DISTRHEAT

Digital intelligent and scalable control for
renewables in heating networks

Deliverable D2.1

Report of the characteristics of the small DHC and the requirements

Costanza Saletti, University of Parma

September 2021

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative Integrated, Regional Energy Systems, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 775970.

Smart
Energy
Systems
ERA-Net

Document status

Deliverable No.:	D2.1
Deliverable title:	Report of the characteristics of the small DHC and the requirements
Version:	1.0
Date created:	2021-09-15
Date updated:	2022-04-29
Date submitted:	2022-05-10

Document preparation

	Date	**Name**	**Organization**
Authored by:	2021-09-15	Costanza Saletti	University of Parma
Reviewed by:	2022-03-17	Mirko Morini	University of Parma
	2022-04-29	Riccardo Malabarba	Siram Veolia
Approved by:	2022-05-05	General assembly	

Document sensitivity

Status option

Available status options:

- Not sensitive
- Moderately sensitive ✓
- Sensitive
- Highly sensitive & confidential

Table of Contents

Executive summary

The deliverable summarizes the results from task “T2.1 Analysis of the case study”, in which it was stated that the small-scale case study would be deeply analyzed in order to understand the relevant sub-systems and the characteristics to be tackled in the WP following tasks.

The test site is the Sant’Anna Hospital of Cona, located close to the city of Ferrara, in the north-east of Italy (Emilia-Romagna region). The system comprises (i) the thermal power station and (ii) a small-scale district heating and cooling network.

The thermal power station can be divided into the following sub-systems:

- **Trigeneration plant**, which comprises a cogenerator and an absorption chiller. Electricity is produced to power the electric utilities of the hospital. At the same time, heat is recovered from the cogenerator by means of heat exchangers, which produce hot water to be supplied to the hospital buildings. A portion of the hot water produced through heat recovery from the engine may be used to feed a lithium bromide absorption chiller.
- **Boilers**. the water that leaves the cogenerator is further heated by four gas-fired boilers working in parallel.
- **Electric chillers**. The water that exits from the absorption chiller is further cooled down by four electric chillers.
- **Connection to the power grid**. In certain operating conditions, there may be a surplus electric power produced by the cogenerator which may be sold to the power grid or the the demand which cannot be fulfilled by the cogenerator production is met by purchasing it from the power grid.

Based on the analysis of the site selected as small DHC case study and on the investigation of the thermal power station composition, it is possible to draw the requirements for the subsequent tasks of the WP.

For each energy conversion unit in the thermal power station, it is required (i) its numerosity, (ii) the nominal input power, (iii) the minimum input power and, (iv) the nominal efficiency. Moreover, it is recommended to collect the minimum efficiency, ramp up and ramp down limits, start-up cost, idle cost, minimum up-time and down-time.

Regarding the whole site, in order to develop the optimization algorithm, the forecast of the following disturbances is required: thermal power demand, cooling power demand, electrical power demand, steam demand, outdoor temperature, cost of electricity sold to the grid, cost of electricity bought from the grid and cost of fuel.

1. Introduction

This report is the deliverable D2.1. of work package WP2 of the DISTRHEAT project, led by University of Parma. The work package “WP2 – System study, modeling and algorithm development for small DHC” aims to develop a system model of a small-scale District Heating and Cooling network (DHC), in particular of the small-scale case study, and an optimization algorithm suitable for its optimal management within a Model Predictive Controller.
The coordinated activities of WP2 are illustrated in Figure 1.

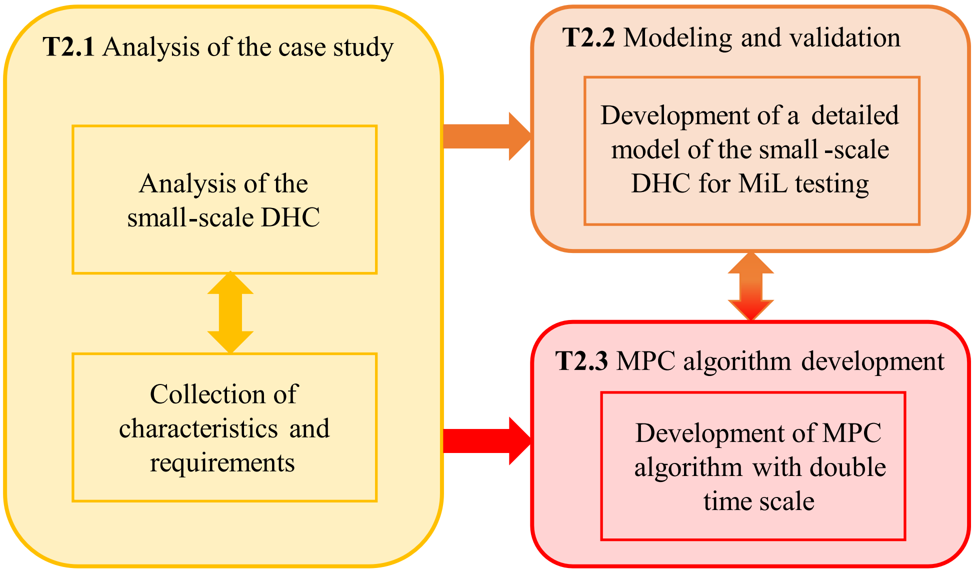

Figure 1. Schematic representation of main tasks and activities of WP2. The present deliverable focuses on T2.1.

The deliverable summarizes the results from task “T2.1 Analysis of the case study”, in which it was stated that the small-scale case study would be deeply analyzed in order to understand the relevant sub-systems and the characteristics to be tackled in the WP following tasks.
The deliverable describes the investigation of the system selected as small-scale case study, the description of its components as well as the relevant characteristics required to model the system and to develop the optimization algorithm. The information reported in this deliverable will be useful in tasks T2.2, where the characteristics of the system will be used to setup the dynamic model of the case study, and in task T2.3, where the optimization algorithm will be developed based on the structure of the case study. Moreover, there is an interaction with WP3, related to the actual implementation of the methods proposed in WP2 in the real small-scale case study.
The work has been conducted from M7 to M14 of the project.

2. Characteristics of the small-scale DHC

2.1. Choice of the small-scale DHC

The test site was selected in T3.1 of WP3, coordinated by the company Siram Veolia, which is the system operator of several small-scale DHCs for commercial and third-sector users (e.g. school complexes, university campuses, hospitals). The test site is the Sant'Anna Hospital of Cona (Figure 2), located close to the city of Ferrara, in the north-east of Italy (Emilia-Romagna region).

Figure 2. View of the Sant'Anna hospital of Cona (Italy).

The site requirements are represented by heating and cooling demands for space heating and cooling, electrical demand for the hospital appliances as well as a steam demand for other hospital special utilities such as the laundry, the sterilization department and the kitchen. The yearly demands, normalized with reference to the yearly electrical demand for the sake of confidentiality, are reported in Table 1, in order to give a perception of the hospital requirement in terms of form of energy.

Table 1. Normalized yearly energy demands of all energy vectors. The values are normalized with reference to the yearly electrical demand.

Demand	Heat	Cold	Electricity	Steam
Normalized value	0.98	0.83	1	0.12

The system comprises:

- The **thermal power station**, where heating, cooling and electrical power, as well as thermal power for steam, are produced.
- A **small-scale district heating and cooling network** that distributes heating and cooling energy to the Hospital buildings. The flows of hot and cold water exiting the

thermal power station are pressurized by a set of hydraulic pumps and split to be sent to different substations of the hospital. In particular, the heating network supplied heat for space heating and production of sanitary hot water, while the cooling network is used for air conditioning and for cooling the operating rooms.

The relevant sub-systems can be identified as the heating circuit, the cooling circuit, and the thermal power station itself, the different power units of which are investigated in detail in the next section.

2.2. Thermal power station composition

The thermal power station can be divided into the following sub-systems:

- **Trigeneration plant**, designed to fulfill the energy needs of the hospital in a more sustainable way, through the combination of electricity, heat, and cooling energy production. The trigeneration plant comprises a cogenerator and an absorption chiller. The former is a natural gas-powered internal combustion engine, which operates in parallel with the electric power grid. Electricity is produced to power the electric utilities of the hospital. Given the plant size and the historical electrical demand, it is expected that all electricity produced is entirely self-consumed by the hospital, except for a small amount of electricity which may be injected into the power grid (sold at market price) when the hospital demand is lower than the power produced by the cogenerator. At the same time, heat is recovered from the cogenerator by means of heat exchangers, which cool down the engine and produce hot water to be supplied to the hospital buildings. A portion of the hot water produced through heat recovery from the engine may be used to feed a lithium bromide absorption chiller, so that inlet heating power is converted into cooling power, and cold water is supplied to the hospital buildings. In the actual operating conditions, this is realized during the summer season or, generally, when heat recovery is larger than the hospital demand. Conversely, the residual heat recovered from the engine is dissipated into the environment.
- **Boilers**. The heating and cooling energy necessary to fulfill the demands are produced by conventional plants. In particular, the water that leaves the cogenerator is further heated by four gas-fired boilers working in parallel with independent pipelines. The water reaches an outlet temperature that ranges from 80 °C to 85 °C depending on its setpoint, which is generally established by means of a climatic curve.
- **Electric chillers**. The water that exits from the absorption chiller is further cooled down by four electric chillers to an outlet temperature ranging from 6°C to 7°C.
- **Steam generators**. There is an additional distribution system for supplying steam, independently from the heating and cooling systems. Saturated steam is produced by three gas-fired steam generators at a pressure of 0.7 MPa and injected into the related distribution system. Its pressure is reduced locally at each facility (depending on its specific requirement) by means of vapor-vapor heat exchangers.
- **Connection to the power grid**. As stated previously, in certain operating conditions, there may be a surplus electric power produced by the cogenerator which may be sold to the power grid. In all other conditions, the portion of electricity demand which cannot be fulfilled by the cogenerator production is met by purchasing it from the power grid.

A schematic representation of the thermal power station composition, as well as the interaction between the different units and energy vectors, can be found in Figure 3.

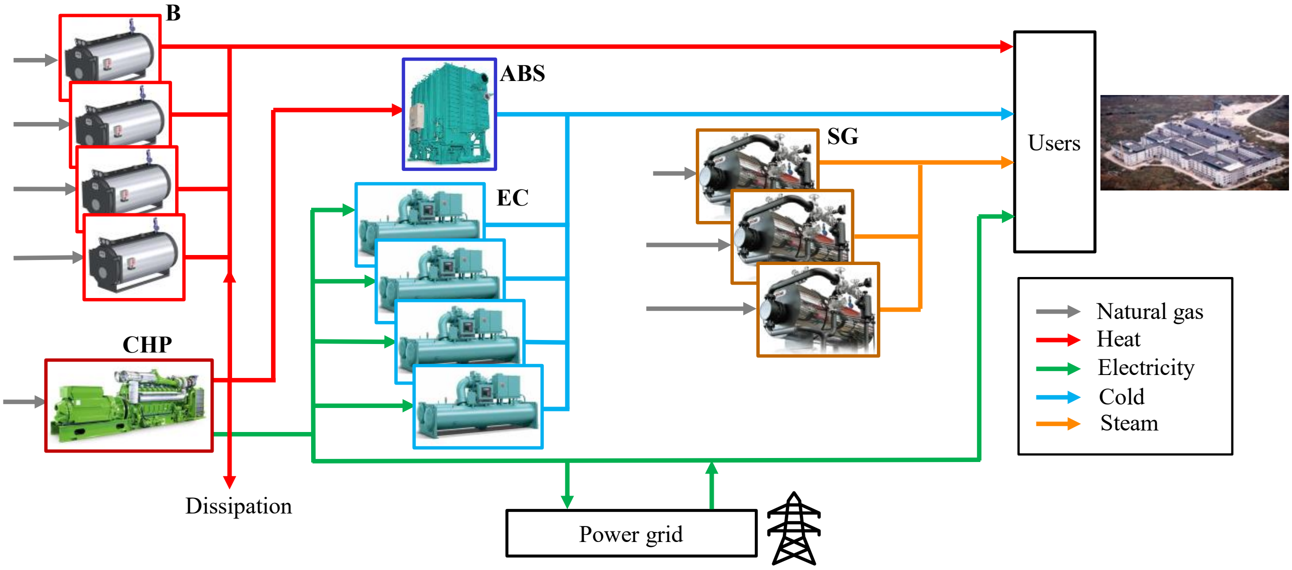

Figure 3. Schematic representation of the thermal power station of the Cona Hospital. B: boilers. CHP: Combined Heat and Power. ABS: absorption chiller. EC: electric chillers. DHC: District Heating and Cooling network.

2.3. Unit characteristics

The analysis of the case study aims to collect relevant information for the subsequent development of (i) a model of the case study and (ii) an optimization algorithm for performing optimal control of the whole system.

Thus, the main characteristics of the units in the thermal power station described above, especially those that can impact the activities of the subsequent WP tasks, were identified. For this purpose, all manufacturers' datasheets were collected and analyzed, and the missing features were deducted after constant communication with the partners.

A further investigation of the scientific literature on optimization of energy systems with several interacting conversion units and energy vectors (also known as multi-energy systems) led to the selection of other potentially relevant operating features of the conversion units.

The deriving list of relevant parameters related to the conversion units in a thermal power station that have to be extracted is reported below:

- Number of units: it represents the number of units of a given type of conversion plant.
- Input energy vector: it represents the form or forms of energy which are inputs to the unit.
- Output energy vector: it represents the form or forms of energy which are outputs from the unit.
- Nominal output (upper boundary of operation): it is the nominal power output (of a given energy vector) of the unit when it operates at full or nominal load, and it can generally be found from the manufacturers' datasheet.
- Nominal efficiency: it is the conversion efficiency from the input power to the output power, when the unit operates at full or nominal load.
- Minimum output (lower boundary of operation): it represents the minimum power output of the unit or, alternatively, the minimum load modulation expressed as a percentage of the nominal power output.
- Minimum efficiency: it is the conversion efficiency from the input power to the output power, when the unit operates at minimum load. The minimum efficiency is often not

specified in the manufacturers' datasheets, nor is the efficiency variation with the load. In some cases, however, the datasheet of a unit reports it in form of a graph or a table. Thus, it is possible to obtain several operating points.

- Ramp boundaries: they represent the maximum increase or decrease in output power (namely upper and lower ramp, respectively) over a given time interval, e.g. time-step of the algorithm.
- Start-up cost: it represents the additional cost in terms of energy input (or fuel input) that needs to be supplied to the unit when there is a start-up.
- Idle cost: it represents the additional cost in terms of energy used (or fuel used) when the plant is in idle (or standby) mode, i.e. the plant is kept in standby. It is for instance assumed that it operates at minimum load but it is not producing useful power.
- Minimum up-time: it represents the minimum time interval for which the plant has to be switched on after a start-up.
- Minimum down-time: it represents a minimum time interval for which the plant has to be switched off after a shut-down.

The main parameters of the thermal power station of the Cona hospital are reported in Table 2. All power values have been normalized with respect to the nominal electrical power output of the cogenerator for the sake of confidentiality.

Table 2. Main parameters of the thermal power station of the Cona Hospital. The plant outputs are normalized with reference to the electrical output of the cogenerator for confidentiality reason.

Parameter	Boiler	Cogenerator	Absorption chiller	Electric chiller	Steam generator
Number of units	4	1	1	4	3
Input	Natural gas	Natural gas	Heat	Electricity	Natural gas
Output	Heat	Electricity | Heat	Cold	Cold	Heat for steam
Nominal output [-]	2.6	1 | 0.93	0.52	1.6	1.3
Nominal efficiency [-]	0.92	0.447 | 0.422	0.77	2	0.87
Min modulation [%]	5	50	20	5	5
Max operating hours [h]	-	8400	8400	-	-

2.4. Thermal power station control

As for system management, a centralized Building Management System (BMS) automatically monitors and controls the plants in the thermal power station as well as the networks for distribution of hot and cold water and the heating systems in the buildings. It is possible to dinamically modify the set-points of the BMS in order to actuate an optimal control logic calculated by an external optimization algorithm, which is the scope of this WP.

Within WP3, a new computer with a touch panel and a resilient power supply unit is installed as an external system within the thermal power station, next to the control panel of the cogenerator. The system BMS is able to exchange data with this computer via the Modbus TPC communication protocol.

After the commissioning phase, this computer is able to run the optimization algorithm (expected from T2.3) and to implement the optimization results as new set-points for the thermal power station. In this way, it may be controlled in an optimal way according to the forecast of boundary conditions and disturbances such as energy demand, electricity price and contractual constraints.

The most important set-points that can currently be controlled directly by the new computer are listed in Table 3. The remaining variables are controlled in cascade based on standard methods. For instance, the electric chillers are activated if the supply temperature of the cooling circuit is higher than the set-point indicated in Section 2.2. Similarly, the steam generators are activated based on the actual steam request.

Table 3. Set-points of the thermal power station that can be directly controlled by the new computer installed within the project.

Set-point	Unit	Notes
Number of active boilers	-	
Activation of cogenerator	-	0 if the cogenerator is off, 1 otherwise.
Load modulation of cogenerator	%	It is a percentage comprised between minimum load modulation and 100%.
Activation of absorption chiller	-	0 if the absorption chiller is off, 1 otherwise.

3. Requirements

Based on the analysis of the site selected as small DHC case study and on the investigation of the thermal power station composition, it is possible to draw the requirements for the subsequent tasks of the WP, in particular the characteristics and data that shall be collected for detailed system modeling and optimization algorithm development. It has to be remarked that the following requirements may be valid not only for the present case, but also for generic multi-energy systems supplying small-scale thermal networks.

The list of the parameters and features that shall be collected about each conversion unit in the thermal power station is summarized in Table 4. The detailed description can be found in Section 2.3. The features are labelled as “required” if they are necessary for the optimization algorithm setup, while they are “recommended” if their availability improves the algorithm accuracy but is not strictly necessary.

In parallel to the aforementioned fixed parameters, the other required data are the external disturbances. Since the algorithm for optimal control solves an optimization problem over a time horizon in the near future, in order to calculate the sequence of optimal control actions that shall be used to manage the system, the disturbances have to be forecast for the entire prediction horizon in the future. In the case of the thermal power station supplying a small DHC, typical disturbances are outdoor conditions, energy demands of all energy vectors, and the prices of electricity. They are reported in Table 5.

Table 4. Required and recommended features regarding each energy conversion unit in the thermal power station.

Feature	Unit	Required/Recommended
Number of units	-	Required
Nominal input power	[kW]	Required
Minimum input power	[kW]	Required
Nominal efficiency	-	Required
Minimum efficiency	-	Recommended
Ramp up	[kW]	Recommended
Ramp down	[kW]	Recommended
Start-up cost	[kJ] or [kg]	Recommended
Idle cost	[kJ] or [kg]	Recommended
Minimum up-time	[s] or [h]	Recommended
Minimum down-time	[s] or [h]	Recommended

Table 5. Required disturbances for the development of the optimization algorithm.

Disturbance	Unit	Required/Recommended
Thermal power demand	[kW]	Required
Cooling power demand	[kW]	Required
Electrical power demand	[kW]	Required
Steam demand	[kW]	Required
Outdoor temperature	[°C]	Required
Cost of electricity sold to the grid	[EUR/kWh]	Required
Cost of electricity bought from the grid	[EUR/kWh]	Required
Cost of fuel	[EUR/kg]	Required

As for control of the distribution network sections and the supplied buildings, the method developed and validated in (Saletti et al., 2020) and (De Lorenzi et al., 2020) is used. All details and requirements are reported in the related publications.

4. Conclusions

In this report, the activities of the first task of WP2 are reported. The small-scale district heating and cooling networks case study was identified in T3.1, led by the industrial partner Siram Veolia, as the Sant'Anna Hospital of Cona, near Ferrara, Italy. The hospital is composed of a heating loop and a cooling loop, supplying thermal power to the substations of the hospital buildings, and a thermal power station where heating, cooling, electrical power and a steam flow rate are produced.

All units in the thermal power station plants were identified, and their relevant properties were collected starting from the datasheet and communication with the utility technicians. Additional properties, potentially useful for a better accuracy of an optimal control algorithm, were identified from the literature on the topic.

The output of the task is a list of required and recommended features related to the energy conversion units of a small-scale district heating and cooling network, as well as a list of required disturbances that shall be forecast in order to obtain a suitable optimization algorithm for its optimal management. The identified features will be used in the subsequent tasks of the WP, which are T2.2 (development of a detailed model of the case study) and T2.3 (development of an optimization algorithm with a double time scale for the case study).

List of references

De Lorenzi, A., Gambarotta, A., Morini, M., Rossi, M., Saletti, C., 2020. Setup and testing of smart controllers for small-scale district heating networks: An integrated framework. *Energy*, 205, p.118054. https://doi.org/10.1016/j.energy.2020.118054

Saletti, C., Gambarotta, A. and Morini, M., 2020. Development, analysis and application of a predictive controller to a small-scale district heating system. *Applied Thermal Engineering*, *165*, p.114558. https://doi.org/10.1016/j.applthermaleng.2019.114558