

Grant Agreement: 768936



## **D4.3: REPORT – INTEGRATED IMPROVED INNOVATIONS IN A2A NETWORK**



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## EXECUTIVE SUMMARY

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 networks. TEMPO aims to reduce district heating network 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.

The A2A demonstrator is in the town of Brescia, in Northern Italy, 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 high temperature district heating systems. This solution package consists of the 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.

**Supervision ICT platform & Visualization tools for expert and non-expert users:** the supervision ICT platform has two basic functionalities a) enabling the connection and communication of the Smart district heating control with the multi-family demo site building and b) visualisation of the monitoring data from the demo site.

Baseline versus TEMPO implementation (state of the art): The focus of the first version of the ICT platform was to create a functioning platform for data management, including functionality for accessibility for systems and users. The visualization part of the first version focused on the EnergyView platform.

Improvements to state of the art implementation: The basic ICT platform added tools for improved data management for the second version. From a fault detection perspective, the dynamic analysis was an important focus of the second version. The visualization tool, version 2 of the system added an integration with Google Data Studio. This provides a way to test different versions of visualization techniques in a business intelligence dashboard environment.

Functionality: For the Brescia demo, the primary visualization tool was based on the Data Studio dashboard. This used data analysis results from the ICT platform as input for visualization. This combination has made it possible to use the system within the demo to view the operational behaviour of the system. The dashboard, in its current form, is primarily focused on expert users. However, Data Studio can also be used to elaborate on other types of visualization techniques.

### **Smart district heating controller:**

Baseline versus TEMPO implementation (state of the art): The controller developed in TEMPO builds further on the STORM-controller, developed in a previous Horizon 2020 project. In essence, the STORM-controller is a demand side management system for district heating networks. It makes use of the thermal mass of the buildings connected to the DHC network. The controller is able to achieve 3 different control objectives (i.e. peak shaving, market interaction and cell-balancing). The STORM controller influences the power demand of a building: by overriding the outdoor temperature measurement, it 'fools' the control system of the substation by telling it that it is colder or warmer outside than it actually is.

Improvements to state-of-the-art implementation: In TEMPO, additional functionalities are added to the STORM controller. Instead of only controlling the power, the objective of the TEMPO project is to control the network temperatures. Three different control strategies were developed and implemented: 1) Return temperature minimization: By temporarily reducing the heat demand of connected buildings, it is possible to temporarily lower the return temperature. 2) Supply temperature optimization: the water in the network pipes itself is used to store heat temporarily. 3) Combination of supply and return temperature. These three control strategies use a model predictive control framework. The inputs are forecasts of the outdoor temperature and the solar irradiation. The output of this control framework gives an optimal plan for the next 24 hours. These functionalities were integrated in the Brescia demonstration side, in order to be tested in the heating season 2021/2022.

### **Optimization of the building installations**

Baseline versus TEMPO implementation (state of the art): the return temperatures depend on the cooling taking place on the secondary side, which may be insufficient for a variety of reasons, including faults in the design or construction phase or in the operation of the system. For the detection of anomalous substations, a variety of methods is available. These methods often make it possible to identify suboptimal behaviour, but not to assess or predict its causes, or to provide indications with regards to further diagnosis and resolution steps. Compared to the state of the art, one distinctive feature of the TEMPO innovation was a general investigation of situations leading to high return temperatures and their modelling in coupled building and system simulations.

Improvements to state of the art implementation: Several improvements were made in version 2 as compared to version 1, including continuous improvements in terms of simulation models, calibration of simulations and adjustments to the practical guide, but the main improvements were a) Fault detection and diagnosis with new algorithms and for shorter periods, b) Interactive guide for technical audit of building installations in the form of a web page and c) Connecting fault predictions with the guide: Having a web version of the guide for technical audit of building installations made it possible to establish a connection between two outcomes of the innovation which were not yet connected in version 1.

Functionality: two related functions are combined: The simulation-based fault detection and diagnosis for secondary systems as well as the guide for auditing building installations. Simulation-based fault detection and diagnosis is based on data-driven algorithms which

have been trained on simulation data and are applied on monitoring data from the individual substations. The predictions made by the algorithms for a given period are summarized in an HTML document. This document also includes links to relevant sections of the guide for auditing building installations.

## TABLE OF CONTENTS

<b>1</b>	<b>Introduction .....</b>	<b>9</b>
<b>2</b>	<b>Supervision ICT platform &amp; Visualization tools for expert users 10</b>	
2.1	Baseline versus TEMPO implementation (state of the art) .....	10
2.2	Improvements to state of the art implementation .....	11
2.3	Functionality .....	14
<b>3</b>	<b>Smart district heating controller .....</b>	<b>17</b>
3.1	Baseline versus TEMPO implementation (state of the art) .....	17
3.1.1	Traditional district heating control – the baseline .....	17
3.1.2	The legacy STORM controller .....	18
3.2	Improvements to state of the art implementation .....	20
3.3	Functionality .....	21
<b>4</b>	<b>Optimisation of the building installations and visualization for non-expert users .....</b>	<b>25</b>
4.1	Baseline versus TEMPO implementation (state of the art) .....	25
4.2	Improvements to state of the art implementation .....	25
4.3	Functionality .....	26
<b>5</b>	<b>References .....</b>	<b>29</b>



## GLOSSARY / LIST OF ACRONYMS

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

## 1 INTRODUCTION

The A2A demonstrator is in the town of Brescia, in Northern Italy, consists of a portion of a peripheral branch of the existing HT DH system. In the H2020 TEMPO project, this site was assessed to demonstrate the solution package proposed for existing urban high temperature district heating systems. This solution package consists of the 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.

This report summarizes all important aspects of the innovations related to the implementation at the A2A demo site. Furthermore, the report also describes the state of the art and the improvements the TEMPO has made and the functionality of each innovation.

## 2 SUPERVISION ICT PLATFORM & VISUALIZATION TOOLS FOR EXPERT USERS

It should be noted, that the supervision ICT platform has two basic functionalities:

- a) Enabling the connection and communication of the Smart DH controller with the MFH demo site building,
- b) Vizualisation of the monitoring data from the demo site.

### 2.1 BASELINE VERSUS TEMPO IMPLEMENTATION (STATE OF THE ART)

The ICT platform and the visualization tools are closely connected. They operate on the same database structure, while the visualization tool showing data from that database and the ICT platform is operating on data from that same database.

The focus of the first version of the ICT platform was to create a functioning platform for data management, including functionality for accessibility for systems and users (see D4.2). From a fault detection perspective, the focus was on static detection. This can be compared with dynamic detection which is more of a focus in the second version. Dynamic detection studies change over time.

From an accessibility perspective the focus of the first version was to ensure secure communication. For communication, the default system always uses the latest version of TLS/SSL as a cryptographic protocol to provide secure communication. Currently, this is TLS 1.3 with SHA-256 RSA for certificate signature validation. Using TLS facilitates private and secure communication through symmetric cryptography, identity authentication and message integrity.

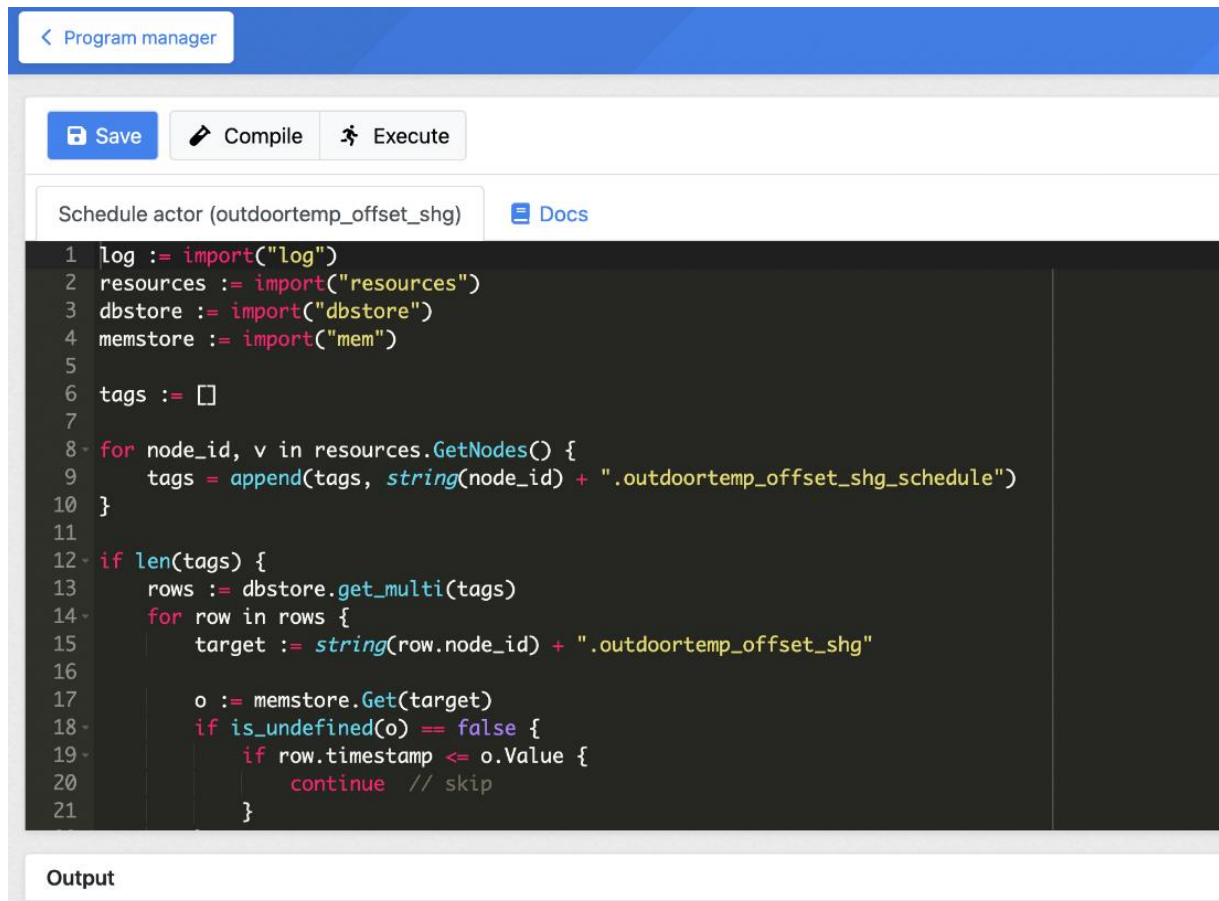
The data management in the first version was focused on creating robust pre-processing, including management of missing data, incorrect meter readings and general outliers. Core functionality for such pre-processing was implemented and deployed in the first version of the ICT system. This also includes data transformation, relating to standardization of sensor names and units of measure and also time dependent transformation such as resampling of data to the desired time resolution. It also relates to standardization of control signals, which is important of the TEMPO project since it makes use of active control on several levels of optimization.

The visualization part of the first version focused on the EnergyView platform provided by NODA. This co-exists with the underlying ICT data management system. The first version also included an improved alarm system, with a complete alarm management pipeline in place. Depending on how the EnergyView visualization tool is configured it can be used for expert as well as non-expert visualization.

## 2.2 IMPROVEMENTS TO STATE OF THE ART IMPLEMENTATION

The basic ICT platform (second version) added tools for improved data management. One of the more important additions relates to the script manager that was included in the system. This is also tied to the EnergyView front-end in order to create a complete tool that can be used in a practical setting. This functionality can be used for simple scripting tasks, and while seemingly simple, it adds a lot of practical usability and therefore supports future scalability.

Figure 1 shows an example for the A2A domain, in which the scripting feature is used for simple additions to the behaviour of the system. This would otherwise require updates to the underlying software system, which makes the process much more costly and prone to errors. This addition to the system has made it possible to relatively easy adapt to changes in requirements throughout the project and it forms an important feature for post-TEMPO usage of the system in industrial settings.



```
1 log := import("log")
2 resources := import("resources")
3 dbstore := import("dbstore")
4 memstore := import("mem")
5
6 tags := []
7
8 for node_id, v in resources.GetNodes() {
9     tags = append(tags, string(node_id) + ".outdoortemp_offset_shg_schedule")
10 }
11
12 if len(tags) {
13     rows := dbstore.get_multi(tags)
14     for row in rows {
15         target := string(row.node_id) + ".outdoortemp_offset_shg"
16
17         o := memstore.Get(target)
18         if is_undefined(o) == false {
19             if row.timestamp <= o.Value {
20                 continue // skip
21             }
22         }
23     }
24 }
```

Figure 1: Online scripting facility for the ICT system

The final version of the system also includes improved functionality that has made it possible to ease the integration with different types of hardware controllers and other data sources. Traditionally, interaction between automation system has been a huge barrier for large scale implementation of TEMPO-like technology. Simply because automation systems are usually not designed well to work outside of their own technical silos. However, being

able to create systems of systems is an important part of facilitating a broader usage of the TEMPO system in the future. Figure 2 shows an example of an integration with a hardware device in the A2A network.

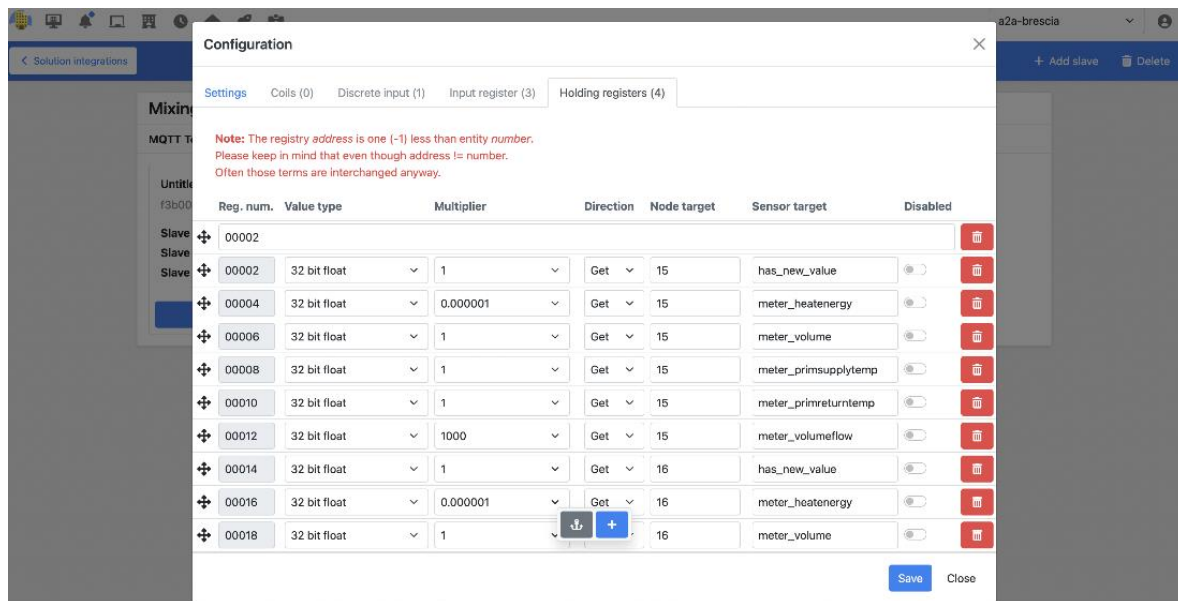
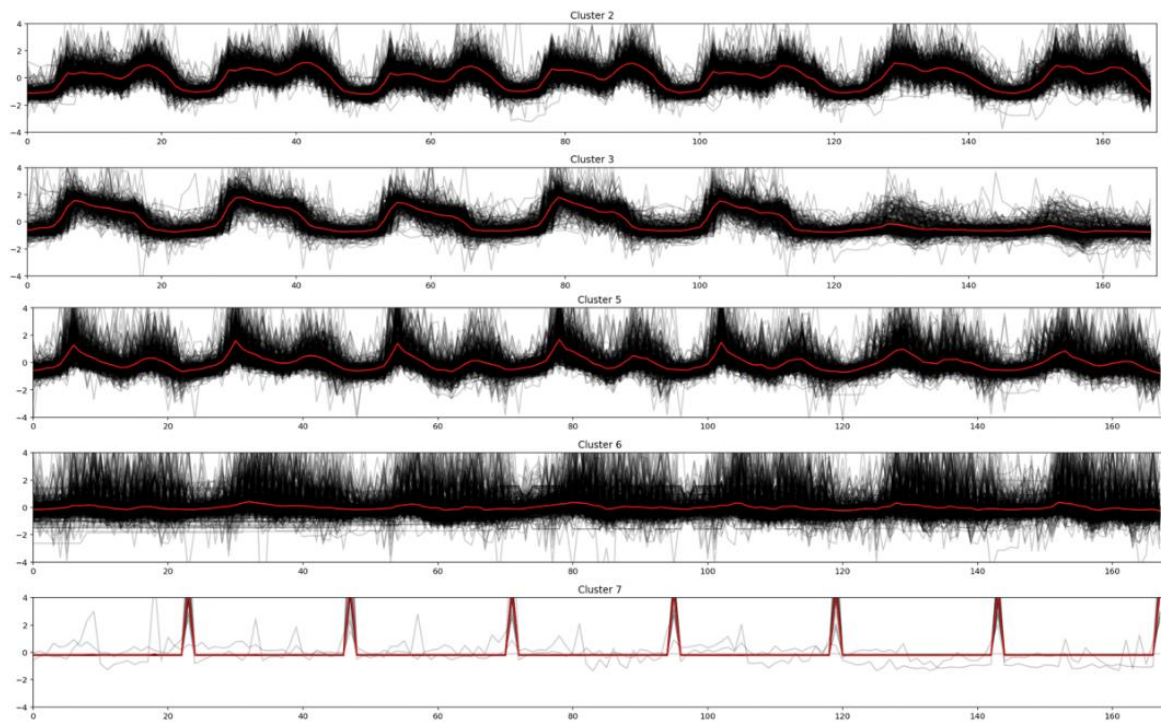


Figure 2: Online integration facility for the ICT system

From a **fault detection** perspective, the dynamic analysis was an important focus of the **second version**. This is heavily dependent on clustering methods from an algorithmic perspective. Tracking how individual data time series move from one cluster to the next is an important part of **capturing the dynamic behavior** of the underlying data. In version two, improved clustering was implemented based on k-shape time series analysis in relation with dynamic time warping. The primary additions in the version two related to improved ways to automate the process of accessing the clustering results in different ways and to used input features from neighboring peers (i.e. individuals from the same cluster) to improve the predictive capacity in relation to overflow calculations. The following figure shows an **example of clustering** among a larger group of time series.



*Figure 3: Example of clustering among a larger group of time series*

The clustering mechanism has also been expanded with geographical clustering as well as improved ways to manage automated selection of cluster solutions. This ability was purposely added to the system to benefit the system temperature optimisation, since it provides the ability to generate a data-driven and self-learning digital twin of sorts of network temperature propagation.

Figure 4 shows an example of this using external large-scale data, since the data-set for the A2A was too small to fully explore the potential of this technology. The external dataset included more than 5000 substations.



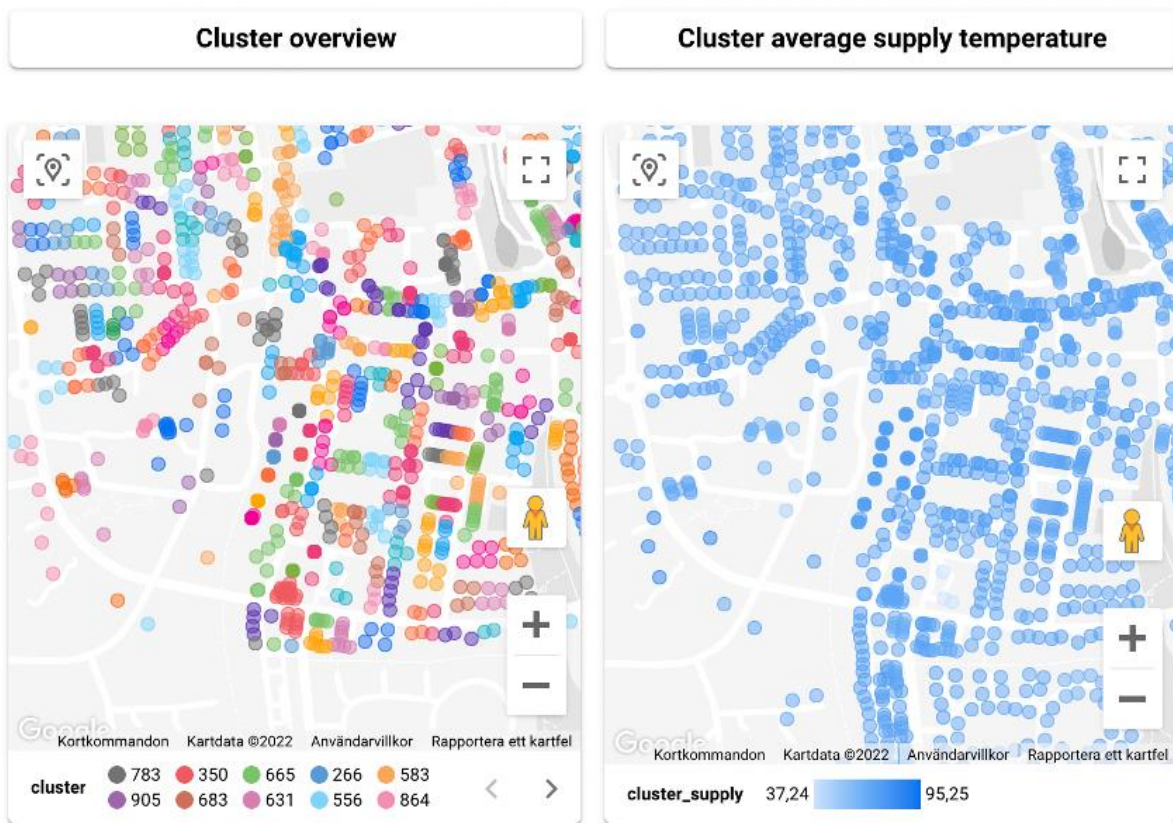


Figure 4: An example of geographical clustering in relation to network supply temperatures.

From the perspective of the **visualization tool, version 2** of the system added an **integration with Google Data Studio**. This provides a way to test different versions of visualization techniques in a business intelligence **dashboard** environment. For the final version of the ICT platform, a prototype implementation of differential privacy has been developed using the software library PyDP, which is a Python wrapper for Google's differential privacy project.

## 2.3 FUNCTIONALITY

For the Brescia demo, the primary visualization tool was based on the **Data Studio dashboard**. This used data analysis results from the ICT platform as input for visualization. This combination has made it possible to use the system within the demo to view the operational behavior of the system. The following picture shows an **example of the front tab of the business intelligence dashboard** for the Brescia demo. This has been translated into Italian to provide easier access for local stakeholders.



Figure 5: Example of the front tab of the business intelligence dashboard for the Brescia demo

For the final version of the ICT platform, additions have been made to facilitate dynamic analysis as well as making this easier to access for people working with the system. Primarily, the focus has been to keep it as simple as possible, while hiding the complexity for everyday-users. An example of this is the dynamic temperature deviation sensitivity, which in itself is a rather complex statistical analysis. However, the visualisation output is very simple indeed, with analysis results being put into different categories that easy to understand. Figure 6 shows an example of this.



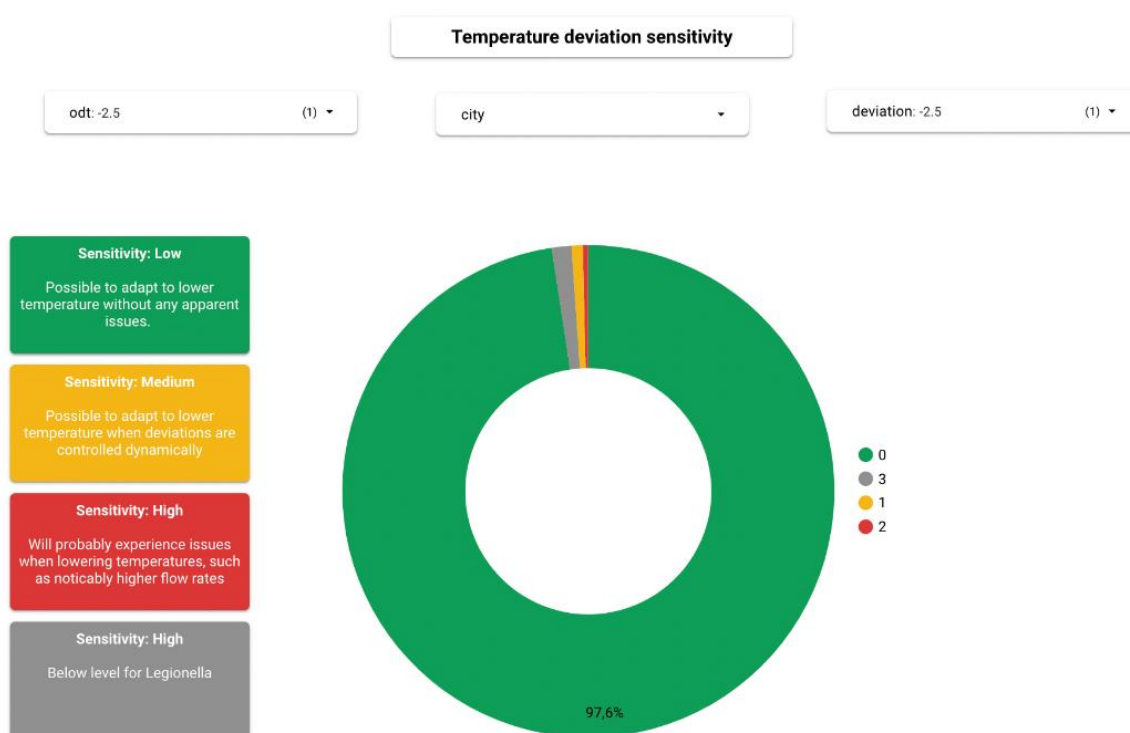


Figure 6: Visualisation of dynamic temperature deviation sensitivity

## 3 SMART DISTRICT HEATING CONTROLLER

### 3.1 BASELINE VERSUS TEMPO IMPLEMENTATION (STATE OF THE ART)

#### 3.1.1 Traditional district heating control – the baseline

A district heating (DH) network is demand driven. This means that the heat produced is following the heat demand. Typically, the control of heat consumption and heat production in DH networks is achieved by means of 4 independent, non-interacting control actions (see Figure 7).

- **Loop #1** controls the heat consumed by the individual buildings. This is controlled by the end user itself, either directly by opening a valve for domestic hot water consumption, or by applying a setpoint for the indoor temperature, in which case a thermostatic control system will control the flowrate through the heating supply system.
- **Control loop #2** follows loop #1. This control loop, part of the substation control logic, determines how much DH water is extracted from the DH network in order to reach the set points defined by loop #1. Control loops #1 and #2 are located at the consumers side of the network; each building has such individual control loops.
- **Control loop #3**, at the production side, will make sure that the aggregated flow rate demand from the buildings is fulfilled, often by means of a differential pressure control, speeding up or down the central circulation pumps.
- **Finally loop #4** controls the supply temperature of the network, often based on an outside temperature measurement and a heating curve. More information about the typical control can be found in<sup>1</sup>.

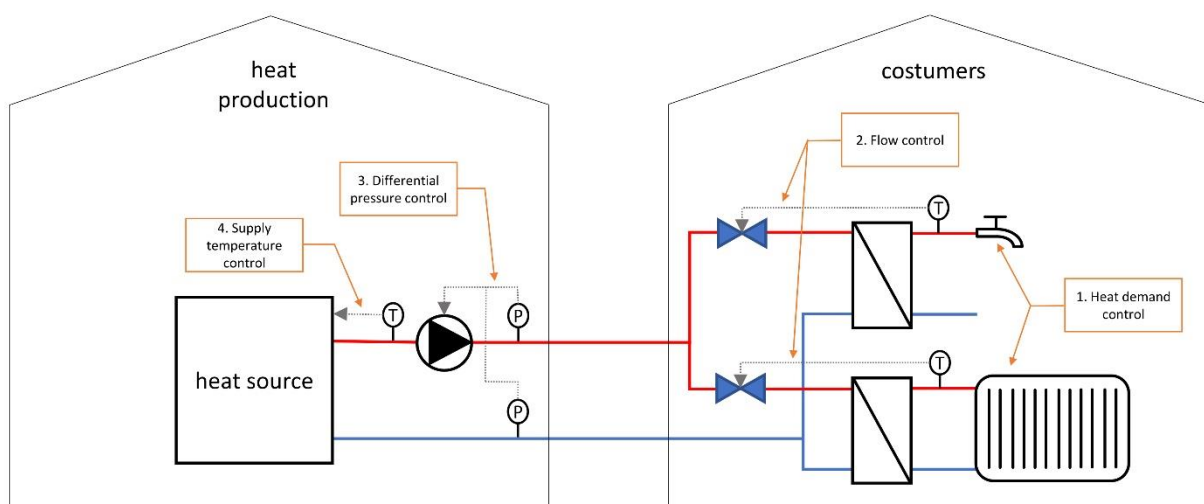


Figure 7: Typical control loops in district heating systems

<sup>1</sup> Frederiksen S.; Werner, S. District Heating and Cooling; Student Literature; 2013

As mentioned, the control loops #1, #2, #3 and #4 are independent from each other. They do not interact with each other, and as such do not contribute to the optimization of the global system.

### 3.1.2 The legacy STORM controller

The controller developed in the TEMPO project builds further on the STORM-controller, developed in a previous Horizon 2020 project (Vanhoudt et al., 2017<sup>2</sup>). The STORM controller successfully tackled this with the development and implementation of a solution for an online coordination of supply and demand. More information and background on the STORM controller technology can be found on: <https://stormcontroller.eu/en>.

In essence, the STORM-controller is a **demand side management** system for DHC networks. It makes use of the thermal mass of the buildings connected to the DHC network. By temporary delivering more or less energy to the building than needed in a coordinated way, the heat demand of the network can be temporary shifted. And since heat networks are demand driven, controlling the demand results in controlling the heat production of the network. As such, the controller is able to achieve a global benefit on the network level. Concretely, the controller is able to achieve 3 different control objectives (i.e. peak shaving, market interaction and cell-balancing). Since the thermal mass of the buildings is typically very large, this can be achieved without violation of indoor climate: the indoor temperature will only marginally be influenced, without people or thermostats noticing it.

A common way to influence the heat demand of a building is by influencing the set point supply temperature of the heating installation (Figure 8). Typically, the set point of the supply temperature of the heating installation is determined by the outdoor temperature measurement and a heating curve. The colder it gets outside, the higher this set point. If the set point is increased, the valve control will open the DH valve more and more heat is being pumped in the building. Alternatively, when the outdoor temperature rises, the set temperature decreases, the valve closes, and less power is delivered to the building.

Making use of this functionality, it is possible to temporary increase/decrease the power a building consumes by decreasing/increasing the outdoor temperature measurement, without adjusting the inner control software of the substation<sup>3</sup>. This is exactly how the STORM controller influences the power demand of a building: by overriding the outdoor temperature measurement, it 'fools' the control system of the substation by telling it that it is colder or warmer outside than it actually is.

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<sup>2</sup> Vanhoudt et al., 2017, Status of the H2020 STORM project, Energy Procedia Vol. 116, June 2017, p. 170 – 179, <https://doi.org/10.1016/j.egypro.2017.05.065>

<sup>3</sup> Remark: this temperature override method is not the only way to influence the power. Some controllers have a possibility to integrate with directly. In that case, the outdoor temperature override trick is not necessary. However, most control systems are closed, making it impossible to interact with. In that case, only temperature override is possible.

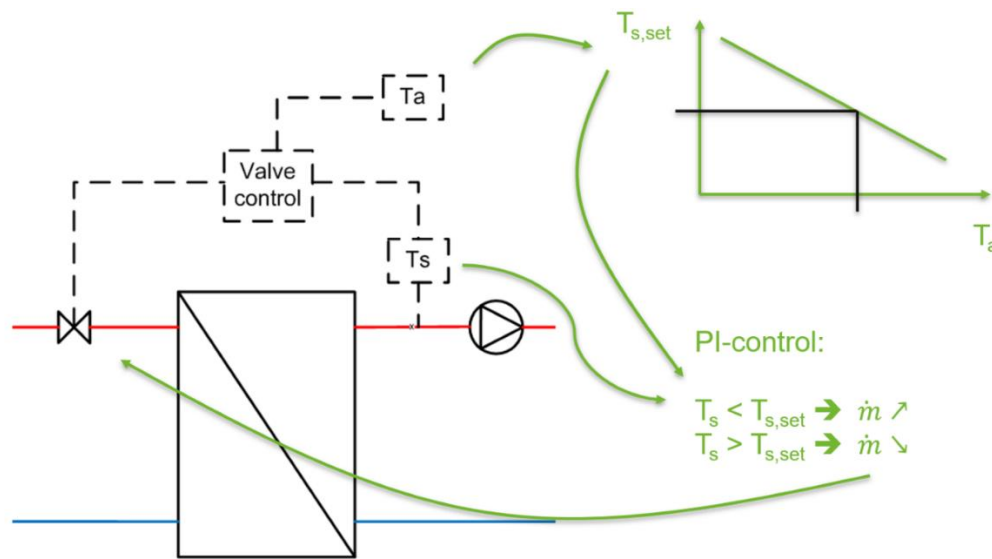


Figure 8: Typical control system of a DH substation heating system

The STORM controller algorithms consist of 4 modules:

- The **Forecaster** module. It forecasts the energy demand in the network for the upcoming few days based on weather forecasts and the historical behavior of the network, making use of machine learning algorithms. Moreover, it also forecasts the flexibility available in the network, i.e. it forecasts how much energy can be stored or released from the virtual buffer, based on the building thermal mass and the thermal state within the building.
- The **Planner**, which is like an optimizer. It uses the forecasts calculated by the Forecaster and has a certain objective to fulfil, e.g. peak shaving. Based on these inputs, the Planner will calculate to which extend the demand profile of the network can be shaped towards the objective by using the available flexibility. In this exercise, the comfort constraints of each individual building are always taken into account. The output of the Planner is a control plan, which normally spans the coming 24 hours.
- The **Tracker** module, which disaggregates the desired control plan generated by the Planner into individual control power demands for each building. Thereby, it tries to make sure that the actual heat demand curve of the network corresponds as close as possible to the optimized one from the Planner. Because of unavoidable model errors in the building and network models, it acts and reacts in real-time, by constantly updating the power demands sent out to the buildings. While the Forecaster and Planner operate on longer time periods of hours and days, the Tracker will normally operate on near-real-time time levels.
- **Agents:** each building connected to the control signal is represented by a software agent called a virtual Distributed Energy Resource (vDER). The vDER translates the power demand from the Tracker into a control signal able to be used in the control system of the building substation controller or building management system. This control signal makes the building react in the way the controller wants it to, in order to meet the control objective. Each vDER also continuously communicates with the Forecaster to provide the basis for making predictions on the available thermal flexibility.

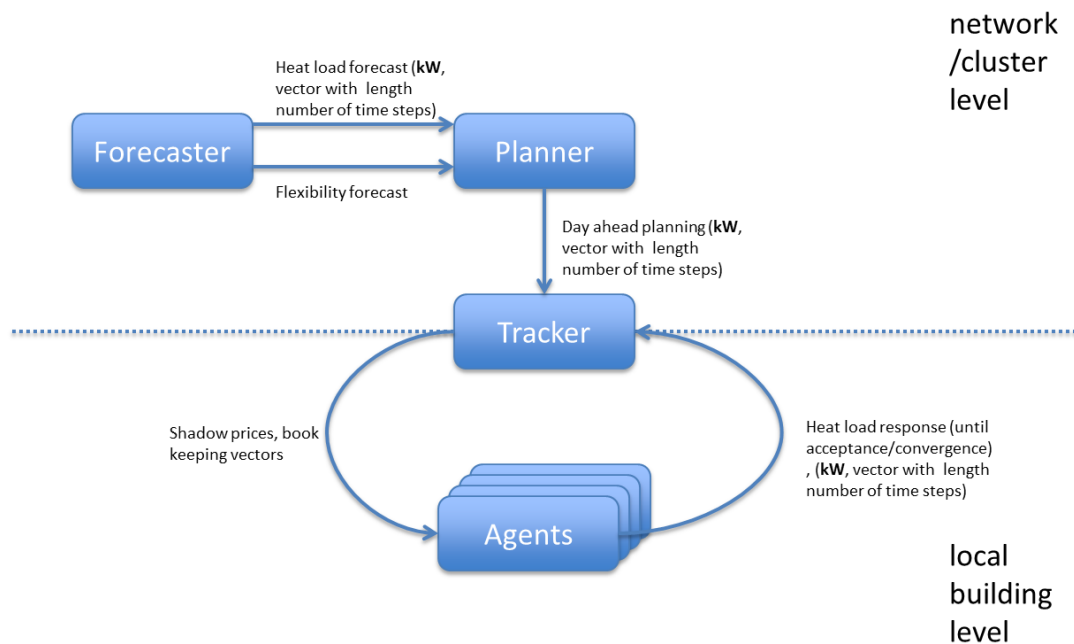


Figure 9: Schematic representation of the STORM-controller software architecture

## 3.2 IMPROVEMENTS TO STATE OF THE ART IMPLEMENTATION

In TEMPO, additional functionalities are added to the STORM controller. Instead of only controlling the power, the objective of the TEMPO project is to control the network temperatures. The added functionalities consist of return temperature minimization, supply temperature optimization and a combination of both. The smart controller aims at controlling the operation of the network, in order to optimize the temperature levels in the network. Three different control strategies were developed, tested and implemented in the demonstration site of A2A:

- **Return temperature minimization**

By temporarily reducing the heat demand of connected buildings, it is possible to temporarily lower the return temperature to the district heating network. Eventually, the average return temperature can be decreased. In the A2A demo site in Brescia, this control strategy is applied to reduce the return temperature from the multi-family house.

- **Supply temperature optimization**

With this control strategy, the water in the network pipes itself is used to store heat temporarily: by increasing the temperature of the water in the supply pipes when excess heat is available, heat can be stored for a limited time. Doing so, unlocks the available energy flexibility to achieve a certain objective for the network. In the A2A demo site in Brescia, this control strategy is applied to shave off the heat supply peaks of the mixing station.

#### – **Combination of supply and return temperature**

The last functionality of the smart DH controller integrates both the supply and return temperature features. The controller algorithm manages the network operation from the secondary side of the mixing station up to the multi-family house in the A2A demo site.

### **3.3 FUNCTIONALITY**

Three different objectives for the smart district heating controller are possible:

1. Minimization of the primary return temperature of an individual, controllable building, by optimally controlling the secondary-side supply temperature, i.e., corresponding to the return temperature minimization functionality.
2. Minimization of the thermal power peaks of the heat source, by optimally controlling the network supply temperature, i.e., corresponding to the supply temperature optimization functionality.
3. Minimization of a mixed objective function weighting the above two objective functions, by optimally controlling both the network supply temperature and the secondary-side supply temperature of the building, i.e., corresponding to the integrated supply and return temperature optimization functionality.

These functionalities were recently integrated in the Brescia demonstration site, in order to be tested in the heating season 2021/2022.

#### **Return temperature minimization**

The objective of the return temperature minimization controller functionality is to achieve an overall lower average return temperature in the network by controlling the heat demand of individual active buildings. The power consumed by the building is influenced by sending outdoor temperature offsets as control signals. This is achieved by (indirectly) modifying the supply temperature to the heating supply circuit of the building:

- positive outside offset temperature → lower heating system supply temperature → less power consumed;
- negative outside offset temperature → higher heating system supply temperature → more power consumed.

A side effect of a drop in heating system supply temperature however also is that the return temperature drops (Figure 11). After all, when the radiators receive a lower supply temperature, the emitted heat will drop, and the return temperature will drop as well.



*Figure 11: When sending a positive temperature offset to a building (green line), the return temperature of the building (orange line) drops.*

It is this effect which is used in the 'return temperature minimization' controller. Since, if this is realized in many buildings, it is possible to achieve a lower average return temperature in the entire network.

### **Supply temperature optimization**

In order to unlock additional flexibility of district heating networks, supply temperature optimization is investigated to temporarily store thermal energy in the network pipes. A practical application could be to increase the supply temperature of the network before a peak in heat demand from the buildings is forecasted. This way, it is possible to reduce the operating time of peak heat production capacity. Using the thermal capacity of the network as thermal storage is still unknown terrain and subject to research. Therefore, within version 1, the aim was to investigate the physical behavior of the A2A network branch in Brescia and gain useful information for the development for the supply temperature optimization feature in the version 2 of the TEMPO solution package.

In Figure 10 a conceptual scheme of the A2A network branch in Brescia is shown. At the mixing station secondary side (i.e., after mixing), the flow rate, supply and return temperatures were recorded. At the multi-family house substation, supply and return temperatures were recorded on both the primary and secondary sides while the flowrate was recorded only on the primary side. Finally, the indoor temperature at the multi-family house is monitored through a series of sensors located at different floors. Finally, the outdoor temperature and solar irradiation forecasts are also available.

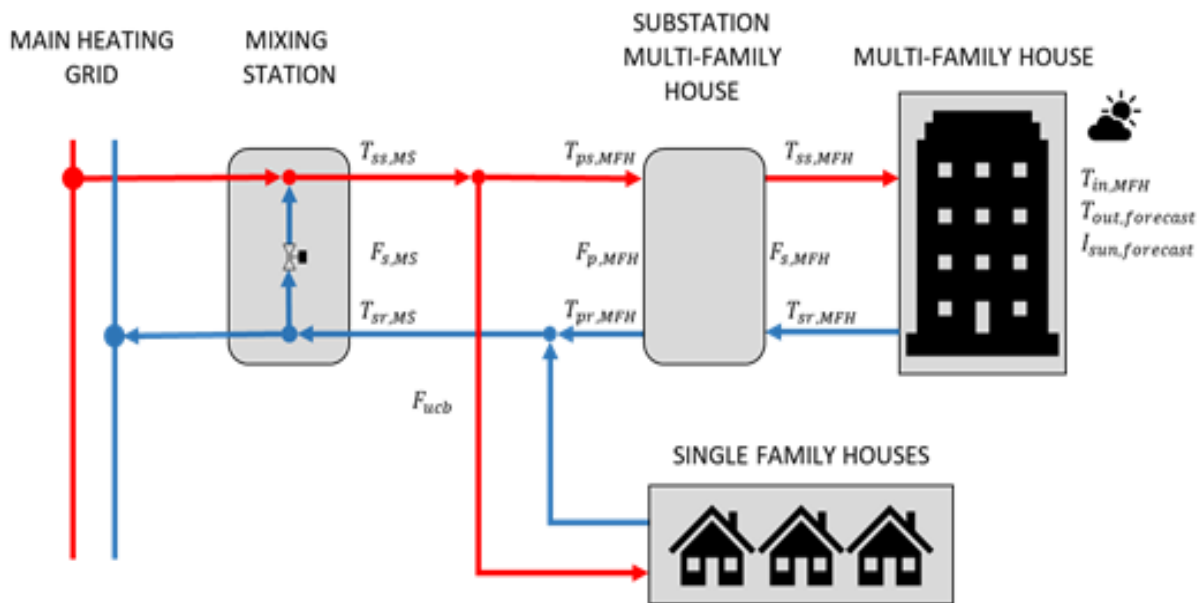


Figure 10: A2A network branch conceptual scheme with the relevant temperatures ( $T$ ) and flow rates ( $F$ ).

### Implementation of the smart district heating controller

The implementation of the smart district heating controller in the demonstration site takes the following steps:

1. Testing of the communication
2. Response tests
3. Model training and validation

### Testing of the communication

Before response tests can be performed on the district heating network, the communication between the control framework and the A2A network needs to be verified. This is necessary to guarantee that control signals sent to the A2A network actually influence the network or change the setpoints of the system. After this test, the response tests can be performed.

### Response tests

The focus of the response test during the heating season 2020/2021 was the variation of supply temperature at the secondary side of the mixing station. Here, a step function was applied and the network response (flows, supply and return temperature) was monitored to understand the dynamic behavior of the thermal network behind the mixing station.

These response test consists of changing the supply temperature setpoint at the mixing station stepwise and record how the network reacts to this change. During this campaign different supply temperature pulses were sent from the mixing station. As can be seen from the figure, the temperature propagation time depends on the flowrate's magnitude. At night, with low flow rates, the propagation time is higher ( $\sim 1$  hour and 30 minutes) while during the day it is much shorter ( $\sim 20$  minutes). Regarding the flow rates, especially during the day, they are controlled by the substations based on the heat demand and the



supply temperature. For the same heat demand, an increase in supply temperature leads to a decrease in flow rate and vice versa.

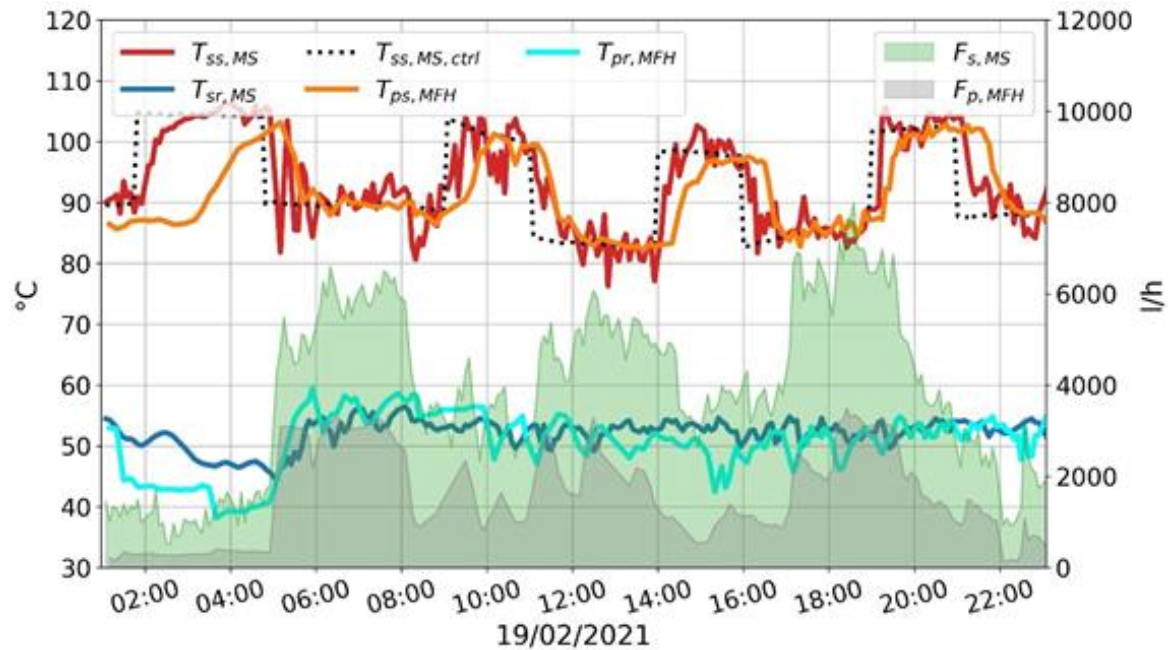


Figure 11: Test day: 19/02/2021. Supply and return temperature, mixing station supply temperature control signal, and flow rates at the mixing station and at the multi-family house.

### Model training and validation

The models need to be trained and validated with measurement data of the A2A demo site. Only models that provide a good representation of the behaviour of the A2A network can be used for the smart controller.

## **4 OPTIMISATION OF THE BUILDING INSTALLATIONS AND VISUALIZATION FOR NON-EXPERT USERS**

### **4.1 BASELINE VERSUS TEMPO IMPLEMENTATION (STATE OF THE ART)**

While primary supply temperatures are under the control of district heating operators, return temperatures depend on the cooling taking place on the secondary side, which may be insufficient for a variety of reasons. Causes for high return temperatures may differ in their origin, temporal behaviour, location in the system. They include faults in the design phase (e.g. over-sizing, misplacing of sensors, unwanted bypasses) or in the operation of the system (e.g. wrong setpoints, unbalanced operation of radiators).

For the detection of anomalous substations, a recent survey with Swedish utilities (Månsson, Kallioniemi, Thern, Van Oevelen, & Sernhed, 2019), showed a variety of methods, including monthly checks of customer billing data and the analyses based on return temperature, flow and overflow. The same study highlighted the importance of having physical access to the customers' installations, which is done either by signing service agreements or by including yearly inspections in the district heating pricing. The most advanced approaches proposed in the state of the art (e.g. (Gadd & Werner, 2015)) are usually based on the evaluation of automatic meter readings, for instance with clustering and threshold methods. These methods often make it possible to identify suboptimal behaviour, but not to assess or predict its causes, or to provide indications with regards to further diagnosis and resolution steps.

Compared to the state of the art, one distinctive feature of the TEMPO innovation was a general investigation of situations leading to high return temperatures and their modelling in coupled building and system simulations. This allowed the training of fault detection and diagnosis algorithms (based on simulation data) on the one hand, and the development of a guide for technical audits of building installations on the other hand.

### **4.2 IMPROVEMENTS TO STATE OF THE ART IMPLEMENTATION**

Several improvements were made in version 2 as compared to version 1, including continuous improvements in terms of simulation models, calibration of simulations and adjustments to the practical guide, but the main improvements were as follows:

- Fault detection and diagnosis with new algorithms and for shorter periods.
- Interactive guide for technical audit of building installations: Whereas in version 1 the practical guide for technical audit of building installations was a static (PDF) document, in version 2 it has become a more interactive guide in the form of a web page. This web page makes the exploration of the guide easier by providing a variety of links.
- Connecting fault predictions with the guide: Having a web version of the guide for technical audit of building installations made it possible to establish a connection

between two outcomes of the innovation which were not yet connected in version 1: the fault predictions made for given data and the guide. In version 2, the fault predictions resulting from the application of the simulation-trained fault detection and diagnosis algorithms to actual monitoring data are summarized in reports. These reports refer to fault types and metrics for which links to the guide are provided, enabling a combination of the (automated) data-driven insights with the (manual) audit process.

## 4.3 FUNCTIONALITY

The innovation “optimisation of the building installations” combines the two related functions, which are the simulation-based fault detection and diagnosis for secondary systems and the guide for auditing building installations. Simulation-based fault detection and diagnosis is based on data-driven algorithms which have been trained on simulation data (from detailed simulations carried out in Modelica) and are applied on monitoring data from the individual substations. The predictions made by the algorithms for a given period are summarized in an HTML document (Figure 12) along with metrics calculated for the period. This document also includes links to relevant sections of the guide for auditing building installations (Figure 13).

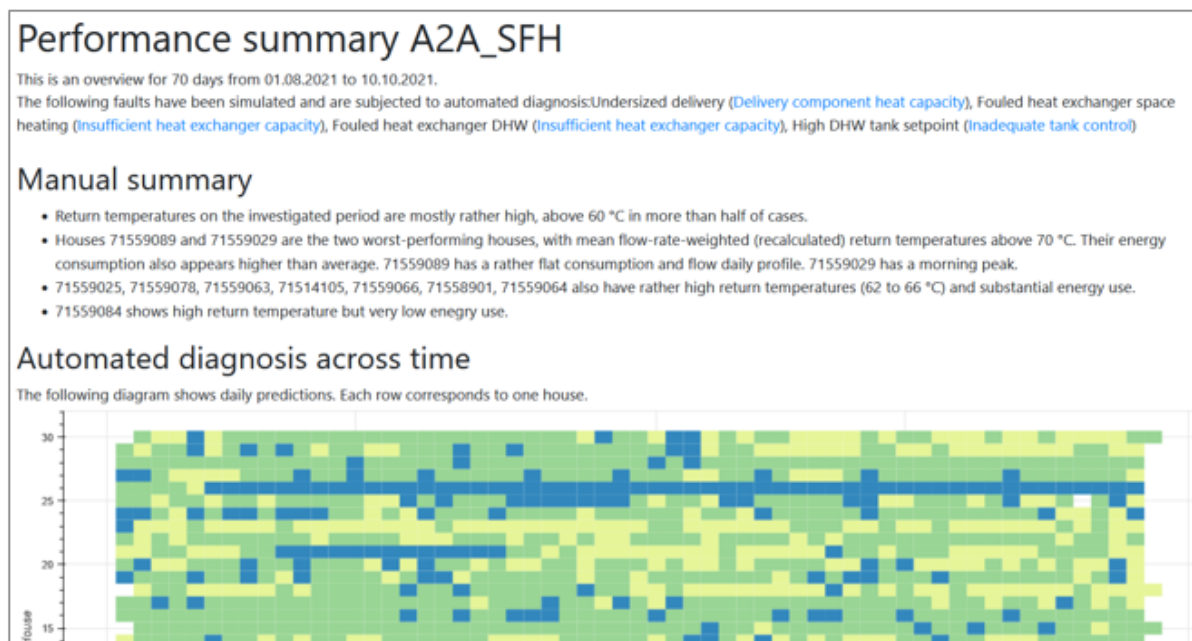


Figure 12: Screenshots of a fault detection and diagnosis summary

## Guide for auditing building installations to reduce high return temperatures

### Contents

- [Introduction](#)
- [Flowcharts](#)
- [Fault profiles](#)
- [Specific faults](#)
- [Metrics](#)
- [General information](#)
- [References](#)
- [Acknowledgement](#)
- [Contact](#)

### Introduction

The present practical guidelines have been developed within the [TEMPO project](#), funded by the European Union's H2020 Programme under grant agreement 768936. They should guide technicians in performing audits on energy systems in building to identify, diagnose and correct components or systems behaving in a suboptimal way. The [flowcharts](#) offer a first to gradually narrow down issues, and thus refer the user to issue profiles corresponding to probable issues. [Issue profiles](#) provide more detailed information on specific types of issues, grouping together issues affecting given components and/or sharing similar mechanisms or symptoms. Links are also provided between issues and [metrics](#) which are related to them and might support diagnosis. [General information](#) on issues causing high return temperatures and [references](#) can be found in the last sections.

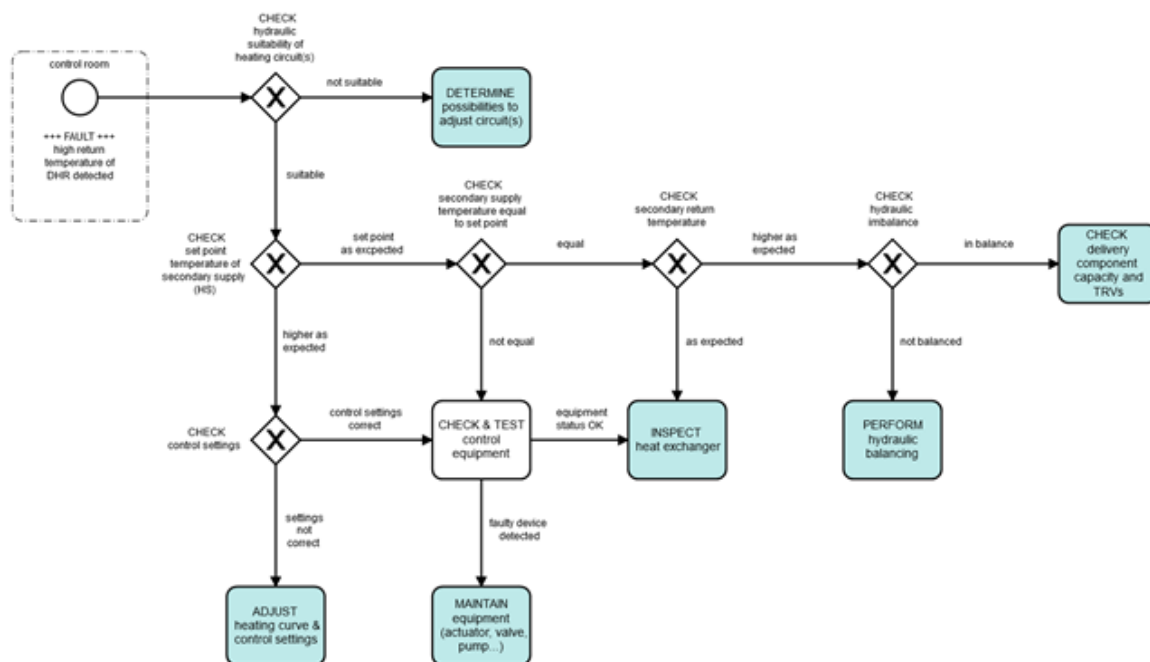


Figure 13: Screenshots of the interactive guide for auditing building installations, see also <http://tempo-dhc.ait.ac.at/building-guide/>

Further on, a set of easy to understand and short reports for the buildings were created, including key information of the *actual* performance of the building with regards to the return temperature, the contractual reference return temperatures, and the return temperature of good performing buildings. Also possible improvements measures based on the analysis for the building optimization were suggest. For more detailed test results we refer to the deliverable D5.3.

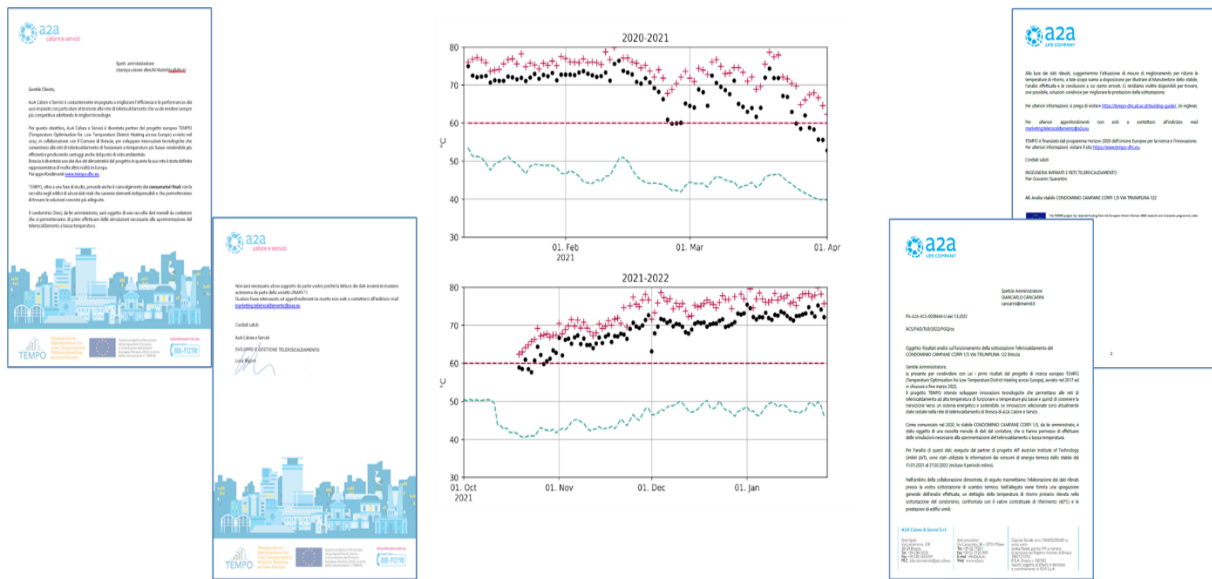


Figure 14: Visualization for non-expert users: easy to understand and short reports for the buildings in the A2A city demo.

## 5 REFERENCES

- Gadd, H., & Werner, S. (2015). Fault detection in district heating substations. *Applied Energy*.
- Månsson, S., Kallioniemi, P.-O., Thern, M., Van Oevelen, T., & Sernhed, K. (2019). Faults in district heating customer installations and ways to approach. *Energy*.