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TEMPO

D4.2: REPORT - INTEGRATED INNOVATIONS IN A2A NETWORK

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SUMMARY

The present document represents the deliverable D4.2 "Report integrated innovations in A2A network" developed within WP4 of the H2020 TEMPO project. TEMPO is the acronym for: Temperature Optimisation for Low Temperature District Heating across Europe and focusses on the development, demonstration and deployment of innovations for low temperature district heating (DH) networks. TEMPO aims to reduce DH network system temperatures to achieve improved network efficiency, costs competitiveness and capability of integrating sustainable energy sources like renewable and residual heat.

This deliverable describes the innovations installed in the A2A demonstrator as well as the main technical and economic aspects of those implementation, the measures for the implementation quality control, the commissioning of the demo site and initial operation.

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GLOSSARY / LIST OF ACRONYMS

ACRONYM	DEFINITION
ICT	Information and Communication Technologies
LT	Low Temperature
HT	High Temperature
DH	District Heating
SH	Space Heating
DHW	Domestic Hot Water
SFH	Single-Family House
MFH	Multi-Family House
KPI	Key Performance Indicator

1 INTRODUCTION

The A2A demonstrator is located in the town of Brescia, in Northern Italy, and consists of a portion of a peripheral branch of the existing HT DH system. In the TEMPO project, this site was assessed to demonstrate the solution package proposed for existing urban HT DH systems. This solution package consists of following innovations:

- Supervision ICT platform for fault detection and diagnosis
- Visualization tools for expert and non-expert users
- Smart DH controller
- Optimization of the building installations

The deliverable D1.1 gives a general description of these innovations. The present deliverable D4.2 illustrates how the innovations are implemented in this specific demonstration site as well as the preliminary work for the site preparation, the main technical and economic aspects of the implementation, the reasons for discrepancies from the original time schedule and the adopted countermeasures, the quality control of the implementation, the commissioning of the demo site and initial operation.

The preparation of the site was the assignment of Task 4.2 and comprehended the laying of new pipes to hydraulically decouple the main DH network from the demo site and the installation of a supply/return mixing station. These activities have the purpose to enable the demo site to decrease the operating temperatures without affecting the rest of the network and to host the TEMPO innovations. Customer involvement (included in Task 4.1) was another essential activity to the implementation of the solution package. The structure of following chapters is:

- The A2A demonstration site
    - Overview of the DH network
    - Details of the demonstration site
    - Implementation of the mixing station
- Description of the implemented innovations
    - Supervision ICT platform
    - Visualization tools for expert and non-expert users
    - Smart DH controller
    - Optimization of the building installations
- Technical and economic aspects of the implementations
    - Instrumentation for data transmission
    - Installation of NODA boxes
    - Costs and time for implementation
- Description of the quality control measures
    - Subnetwork and mixing station
    - Data Transmission
    - Calibration
    - Smart DH controller
- Commissioning and initial operation
    - Monitoring concept
    - Operation phases
- Conclusions

2 THE A2A DEMONSTRATION SITE

The A2A demonstration site is located in the town of Brescia, in Northern Italy, and consists of a portion of a peripheral branch of the existing HT DH system. This portion of the branch delivers heat for SH and DHW preparation in a residential area in the southern part of the town and of the DH network.

In the operation of Brescia DH system preceding the TEMPO project, this site was hydraulically connected to the network branch to which it belongs. As TEMPO intends to reduce the operating temperatures just in the demonstration site, it was necessary to decouple it from the branch, in order to allow different temperatures without affecting the remaining part of the branch not included in the TEMPO project. Therefore, it was necessary to lay new supply and return pipes and create a local subnetwork that can be independently operated.

2.1 OVERVIEW OF THE DH NETWORK

Brescia district heating (DH) system started functioning in 1972 and since then it has widely developed in the city; in fact, the network length is today around 670 km (trench length). The network consists of two pipes laying parallel; the supply pipeline distributes the heat vector to the customer substations, consisting in a heat exchanger subtracting heat from the vector, which cool down and then flows back at decreased temperature through the return pipeline to the plant. The DH system delivers heat for both SH and DHW preparation. The network works 24/7, meaning that water is always flowing in both pipes; flow and return temperature are demand controlled. The highest flow is in winter during the morning and evening peaks; the rest of the day the flow is lower, reaching the minimum at night.

The supply temperature reach a maximum of 130 °C in winter and 90 °C in summer, while the return temperature is around 60 °C and almost constant all the year; the maximum operating pressure of the network is 16 bar.

Since the network has been constructed in more phases starting in the early ´70s, the pipe characteristics has changed according to the construction phase; today, the network comprehends three different types of pipe:

- From 1972 to 1979, steel pipes were installed in concrete ducts and sustained by rollers or metallic saddles; this type of pipe covers around 20% of the entire network length.
- From 1979 to 1985, the "wanit" technology was employed, which now covers less than 2% of the network length. According to this method, pipes were laid in preinsulated sheathes, composed by two concentric fibrocement pipes with a layer of polyurethane in the middle.
- The remaining 78% of network length consists of preinsulated pipes: they consist of an internal steel carrier pipe, an insulating layer of polyurethane foam (PUR foam) and a polyethylene outer casing.

2.2 DETAILS OF THE DEMONSTRATION SITE

An air photography of the demonstration site is shown in Figure 1. The site is a quite small area extending within a radius of 150 m. The connected buildings (highlighted by the red rectangles) are exclusively residential, more exactly 34 SFHs and one MFH with 43 flats. The blue circle indicates the supply/return mixing station (s. deliverable D4.1 and Figure 2), which was built within the TEMPO project to decrease the supply temperature of the demo site.

Figure 1: Aerial photography of the A2A demonstration site

Figure 3 gives an overview of the work necessary to hydraulically decouple the site from the network branch. To create the subnetwork for LT operation, it was necessary to lay about 100 m of new pipes (represented by the black lines); these extend from the mixing station (in the blue circle) to the MFH and to the branch (already existing) that supplies the interested SFHs, as visible in the Figure 3. The mixing station consists in one container including all the pipes and the instrumentation necessary to decrease the supply temperature of the demo site; a dedicated description is in the paragraph 2.3. Mixing station and new pipes, as necessary activities for the preparation of the demo site, were part of the Task 4.2. The pipes were laid in June 2019 and the works ended on August 12th, 2019. The mixing station was ready to operate in October 2019.

Figure 2: External view of the supply/return mixing station at the A2A demonstration site

Figure 3: Scheme of the A2A demonstration site

2.3 IMPLEMENTATION OF THE MIXING STATION

The installation of a mixing station, main focus of Task 4.2, was necessary to make the demo site able to operate at lower temperature and host the TEMPO innovations. A simplified scheme of this station is shown in Figure 3, while Figure 4 reports the detailed P&ID. Basically, in the mixing station, part of the water returning from the demo site (in blue in Figure 3) enters the supply pipeline in order to decrease the supply temperature, the set-point of which will be assigned by the TEMPO smart controller (s. § 3.3).

As illustrated in Figure 4, the supply water (in red) arrives from the existing network (in black) and passes through a throttle valve (V1), the opening of which determines the inflow of the return water. In fact, throttle decreases the pressure of the supply line, so that cold water from the return line can partly mix. The temperature of the supply line decreases accordingly. The part of return water not mixing with the supply will flow back into the return line of the HT network. The pump downstream of the throttle valve V1 has the role to reestablish the pressure of the supply water, ensuring in this way the heat supply in the demo site. The supply water flows then to the costumers, passes through the heat exchangers and returns back through the site return line. Once in the mixing station, it partly mixes again with the supply water as previously described. In case of pump failure, the throttling valve V1 is closed, so that the water follows the black path, passing through the check valve V2 and then arriving unmixed to the customers. The check valve V3 is installed on the return pipe to prevent backflow.

A series of sensors and instrumentation (Figure 5) were installed in the mixing station for the operation monitoring. The monitoring data is collected on a local PLC at time intervals of 15 seconds. The main monitored parameters are summarized in Table 1, while Table 2 shows the list of the KPIs (defined in the deliverable D5.1) to assess the effects of the TEMPO implementations.

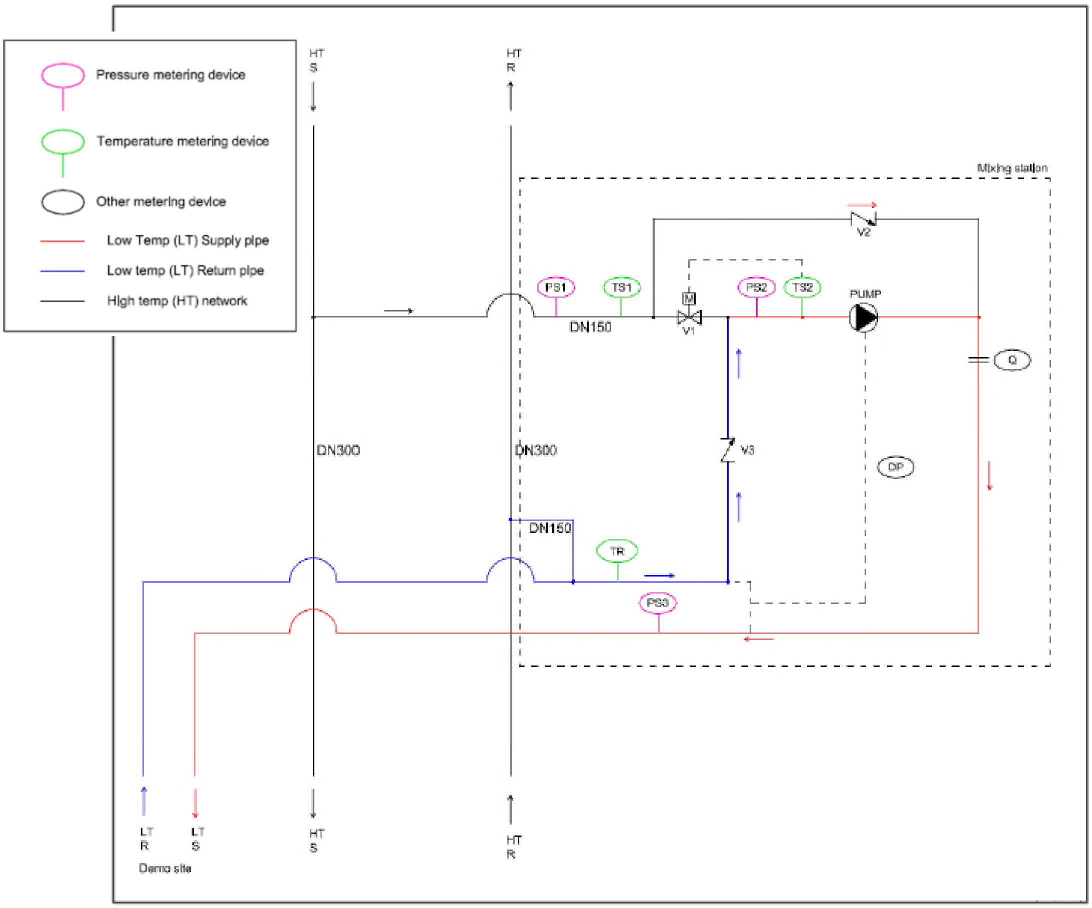


Figure 4: Simplified scheme of the mixing station

Table 1: Monitored parameters of the mixing station

ID	Parameter	Units
QT-0-002	Energy on HT side	MWh
JT-0-002	Power on HT side	kW
FT-0-002	Flow rate on HT side	l/h
TT-0-001	Supply temperature on HT side	°C
TT-0-003	Supply temperature on LT side	°C
TT-0-004	Return temperature	°C
TT-0-007	Outdoor temperature	°C
DPT-0-001	Pump differential pressure	bar
Energ_EE_Ass	Total energy consumption	MWh
Potenza EE	Electrical power of the mixing station	kW

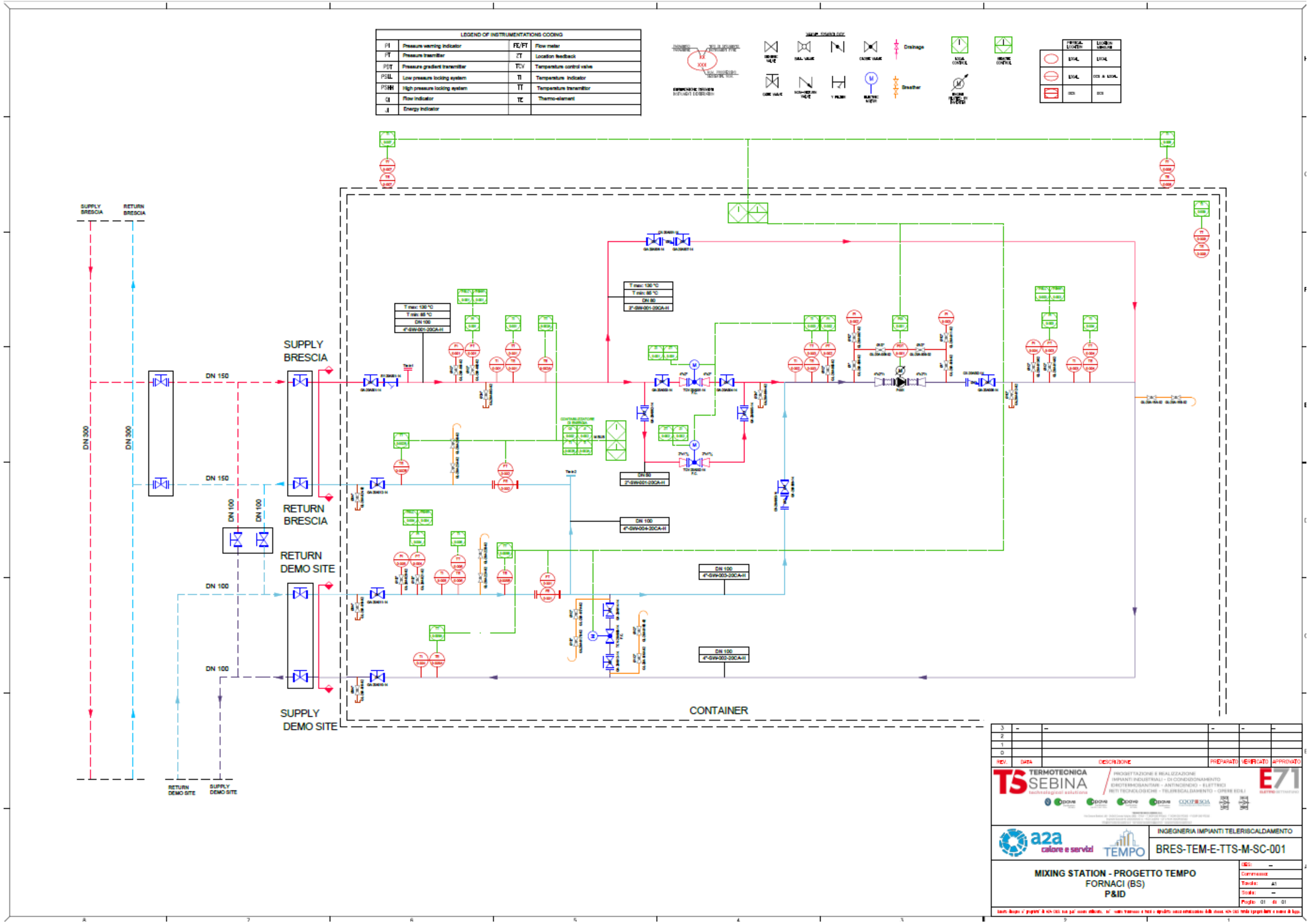


Figure 5: P&ID of the mixing station

3 DESCRIPTION OF THE IMPLEMENTED INNOVATIONS

The solution package of the A2A demonstrator consists of following innovations:

- Supervision ICT platform for fault detection and diagnosis
- Visualization tools for expert and non-expert users
- Smart DH controller
- Optimization of the building installations

The deliverable D1.1 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

The on-site control systems installed in the Brescia demonstration site is connected to the NODA data management platform (Figure 6). This platform handles the data collection and storage, as well as includes 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.

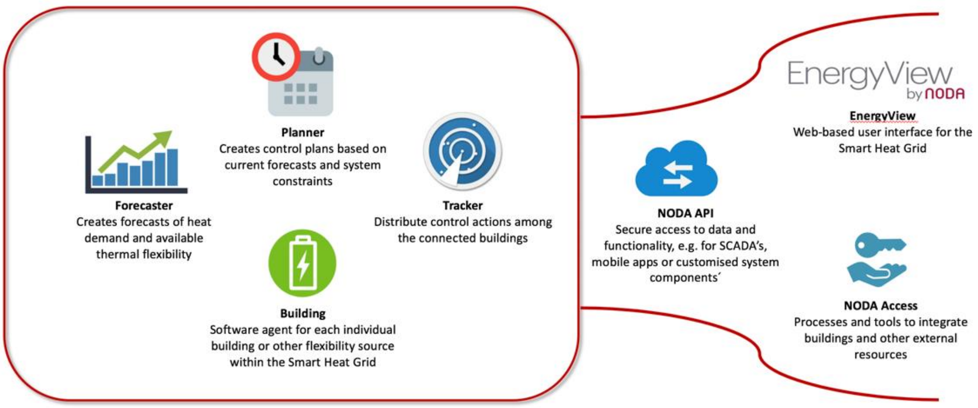


Figure 6: A conceptual overview of the ICT platform used in the Brescia demonstrator

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. One specific goal of TEMPO is to create tools for large-scale ranking. However, the Brescia demonstrator is rather small for this purpose (there are only small buildings connected). Therefore, such ranking is not a priority of the Brescia demo. Differently, the focus here is to study the operational behaviour of the overall system, including the mixing station.

3.2 VISUALIZATION TOOLS FOR EXPERT AND NON-EXPERT USERS

The data that is now being collected through the ICT platform is available for visual inspection through the NODA EnergyView system. This is a web-based front-end for data analysis and service. Figures 6-8 show some examples of the visualization available in EnergyView. In EnergyView it is possible to combine all available data in joint reports and graphs, and the system is flexible in how to present this. All data collected will be available through EnergyView throughout the project, so no data is ever deleted (unless the owner of the data specifically requests this). Through EnergyView it is also possible to download any type of data as CSV-files. This makes it easy to further analyse the data in other tools such as Excel or Matlab, even if the user doesn't want to use the API to access data.

The EnergyView system is primarily aimed at expert users, e.g. heat network operators, maintenance contractors or building owners with technical expertise. Once the supply temperature optimisation system is fully activated, it will be possible to overview the continuous behaviour of the system through the Grid Manager module in EnergyView.

From Figure 7 it is clear that there is some type of night-time set-back in the MFH. This causes high rebound demands every morning when the system ramps up, which is not beneficial to the overall system. Most likely this rebound demand would have to be controlled better to ensure that the mixing station can sustain the required demand even at lower primary temperatures.

Figure 7: Data collection from the MFH. The top graph shows data from the district heating substation data, while the bottom graph shows indoor temperature data

Figure 8 represents the energy signature of the MFH, based on hourly values. The energy signature shows the relationship between outdoor temperature (horizontal axis), and consumed energy (vertical axis). However the amount of values is still limited, also here the night set back effect is already clearly visible. The data can be split in three different sets: a set (1) of daily operation data whereby the consumption is more or less proportional to the inverse of the outdoor temperature; a set (2) of consumption data close to zero, independent of the outdoor temperature (this is the night setback); and a set (3) with high peak consumption values independent of the outdoor temperature (representing start-up peaks after switching from night set back to daily operation.

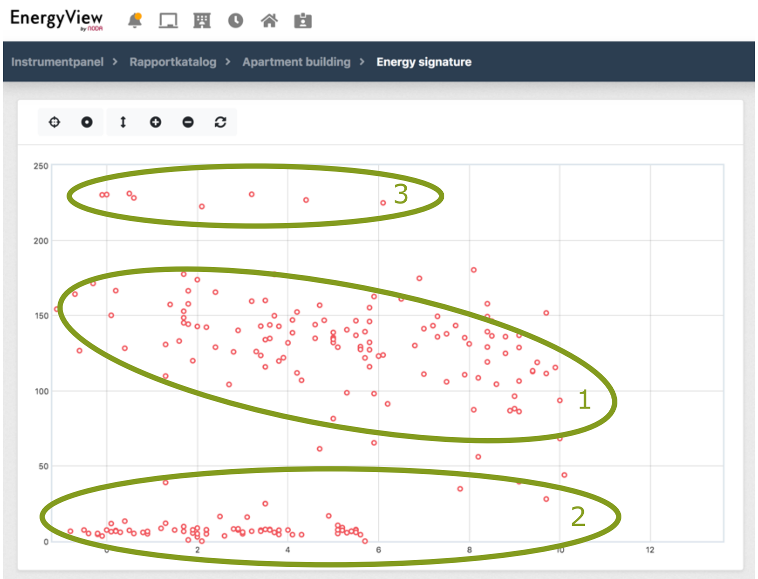


Figure 8: The energy usage in relation to the outdoor temperature in the MFH.

Finally, Figure 9 shows the temperatures in the substation of the MFH. As can be seen, the temperature in the heating system (secondary side of the substation) is way lower than the temperature in the DH network (primary side of the substation). This suggests that there is a potential of temperature reduction in the heat network, however taking into account the necessary temperature for legionella prevention during DHW production.

Figure 9: The primary (green) and secondary (orange) supply temperatures of the MFH.

At the time of writing a large data set is not available from the Brescia demo. However, the technology innovations have been tested on other available data sets, in order to ensure an on-going development process. The performance metrics in TEMPO relate to a range of analytics steps, including pre-processing, peer-grouping, detecting, diagnosing and quantifying. The first version of TEMPO is focused on primary side data from substations, which normally implies data from the substation heat meters. This is then combined with external weather data, if it is not included in the dataset collected from the buildings themselves. Figure 10 shows an example of visualisation of the pre-processing step. In this case, the distribution of data measurement errors is shown. Without any errors the full distribution would be at clustered at 1 (i.e. 100% data quality). However, as can be clearly seen, it is possible to see a distribution across the whole range of error levels, with a significant portion of the data displaying a high level of error (i.e. a value less than 1).

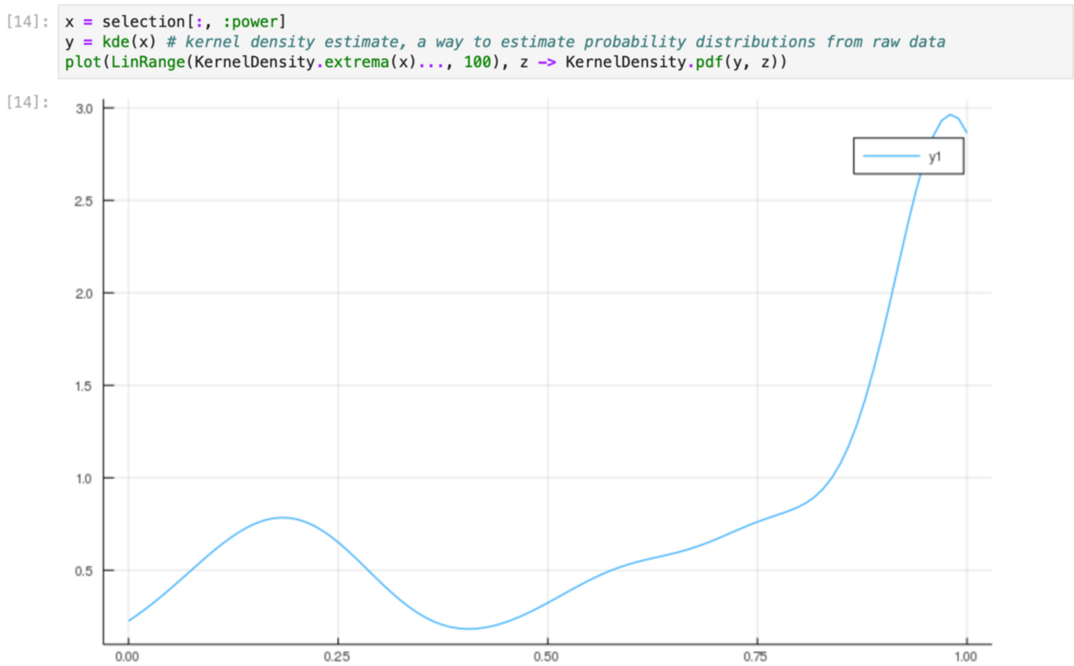


Figure 10: Error distribution during pre-processing on external data set (0 = all data is erroneous, 1 = no data is erroneous)

This is just one example of pre-processing, but it shows the value of performing structured analysis. Even though this example data contains a lot of errors, the data is still good enough for basic billing purposes. This means that errors such as this will most likely keep themselves under the radar, until a more thorough analysis is started.

One of the core performance metrics used in the TEMPO project is the overflow metric. This metric relates the flow required to generate a certain amount of energy. In district heating energy is generated by a combination of temperature difference and flow, and it is normally desirable to have as much energy to be generated from the temperature difference, rather than the flow. Therefore, this metric, or alternatives thereof, is quite convenient as a starting point for analysis. Figure 11 shows an example of an absolute normalised flow in one building.

```
[58]: @df data[k] plot(:absnflow) # absolute normalised flow [m3/MWh]
```

[58]:

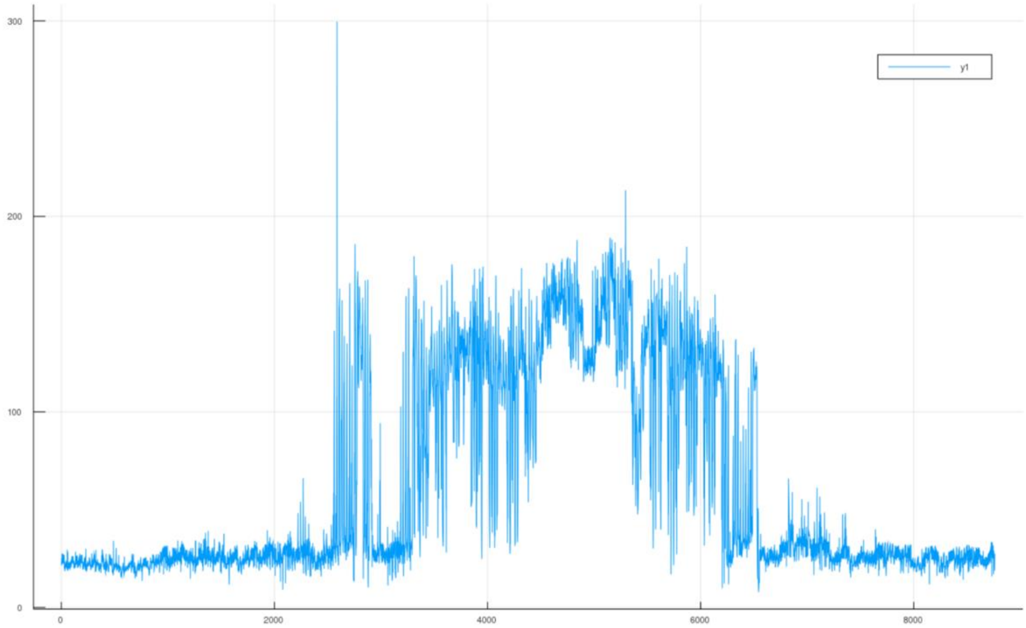


Figure 11: Absolute normalised flow in an individual building (generic data).

The flow data is for a whole year from January to December. Just by looking at this data it can be understood that the normalised flow [m3/MWh] is highest during the summer (in the middle of the data set). However, if this data is then related to the data shown in Figure 12, it becomes apparent that the most important periods are during the early and late periods of the year (i.e. during the heating season).

```
[61]: @df data[k] plot(:power)
```

[61]:

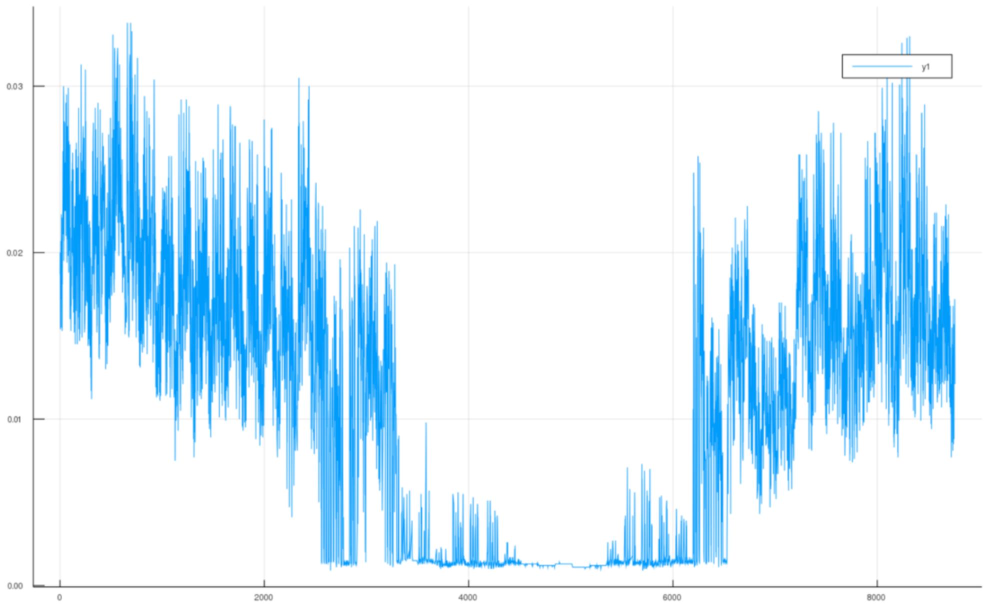


Figure 12: Yearly demand profile of an individual building (generic data).

By relating these values, it is possible to create the overflow metric. This metric provides a good way to analyse building behaviour. Figure 13 shows the overflow metric for the same building data. If the metric is below 0 it is considered "good", while a value above 0 is considered "bad".

```
[60]: @df data[k] plot(:overflow) # overflow [m3]
```

[60]:

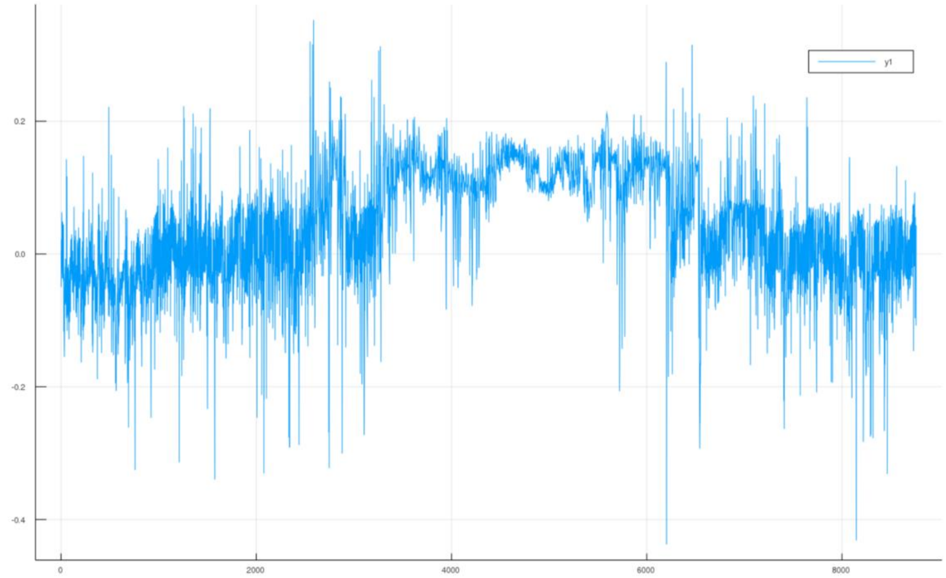


Figure 13: Yearly overflow of an individual building (generic data)

The overflow metric is also convenient to use for ranking data. Figure 14 shows an example of a large data set with many hundreds of buildings ranked according to their overflow in relation to supply and return temperatures as well as the size of the buildings (as expressed in the amount of energy they use). Please note that the size is in logarithmic scale, so the big circles are substantially bigger than their smaller peers.

[63]:

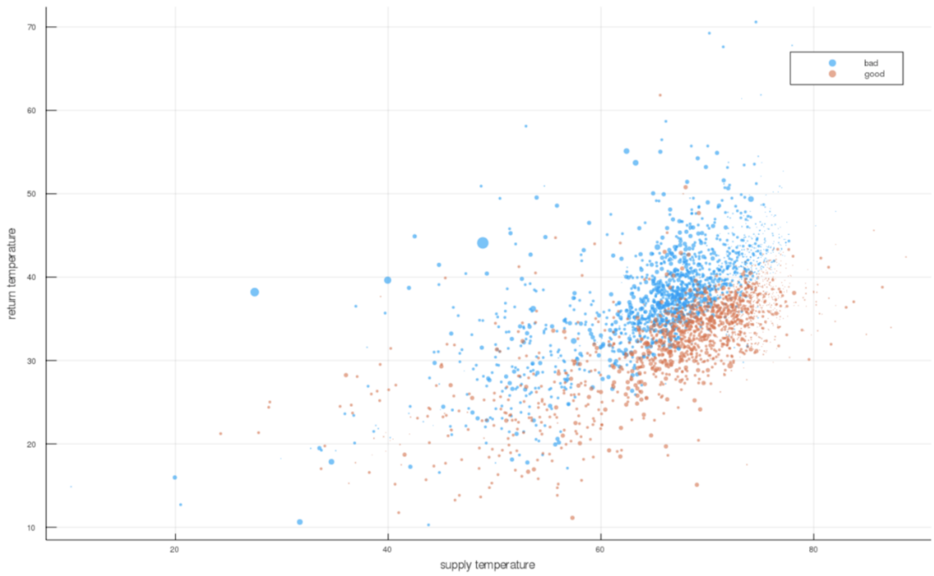


Figure 14: The overflow (colour) plotted in relation to system temperatures and size among a large group of buildings (generic data)

In the overflow picture it is easy to see the difference based on the overflow metric, since they are coloured red or blue, even among all those buildings. It is also easy to see the largest buildings, and get an understanding about the overall trend of the data. Figure 15 furthers this analysis by directly relating the overflow metric with the differential temperature over the substation.

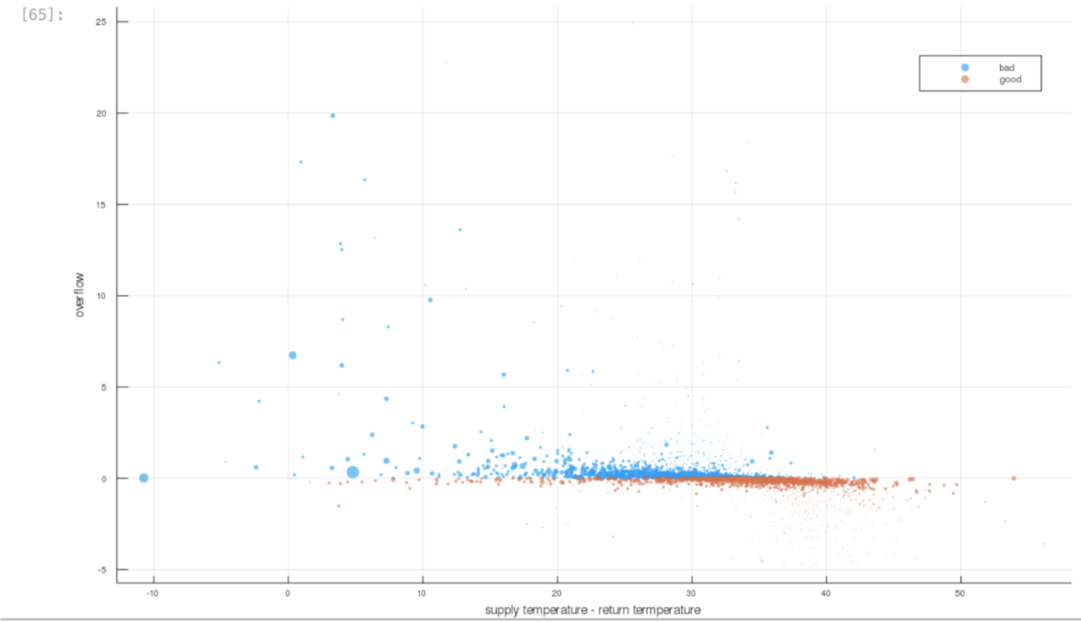


Figure 15: Overflow (y-axis) in relation to differential temperature (x-axis).

This makes it even easier to pin-point badly performing substations as part of a decision support system. Please note that the generic data set used in these graphs contain a few individual buildings using district cooling (i.e. they have a negative differential temperature). The above examples show the development of the TEMPO system that is currently being deployed in the Brescia demonstrator. Although generic data is used for the clarity, the same technology is now being installed in the current demonstrator.

3.3 SMART DH CONTROLLER

The active control in the Brescia demonstrator consists of two types of TEMPO technology. Firstly, there is the control of the mixing station, where the purpose is to be able to achieve as low supply temperatures as possible on a given optimization horizon. Secondly, there is the control of the MFH. The purpose of the control in the MFH is two-fold:

- First of all, it will be able to adapt to the control of the mixing station, and, in this regard, it will act as suspension system for the active supply temperature optimization.
- Secondly, it will control the behavior of the operations in the substation in such a way that the return temperature is minimized. Having a lower return temperature will turn in help keeping the supply temperature in the mixing station lower, hence these two control systems will interact.

For the Brescia demo, the mixing station is technically considered as a production unit, in which the supply temperature is to be optimised. This supply temperature optimisation is

implemented in the Planner module as shown in the Figure 6 above. It will then treat the mixing station as a single virtual distributed energy resource that can be used to influence the operational behaviour of the system.

The Forecaster module handles the heat load forecast as well as the forecast of the available thermal flexibility. In the Brescia demo, the thermal flexibility is generated through the MFH, since it is possible to actively control this building (unlike the SFH, which is only used for reading measurement data). Furthermore, since the Brescia demonstrator uses supply temperature optimisation, forecasts of the thermal propagation in the network are also required. These forecasting models are also implemented in the Forecaster module.

The Tracker module is used to distribute control actions among groups of distributed energy resources. However, in the Brescia demonstrator, there are only two components that will be actively controlled, i.e. the mixing station and the MFH, and they are managed separately. Therefore, there is not explicit need for tracker functionality. However, from a software architectural perspective, the Tracker module is still there to translate the optimisation plans generated by the Planner into relevant control actions in either the mixing station or the MFH.

3.4 OPTIMIZATION OF THE BUILDING INSTALLATIONS

The optimization of the building installations includes the use of simulations to evaluate the impact of faults and the use of the practical guide for technical audit of building installations.

For the simulation approach, a simulation model for the substation type present in this demonstrator (indirect connection with parallel heat exchangers for SH and DHW preparation) is already available. For the simulation, assumptions on the building properties have to be made. Assumptions can be made according to the construction years (1997-1998), but uncertainties are present, especially in terms of the refurbishments which may have taken place since construction.

Additionally to the operating parameter of the mixing station, measured with 15-second frequency (as described in the paragraph 2.3), monitoring data with 10-minute frequency is available for the MFH and the SFHs. For the MFH, the monitoring includes the readings of the primary-side heat meter and the secondary temperatures, as well as outdoor temperature and a few indoor temperature sensors. For the SFHs, monitoring data are restricted to heat meter data (including primary flow rate) of all substations and to the secondary-side supply and return temperatures (measured with clamp-on sensors) of one customer.

The practical guide for a technical audit of building installations, included in the project deliverable D1.1, is made available to A2A for application in the demonstrator. As the installations are already twenty years old, faults of various types can be expected.

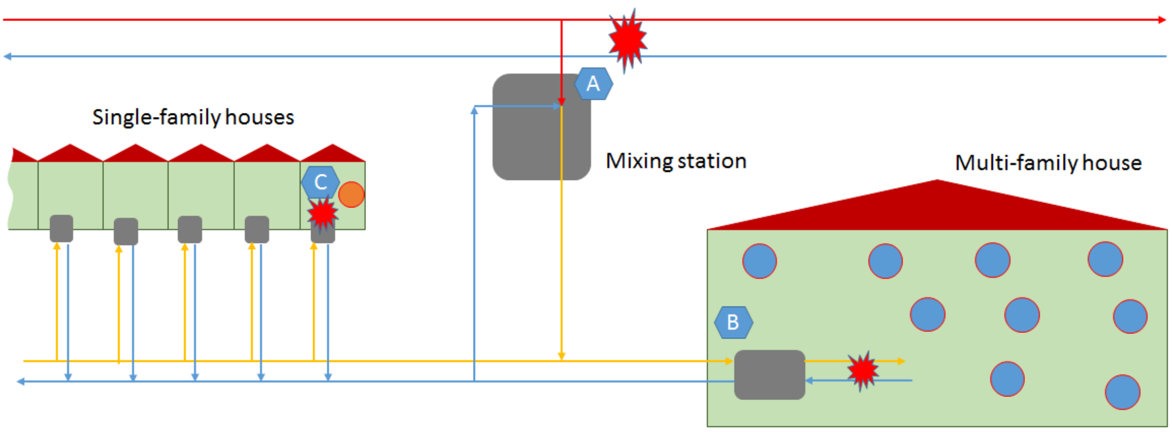
Furthermore, since the technical staff which may carry out the audit of building installations may have limited knowledge of English, it is in discussion whether the practical guide should be translated to Italian.

4 TECHNICAL AND ECONOMIC ASPECTS OF THE IMPLEMENTATIONS

4.1 INSTRUMENTATION FOR DATA TRANSMISSION

Besides the sensors listed in Table 1, additional metering and data transmission components were installed to enable the implementation of the TEMPO solution package described in the chapter 3 as well as to enable the site operation monitoring in accordance with the deliverable D5.1. Figure 16 gives an overview of this additional instrumentation. The main installed components are:

- 3 NODA boxes (s. § 4.1): 1 in the mixing station, 1 in the MFH, 1 in one SFH. A NODA box is a tool enabling data transmission from local sensors to a cloud as well as control actions from the cloud by means of sensor overwriting.
- 10 indoor-temperature sensors: 9 in the MFH, 1 in the same SFH as above
- 3 pairs of clamp-on sensors to measure supply and return temperatures: 1 pair on the HT side of the mixing station, 1 pair on the secondary side of the MFH, 1 pair on the secondary side of the same SFH as above
- 2 outdoor-temperature sensors: 1 at the mixing station (apart a second one for backup), 1 at the MFH



Symbol	Description	Quantity	Signal(s) transmitted to
x	NODA box	3	NODA cloud
	Indoor T sensor in MFH	9	B
	Indoor T sensor in SFH	1	C
	Clamp-on T sensors	3 pairs	x

Heat meter	Sends data to
Mixing station LT	A
MFH	B
One SFH	C
All 35 meters	A2A PLC

Figure 16: Monitoring and data transmission for the implementation of the TEMPO solution package.

4.2 INSTALLATION OF NODA BOXES

NODA shipped 4 NODA boxes to A2A, which installed them as follows:

- 1 in the mixing station (December 2019)
- 1 at the substation of the MFH (November 2019)
- 1 at the substation of one of the SFHs (November 2019)
- 1 was kept as backup

In this demo site, the NODA boxes have essentially two purposes:

- Transmit monitoring data from local sensors to the NODA cloud
- Transmit data from the smart controller to the local system to enable smart control.

To accomplish the first task, each box is equipped with an optical eye to read the data registered by the heat meters (supply and return temperature, flow rate, heat, cumulated energy) and one pair of clamp-on connections to measure the water temperature in the supply and return line. Furthermore, each NODA box was shipped together with a communication module and a SIM card to directly transmit the registered data on the NODA cloud. To accomplish the second task (enabling the smart control), each box is connected to the local controller.

The NODA box in the mixing station collects data from the heat meter on the LT side (energy consumption, instantaneous power, supply and return temperatures, and flow rate), from the outside temperature sensor, and from the clamp-on sensors on the supply and return line on the HT side. These sensors are installed on the pipe wall rather than in the water flow of the heat meter temperature sensors, and are therefore somewhat less accurate.

The NODA box in the MFH collects data from the primary side of the heat meter (energy consumption, instantaneous power, supply and return temperatures, and flow rate), from the outside temperature sensor, from the 9 indoor temperature sensors, and from the clamp-on sensors on the secondary supply and return line.

The NODA box installed in the SFH can only collect data from the indoor temperature sensors and from the clamp-on sensors on the secondary side. Data collection from the heat meter is not feasible because the heat meter is located in a cabinet on the street and the substation in the cellar of the house. In these conditions, the available optical eye cannot be connected to the NODA box at the substation. The alternative of an additional NODA box at the heat meter to collect the readings is not feasible owing to lack of space and of power point in the cabinet (power is necessary for the use of the NODA box).

The NODA boxes communicate all collected data to the cloud platform, explained in §3.1. It is in this cloud system where the control signals for smart control are calculated by the Forecaster, Planner and Tracker. The smart control, as described in § 3.3, is applied only at the mixing station and at the MFH. The smart control is enabled by the relevant NODA boxes, which transmit data for the control action from the TEMPO cloud system to the local controller. On the contrary, the NODA box in the SFH has just the purpose of local monitoring.

4.3 COSTS AND TIME FOR IMPLEMENTATION

The preponderant costs and time for the implementation of the solution package were invested in the site preparation described in § 2.3:

- Laying of the new pipes for decoupling the site from the network
- Construction of the mixing station

The location for the mixing station was selected taking into consideration, among others, also the presence of two dismissed boilers still owned by A2A Calore e Servizi. Brescia City Council authorized the installation of these boilers in 1997 and a not complicated procedure, similar to thence, was expected for the authorization of the mixing station.

The authorization process consisted of three different steps:

1. Concession of the area, which was approved on March 8th, 2019.
2. Authorization on the construction site to remove the dismissed boilers, which was released on April 15th, 2019.
3. Authorization to construct the mixing station. The needed documentation was submitted on March 21st, 2019 and the construction was authorized on September 30th, 2019.

Due to the timing of the City Council to release the necessary authorizations, it was possible to install the mixing station only in the beginning of October 2019. The container was installed the following week and after that, it was possible to proceed with the installation of all the required instrumentation inside it.

In order to avoid additional delay, it was decided to use existing contracts instead of specific tendering for the construction of the mixing station and for the installation of the equipment for monitoring and control; moreover, other companies of A2A Group provided support during the site preparation, such as A2A Ambiente for the electronic part and A2A Smart City for the optical fiber connection. The latter is used to transmit data describing the demo site to the main plant where the Mixing station can be controlled remotely.

Customer involvement was another important phase in the project. Starting from the beginning of 2019, A2A has approached the customers of the MFH through the building manager and the SFH inhabitants. In June 2019, a public assembly was organized for customers to describe the project and to collect acceptances for installing the indoor temperature sensors. Despite the number of people present at the public assembly was small, the number of customers accepting to receive the sensors was higher than expected.

A2A employees with the support of Brescia City Council performed all the aforementioned activities, while expenses were on A2A. In overall, considering the administrative time, two years resulted necessary to prepare the site. In economic terms, almost 2600 person-hours of A2A personnel were used and the material costs for authorization, design, transport, construction of mixing station and subnetwork, performance tests, instrumentation resulted about 170 k€.

5 DESCRIPTION OF THE QUALITY CONTROL MEASURES

5.1 SUBNETWORK AND MIXING STATION

The TEMPO subnetwork was designed with a logic to minimize operational inconveniences. In fact, the mixing station is by-passable by closing the valves V2 and V4 (see zoom of P&ID in Figure 17), preventing in this way any service suspension. After the construction of the mixing station, some operational tests were performed to ensure the correct installation and functioning of all the instrumentation. With this purpose, the valves V2 and V4 were opened and the valve V3 was closed; this configuration is the one used during both in the monitoring of the reference scenario and in the optimized LT scenario.

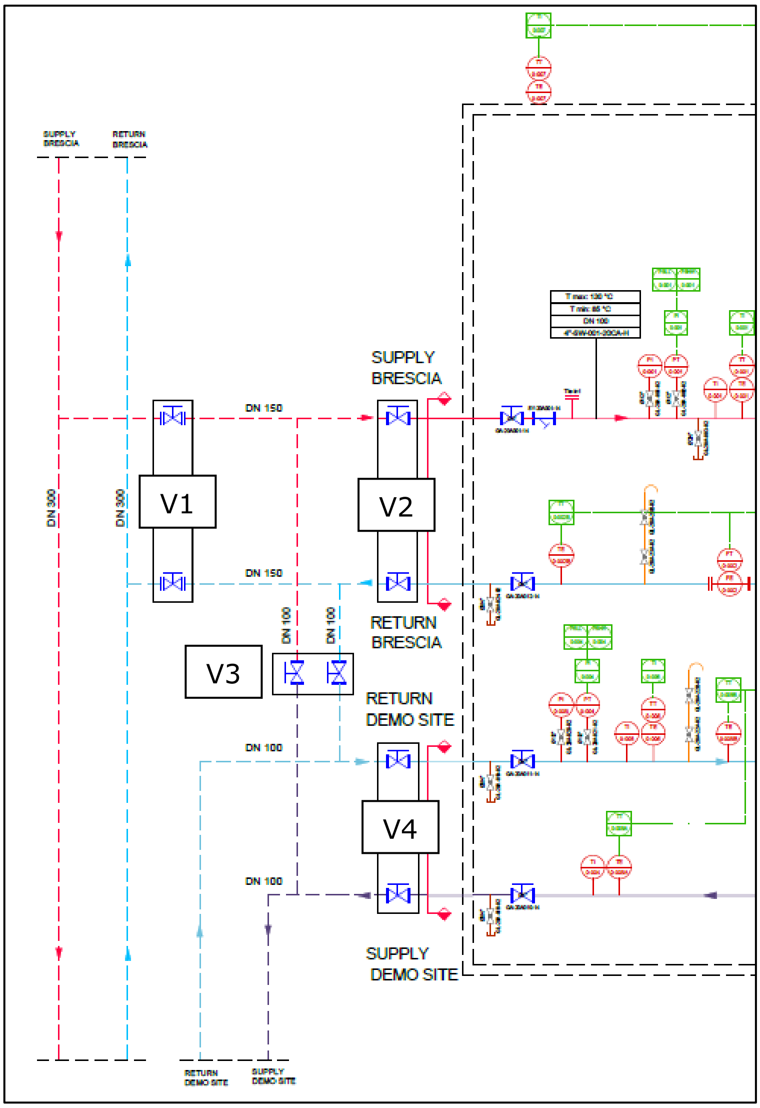


Figure 17: Detail of the P&ID of the mixing station.

An important aspect to consider in the operation of the mixing station is the noise of the LT-side supply pump. The quality check of the implementation should comprehend the

verification that the pump noise is within the legal limit. This was a necessary and critical step in consideration of the mixing station being located in close proximity to the MFH. The check was performed successfully in January 2020.

5.2 DATA TRANSMISSION

The transmission of the monitoring data to the PLC was verified by A2A personnel. The daily transmission of the data from the PLC to the AIT server (15-second readings), intended for the purposes of the WP5, was verified by personnel of both A2A and AIT. Some problems emerged during the transmission, which took some weeks to be solved. The continuous transmission started working properly on December 23rd, 2019 (monitoring data was incomplete and with gaps before, as shown in Figure 18).

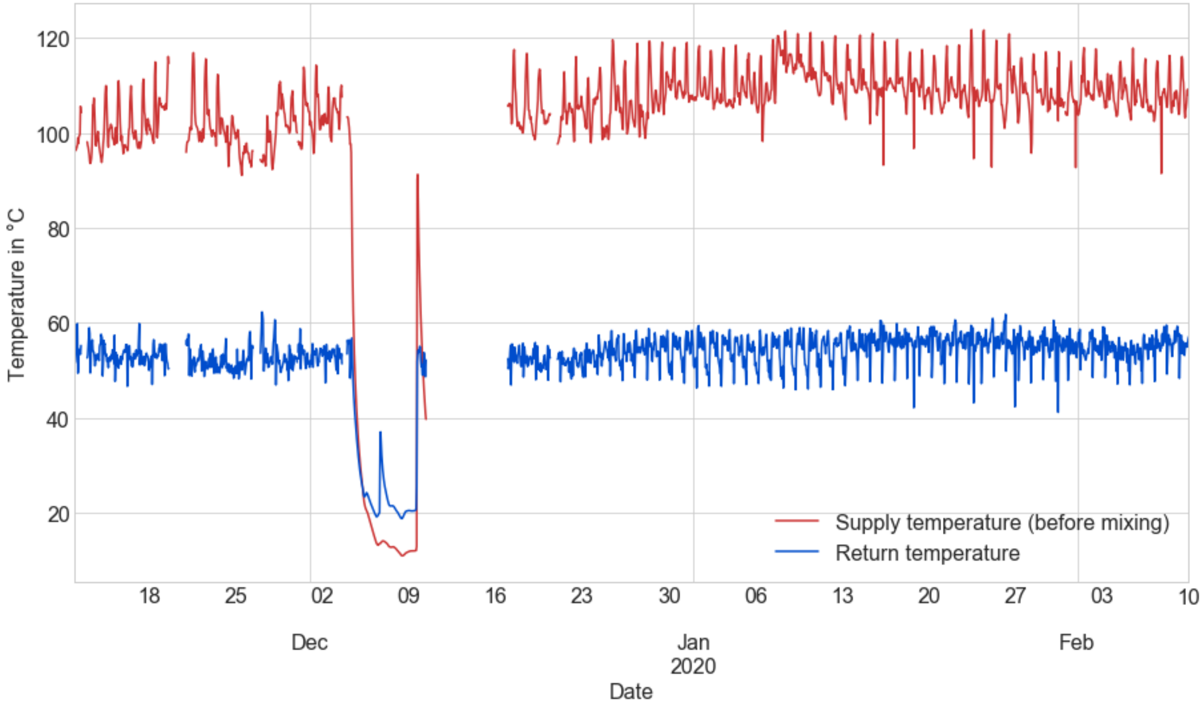


Figure 18: Monitored temperatures at the mixing station for December 2019 and January 2020.

5.3 CALIBRATION

To properly read the outdoor temperature data, the NODA boxes assigned to the TEMPO control require to be calibrated. In the project, the calibration is performed by remote, involving A2A personnel on-site and Noda personnel in Sweden. Due to the complexity of managing a remote calibration, requiring availability of all the involved persons at the same time spot, the two Noda boxes working as smart DH controllers were calibrated some weeks after the installation (January-February 2020).

5.4 SMART DH CONTROLLER

In the reference scenario, i.e. without TEMPO optimization, the primary-side supply temperature of the local network is the same as in the rest of the Brescia DH network and is subordinated to the logics of the production plants. In standard operation, without smart

control, the temperature of the secondary side of the building substations is regulated according to the substation control of the specific building:

- In the MFH, the secondary supply temperature is controlled by a heating curve depending on the outside temperature and the pump hydraulic head
- In the SFHs no heating curve is implemented and the set-point of the secondary supply temperature is assigned by the customer.

The mixing station is equipped with a Phoenix Contact PLC implementing (similarly to the substation controller of the MFH) a heating curve, i.e. assigning a set-point of the LT-side supply temperature.

In both the mixing station and the MFH, the smart TEMPO control is enabled by the NODA boxes, which overwrite the signals of the outdoor temperature measurements. By overriding these temperature measurements, the supply temperature to the local network, as well as for the MFB, can be temporarily manipulated, resulting in a higher or lower heat consumption and an optimized return temperature.

The quality control of the smart controller is planned in two steps:

1. First, the communication of the values to overwrite is checked with short tests in which manually selected values of the external temperature are transmitted via EnergyView. This activity is planned the first week of March 2020.
2. Second, the smart controller is implemented. This controller relies essentially on model-based prediction and, consequently, the quality of the control depends on the quality of the models, which will be calibrated and adapted (also through machine learning) according to the first test results. This activity, which will start once the previous one is completed and a first model of the thermal system is available, is expected in the second week of March 2020.

6 COMMISSIONING AND INITIAL OPERATION

6.1 MONITORING CONCEPT

The sensors for the monitoring of the mixing station are reported above in Table 1. Table 2 shows the list of the KPIs (already defined in the deliverable D5.1) to assess the effects of the TEMPO solution package, while Table 3 reports the procedure for their calculation.

Table 2: List of the key performance indicators.

KPI	**Units**
Primary energy demand savings [4]	kWh/year, %
Greenhouse gas emission savings [4]	t/year
Reduced heat distribution losses	kWh/year, %
Share from residual or renewable energy sources	%
Heating degree days [4]	Kd/year
Return temperature reduction	K

The monitoring data of the mixing station are collected every 15 seconds on a CSV file. A2A is sending data once per day to AIT via an automated transmission. The comma separated CSV file describing the mixing station contains the following parameters: time, date, energy, power, flow rate, supply temperature (before and after mixing), return temperature, outdoor temperature, differential pressure pump, total power consumption, electrical power. The transmission will go through an AIT FTP server into a folder in AIT network drive for storage for the project duration. The files are aggregated and resampled at larger intervals (15 minutes). The numerical resolution for the monitored parameters is 4 digits.

The measures from all the 35 heat meters of the customers of the demo site are collected every 15 minutes and will be sent to the PLC of the mixing station to enable a second transmission to AIT for the calculation of the heat distribution losses. A2A will store the collected data for 1 year after the end of the project.

Concerning the data protection, A2A provide anonymized data to the consortium partners, in order to protect personal data of own customers.

Table 3: Determination of the key performance indicators.

KPI	**Required sensors**	**Sensor labels in A2A demonstrator**
Primary energy demand savings $PE_{savings}=PE_{baseline} - PE_{improved}$ $PE = TE*PEF_{T} + EE*PEF_{E}$	Heat meters Electricity meters	Heat: flow DH main: FT0002 supply T DH main: TT0002A return T DH main: TT0002B Heat output: calculated from sensors above flow DH LT: FT0001 supply T DH LT: TT0004 TRL DH LT: TT0005 Heat output from heat meter (kW or kWh) Electricity: Potenza EE Baseline scenario: (same sensors as in the TEMPO scenario): flow DH main: FT0002 supply T DH main: TT0002A return T DH main: TT0002B
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}: flow DH LT: FT0001 supply T DH LT: TT0004 return T DH LT: TT0005 Q_{out}: All heat meters in connected substations Same sensors as in the LT configuration.
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 $EE_{g,ren}$: NA

Heating degree days … see Del 5.1	Temperature sensor for ambient air	TT 0-006 TT 0-007
Return temperature reduction $\Delta T_{rt} = T_{rt,baseline} - T_{rt,improved}$	Temperature sensor Heat meter (calculation of weighted mean return temperature)	TT0004

6.2 OPERATION PHASES

As described in the Grant Agreement, the original idea of operational plan comprehended two phases:

- Phase 1 (2018-2019), with temperature progressively lowered to verify the minimum feasible temperature and detect the customers in critical conditions as well as parts of the system with still available margin for temperature decrease.
- Phase 2 (2019-2020 and 2020-2021), with temperature lowered and optimized by means of the TEMPO solution package for this demonstration site.

In the project execution, the phase 1 had to be postponed to January 2020. The reasons were:

- The delay in the realization of the mixing station due to the long administrative process described in § 4.2. Owing to that, the mixing station was not ready to operate until October 2019.
- The need for monitoring data in the reference scenario. In fact, the abovementioned delay reflected also in a postponed installation of the monitoring equipment. This monitoring is essential to calculate the KPIs of the system in the HT operation, which, in accordance with the deliverable D5.1, will define the reference for the future assessment of the KPIs at LT. For this reason, it was decided to operate the demo site at the same supply temperature as the central DH system (HT) to mid–January 2020.

Then, starting in mid-January 2020, the supply temperature of the demo site was progressively lowered from the value of the main network (110÷120 °C) to around 90 °C. No issue was encountered during this phase, apart from the need mentioned in § 5.1 to verify that the noise of the pump respects the legal constraints.

Following the adjustment of the operational plan, the first steps of the phase 2 will start in the beginning of March 2020. As described in 5.4, manual tests of the communication between smart controller and NODA boxes as well as checks of the system responses and adaption of the predictive models will precede the complete commissioning, which is therefore expected in the first half of March 2020.

The phase 2 will consist in the implementation of the solution package for the A2A demonstrator, which consists of following innovations:

- Supervision ICT platform for fault detection and diagnosis
- Visualization tools for expert and non-expert users
- Smart DH controller
- Optimization of the building installations

Monitoring will be performed continuously. The monitoring data will be then analyzed more in detail after the heating season 2019-2020, with the purpose to further optimize the smart instrumentations in charge of the temperature lowering. Based on this analysis, in the subsequent heating season (2020-2021) the optimization will be enhanced.

7 CONCLUSIONS

The present deliverable D4.2 illustrates how the TEMPO innovations are implemented in the A2A demonstrator as well as the preliminary work for the site preparation, the main technical and economic aspects of the implementation, the reasons for discrepancies from the original time schedule and the adopted countermeasures, the quality control of the implementation, the commissioning of the demo site and initial operation.

The A2A demonstrator consists of a portion of a peripheral branch of the existing HT Brescia DH system. In includes 1 MFH with 43 apartments and 34 SFHs. The solution package consists of following innovations:

- Supervision ICT platform for fault detection and diagnosis
- Visualization tools for expert and non-expert users
- Smart DH controller
- Optimization of the building installations

The most important preliminary activities were the customer engagement (included in the Task 4.2) and the preparation of the site (Task 4.2). The latter comprehended the laying of new pipes to hydraulically decouple the main DH network from the demo site and the installation of a supply/return mixing station. These activities have the purpose to enable the demo site to decrease the operating temperatures without affecting the rest of the network and to host the TEMPO innovations.

In overall, considering the administrative time, two years resulted necessary to prepare the site. In economic terms, almost 2600 person-hours of A2A personnel were used and the material costs for authorization, design, transport, construction of mixing station and subnetwork, performance tests, instrumentation resulted about 170 k€.

The long time for the site preparation was mainly due to the authorization process for the construction of the mixing station. Due to the timing of the City Council to release the necessary authorizations, it was possible to install the mixing station only in the beginning of October 2019. This fact reflected on delays in the subsequent activities. The original idea for the operational plan (described in the Grant Agreement) had to be adjusted with following schedule:

- Phase 1 (with temperature progressively lowered to verify the minimum feasible temperature) took place in January 2020. The supply temperature of the demo site was progressively lowered from the value of the main network (110÷120 °C) to 90 °C.
- Phase 2 (with temperature lowered and optimized by means of the TEMPO solution package) is planned to start in February 2020.

During the quality control, following main issues were detected:

- Noise of the pump at the LT-side of the mixing station: verifying that the pump noise is within the legal limit was a necessary and critical step in consideration of the mixing station being located in close proximity to the MFH. The check was performed successfully in January 2020.

- The daily transmission of the data from the PLC to the AIT server (15-second readings), intended for the purposes of the WP5, showed some problems (such as failures and interruptions), which took some weeks to solve. The continuous transmission started working properly on the beginning of December 23rd, 2019.
- Calibration of the NODA boxes to properly read the outdoor temperature sensors. In the project, the calibration is performed by remote, involving A2A personnel on-site and Noda personnel in Sweden. Due to the complexity of managing a remote calibration, requiring availability of all the involved persons at the same time spot, the two Noda boxes working as smart DH controllers were calibrated some weeks after the installation (January-February 2020).

The next planned activity is the quality control of the smart controller, which will act on the mixing station and on the substation of the MFH. The quality check will be performed in two steps:

1. First, the communication of the values to overwrite is checked with short tests in which manually selected values of the external temperature are transmitted via EnergyView. This activity is planned in the first week of March 2020.
2. Second, the smart controller is implemented. This controller relies essentially on model-based prediction and, consequently, the quality of the control depends on the quality of the models, which will be calibrated and adapted (also through machine learning) according to the first test results. This activity, which will start once the previous one is completed and a first model of the thermal system is available, is expected in the second week of March 2020.

Monitoring will be performed continuously. The monitoring data will be then analyzed more in detail after the heating season 2019-2020, with the purpose to further optimize the smart instrumentations in charge of the temperature lowering. Based on this analysis, in the subsequent heating season (2020-2021) the optimization will be enhanced.

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