating systems. A low primary return temperature is only one benefit. Another benefit is the possibility to use the higher primary supply temperatures without losses directly for the DHW-station.
- Space optimised
  - A space of only 0,61 m x 0,61 m is required. This enables the installer to use niches, small rooms or even the utility room for installing.
- DHW station
  - Using primary water for the station makes the process of DHW preparation more efficient.
  - The primary supply temperature has not to compensate the terminal temperature difference in a second heat exchanger.
  - Cooled primary water flows flows back into the buffer or directly into the primary return pipes depending on the temperature. This allows to control the operation in a way leading to lower primary return T.
- Quick and easy installation of the unit
  - The unit is completely pre-installed. All components are built-in the unit. The installer has to do the connections for domestic water, heating system on the secondary side and the pipe connection on the primary side. All connections are from above. All required components (expansion vessel, pressure gauge, Safety Valve, drain tap, sensors, DHW-station) are integrated. The electric components (pumps, valves, sensors) are completely wired.
- Circulation unit
  - ENERPIPE developed a circulation lance which is built-in directly into the buffer. Thanks to this concept no operation of the DHW-station is needed during circulation. This saves electrical energy for the pump and reduces heat losses. The circulation lance was carefully conceived not to disturb the buffer stratification."

3.4.2 INSTALLATION

The decentralised buffer unit 250l is completely pre-installed and wired. The buffer panel is mounted too. The complete unit can be transported into the building to its provided place.

Hydraulic installation:

*Figure **18*** shows the mounting instructions for the decentralised buffer 250l. All hydraulic connections are from above.

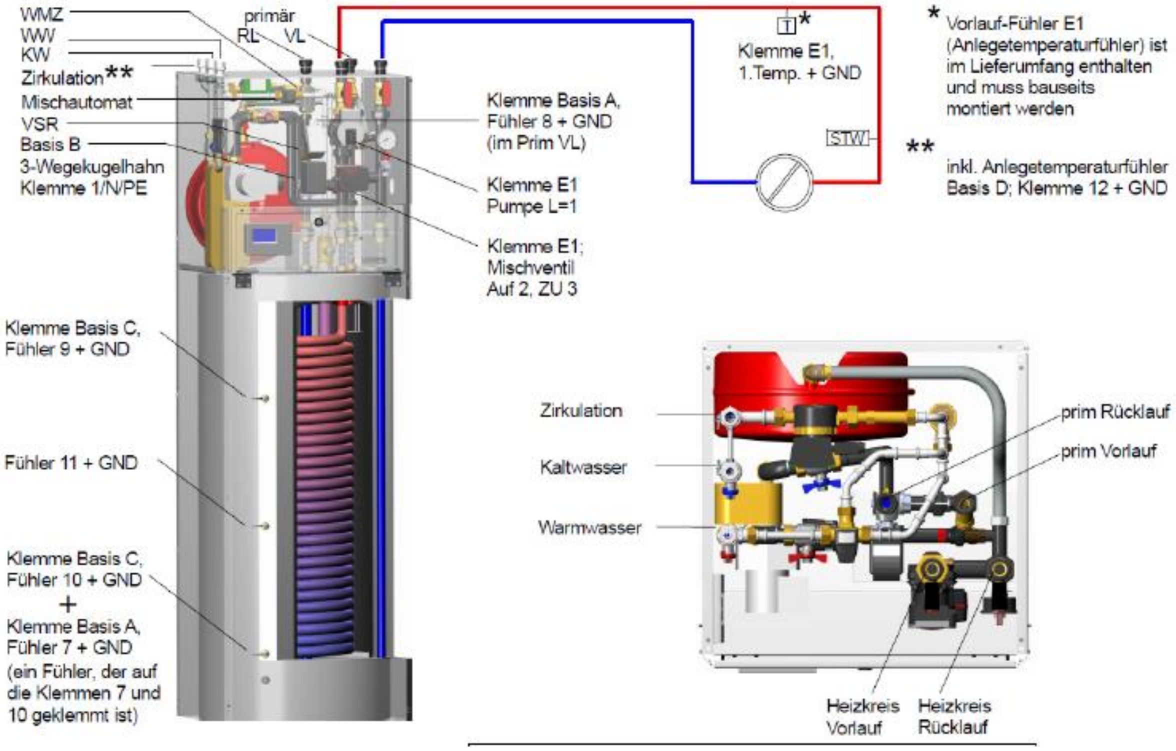


Figure 18: CaldoTHERM mounting instructions

The following pipe sizes are foreseen:

Primary side:	DN 32 (flat sealing)
Secondary side:	DN 32 (flat sealing)
Domestic water side:	DN 25 (flat sealing)
Circulation:	DN 25 (flat sealing)

Electrical installations:

All necessary electrical connections are pre-installed. The secondary supply temperature sensor has to be positioned on the supply pipe outside of the buffer unit.

The following electrical house connection has to be done:

- 230 V AC
- 50 Hz

Figure 19: electrical connections shows the controller with all connected devices and the electrical house connection.

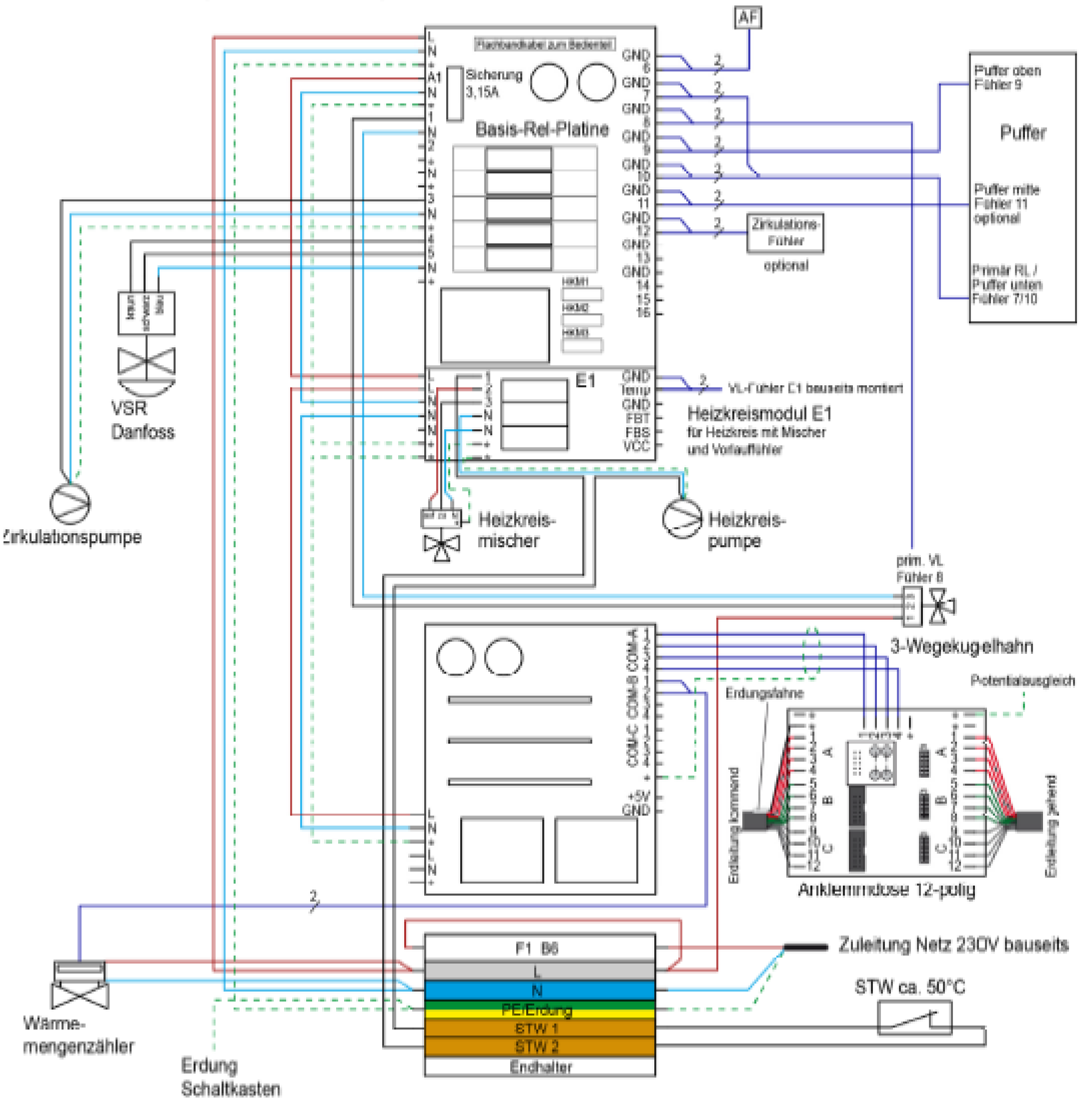


Figure 19: electrical connections

Bus communication installations:

Figure 19: electrical connections shows also the connection to the bus communication.

Controller:

The software and the specific parameter for the controller is pre-installed too. After commissioning, the unit is running without deeper knowledge of the controller settings.

3.4.3 QUALITY CONTROL MEASURES

The intention is to provide developer, designer, architects, contractor, network owner, municipalities and installers with all necessary information as soon as possible. From the beginning of a new project all parties have the opportunity to check the installation conditions and the possibility of use.

ENERPIPE issued a technical description to inform interested people. The following information are important, necessary and content of the description:

- Overview of the product
- Technical description and installed components
- Optional equipment
- Controller
- Planning and Space requirements
- Hydraulic schemes
- Mounting conditions (hydraulic, electric), connections, dimensions
- Mounting schemes and controller configuration
- Datasheet
- Technical data from the installed components
- Domestic hot water preparation
- Pressure drops graphs

This document helps to avoid problems during all phases of the project, because all requirements are described. In case of failures or deficiencies the document helps to discuss and solve the problems and to avoid them in the future.

Training

Enerpipe offers installer and network owner the opportunity to instruct them in the Enerpipe controller EPC17 and the specific installation requirements.

Manufacturing:

To produce high quality products Enerpipe pursued different quality control measures.

The unit is designed with the 3D-Drawing-Software Creo.

Every component for welding and screwing is available with its specific dimensions.

After manufacturing the components will be tested with pressure.

Before shipping there is a final check. This test protocol will be stored.

Installation:

The technical description contains all information for the installation.

Maintenance:

The visualisation offers the opportunity to check all connected substations. The network Owner could examine the following components and behaviour:

- Volume requirement m^3/MWh in the cockpit
- Primary return temperatures
- Position of the primary valve
- Buffer temperatures

Due to the fact that all data will be logged from Winmiocs, a chart for every value is available. Failures or controller behaviour can be recognised and optimised, e.g. charge cycles, valve positions, etc.

3.4.4 COST AND TIME EFFORTS

Planning steps construction site:

Phase 1	**October 2017 to October 2019**
10/2017	pipe dimensioning construction site (phase 1 and 2) and pipe delivery for phase 1
10/2017 to 11/2017	pipe and communication cable installation
02/2018 to 05/2018	construction and installation plant room
From 03/2018	start construction of the first houses
06/2018	commissioning control technology and visualisation in the plant room
From 06/2018	delivery of the first decentralised buffer unit
	Commission of the bus communication.
	1st house is visible in the visualisation
07/2018-09/2018	developing an improved versionof the decentralised buffer unit
	Developing and delivering of a bigger (600 l) decentralise buffer unit
08/2018	developing and delivering the buffer concept for the multi-family-house
10/2018-12/2019	developing an improved third version of the decentralised buffer unit
From 12/2019	delivering of the third version
01/2019-02/2019	developing an improved fourth version of the decentralised buffer unit
From 03/2019	delivering of the fourth version
06/2018 – 10/2019	optimisation of the buffer controller and visualisation
Phase 2	**October 2019 to now**
10/2019	review pipe dimensioning for phase 2
10/2019	pipe delivery for phase 2

10/2019-12/201	pipe and communication cable installation
02/2020	start construction of the first houses

Implementation of the innovations:

10/2019	Meeting in Hilpotstein to discuss the implementations
11/2019-02/2020planning,	definition and installation of the interface from Winmiocs to EnergyView (noda)

3.5 OPTIMIZATION OF THE BUILDING INSTALLATIONS

3.5.1 DESCRIPTION

The optimization of the building installations includes:

- practical optimization of the customer installations based on feedback from the demo site
- the use of the practical guide for technical audit of building installations
- the use of simulations to evaluate the impact of faults

Given the unusual substation type used in the Enerpipe demonstrator, the preparation of a detailed simulation model including controls is expected to be time-consuming and the focus is set on the use of the practical guide.

The first version of the practical guide has been reviewed by ENERPIPE. The practical guide will be made available to Wärme.natürlich Gbr, who may use it to diagnose suboptimal behaviour in building installations and notify the owners. It is desirable that the practical guide should be tailored to the installations present in the demonstrator. This means that certain issues can be left out altogether, as they are not applicable in this case (e.g. heat exchanger transfer capacity or heat exchanger control issues), while others are known to be relevant (e.g. sensor faults). In contrast to the first version of the practical guide, which was a static (PDF) document, a more interactive presentation of the practical guide is being designed by AIT and NODA, in the form of a website containing links from the general flowchart to individual issue profiles. It should be noted that the practical guide, even in its more interactive version, is not intended to replace visualization software (in this case Winmiocs) but rather to have a complementary guiding role.

3.5.2 POSSIBLE OPTIMIZATIONS

During installation we got some feedback from the installer company. This feedback gave us the opportunity to develop the unit further and to evolve new ideas for a new version.

Here are some comments:

- Connections from above are the right choice. This gives the installer more opportunities for pipe installation and connection.
- The weight of the buffer is very heavy, especially when the buffer has to be transported into the cellar.

  - Enerpipe plans to separate the buffer into a hydraulic module and a storage module. These 2 pieces must be connected in the heating room.
- Sometimes after transportation the buffer panel could be damaged or scratched.
  - For future version ENERPIPE considers to develop a removable insulation with EPP.
  - After the first installation we got the feedback that not all components are easy to do the service afterwards. This leads to an optimization and a rearrangement of some of the pre-installed components.
  - Installations provided by customers are not plannable. The buffer unit has to be connected to the domestic water system and the heating system of the building. Installers don't consider or know the benefits and requirements of the these different units. This leads to unnecessary installations of a second expansion vessel, pressure gauges or safety valves. ENERPIPE and the network owner should clarify the interface and required performance.

3.5.3 INSTALLATION

The practical guide will be made available online.

4 COMMISSIONING AND INITIAL OPERATION

The original plan which was described in the Grant Agreement described the following phases:

- Winter 2018 – 2019
  - DHS is operational but all innovations, besides the decentralized buffers, are not yet installed
  - During this winter reference data will be gathered
- Winter 2019 - 2020
  - All innovations are installed and performance of the innovations can be quantified by comparing with the reference data from the previous winter
- Winter 2020 – 2021
  - Based on the results of the previous winter adaptations are made to the installed innovations and a final monitoring phase takes place

The installations for the winter of 2018-2019 were conducted according to plan. However the planned innovations for the winter of 2019-2020 were not installed on time due to unexpected challenges during the integration of the different systems. The complete integration was finished by half of February 2020 and the first buffer control signals have been sent. The innovations will now be tested during the winter of 2020-2021.

For the commissioning of the decentralized buffers, ENERPIPE pursues a 2 step approach:

1. **Pre-Installation**
   The main aim in the development was to integrate as much components as possible into the unit. This gives us the opportunity to wire every component which is necessary for operation. Apart from the main electrical connection and the pipe connections there are very less components to add on the site. The controller will be delivered with the specific configuration.

2. **Commissioning instructions**
   Every buffer unit delivery contains a document named "short commissioning instructions". The installer has got all needed information regarding pipe connection, electrical connection and controller configuration. If necessary the installer could change or adjust the parameter.

4.1 INITIAL PHASE

After the first months of operation ENERPIPE checked the buffer behaviour and the charge cycles. In the chart below are the buffer temperatures top and bottom (red, yellow) and the position of the primary valve on October 4th, 2019. What we can see is that the number of cycles is very high.

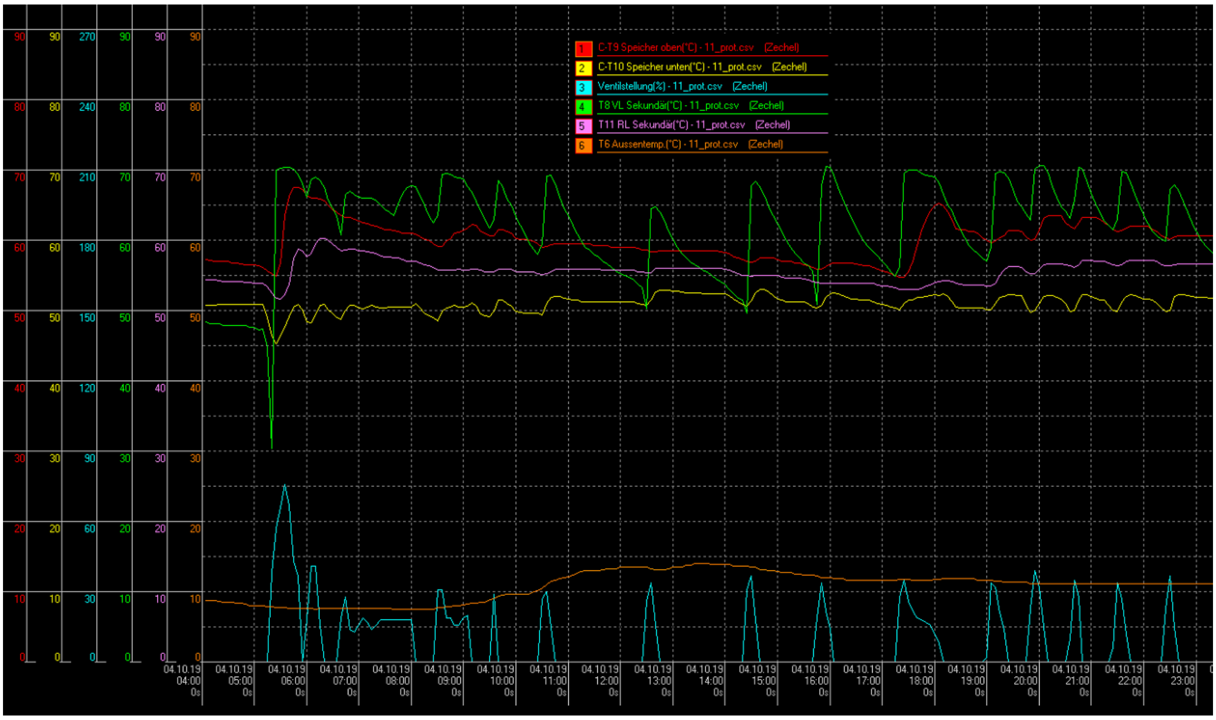


Figure 25: Charge cycle before optimisation

After optimisation of the buffer setpoint temperatures and its hysteresis the charging cycles are significantly lesser and the buffer capacity can be used more efficiently. The efficiency parameter Volume Requirement is therefore much better.

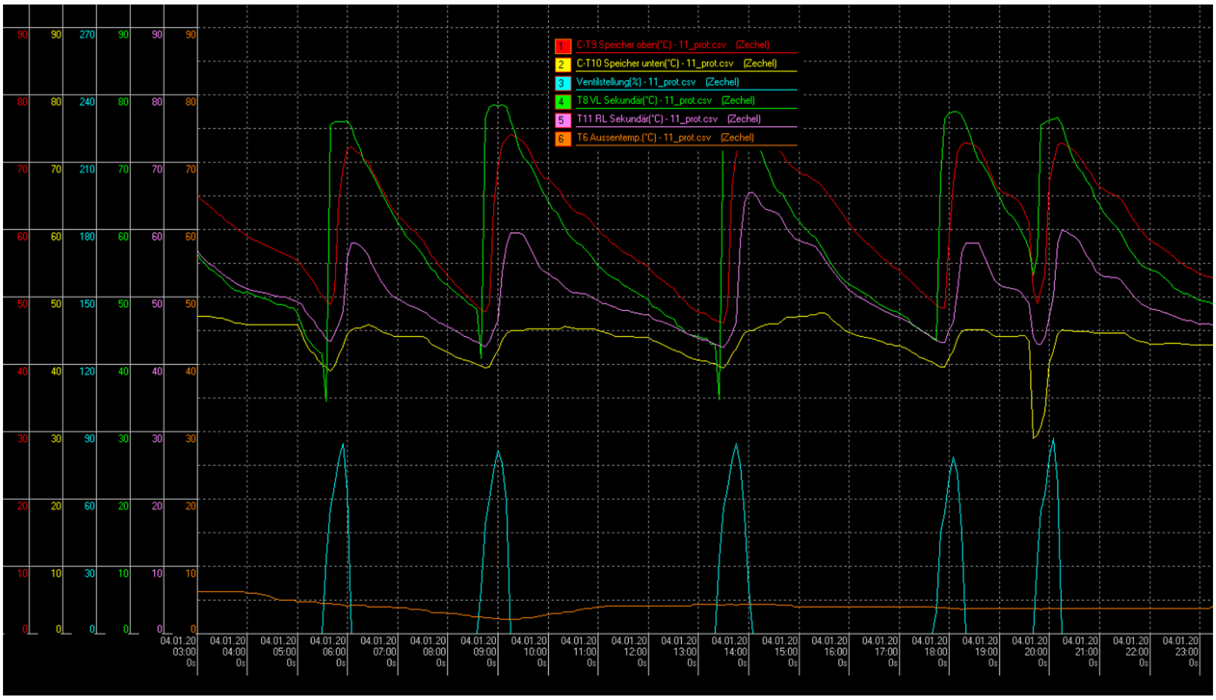


Figure 26: Charge cycle after optimisation

5 MONITORING

This chapter describes the monitoring concept for the demonstrator. Basic requirement for the monitoring concept is to make sure that the evaluations defined in Del. 5.1 are possible when the demonstrator is in operation.

Monitoring will be done predominantly by means of the existing monitoring sensors that are required for control, operational and billing purposes in central heating plant and in the consumer substations.

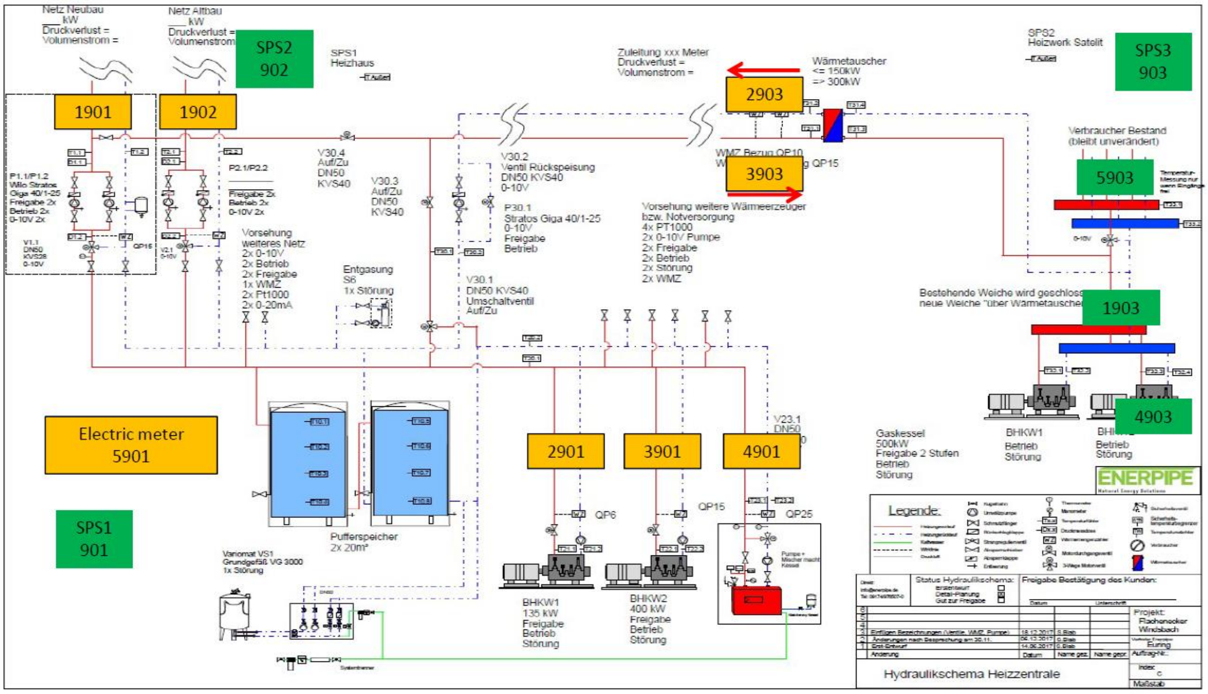


Figure 27: hydraulic concept and monitoring concept of the central heating plant

5.1 KEY PERFORMANCE INDICATORS

General key performance indicators for monitoring in TEMPO are defined in Deliverable D5.1 and summarized in *Table 5***Error! Reference source not found.**.

Table 5: Key performance indicators.

Key performance indicators	Unit
Primary energy demand savings**Error! Reference source not found.**	kWh/year, %
Greenhouse gas emission savings	t/year
Reduced heat distribution losses	kWh/year, %

Share from residual or renewable energy sources	%
Heating degree days	Kd/year
Return temperature reduction	K

Most of the KPIs correspond to the difference between values in a baseline period and values in improved conditions, i.e. after implementation of the innovation(s). In the Enerpipe demonstrator, the innovation of decentralized buffers is implemented from the start, so that a baseline period without decentralized buffers is not possible. Thus, it was decided to define the baseline period as a period with decentralized buffers but without smart controller. Additionally, the impact of the decentralized buffers in terms of reduction of the heat distribution losses is calculated from the comparison of sizing data for the implemented system (with decentralized buffers) and for a hypothetical reference case without decentralized buffers.

The calculation of the KPIs is based on substation monitoring data and primary-side monitoring data. Substation monitoring data includes about 80 variables logged at 2-minute intervals in each of the active substations. It is transmitted automatically through FTP to AIT on a daily basis. Primary-side data includes temperatures and energy values logged in the plant room. It is logged at 5-minutes intervals and transmitted to AIT manually every 6 months.

PRIMARY ENERGY DEMAND SAVINGS

Primary energy demand is calculated based on final energy consumption monitored in the plant room and primary energy factors from the German standard DIN V 18599-1 as summarized in *Table 6***Error! Reference source not found.**.

Table 6: Primary energy factors.

Energy carrier	Primary energy factor (total)	Primary energy factor (non-renewable)
Biogas	1.5	0.5
Electricity	2.8	1.8

Electricity generated by the cogeneration plants is not considered in the calculation.

GREENHOUSE GAS EMISSION SAVINGS

Greenhouse gas emissions are calculated based on final energy consumption monitored in the plant room and CO2 conversion factors. CO2 conversion factors are taken from an official data sheet of the German Federal Office of Economics and Export Control (BAFA)[1] and summarized in *Table 7*.

[1] Bundesamt für Wirtschaft und Ausfuhrkontrolle. 2019. Merkblatt zu den CO2-Faktoren. Stand 01.01.2019

Table 7: CO2 conversion factors.

Energy carrier	CO2 conversion factor in kg CO2 equivalent/kWh
Biogas	0.148
Electricity	0.537

REDUCED HEAT DISTRIBUTION LOSSES

As mentioned above, this KPI is calculated twice:

- A first time comparing measurement data in the baseline period (without smart controller) and in the improvement period (with smart controller). Here, heat distribution losses are calculated from the difference between energy amounts measured at the demand end of the plant room (heat meter 1901) and the sum of energy amounts supplied to the individual houses.
- A second time based on sizing data, comparing sizing data with and without decentralized buffers.

SHARE FROM RESIDUAL OR RENEWABLE ENERGY SOURCES

The share from residual or renewable energy sources is very high, since heat is mostly supplied from biogas and residual heat.

RETURN TEMPERATURE REDUCTION

Return temperature reduction is calculated based on the return temperatures and heat loads measured at the demand end of the plant room (heat meter 1901).

HEATING DEGREE DAYS

Heating degree days in Kd are used to normalize energy consumption in different climate conditions.

5.2 SENSOR LIST

Table 8 shows a specific list of monitoring sensors in the A2A demonstrator mixing station for evaluation of the KERs defined in *Table 5*.

Table 8: List of sensors for determination of key performance indicators

Key performance indicators	Required sensors	Sensor labels
Primary energy demand savings $PE_{savings} = PE_{baseline} - PE_{improved}$ $PE = TE*PEF_T + EE*PEF_E$	Heat meters Electricity meters	Heat: WZ 2901; WZ 3901; WZ 4901; WZ 2903 Gas: manually logged operation data Electricity: electric meter 5901 + manually logged operation data Baseline scenario: period before smart control.
Greenhouse gas emission savings $GGE_{savings} = GGE_{baseline} - GGE_{improved}$ $GGE = TE * GEF_T + EE * GEF_E$	Heat meters Electricity meters	*Same sensors as for PE*
Reduced heat distribution losses $Q_{losses,reduction} = Q_{losses,baseline} - Q_{losses,improved}$ $Q_{losses} = Q_{in} - Q_{out}$	Heat meters	Q_{in}: WZ 1901; WZ 1902; WZ 3903 Q_{out}: All heat meters in connected substations Baseline scenario: a) period before smart control b) alternative network design without decentralized buffers
Share from residual or renewable energy sources $f_{ren} = \frac{TE_{g,ren} + EE_{g,ren}}{TE_g + EE_g} \cdot 100$	Heat meters Electricity meters	TE_g and EE_g : *same sensors as for PE* $TE_{g,ren}$ and $EE_{g,ren}$:
Heating degree days (see [2])	Temperature sensor for ambient air	TAußen

Return temperature reduction $\Delta T_{rt} = T_{rt,baseline} - T_{rt,improved}$	Temperature sensor Heat meter (calculation of weighted mean return temperature)	T1.2, T2.2, T33.2 Power rates from WZ 2901; WZ 3901; WZ 4901

Table 9: List of sensors for determination of additional performance indicators

Indicators	Required sensors	Sensor labels in A2A demonstrator
Solar total horizontal irradiation	Radiation sensor	NA

Besides the evaluation of performance indicators for concept assessment and comparison between demonstrators, monitoring is also necessary for the intended innovations 'fault detection platform' (FDP), 'visualisation tools' (VT), 'smart district heating controller' (SC) and 'optimisation of building installations' (BI).

5.3 DATA PROCESSING

This section describes the collection, transfer and storage of the monitoring data from the sensors listed in the previous section.

Data collection and transfer: Substation monitoring data is logged at 2-minute intervals in each of the active substations. It is transmitted automatically through FTP to AIT on a daily basis. Primary-side data includes temperatures and energy values logged in the plant room. It is logged at 5-minutes intervals and transmitted to AIT manually every 6 months.

The numerical resolution is one decimal place for most temperatures (0.1 °C), 2 decimal places for some heat meter temperatures, 1 kWh for energy amounts, 0.01 m³ for volumes, 0.1 kW for powers, 1 l/h for volume flow rates.

Data protection: Substation data is stored with anonymous substation IDs. Data are not shared outside of the project.

Data storage: Data is stored on an AIT server as time series in CSV format.

6 CONCLUSIONS

The work on the construction site started according to plan. The pipe installation of phase 1 was finished in winter 2017 and the plant room was commissioned in spring 2018. At the same time the visualisation-system Winmiocs was installed. From then on Winmiocs is logging all data from the plant room and the already connected substations.

The first decentralised buffer units were also connected in spring 2018. First, the main task was to optimise the controller and to learn about the behaviour of the buffer unit in the field. After conducting comprehensive tests in the ENERPIPE lab, the controller settings and setpoints were optimised. During these optimisation works it was observed that the bottom buffer temperature was not as low as in the lab. This was solved by adapting the hydraulic system and the already installed buffers were also adapted in February 2019.

Since the commissioning of Winmiocs and the communication network, controller optimisation and improvement was steadily realised. During the complete construction phase there were rare interruptions in the communication between Winmiocs and the substations. These were mostly caused by new house connections or damaged wires because of excavation works. In March 2019 an automatic data upload from the Winmiocs system to AIT was established by transferring csv files of the logged data via an ftp server. In autumn 2019 the integration of the Winmiocs system and the NODA EnergyView system started. By half February 2020 this was finished and the Winmiocs data of the ENERPIPE demo is now available through the NODA API. This enables us to use real-time data in the control algorithms under development. A first test to control the buffers in Windsbach has also been conducted successfully. However it should be noted that this test was not testing the complete workflow as it was only sending data straight to the Winmiocs system, without using the EnergyView system. In March 2020 a first complete chain test will be carried out. After that, the first control algorithms will be tested in spring and summer 2020 so they will be ready at the start of heating season 2019-2020.

7 REFERENCES

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