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|  | Project Acronym: CELSIUS                                                  |
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|                                                                                   | Project duration: 48 months                                               |

## D 4.3

# Progress and achievements on each demonstrator and analysis of causes for deviation

|                     |                                                                         |
|---------------------|-------------------------------------------------------------------------|
| Submission date     | Task leader                                                             |
| 30-04-2017          | DAPP                                                                    |
| Dissemination Level | Prepared by:                                                            |
| Confidential        | DAPP in collaboration with RETI, WARM, GOTE, RHEI, COLU, LBOI, UKPN, SP |

### Revision History

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## Impact in Celsius

The present deliverable has been developed in the framework of Work Package 4 which aims at identifying methodologies and protocols to be used for measurements, monitoring and evaluation of the demonstrators included in the framework of the Celsius project. Monitoring activities are related to:

- the assessment of progress towards the development of new demonstrators;
- the evaluation of performance and impacts for:
  - new demonstrators in operation;
  - already existing demos which have not been realized in the framework of the Celsius project, but that are relevant to be analysed in order to widen the learning from different technological solutions implemented in the involved cities

In addition information about the collaboration established between the CELSIUS project and the Smart Cities Information System project (SCIS project - <http://smartcities-infosystem.eu/>) are included.

*How does this knowledge/information help a city implementing and/or optimizing smart district heating and cooling?*

The present deliverable is aimed at providing possible replication cities with useful information about the realization process of one particular technology and with indications and estimations of possible impacts deriving from the choice of one technology rather than a different one.

Specifically, qualitative information in terms of lesson learnt from the realization process of the new Celsius demonstrators is reported together with quantitative information in terms of key performance indicators for assessing the performance of demonstrators in operation.

*How is this knowledge/information best communicated to a city implementing and/or optimizing smart district heating and cooling?*

Being the information included in this deliverable confidential, the best way to communicate them to potential interested cities is to show them the "Demonstrators" webpages included in the CELSIUS toolbox. As a matter of fact, the content of those webpages is built on information (agreed with demonstrators responsible) included in the present deliverable, as further explained in the following paragraph.

*How does this knowledge/information interact with other deliverables and actions in Celsius?*

Since the information included in this deliverable is "living", periodical submissions for present deliverable have been scheduled (submission frequency: six months) providing a continuous update and integration with new data and evaluations. Thus, the previous submission of D4.3 [1] should be taken as a reference for the present deliverable.

Furthermore, the information presented is relevant for the purposes of the CELSIUS roadmap developed in the framework of WP2 and of the toolbox developed in WP5.

Specifically, both qualitative and quantitative information have been included (and will be periodically updated until project closure) on the CELSIUS toolbox webpages dedicated to demonstrators, where the following sub-sections are included:

- "Replication matrix": combining together information on replicability requirements and performance of each demonstrator
- "Lesson learnt" during each new demonstrators realization process
- "Demonstrators Monitoring"

The deliverables provides useful insights on either the realization process and operation of the CELSIUS demonstrators clearly showing the feasibility of such technologies providing practical evidences during the realization and operation and thus facilitating their replication in different European urban frameworks.

## 1. Introduction

*The present deliverable represents the update of the previously submitted deliverable D4.3 (M43). Additional information has been included with regards to the following demonstrators based on the new set of data collected: GO1, GO2, GO3, GO4, CO1-SET1 and RO1. Further to that data from already existing demonstrators in Gothenburg and Rotterdam have been collected and included with regard to 2GOe, 19GOe, 15ROe, 32ROe and 33ROe.*

The present deliverable has been developed in the framework of Work Package 4 which aims at identifying methodologies and protocols to be used for measurements, monitoring and evaluation of the demonstrators included in the framework of the Celsius project. Monitoring activities are related to:

- The assessment of progress towards the development of new demonstrators;
- The evaluation of performance and impacts for:
  - New demonstrators in operation;
  - Already existing demos which have not been realized in the framework of the Celsius project, but that are relevant to be analysed in order to widen the learning from different technological solutions implemented in the involved cities.

In light of this, the present deliverable is aimed at providing possible replication cities with useful information about the realization process of one particular technology and with indications and estimations of possible impacts deriving from the choice of one technology rather than a different one.

Since the information included in this deliverable is “living”, periodical submissions for present deliverable have been scheduled (submission frequency: six months) providing a continuous update and integration with new data and evaluations. Thus, the previous submission of D4.3 [1] should be taken as a reference for the present deliverable.

The present document can be split into two different sections:

- The first qualitative section (Chapter 3) describes the progress in the realization process of new demonstrators, highlighting main achievements, main conclusions, possible lesson learnt and foreseen next steps (GE1, GO1, GO2, GO3, GO4, CO1-SET1, CO1-SET2, LO1, LO2, LO3, RO1, RO2, RO3, RO4);
- The second section (Chapter 4) includes quantitative information related to monitored data and key performance indicators calculated for those demonstrators already in operation (6COe, 7GOe, 8GOe, 9GOe, 29GOe, 36GOe, 20GOe, 11GOe, 2GOe, 19GOe, 15ROe, 32ROe, 33ROe, 16ROe, GO1, GO2, GO3, GO4, RO1, CO1-SET1, LO1).

Monitoring protocols followed and data considered are in accordance to the parameters and KPIs respectively defined in deliverable D4.2 [2] and D4.1 [3]. Data analysis related both to new demonstrators and already existing demonstrators are included.

An additional chapter (Chapter 5) has been dedicated to the analysis of the replication potential of some of the CELSIUS technologies. Further analyses will be included in the final version of the present deliverable.

In addition Chapter 6 includes information about the established collaboration between the CELSIUS project and the Smart Cities Information System project (SCIS project - <http://smartcities-infosystem.eu/>).

Finally conclusions are reported in Chapter 6.

*KPI calculations have been adapted to the current status of data availability at demo sites. In some cases, indicators presented in D4.1 have been slightly modified according to the system operation as well as to data availability. Updated calculations will be included in the final versions of current deliverable, foreseen at M57.*

## **2. List of Abbreviations & Acronyms**

In the following list, abbreviations and acronyms used throughout the deliverable are presented.

CHP: Combined Heat and Power

COP: Coefficient of Performance

DC: District Cooling

DH: District Heating

DHN: District Heating Network

E: Emission Factor

KPI: Key Performance Indicator

NG: Natural Gas

PEF: Primary Energy Factor

SCIS: Smart Cities Information Systems project

SPF: Seasonal Performance Factor

### 3. Monitoring of progress in the design and realization of the demonstrators

Monitoring of progress in design and realization of the new Celsius demonstrators has been carried out in accordance to the protocols presented in the previous submission of D4.3 [1]. In particular, following the settled rules, the specific template was periodically sent to demo responsible partners in order to collect information on the demos' advancement status. Telephone interviews have been performed for deepening the understanding of specific issues. The aim of such interviews has been to identify possible bottlenecks/barriers, sharing with demo responsible partners strategies for overcoming them.

A graphical summary of the information collected is presented in figure below while in the following sections tables summarizing main achievements, conclusions, possible lessons learnt and foreseen next steps are presented. Each section is structured as a storyboard, thus the information collected by means of the previous monitoring sessions are included as well to keep track of the whole realization process of one demonstrator.

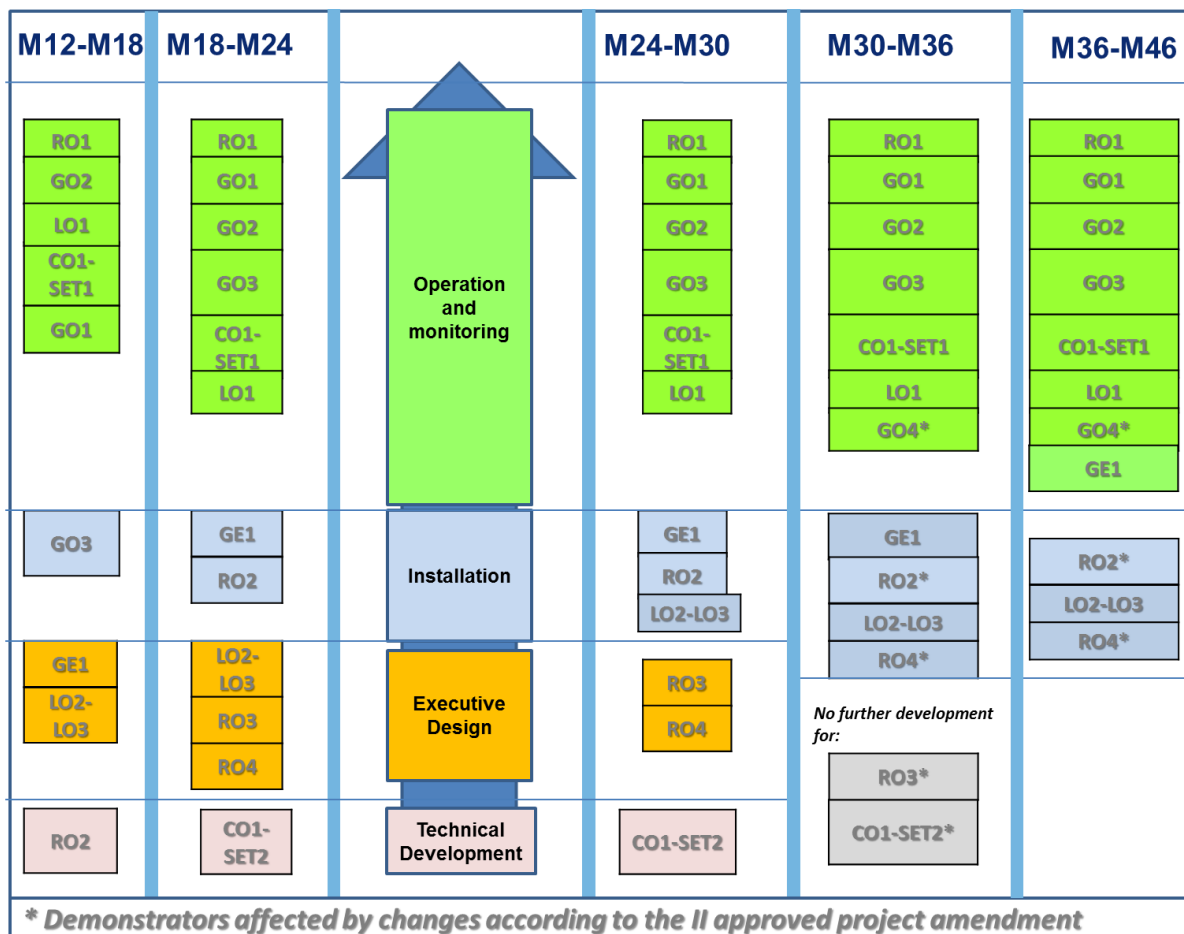


Figure 1: New demonstrators- Status at M46

### 3.1.1 Genoa demonstrator GE1-“Energy recovery from the natural gas distribution network”

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M43-M46)</b>                                                                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | All installation finalized; Testing of the two main systems components, namely the turbo-expander and the CHP, has been successfully performed in December 2016 at the presence of systems' suppliers. In addition, IRETI got the fire prevention certificate and the required authorization from the electric utility while they are still waiting for the inspections from the customs agency. |
| <b>Main conclusions</b>           | Start up at end of January/begin of February 2017                                                                                                                                                                                                                                                                                                                                                |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | Analysis of demonstrator's performance on the basis of monitored data from February 2017.                                                                                                                                                                                                                                                                                                        |
| <b>Progress monitoring period</b> | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          | Turbo-expander machine installed                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Main conclusions</b>           | All installations are completed. Demonstrators' start up in Nov 2016 followed by a testing period at low gas flow rate; Dec 2016: full operation.                                                                                                                                                                                                                                                |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | Analysis of demonstrator's performance on the basis of monitored data from Jan. 2017.                                                                                                                                                                                                                                                                                                            |
| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                                                                                                                                                                                                                                                                        |
| <b>Main achievements</b>          | Ongoing activities to finalize all the works on site and to assembly all the auxiliary components of the turbo-expander machine; delays in turbo expander delivery.                                                                                                                                                                                                                              |
| <b>Main conclusions</b>           | Demonstrator start-up will be delayed due to unexpected critical issues occurred with the EPC contractor responsible for procuring the TE machine.                                                                                                                                                                                                                                               |
| <b>Lessons learnt</b>             | The TE is not a standard machine, due to the innovative character of the equipment. Thus, it is important to take into account that extra time might be needed to customize the equipment according to the needs.                                                                                                                                                                                |
| <b>Next steps</b>                 | TE installation; demo start up and trial test during Q3-2015; full operation from Q4-2015.                                                                                                                                                                                                                                                                                                       |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          | Authorization process accomplished.<br>Finalization of the civil works for area preparation<br>CHP generator installed                                                                                                                                                                                                                                                                           |
| <b>Main conclusions</b>           | Permitting and area preparation phases have been finalized                                                                                                                                                                                                                                                                                                                                       |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | Turbo expander procurement within November-December 2015.<br>Demo start up within the end of the year 2015. Full demo operation from Q1-2016.                                                                                                                                                                                                                                                    |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | Authorization procedure ongoing<br>Start date for civil works for area preparation is April 2015.                                                                                                                                                                                                                                                                              |
| <b>Main conclusions</b>           | The realization process of the demo is on-time                                                                                                                                                                                                                                                                                                                                 |
| <b>Lessons learnt</b>             | Problems in managing communication with EPC contractor, physically located outside Genoa area, had an impact on timeline of the scheduled detailed engineering activities.<br>The implementation of dedicated templates for collecting info from the EPC contractor would have made more efficient the process of exchanging info and to use them in the framework of CELSIUS. |
| <b>Next steps</b>                 | Turbo expander procurement within Q2-2015.<br>Demo start up and functional tests in September 2015 (Q3-2015). Demo operation in standard conditions from November 2015 on.                                                                                                                                                                                                     |

|                                   |                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | Detailed design for Genoa's Demonstrator has been accomplished by the end of July 2013<br>Supplier identification (i.e. EPC contractor) accomplished: administrative procedures have been finalized and the contract with the identified supplier has been signed.<br>Achievement of fire prevention preliminary certificate |
| <b>Main conclusions</b>           | Procurement phase has been finalized<br>Identification of the EPC contractor                                                                                                                                                                                                                                                 |
| <b>Lessons learnt</b>             | Including some preliminary activities (pre-authorization phase and investigations for civil works for preparing the area) in the business plan defined as an outcome of the feasibility phase.                                                                                                                               |
| <b>Next steps</b>                 | Civil works required for area preparation by Q1-2015, under RETI responsibility<br>Civil works for turbo-expander installation by Q1-2015, under EPC contractor responsibility<br>Application for authorizations related to upcoming civil works                                                                             |

### **3.1.2 Gothenburg demonstrator GO1-“Short term storage”**

|                                   |                                                                                                                                                                                  |
|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M43-M46)</b>                                                                                                                                     |
| <b>Main achievements</b>          | Installation phase finalized in 12 buildings. 4 buildings are currently monitored.                                                                                               |
| <b>Main conclusions</b>           | The total number (17) of buildings provided with GO1 technology stated in the DoW will difficulty be reached at project closure.                                                 |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                |
| <b>Next steps</b>                 | GOTE will collect and share information and data from the project Angered in February 2017. DAPP will analyze this data and possibly include them in the release of D4.3 at M49. |

|                                   |                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | In operation in 12 buildings                                                                                                                                                                                                                                                                                                                 |
| <b>Main conclusions</b>           | The total number (17) of buildings provided with GO1 technology stated in the DoW will difficulty be reached at project closure.                                                                                                                                                                                                             |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                            |
| <b>Next steps</b>                 | The reduced amount of monitored data could be overcome by using additional information coming from a similar project (under GOTE responsibility), running in Angered (Sweden), where the same technology has been implemented by GOTE                                                                                                        |
| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          | Installations of the short term storage technology are finalized for 6 additional buildings. Total no. of buildings involved 12. Tests during the winter season have been carried out on 4 buildings.                                                                                                                                        |
| <b>Main conclusions</b>           | Demonstrator's performance has been preliminarily and positively assessed. No effect on end-users (i.e. changes in indoor temperature) has been recorded. Effects on peak shaving at energy production facilities still to be demonstrated as more buildings are required.                                                                   |
| <b>Lessons learnt</b>             | Need for developing proper business models for attracting buildings' owners                                                                                                                                                                                                                                                                  |
| <b>Next steps</b>                 | To keep on assessing demonstrator performance in view of next winter season<br>To continue the definition of proper business models for buildings owners willing to adopt GO1 technology.<br>To continue with the procedures for signing new contract and involve more buildings, maximizing the impact of GO1 technology                    |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | Installation of the short term storage technology is currently ongoing for 6 additional buildings. Total no. of buildings involved 12.                                                                                                                                                                                                       |
| <b>Main conclusions</b>           | The process of recruitment of new buildings to install GO1 technology is ongoing and with better results with respect to the previous monitoring period                                                                                                                                                                                      |
| <b>Lessons learnt</b>             | Need for developing proper business models                                                                                                                                                                                                                                                                                                   |
| <b>Next steps</b>                 | To fully run the demonstrator during the winter season 2015/2016 in the 12 involved buildings.<br>To continue the definition of proper business models for buildings owners willing to adopt GO1 technology.<br>To continue with the procedures for signing new contract and involve more buildings, maximizing the impact of GO1 technology |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                   |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Main achievements</b>          | Short term storage technology has been applied to 5 buildings. Testing activities have been carried out during January and February 2015 (6 days of trial).                                                                                                                                                                                                                                                                      |
| <b>Main conclusions</b>           | Testing and operation for the present demonstrator have been subjected to delay (approximately 1 year). Unexpected climate conditions (i.e. winter warmer than average condition) have thwarted so far the proper test and start-up of the demonstrator.                                                                                                                                                                         |
| <b>Lessons learnt</b>             | Need for developing proper business models<br>The procedure for signing contracts with tenants for the other buildings is longer than expected because buildings owners seem not be really interested in adopting that technology since they are getting no real benefit from it.                                                                                                                                                |
| <b>Next steps</b>                 | GOTE has found an agreement to use 1 building from STENA companies' for installing short term storage technology. If no problems occurs with this first installation, other buildings will be offered and used (60/70 buildings).                                                                                                                                                                                                |
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          | Testing phase (on radiator system and remote control) finalized in 5/17 buildings, start up in October 2014. Ongoing procedure for contract signature for 2 additional buildings                                                                                                                                                                                                                                                 |
| <b>Main conclusions</b>           | The implementation of the corrective measures is running as scheduled                                                                                                                                                                                                                                                                                                                                                            |
| <b>Lessons learnt</b>             | There is the need for implementing and adopting a different business model, which should foresee direct economic benefits also for the building owners, beyond the energy company. One possible proposal at this purpose could be the possibility to stipulate energy agreements between the energy company and the construction company for the costs that the construction company has to sustain for works necessary for GO1. |
| <b>Next steps</b>                 | 1. By November 2014 an additional building will be ready (i.e. all the required installations completed) for the following operation and monitoring phase;<br>2. By the end of 2014, 2 more contracts will be signed between GOTE and the construction company;<br>3. GOTE will provide more detailed information with regards to finalization of the contracts signature for the upcoming year.                                 |

### **3.1.3 Gothenburg demonstrator GO2-“District heating to white goods”**

|                                   |                                                                                                                                                                                                                     |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M42-M46)</b>                                                                                                                                                                        |
| <b>Main achievements</b>          | 45 washing machines have been rebuild to solve critical issue related to the operation of the machine pump (cause of breakdown: obstructions and blockages). Those 45 replaced machines are currently in operation. |
| <b>Main conclusions</b>           | 214 machines are currently in operation.                                                                                                                                                                            |
| <b>Lessons learnt</b>             | The new machines are provided with a filter at the pump to prevent obstructions.                                                                                                                                    |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   | In addition, customers will be provided with guidelines and detailed instructions for the correct use of the machines.                                                                                                                                                                                                                                                                                                       |
| <b>Next steps</b>                 | Continue monitoring and assessing demonstrator performance                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Progress monitoring period</b> | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | In operation                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Main conclusions</b>           | 223 machines fully operating                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <b>Next steps</b>                 | To further assess demonstrators performance by progressively collecting monitored parameters and calculating KPI                                                                                                                                                                                                                                                                                                             |
| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          | All the machines have been installed<br>10: monitored since July 2014<br>43: replaced for malfunctioning<br>171: monitored data are expected within Q3-2016                                                                                                                                                                                                                                                                  |
| <b>Main conclusions</b>           | Once replaced the malfunctioning machines, the demonstrator will fully achieve its target in terms of installed machines                                                                                                                                                                                                                                                                                                     |
| <b>Lessons learnt</b>             | Malfunctioning at the machine pump highlighted the need of optimizing machine's design by including filters to prevent obstructions and blockages                                                                                                                                                                                                                                                                            |
| <b>Next steps</b>                 | To collect monitored data from all machines in operation<br>To keep in assessing demonstrator operation to detect any malfunctioning and to clearly show its environmental benefits                                                                                                                                                                                                                                          |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | All the machines have been installed and are in operation<br>10/214: monitored since July 2014<br>204/214: monitored data are expected within Q4-2015                                                                                                                                                                                                                                                                        |
| <b>Main conclusions</b>           | All the machines are running and are ready for the monitoring phase                                                                                                                                                                                                                                                                                                                                                          |
| <b>Lessons learnt</b>             | The behaviour of end users has been closely monitored and one finding is that electricity price is greatly influencing the usage of the demo. As a matter of fact when tariffs for heat from DHN exceed electricity price, end-users have no economic benefits and their preferences are oriented towards the traditional usage of the machines (i.e. electrically driven) neutralizing machines' environmental performance. |
| <b>Next steps</b>                 | To start collecting monitored parameters from the installed machines in order to get the overall picture of the demonstrators impact                                                                                                                                                                                                                                                                                         |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Main achievements</b>          | All the machines have been sold (total no.220)<br><i>The total no. is different from the figure reported in the Technical Annex, 300, since installation costs are actually higher in comparison to estimations foreseen at early project phase, 2011</i>                                                                                                                                                                    |
| <b>Main conclusions</b>           | The realization process is under finalization.                                                                                                                                                                                                                                                                                                                                                                               |
| <b>Lessons learnt</b>             | The most important lesson learnt is related to the identification                                                                                                                                                                                                                                                                                                                                                            |

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|                   | <p>of suitable location for machines installation. As a matter of fact, laundry rooms located at a distance not bigger than 5 m for the DH network are perfectly suitable, while if distances are bigger the installation costs for customers are too high.</p> <p>Currently GOTE is analysing how to reduce/avoid taxation of high water return temperatures to DH network (in order to guarantee the machine wash at 90°C, <math>T_{inlet}</math> is about 80°C and consequently <math>T_{out}</math> is about of 60°).</p> |
| <b>Next steps</b> | Finalization of the installation of 210 machines within Q2-2015 so that to allow start up and monitoring activities for assessing demo performance in terms of KPIs.                                                                                                                                                                                                                                                                                                                                                          |

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| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                 |
| <b>Main achievements</b>          | 18/300 washing machines sold<br>10/300 are currently in operation and monitored since June 2014             |
| <b>Main conclusions</b>           | The sales process took longer than expected                                                                 |
| <b>Lessons learnt</b>             | To hire a dedicated marketing expert fully involved in order to boost machine selling                       |
| <b>Next steps</b>                 | To continue machines sales and to assess demonstrator performance for the ten machines already in operation |

### 3.1.4 Gothenburg demonstrator GO3-“District heating to ships”

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| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M43-M46)</b>                                                                                                                                                |
| <b>Main achievements</b>          | Finalization of all reparations after the accidental collision (December 2015) between the ship and the quay: Monitored parameters have been provided for the period October-December 2016. |
| <b>Main conclusions</b>           | The demonstrator is regularly in operation                                                                                                                                                  |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                           |
| <b>Next steps</b>                 | Continue monitoring and assessing demonstrator performance                                                                                                                                  |

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| <b>Progress monitoring period</b> | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                 |
| <b>Main achievements</b>          | The demonstrator operation was stopped in the period Jan 2016 – Sep 2016 for reparation at quay as a consequence of an accidental collision between the ship and the quay that damaged the connection point to the district heating network |
| <b>Main conclusions</b>           | Reparations have been finalized. Fully operation expected from Oct 2016                                                                                                                                                                     |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                           |
| <b>Next steps</b>                 | To further assess demonstrator’s performance by progressively collecting monitored parameters and calculating KPI                                                                                                                           |

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| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                          |
| <b>Main achievements</b>          | In operation since December 2014;<br>Operation stop from December 2015 to March 2016 for an occurred ship accident |

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| <b>Main conclusions</b>           | Despite operation has stopped in the last months, demonstrator operation during 2015 has been positively assessed                                                                                                                                                                                                              |
| <b>Lessons learnt</b>             | Reductions in both noise and air pollution are relevant impact for people living nearby harbor area                                                                                                                                                                                                                            |
| <b>Next steps</b>                 | To start up demonstrator again and keep on monitoring its performance to clearly show the related impact.<br>To collaborate with STENA company in order to have GO3 technology installed on a second ship in Gothenburg harbor<br>To collaborate with Copenhagen (New Celsius cities) to replicate the demonstrator in Denmark |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          | The demonstrator is currently in operation                                                                                                                                                                                                                                                                                     |
| <b>Main conclusions</b>           | The impact in terms of noise and pollution reduction in the area nearby the STENA ship quay has been notified by people living in the area                                                                                                                                                                                     |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | Demo start-up in December 2014.                                                                                                                                                                                                                                                                                                |
| <b>Main conclusions</b>           | The demonstrator is ready for the monitoring and evaluation phase                                                                                                                                                                                                                                                              |
| <b>Lessons learnt</b>             | Costs were higher than expected for additional activities related to area preparation at quay. A more detailed feasibility phase should have been carried out.                                                                                                                                                                 |
| <b>Next steps</b>                 | Demonstrator performance assessment in terms of KPIs (in the following section of the present deliverable some of the monitored parameters during the period Jan-Mar 2015 are presented).                                                                                                                                      |
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          | Installation phase finalized both on the ship and at quay side                                                                                                                                                                                                                                                                 |
| <b>Main conclusions</b>           | The demonstrator is ready to start-up                                                                                                                                                                                                                                                                                          |
| <b>Lessons learnt</b>             | In order to guarantee the maximum flexibility all the equipment for connecting the ship to the DHN have been placed in a movable container                                                                                                                                                                                     |
| <b>Next steps</b>                 | 1. Demo start-up at November 2014;<br>2. To provide next monitored data to DAPP in February 2015.                                                                                                                                                                                                                              |

### **3.1.5 Gothenburg demonstrator GO4-“River cooling”**

*The “river cooling” demonstrator has been included among the CELSIUS demonstrators, as a consequence of the occurred deviations at some demonstrators (in Cologne and Rotterdam) in 2015. This change has been included in the second approved project amendment.*

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| <b>Progress monitoring period</b> | <b>April 2016- January 2017 (M36-M46)</b>                                                            |
| <b>Main achievements</b>          | In operation                                                                                         |
| <b>Main conclusions</b>           | The demonstrator is currently monitored. Monitored parameters have been provided for the whole 2016. |

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| <b>Lessons learnt</b> | -                                                          |
| <b>Next steps</b>     | Continue monitoring and assessing demonstrator performance |

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| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                         |
| <b>Main achievements</b>          | The demonstrator system has been successfully enhanced by installing additional heat exchangers, thus increasing the plant free cooling capacity. |
| <b>Main conclusions</b>           | The enhanced demonstrator is in operation and under monitoring activities since January 2016.                                                     |
| <b>Lessons learnt</b>             | Not applicable                                                                                                                                    |
| <b>Next steps</b>                 | To collect data set of monitored parameters to enable full evaluation of demonstrator's performance                                               |

### 3.1.6 Cologne demonstrator CO1-SET1-“Heat recovery from sewage water”

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| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M42-M46)</b>                                                                                                                                                                                                                                                                                                                        |
| <b>Main achievements</b>          | <ol style="list-style-type: none"> <li>1. Wahn site: running and monitored since October 2013</li> <li>2. Mülheim site: running and monitored since November 2014</li> <li>3. Nippes site: start up in Feb 2015 but so far no controlled operation because of problems with the sewage pump and the evaporator. RHEI is currently working to solve them.</li> </ol> |
| <b>Main conclusions</b>           | -                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Next steps</b>                 | Continue monitoring and assessing performance of Wahn and Mulheim site; Monitor closely reparations and improvements at Nippes site                                                                                                                                                                                                                                 |

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| <b>Progress monitoring period</b> | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Main achievements</b>          | <p><b>Wahn:</b> The demonstrator is running without failures or setbacks. Since the upgrade in the control system in summer 2015, the demonstrator is running efficiently.</p> <p><b>Mülheim Status:</b> the problem in the sewage heat exchanger was solved in February 2016, since then the heat pump has been operating without problems.</p> <p><b>Nippes:</b> After replacing the cleaning technology in the demonstrator, it is expected that the demonstrator can run without problems in October 2016.</p> |
| <b>Main conclusions</b>           | The demonstrator is fully operated in all the three sites                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Next steps</b>                 | To keep on monitoring demonstrators at Wahn and Mulheim site and to start collecting monitoring data from Nippes site                                                                                                                                                                                                                                                                                                                                                                                              |

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| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                                                               |
| <b>Main achievements</b>          | <b>Porz-Wahn</b> is in the monitoring and evaluation phase; data set are provided regularly; Mulheim demonstrator operation has been stopped in December 2015 (and restored in February |

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|                                   | 2016) as a consequence of a leak at the heat exchanger; ongoing activities to optimize demonstrator's operation in Nippes site                                                                                                                                                                                                                  |
| <b>Main conclusions</b>           | The demonstrator full operation for all three sites is expected for winter season 2016/2017.                                                                                                                                                                                                                                                    |
| <b>Lessons learnt</b>             | <ul style="list-style-type: none"> <li>• The permission process for sewage maintenance works has to be simplified.</li> <li>• The coordination with other parallel maintenance works in case of incidents has to be improved</li> </ul>                                                                                                         |
| <b>Next steps</b>                 | To keep on monitoring demonstrators performance to clearly show the related impact.                                                                                                                                                                                                                                                             |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | The demonstration is currently in operation in all the three sites. The systems were started up in different times.<br>Porz-Wahn site: October 2013;<br>Mulheim site: November 2014;<br>Nippes site: February 2015.                                                                                                                             |
| <b>Main conclusions</b>           | The realization process for all three sites has been finalized.                                                                                                                                                                                                                                                                                 |
| <b>Lessons learnt</b>             | <i>Not applicable</i>                                                                                                                                                                                                                                                                                                                           |
| <b>Next steps</b>                 | To optimize the operation of the demonstrator at the Nippes site                                                                                                                                                                                                                                                                                |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          | The demonstration is currently in operation in all the three sites. The systems were started up in different times.<br>Porz-Wahn site: October 2013;<br>Mulheim site: November 2014;<br>Nippes site: February 2015.                                                                                                                             |
| <b>Main conclusions</b>           | The realization process for all three sites has been finalized.                                                                                                                                                                                                                                                                                 |
| <b>Lessons learnt</b>             | At Nippes site, the modification of the original system layout led to a time delay, as some extra permission(s) had to be complied. It has to be taken into consideration, especially when it's the first time for the appropriate authority to approve the modification(s) in the sewage system that the permission process could take longer. |
| <b>Next steps</b>                 | Demonstrator performance assessment in terms of KPIs for all three sites (in the following section KPI calculation for Porz-Wahn site for which a larger amount of monitored data are available).                                                                                                                                               |
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | The demo is in operation at Muelheim and Porz-Wahn sites. Monitored data are available since March 2014 for Porz-Wahn site. At Nippes sites, the installation phase is finalized.                                                                                                                                                               |
| <b>Main conclusions</b>           | The corrective measure is partially revealing successful, with only 2 quarters delay with respect to its original implementation plan                                                                                                                                                                                                           |
| <b>Lessons learnt</b>             | In the early project stages it is advisable to better consider the formal aspects and the delivery times. Moreover, it is important to work on the build-up of a network of well-informed and                                                                                                                                                   |

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| <b>Next steps</b> | <p>trained group of partners and participant partners.</p> <ol style="list-style-type: none"> <li>1. To complete, by the end of September 2014, the power supply for the evaporators and the pumps in the detention reservoir to transport the sewage to the boiler room, in order to start-up the Nippes site at the beginning of October 2014;</li> <li>2. To start metering at Nippes and Mulheim sites in October;</li> <li>3. To make available to D'Appolonia the first monitored data on Nippes site in November 2014</li> </ol> |
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### 3.1.7 Cologne demonstrator CO1-SET2-“Heat recovery from sewage water-residential buildings and industrial offices”

*The CO1-SET2 demonstrator will not be further developed within CELSIUS project as a consequence of the occurred deviations in 2015. This change has been included in the second approved project amendment.*

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| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Main achievements</b>          | Failure of the negotiation between RHEI and customers to provide additional buildings to provide with CO1-SET1 technology                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Main conclusions</b>           | RHEI, being responsible of Cologne demonstrators, is currently working on the development of a contingency plan                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Lessons learnt</b>             | <i>Not applicable</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Next steps</b>                 | <p>The contingency plan foreseen by RHEI is to re-allocate the budget resulting from the withdrawn of CO1-SET2 demo to set up activities for:</p> <ul style="list-style-type: none"> <li>• Optimizing the operation conditions of the demonstrator CO1-SET1 at Nippes site;</li> <li>• Deploying Smart Home Packages in residential buildings that can empower customers to improve their energy efficiency through access to information on energy usage and billing (e.g., smart metering and demand-side management).</li> </ul> <p>Those corrective measures are described in details in the new and updated version of deliverable D4.4 (dedicated to corrective measures presentation) to be submitted and approved by Steering Committee during the next meeting in London (M32, November 2015).</p> |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | Ongoing feasibility study.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Main conclusions</b>           | <p>In the framework of Cologne demonstrator, a second part (CO1-SET2) is foreseen with the intention to produce heat from sewage network and deliver it to different types of buildings rather than schools (e.g., residential office buildings and shops). Currently the feasibility study for CO1-SET2 is under evaluation and other options/technologies are being considered in order to further increase the impact of the Celsius project.</p>                                                                                                                                                                                                                                                                                                                                                        |
| <b>Lessons learnt</b>             | <i>Not applicable</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Next steps</b>                 | <i>Not applicable</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

### 3.1.8 London demonstrator LO1 “Active network management and Demand Response”

According to CELSIUS Description of Work, LO1 demonstrator achieved its target, thus no further development are foreseen along project duration.

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| <b>Progress monitoring period</b> | <b>September 2014 – March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                  |
| <b>Main achievements</b>          | The demonstrator has run the trial in October 2014 and achieved the expected results within 80% of the expected MW. No further trials are expected.                                                                                                                                                                                                           |
| <b>Main conclusions</b>           | No deviations have been recorded, thus no need for identifying corrective measures.                                                                                                                                                                                                                                                                           |
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                                                   |
| <b>Main achievements</b>          | Operational constraints identified and changes to the CHP control algorithms made.<br>Changes to the thermal store fill up and discharge parameters completed.<br>Installation of the ANM equipment completed.<br>Feasibility study about heat dumping completed.<br>Permitting phase and executive design phase finalized.<br>Further funding sources found. |
| <b>Main conclusions</b>           | The two months delay with respect to the original implementation plan has been overcome by speeding up the trial period. The demo is in operation since the end of September 2014 (i.e. trial week) and monitoring data are being recorded.                                                                                                                   |
| <b>Lessons learnt</b>             | Greater emphasis could have been made to the contractors on the importance and innovative nature of this project in order to enable trials to take place sooner.                                                                                                                                                                                              |
| <b>Next steps</b>                 | To complete trial CHP operation tests by 3 October 2014                                                                                                                                                                                                                                                                                                       |

### 3.1.9 London demonstrator LO2&3-“Capture of identified sources of waste heat and integration of thermal store”&“Extension of the Bunhill seed heating system”

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| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M42-M46)</b>                                                                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          | Ongoing construction                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Main conclusions</b>           | The operation of the demonstrator is foreseen at Q2/Q3-2017. There have been some delays in the construction phase, thus in the operation, as a consequence of the involvement of multiple organizations to manage the complexity of this engineering project                                                                                                                                     |
| <b>Lessons learnt</b>             | LBOI learned a number of lessons from the installation of the pipework. Some of the key ones are detailed below: <ul style="list-style-type: none"> <li>• LBOI did originally look at using 3D surveying but they have learned that traditional 2D surveys give the same information for a considerably lower cost</li> <li>• For district heating contractors in the UK there appears</li> </ul> |

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|                                   |  | <p>to be a bit of a general skills gap and in particular in the area of pipe welding. A lesson learned would be to bear this in mind when tendering.</p> <ul style="list-style-type: none"> <li>• The work associated with installation of district heating pipes is very invasive for surrounding residents and business. Good community/resident engagement and project co-ordination from the contractor is essential.</li> <li>• LBOI contract has exclusion for installation of pipework below 2m. This has resulted in additional cost pressures as a result of having to tunnel below existing services. Realistically contractors won't take on the risk of unknown existing services but efforts should be made at pre-tender stage to establish and highlight, where possible, any existing services.</li> <li>• Pre-stressing pipework before installation is not practical in dense urban environments as it would require all trenches to be open at the same time.</li> <li>• Parking suspensions and road closure permits are required for DH pipe installation work. The cost of this can add-up and should be allowed for.</li> <li>• Road and parking bay closures may also be required for storage of pipework and materials.</li> <li>• The responsibility for any utility diversions should wherever possible be passed onto the contractor or completed prior to going into contract. Utility companies can be slow in undertaking these works.</li> <li>• X-raying of pipe welds is not practical for health and safety reasons given the proximity to other buildings. We would advise ultrasound testing is a better approach in dense urban environments.</li> </ul> |
| <b>Next steps</b>                 |  | To finalize the demonstrator starting collecting parameters to assess its performance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Progress monitoring period</b> |  | <b>April 2016- September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          |  | Ongoing construction phase                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Main conclusions</b>           |  | The operation of the demonstrator is foreseen at Q1-2017. There have been some delays due to waiting on UK power networks to decommission and remove an existing HV substation from the site and also from London Underground in handing back the site.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Lessons learnt</b>             |  | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Next steps</b>                 |  | To finalize construction, start-up the demonstrator and assess its performance                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| <b>Progress monitoring period</b> |  | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Main achievements</b>          |  | <ul style="list-style-type: none"> <li>• Heat pump procured</li> <li>• DN250 branch pipework is now being installed</li> <li>• Contractual development agreement with London</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |

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|                                   | Underground                                                                                                                                                                                                                                                                                                                                                               |
| <b>Main conclusions</b>           | <ul style="list-style-type: none"> <li>Design for energy center under finalization</li> </ul> <p>Delays in demonstrator's realization process will have an impact on demonstrator start up, originally foreseen at Q3-2016 and postponed to Q1-2017</p>                                                                                                                   |
| <b>Lessons learnt</b>             | Not applicable                                                                                                                                                                                                                                                                                                                                                            |
| <b>Next steps</b>                 | <ul style="list-style-type: none"> <li>Enabling works to begin construction of the energy center</li> <li>Completion of main pipework and welding</li> <li>Procurement of the two combined heat and power engines</li> <li>Connection of new pipework and integration into existing phase 1 network</li> </ul>                                                            |
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                                               |
| <b>Main achievements</b>          | Finalization of the authorization process<br>Main contractor appointment                                                                                                                                                                                                                                                                                                  |
| <b>Main conclusions</b>           | Ready to start construction phase                                                                                                                                                                                                                                                                                                                                         |
| <b>Lessons learnt</b>             | Accelerate design to incorporate planning at earlier stages, to allow procurement to commence with clear direction and permission to construct above-ground works.                                                                                                                                                                                                        |
| <b>Next steps</b>                 | To start construction.                                                                                                                                                                                                                                                                                                                                                    |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                |
| <b>Main achievements</b>          | The performance specification and executive design have been issued to tender for both LO2 and LO3.                                                                                                                                                                                                                                                                       |
| <b>Main conclusions</b>           | <p>Work will not start on site in March 2015 as planned, and is likely to be June 2015 at the earliest.</p> <p>Third party delays added to timescales as a result of gaining approval from local administration (i.e. planning permission), which requires procurement to be slowed down to allow confirmation of contract in line with permission to construct.</p>      |
| <b>Lessons learnt</b>             | Accelerate design to incorporate planning at earlier stages, to allow procurement to commence with clear direction and permission to construct above-ground works.                                                                                                                                                                                                        |
| <b>Next steps</b>                 | To finalize procurement phase and start construction.                                                                                                                                                                                                                                                                                                                     |
| <b>Progress monitoring period</b> | <b>March 2014- September 2014 (M12-M18)</b>                                                                                                                                                                                                                                                                                                                               |
| <b>Main achievements</b>          | Planning application (i.e. permitting phase) and procurement have started (i.e. pre-selection phase for the main contractor).                                                                                                                                                                                                                                             |
| <b>Main conclusions</b>           | Ready to qualificate the main contractor                                                                                                                                                                                                                                                                                                                                  |
| <b>Lessons learnt</b>             | <p>Define income and expenditure risk as early as possible in the project.</p> <p>Undertake greater sensitivity on market electrical revenue – not only temperature dependent but also wider weather condition dependency (i.e. windy).</p> <p>Critical reliability of generation required to maximize market electricity revenue – need security of supply for PPAs.</p> |

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**Next steps**

Advertising for procurement of Client Engineer/contract administrator.

Pre Qualification of main contractor

Formal initiation of planning process with Architect, public realm artist and engineer

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### 3.1.10 Rotterdam demonstrator RO1 “The heat hub”

|                                   |                                                                                                         |
|-----------------------------------|---------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>March 2014- January 2017 (M12-M42)</b>                                                               |
| <b>Main achievements</b>          | The demonstrator is in operation.<br>Monitored data have been provided from March 2014 to December 2016 |
| <b>Main conclusions</b>           | No deviations have been recorded, thus no need for identifying corrective measures                      |

### 3.1.11 Rotterdam demonstrator RO2 “Industrial ecology”

*The storyboard for the present demonstrator starts at M18, since in the period M12-M18 the project concept was redefined and rescheduled according to a proposal approved first by the PMO and by EC by means of a request of project amendment (officially approved at M25). In addition, the RO2 demonstrator has been downsized as consequence of the occurred deviations in 2015. This change has been included in the second approved project amendment.*

|                                   |                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M42-M46)</b>                                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | The decision from Meneba to connect to WARM network is still pending.                                                                                                                                                                                                                                                                                            |
| <b>Main conclusions</b>           | Continuously postponement of the go/no go decision could impact on demonstrator start up. In such a perspective, the start-up could occur at Q1-2018 beyond the project's end-date. As a consequence there won't be any monitoring period within the project duration. Moreover, if the decision from Meneba is negative, the demonstrator will be not realized. |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | To closely monitor demonstrators realization                                                                                                                                                                                                                                                                                                                     |

|                                   |                                                                                                                                          |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>April 2016 – September 2016 (M36-M42)</b>                                                                                             |
| <b>Main achievements</b>          | KPN feasibility study delivered<br><b>Meneba plant:</b> the pipeline for enabling the connection to WARM heat transport system is ready. |
| <b>Main conclusions</b>           | The final investment decision of Meneba to connect to the available pipeline is still pending                                            |
| <b>Lessons learnt</b>             | -                                                                                                                                        |
| <b>Next steps</b>                 | To finalize the agreement procedure with Meneba plant allowing demonstrator start up at Q1-2017                                          |

|                                   |                                                                                                                                          |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2015- April 2016 (M30-M36)</b>                                                                                                |
| <b>Main achievements</b>          | KPN feasibility study delivered<br><b>Meneba plant:</b> the pipeline for enabling the connection to WARM heat transport system is ready. |
| <b>Main conclusions</b>           | <b>Water Treatment Plant:</b> this demonstrator will not be further developed within CELSIUS project                                     |
| <b>Lessons learnt</b>             | No applicable                                                                                                                            |
| <b>Next steps</b>                 | To finalize the agreement procedure with Meneba plant allowing demonstrator start up at Q1-2017                                          |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Main achievements</b>          | KPN feasibility study delivered<br>Meneba plant: the pipeline for enabling the connection to WARM heat transport system is ready.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Main conclusions</b>           | <i>WARM pointed out the fact that some changes to local legislation in Rotterdam are currently affecting WARM demonstrators RO2-RO3-RO4. As a matter of fact recently local authorities started a strict policy concerning investigation to unexploded bombs from the 2<sup>nd</sup> World War and polluted soil. This policy is applicable for Rotterdam demonstrators' areas of interest, causing the need of unexpected and mandatory investigations. Moreover, the main decision on the investment to be undertaken by the new customers that were expected to be connected to the WARM grids through the new demonstrators is still ongoing.</i> |
| <b>Lessons learnt</b>             | <i>Not applicable.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | <i>The impact of such deviations on the agreed and scheduled timeline is currently under evaluation.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

|                                   |                                                                                                                                                                                                                  |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                       |
| <b>Main achievements</b>          | Meneba plant: the pipelines for enabling the connection to WARM heat transport system are ready.<br>RWZI Dokhaven plant: a part of the needed pipelines construction is expected to be finalized within Q2-2015. |
| <b>Main conclusions</b>           | The realization process is under finalization.                                                                                                                                                                   |
| <b>Lessons learnt</b>             | Not applicable.                                                                                                                                                                                                  |
| <b>Next steps</b>                 | Meneba and RWZI Dokhaven are finalizing the Final Investment Decision (FID) on the proposal of WARM in order to provide the thermal energy necessary for demo start-up.                                          |

### 3.1.12 Rotterdam demonstrator RO3 “Connecting existing industries”

The storyboard for the present demonstrator starts at M18, since in the period M12-M18 the project concept was redefined and rescheduled according to a proposal approved first by the PMO and by EC by means of a request of project amendment (officially approved at M25).

In addition, the RO3 demonstrator will not be further developed within CELSIUS project as a consequence of the occurred deviations in 2015. This change has been included in the second approved project amendment.

|                                   |                                                                                                                                                                                                                                                                                                        |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>April 2015- September 2015 (M24-M30)</b>                                                                                                                                                                                                                                                            |
| <b>Main achievements</b>          | Demonstrator's work plan changed and officially approved (see amended Description of Work). RO3 foresees the extension of WARM district heating network by means of connecting existing buildings as a result of the increased thermal capacity provided by the heat recovered at RWZI Dokhaven plant. |
| <b>Main conclusions</b>           | <i>WARM pointed out the fact that some changes to local legislation in Rotterdam are currently affecting WARM demonstrators RO2-RO3-RO4. As a matter of fact recently local authorities started a strict policy concerning investigation to</i>                                                        |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   | <i>unexploded bombs from the 2<sup>nd</sup> World War and polluted soil. This policy is applicable for Rotterdam demonstrators' areas of interest, causing the need of unexpected and mandatory investigations. Moreover, the main decision on the investment to be undertaken by the new customers that were expected to be connected to the WARM grids through the new demonstrators is still ongoing.</i>                                                                                                                                                                                                                                                                                                              |
| <b>Lessons learnt</b>             | <i>Not applicable.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| <b>Next steps</b>                 | <i>The impact of such deviations on the agreed and scheduled timeline is currently under evaluation.</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Main achievements</b>          | Ongoing decision making process                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Main conclusions</b>           | In April 2014 WARM submitted the Request for Change on RO3 and RO4 to the PMO. After the formal approval from the EC on the ongoing amendment procedure WARM will start reporting on both demonstrators, finalizing the business cases.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Lessons learnt</b>             | Not applicable.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Next steps</b>                 | <p>Assuming that the decision making process will be finalized within Q3-2015, the following updates are applicable:</p> <p>RO3 "Connection of existing buildings": WARM foresees to start delivering waste heat to the metal treatment companies within Q4-2016.</p> <p>RO4 "Integrating cooling solutions": WARM foresees to start delivering waste heat to the data centre and hospital in accordance within Q2-2016.</p> <p>After the start of heat delivery WARM will be able to deliver the following parameters for monitoring purposes for both demonstrators</p> <ul style="list-style-type: none"> <li>• Volume [MWh];</li> <li>• Supply and return temperatures;</li> <li>• Flow [m<sup>3</sup>/h].</li> </ul> |

### **3.1.13 Rotterdam demonstrator RO4 "Integrating cooling solutions"**

The storyboard for the present demonstrator starts at M18, since in the period M12-M18 the project concept was redefined and rescheduled according to a proposal approved first by the PMO and by EC by means of a request of project amendment (officially approved at M25). ). In addition, the RO4 demonstrator's concept has been reviewed and updated as consequence of the occurred deviations in 2015. This change has been included in the second approved project amendment.

|                                   |                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Progress monitoring period</b> | <b>October 2016 – January 2017 (M42-M46)</b>                                                                                                                                                                                                                                                                                    |
| <b>Main achievements</b>          | Ongoing procurement. Feasibility study concluded; in Q3-2016 WARM decided to proceed to the quotation procedure; quotations did not have the desired and expected results. WARM will tender a more specific question and technical assumptions in Q1 2017. Awaiting the new quotations, engineering will be started in Q1 2017. |
| <b>Main conclusions</b>           | According to the new time scheduling provided by WARM, the                                                                                                                                                                                                                                                                      |

|                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   | start-up is expected at Q3-2017. This will limit the monitoring period up to 6 months.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | To closely monitor demonstrator realization                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <b>Progress monitoring period</b> | <b>April 2016 - September 2016 (M36-M42)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <b>Main achievements</b>          | The feasibility study for RO4 is concluded                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Main conclusions</b>           | Possible future deviations are related to construction phase that will be later than planned and is foreseen in Q2 2017.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <b>Lessons learnt</b>             | -                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <b>Next steps</b>                 | To select a supplier for absorption coolers and proceed with the construction phase                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| <b>Progress monitoring period</b> | <b>April 2015- April 2016 (M24-M36)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Main achievements</b>          | RO4 demonstrator concept was reviewed and updated. Specifically, either the data centre and the hospital pilot project were replaced by a new business case. Specifically, it is foreseen to replace the electric chillers used to cool the speed controllers in heat hub (RO1) with absorption chillers (the maximum cooling capacity needed at the heat hub is 7-10 kW).                                                                                                                                                                                                                                                                                                                       |
| <b>Main conclusions</b>           | No major deviations were recorded, thus no need for identifying corrective measures.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>Lessons learnt</b>             | Not applicable.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Next steps</b>                 | To install the absorption chillers allowing demonstrator's operation at Q1-2017                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Progress monitoring period</b> | <b>September 2014-March 2015 (M18-M24)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <b>Main achievements</b>          | Ongoing decision making process                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Main conclusions</b>           | In April 2014 WARM submitted the Request for Change on RO3 and RO4 to the PMO. After the formal approval from the EC on the ongoing amendment procedure WARM will start reporting on both demonstrators, finalizing the business cases.                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <b>Lessons learnt</b>             | Not applicable.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <b>Next steps</b>                 | Assuming that the decision making process will be finalized within Q3-2015, the following updates are applicable:<br>RO3 "Connection of existing buildings": WARM foresees to start delivering waste heat to the metal treatment companies within Q4-2016. RO4 "Integrating cooling solutions": WARM foresees to start delivering waste heat to the data centre and hospital in accordance within Q2-2016. After the start of heat delivery WARM will be able to deliver the following parameters for monitoring purposes for both demonstrators <ul style="list-style-type: none"> <li>• Volume [MWh];</li> <li>• Supply and return temperatures;</li> <li>• Flow [m<sup>3</sup>/h].</li> </ul> |

#### **4. Monitoring of performance for demonstrators in operation**

*The present deliverable represents the update of the previously submitted deliverable D4.3 (M43). Additional information has been included with regards to the following demonstrators based on the new set of data collected: GO1, GO2, GO3, GO4, CO1-SET1 and RO1. Further to that data from already existing demonstrators in Gothenburg and Rotterdam have been collected and included with regard to 2GOe, 19GOe, 15ROe, 32ROe and 33ROe.*

The Celsius project aims at developing, optimizing and promoting efficient decentralized heating and cooling systems in cities, thus consistently contributing to the reduction of CO<sub>2</sub> emission and of primary energy consumption. In light of this scope, monitoring of performance for demonstrators in operation is strategic for assessing, from a quantitative perspective, the impact of each technology implemented in the framework of CELSIUS demonstrator. According to the monitoring protocols defined in the first phase of the project and properly described in deliverable D4.1 [3] and D4.2 [2], energetic, environmental, social and economic KPIs have been identified, enabling the global understanding and assessment of the performance of the different demonstrators. The aforementioned indicators have been developed on two different levels:

- Specific KPIs, set up on the basis of a specific analysis on each demonstrator's technology;
- General KPIs, relevant in order to define common indicators to all demos enabling to summarize in a clear, measurable and communicable way the most important achievement of the CELSIUS project.

The parameters to monitor in order to effectively calculate the aforementioned KPIs have been defined as well and the data-collecting process has been launched among the partners responsible for each demo in operation. Section 3 reports on calculations of both the aforementioned KPI categories, focusing not only on demonstrators of new realization (i.e., realized and operated during the Celsius project), but also on operational existing demonstrators in the five cities that have been included in the project. Thus, covering a wide range of state-of-the-art demonstrators belonging to different categories, the potential of replicability of the most efficient smart solutions in suitable contexts increases and the impact of the project is maximized.

Information about the following demonstrators has been included:

- Already existing demonstrators: 6COe, 2GOe, 7GOe, 8GOe, 9GOe, 11GOe, 19GOe, 20GOe, 36GOe, 16ROe, 15ROe, 32ROe, 32ROe);
- New demonstrators: CO1-SET1, RO1, GO1, GO2, GO3, GO4, LO1.

*KPI calculations have been adapted to the current status of data availability at demo sites. In some cases, indicators presented in D4.1 have been slightly modified according to the system operation as well as to data availability. Updated calculations will be included in the final versions of current deliverable, foreseen at M57.*

## 4.1 Existing demonstrators

Considering already existing demonstrators, monitored parameters and preliminary KPIs calculation are hereinafter presented with regards to the following demos:

- 36GOe Gothenburg- Total production and distribution system;
- 9GOe Gothenburg - Biofuel CHP;
- 7GOe Gothenburg - Industrial waste heat recovery;
- 8GOe Gothenburg - Recovery of heat, waste incinerator;
- 29GOe Gothenburg - Climate Agreement;
- 20GOe Gothenburg - Solar heat by district heating system;
- 11GOe Gothenburg - Cooling by river water;
- 2GOe Gothenburg – Integration of municipalities;
- 19GOe Gothenburg – Absorption cooling;
- 6COe Cologne - Geothermal heating plant;
- 15ROe Rotterdam - Vertical City;
- 16ROe Rotterdam - Aquifer storage;
- 32ROe 33ROe Rotterdam – Datacenters,

### 4.1.1 Gothenburg demonstrator 36GOe “Total production and distribution system”

#### *Demo description*

The demonstrator encompasses the entire district heating system and is intended to give an overview of an existing, mature district heating system in operation. District heating has been developed in Gothenburg since 1953. The system has gradually expanded in terms of geographical size of the network, number of customers connected and number of production facilities. Over the course of the decades, the sources of heat have changed radically, through the conversion of existing production plants to other fuels as well as through the addition of new heat production plants and technologies.



**Figure 2:** District heating network Gothenburg, 2001

#### *Main assumptions for KPIs calculation*

The assumed baseline considered for KPI calculation is individual oil boilers, approximately corresponding to situation before district heating (implemented in the 1950s). The efficiency of oil boilers has been assumed equal to 75 %.(energy use considered, construction of production facilities, network etc. not included).

##### *4.1.1.1 Demo-specific KPI*

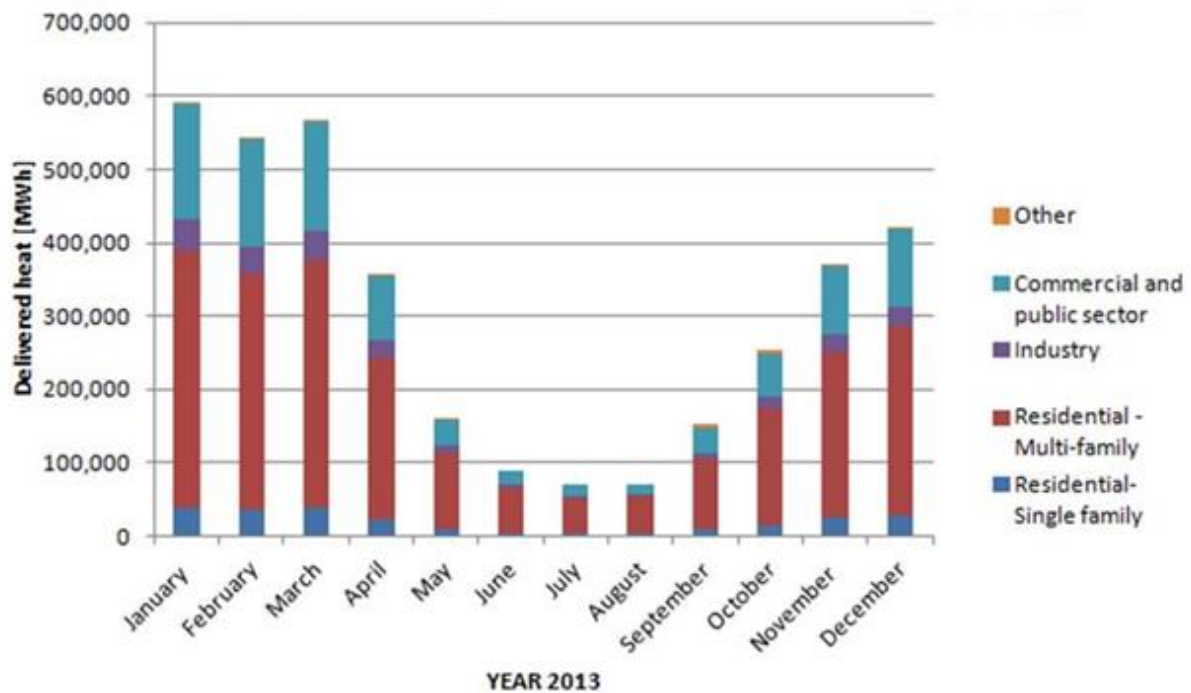
According to the monitoring protocols defined in the first phase of the project and properly described in D4.1 [3], lists of specific and general KPIs have been defined for each demo. In particular, specific KPIs have been set-up on the basis of a specific analysis on each demonstrator's technology in order to evaluate its performance and impact from the technical, economic, social and environmental point of view.

Technical KPIs are shown in table and figure below.

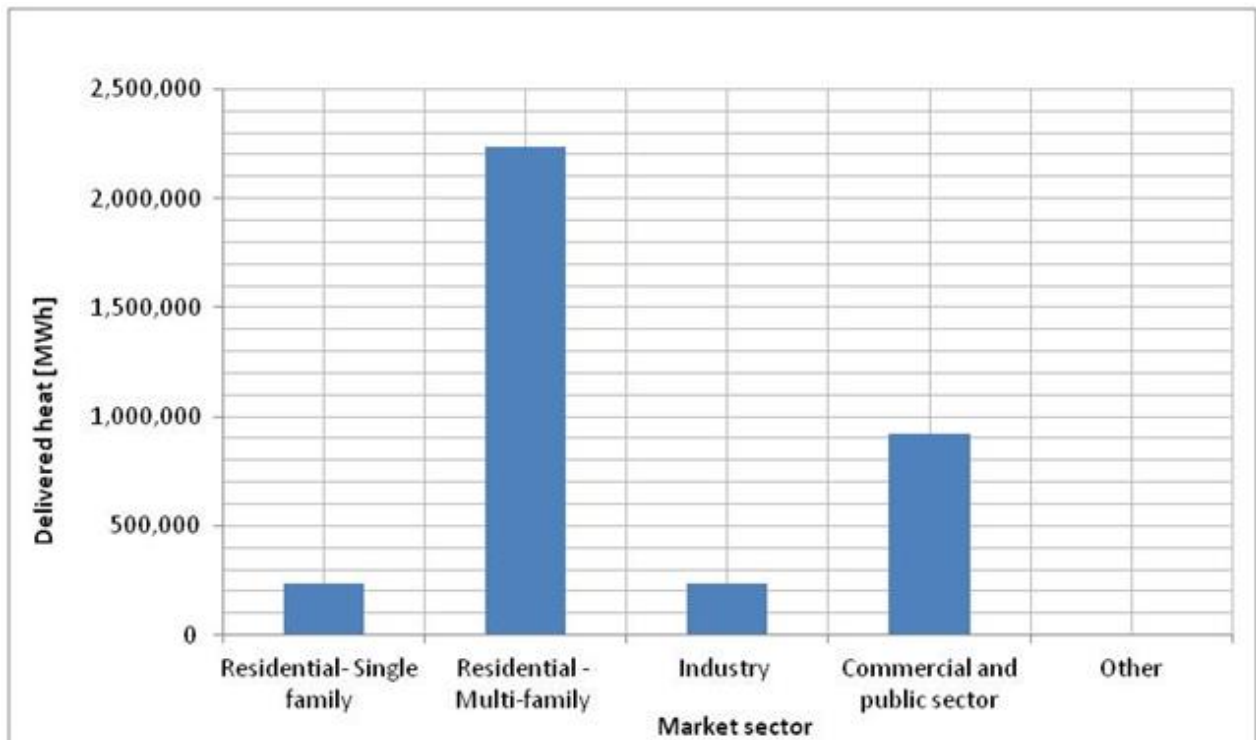
| ID      | KPI                                                  | Unit of Measurement | Categories                          | Value | Reference year |
|---------|------------------------------------------------------|---------------------|-------------------------------------|-------|----------------|
| 36GOeT1 | Yearly delivered heat to customers per market sector | GWh/year            | <b>Total</b>                        | 3,625 | 2013           |
|         |                                                      |                     | Residential single family buildings | 278   |                |
|         |                                                      |                     | Residential multi family buildings  | 2,175 |                |
|         |                                                      |                     | Commercial/public buildings         | 825   |                |
|         |                                                      |                     | Industries                          | 241   |                |
|         |                                                      |                     | Unknown                             | 105   |                |
| 36GOeT2 | Yearly production mix                                | % for each facility | Waste incineration CHP              | 22%   | 2013           |
|         |                                                      |                     | Waste heat industries               | 24%   |                |
|         |                                                      |                     | Waste heat sewage                   | 7%    |                |
|         |                                                      |                     | Waste heat flue gas condensation    | 11%   |                |
|         |                                                      |                     | Biofuel CHP                         | 5%    |                |
|         |                                                      |                     | Biofuel boiler                      | 4%    |                |
|         |                                                      |                     | Electricity to heat pumps           | 3%    |                |

|         |                                                                         |           |                                               |       |      |
|---------|-------------------------------------------------------------------------|-----------|-----------------------------------------------|-------|------|
|         |                                                                         |           | Electricity for assisting systems, pumps etc. | 2%    |      |
|         |                                                                         |           | Natural gas CHP                               | 15%   |      |
|         |                                                                         |           | Natural gas boiler                            | 3%    |      |
|         |                                                                         |           | Imported heat - biofuel and peat              | 4%    |      |
| 36GOeT3 | District heating supply temperature (yearly and winter/summer averages) | °C        | Yearly average                                | 91    | 2012 |
|         |                                                                         |           | Winter average (Jan, Feb, Dec)                | 93    |      |
|         |                                                                         |           | Early spring/late fall (Mar-Apr & Oct-Nov)    | 89    |      |
|         |                                                                         |           | Late spring/early fall (May&Sep)              | 90    |      |
|         |                                                                         |           | Summer average (Jun-Aug)                      | 91    |      |
| 36GOeT4 | District heating return temperature (yearly and winter/summer averages) | °C        | Yearly average                                | 46    | 2012 |
|         |                                                                         |           | Winter average (Jan, Feb, Dec)                | 45    |      |
|         |                                                                         |           | Early spring/late fall (Mar-Apr & Oct-Nov)    | 42    |      |
|         |                                                                         |           | Late spring/early fall (May&Sep)              | 46    |      |
|         |                                                                         |           | Summer average (Jun-Aug)                      | 51    |      |
| 36GOeT5 | Relative distribution losses                                            | %         |                                               | 10%   | 2013 |
| 36GOeT6 | Electric energy consumptions at each production facility                | GWhe/year | Electricity to heat pumps                     | 130   | 2013 |
|         |                                                                         |           | Electricity for assisting systems, pumps etc. | 72    |      |
| 36GOeT7 | Linear heat density                                                     | kWh/m     |                                               | 2,800 | 2013 |

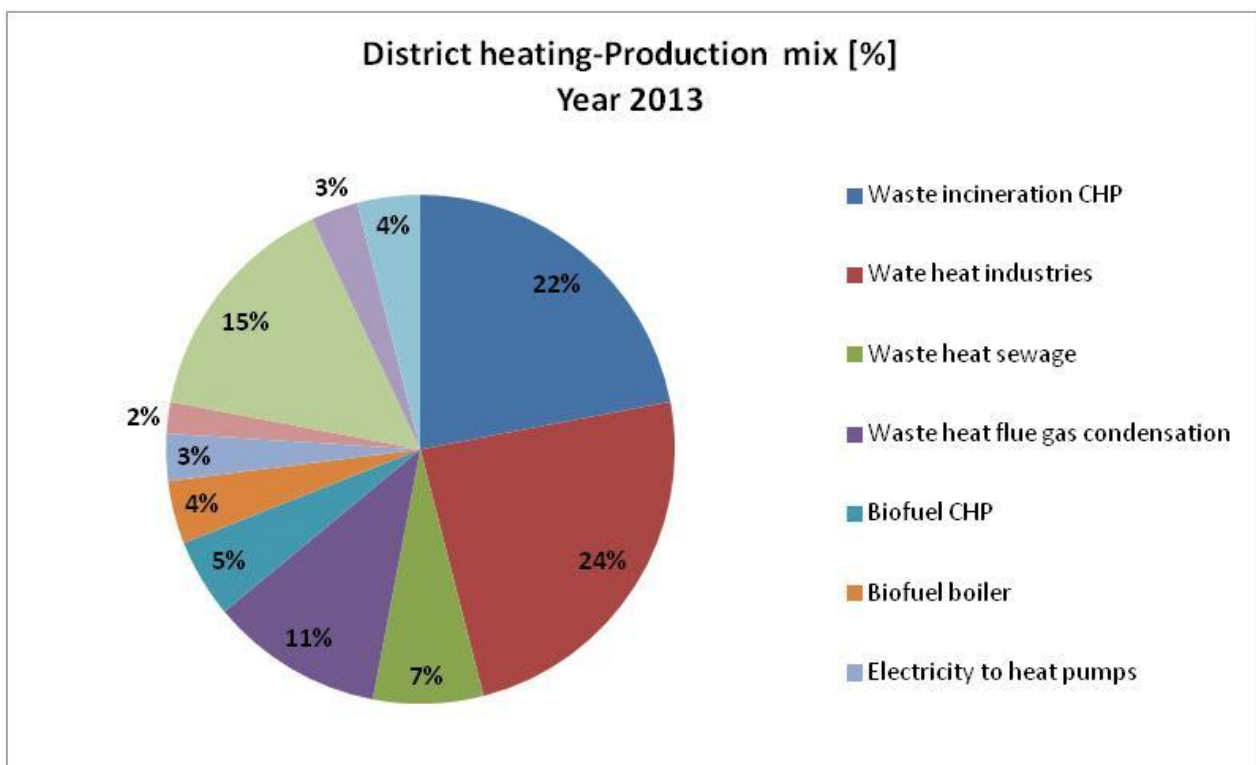
**Table 1:** Specific KPIs - Technical KPIs



**Figure 3:** Monthly delivered heat to customers per market sector [MWh]- Year 2013



**Figure 4:** Yearly delivered heat to customers per market sector [MWh]- Year 2013



**Figure 5:** District heating production mix [%]

Social KPIs are shown in table below.

| ID      | KPI                                                                                              | Unit of Measurement            | Categories                                                                                      | Value   | Reference year |
|---------|--------------------------------------------------------------------------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------|---------|----------------|
| 36GOeS1 | Number of users/customers per market sector                                                      | -                              | Residential single family buildings                                                             | 24,464  | 2012           |
|         |                                                                                                  |                                | Residential multi family buildings                                                              | 191,400 |                |
|         |                                                                                                  |                                | Public sector/Commercial sector                                                                 | 72,600  |                |
|         |                                                                                                  |                                | Industries and construction                                                                     | 21,208  |                |
|         |                                                                                                  |                                | Other categories (farming, forestry, fishery, transportation, other services, holiday cottages) | 9,240   |                |
| 36GOeS2 | Market share in different sectors                                                                | % of total number of customers | Residential single family buildings                                                             | 8%      | 2012           |
|         |                                                                                                  |                                | Residential multi family buildings                                                              | 60%     |                |
|         |                                                                                                  |                                | Public sector                                                                                   | 23%     |                |
|         |                                                                                                  |                                | Industries and construction                                                                     | 6%      |                |
|         |                                                                                                  |                                | Other categories (farming, forestry, fishery, transportation, other services, holiday cottages) | 3%      |                |
| 36GOeS3 | Number of people employed directly and indirectly as a result of the district heating operation. | -                              |                                                                                                 | 400     | 2013           |

**Table 2:** Specific KPIs- Social KPIs

#### 4.1.1.2 General KPI

In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                            | UM                         | 36GOe | Year 2013                                                                                                                       |       |
|---------------|-------------------------------------------------------------------------|----------------------------|-------|---------------------------------------------------------------------------------------------------------------------------------|-------|
| ENERGETIC     | The yearly amount of thermal energy produced/provided by the new system | GWh/year                   | x     | 3,625                                                                                                                           |       |
|               | Saved primary energy in comparison with baseline situation              | GWh/year                   | x     | 4,200                                                                                                                           |       |
|               | Energy efficiency of the project                                        | %                          | x     | Delivered to customer in relation to used fuels, waste heat and electricity                                                     | 90%   |
|               | Energy recovery from waste/renewable sources                            | GWh/year                   | x     | Waste Energy (It Includes waste heat from sewage water, industrial waste heat and flue gas condensation)                        | 1,530 |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation            | %                          | x     | Renewable Energy (Includes biofuels, waste incineration and electricity (environmentally certified electricity "Bra miljöväl")) | 1,450 |
|               | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e/year | x     | 77                                                                                                                              |       |
| SOCIAL        | Number of residents/users benefitting of the new project                |                            | x     | 315,000                                                                                                                         |       |
|               |                                                                         |                            |       | 390,500                                                                                                                         |       |

**Table 3:** General KPIs – 36GOe

#### 4.1.2 Gothenburg demonstrator 9GOe “Biofuel CHP”

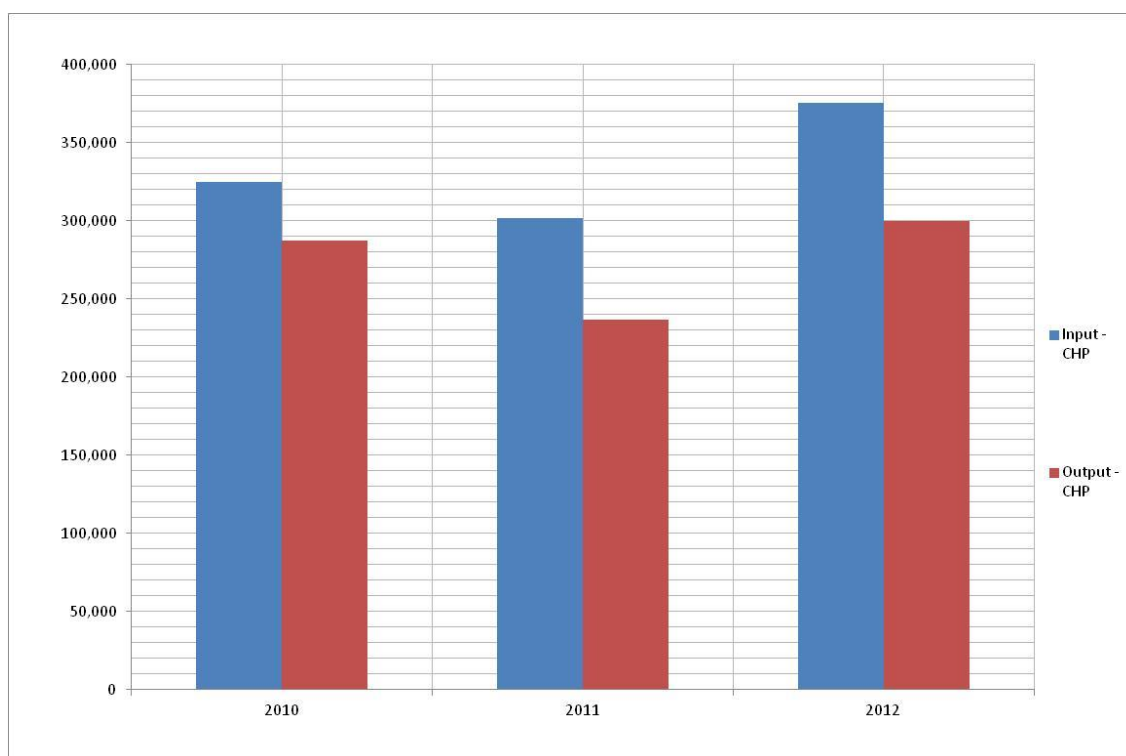
##### Demo description

Sävenäs boiler HP3 was built in 1985 as a clean coal boiler to produce heat for district heating. In the past years, the boiler has been converted to produce heat with cheaper and renewable fuels. In 2004 HP3 was converted into a biomass boiler to burn wood chips for the production of thermal energy. With rising electricity prices and the introduction of green certificates for biomass power, the HP3 was converted into a CHP for the co-production of electricity and thermal energy. The monitored parameters available are related to: CHP inlet energy (wood chips), CHP thermal and electric energy production, backup natural gas boilers thermal energy production, covering the period 2010-2012.

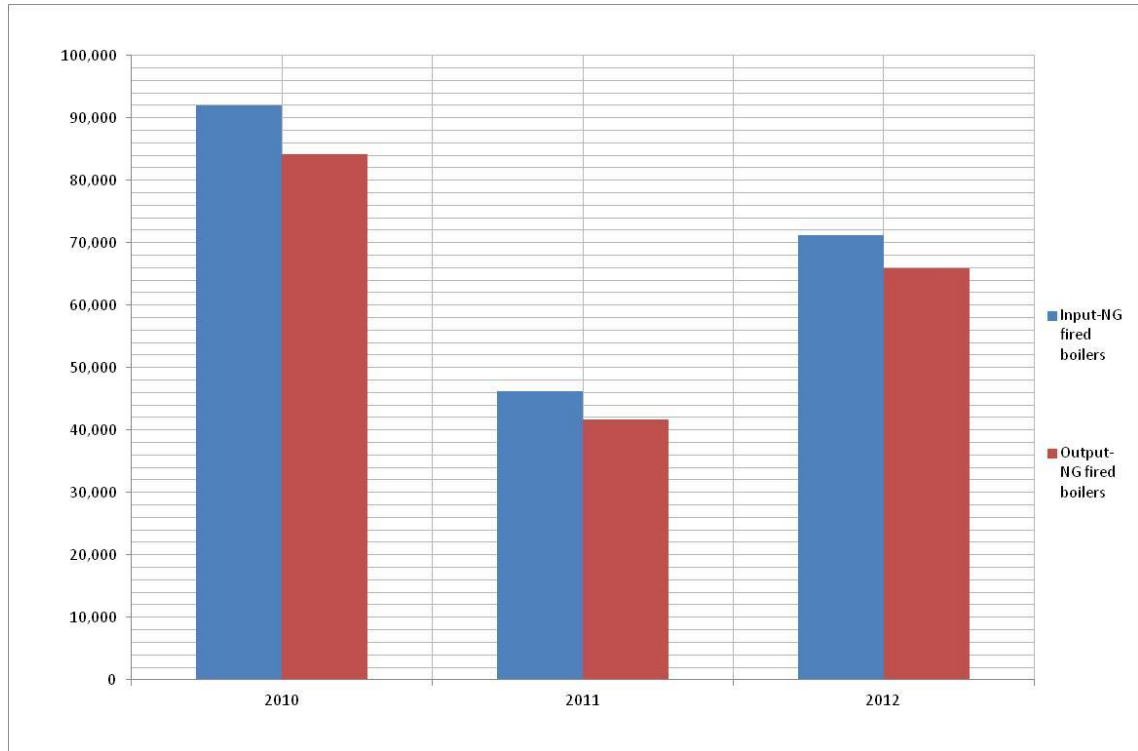
| Technical parameters                                 | Unit of measurement  |
|------------------------------------------------------|----------------------|
| Inlet energy (wood chips)                            | [MWh <sub>th</sub> ] |
| CHP thermal energy production                        | [MWh <sub>th</sub> ] |
| CHP electric energy production                       | [MWh <sub>e</sub> ]  |
| Backup natural gas boilers thermal energy production | [MWh <sub>th</sub> ] |
| District heating supply temperature                  | [°C]                 |
| District heating return temperature                  | [°C]                 |

**Table 4:** 9GOe demo-Monitored parameters

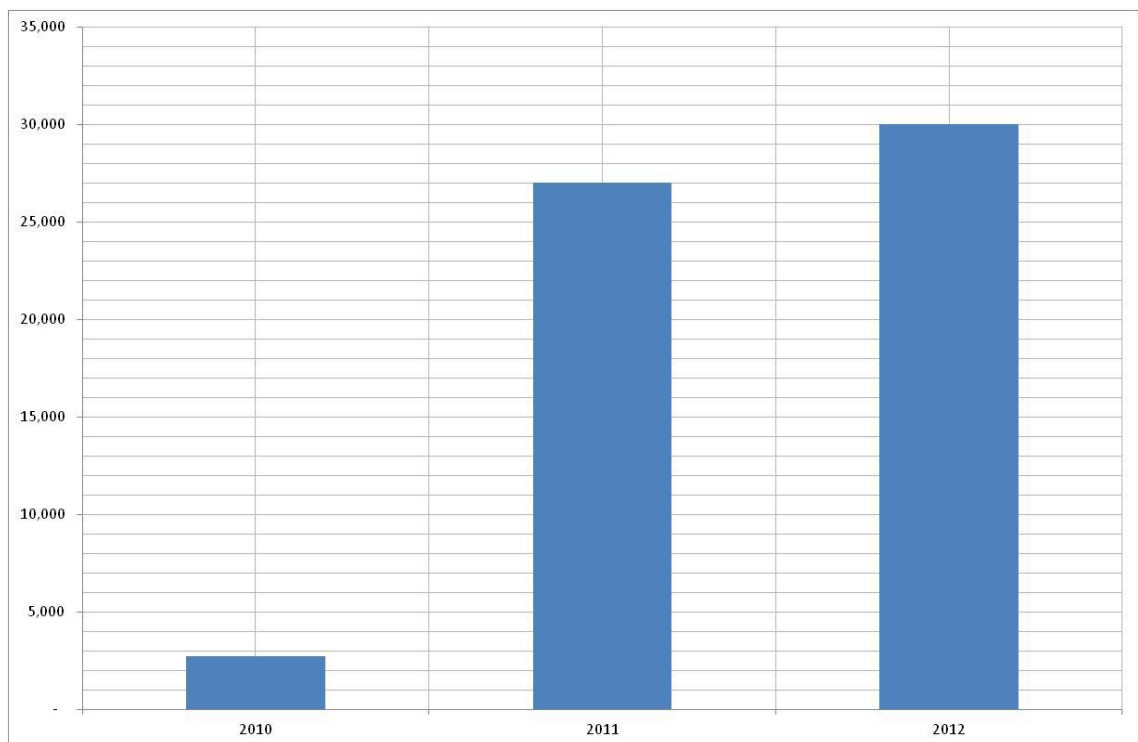
The distributions of the aforementioned parameters are graphically presented in the following charts.



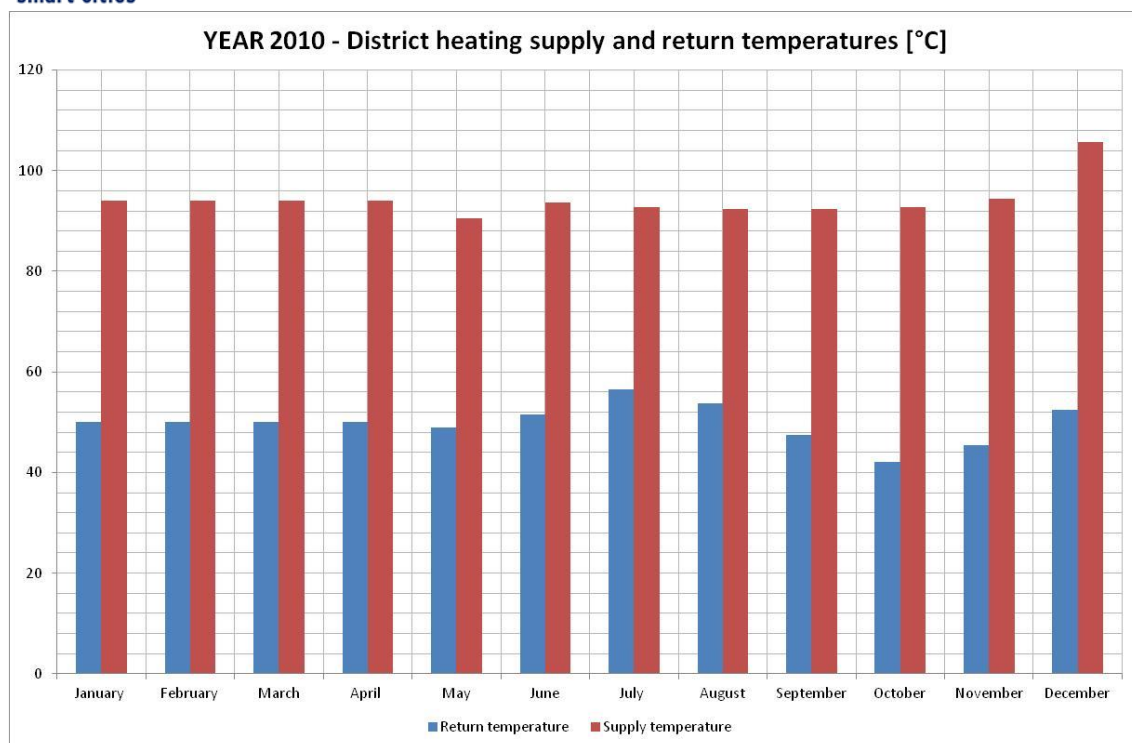
**Figure 6:** 9GOe- Annual inlet and outlet energy - Biomass CHP [MWh<sub>th</sub>]



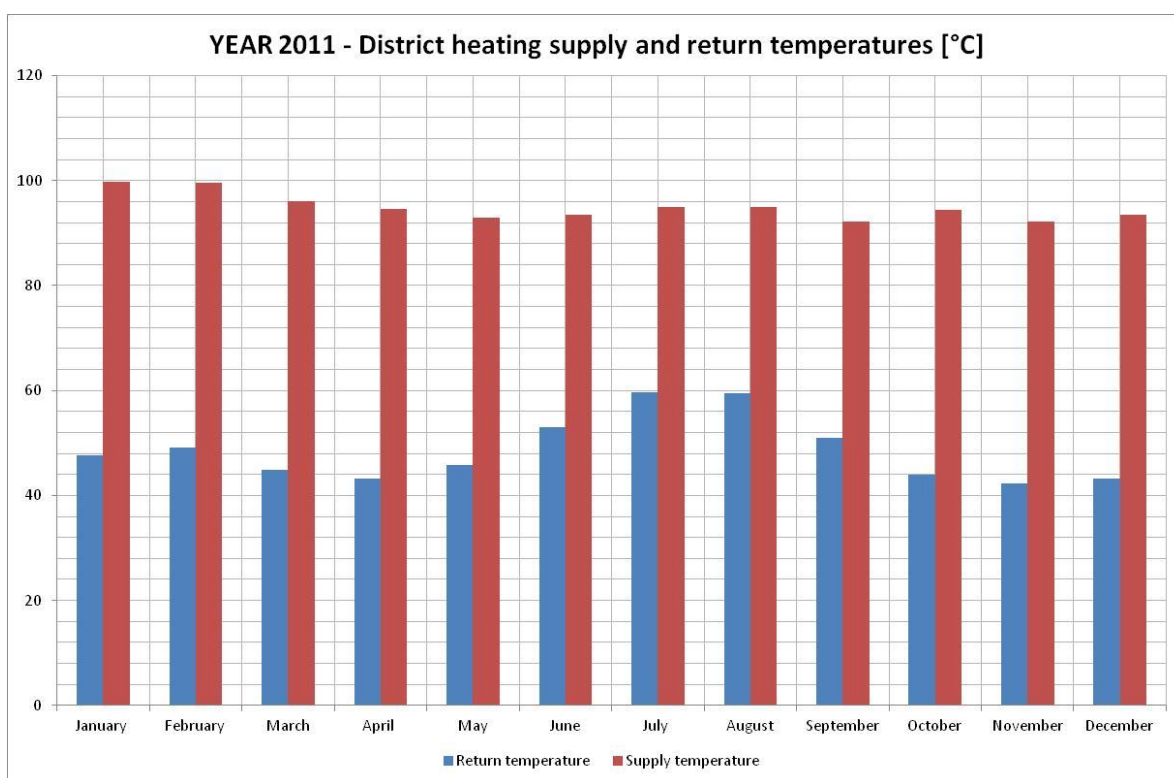
**Figure 7:** 9GOe- Annual inlet and outlet energy- NG boilers [MWh<sub>th</sub>]



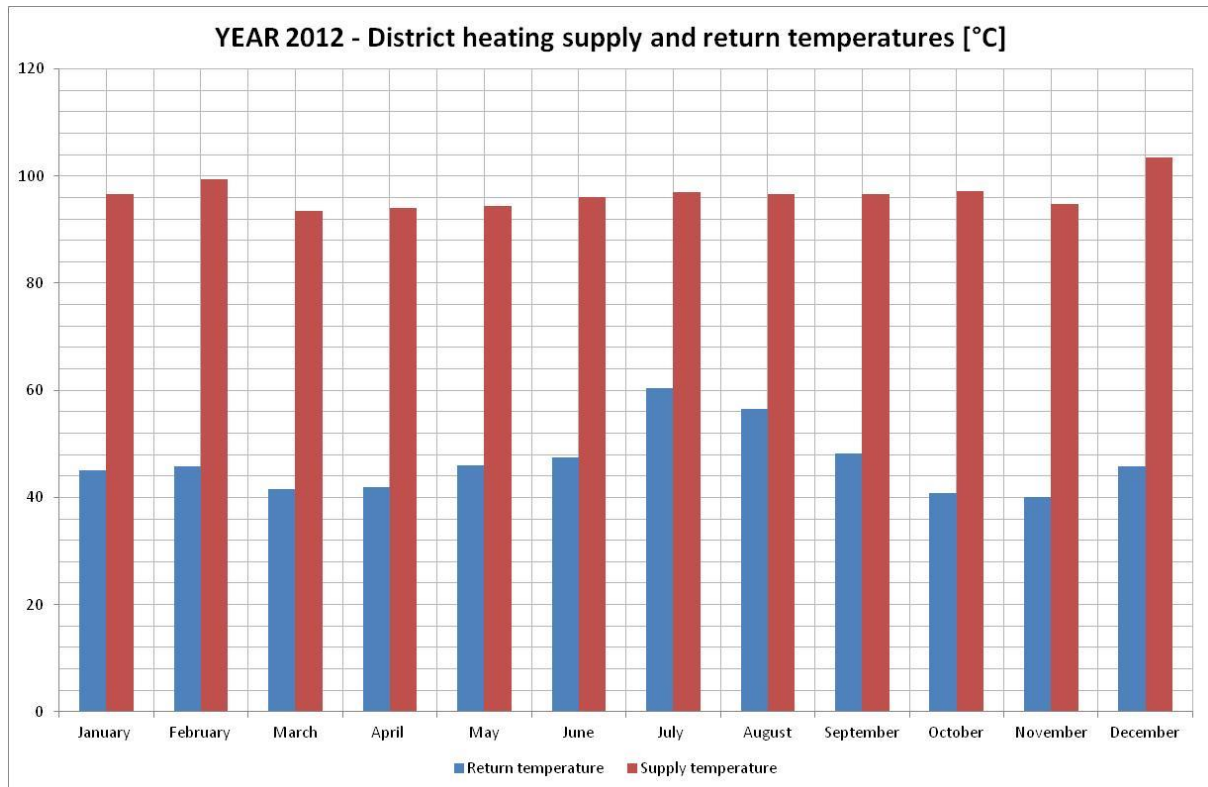
**Figure 8:** 9GOe- Annual electric energy production [MWh<sub>e</sub>]



**Figure 9:** 9GOe- Monthly averaged supply and return temperatures [2010]



**Figure 10:** 9GOe- Monthly averaged supply and return temperatures [2011]



**Figure 11:** 9GOe- Monthly averaged supply and return temperatures [2012]

#### Main assumptions for KPIs calculation

- The original use of coal boiler is assumed as the baseline situation for estimating the performance of the demonstrator. Coal boiler efficiency is assumed equal to 85% [4]. The main parameters used as reference for KPI calculation are presented in table below. The evaluation with the baseline situation has been carried out considering both CHP and natural gas fired boilers (for peak loads) thermal productions.

| Parameter                               | Unit of meas.       | Value                  | Comments and references                                                                                                         |
|-----------------------------------------|---------------------|------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| $\eta_{\text{coal boiler}}$             | -                   | 0.85                   | [4]                                                                                                                             |
| $PEF_{\text{, coal}}$                   |                     | 1.2                    | [5]                                                                                                                             |
| $E_{\text{, CO}_2, \text{Coal boiler}}$ | t/MWh <sub>th</sub> | 0.322                  | [6]                                                                                                                             |
| $E_{\text{, CH}_4, \text{Coal boiler}}$ | t/MWh <sub>th</sub> | $0.038 \times 10^{-3}$ |                                                                                                                                 |
| $E_{\text{, el grid}}$                  | t/MWh <sub>e</sub>  | 0.023                  | [7]                                                                                                                             |
| $PEF_{\text{, el grid}}$                | -                   | 1.8                    | Assuming the following energy production mix:<br>56% renewable ( $PEF=1$ ), 44% nuclear energy and fossil fuels ( $PEF=3$ ) [8] |

**Table 5:** 9GOe-Baseline parameters

- The assessment of the yearly performance of the demonstrators has been estimated on the basis of the available monitored data covering the period 2010-2012. Monitored parameters have been aggregated and used as input data for KPI calculation, as reported in table below. The data used as reference for total thermal energy produced by GOTE DH network are data from the Sweden Energy Authority “Energi Marknads Inspektionen” [9].

| Input parameters          |                                                         | Unit of meas. | Values for 2010 | Values for 2011 | Values for 2012 |
|---------------------------|---------------------------------------------------------|---------------|-----------------|-----------------|-----------------|
| $Q_{in, CHP}$             | Inlet energy at the CHP                                 | $MWh_{th}$    | 324,963         | 301,562         | 375,293         |
| $Q_{out, CHP}$            | Thermal energy produced at the CHP and delivered to DHN | $MWh_{th}$    | 287,426         | 236,862         | 299,777         |
| $Q_{out, CHP+NG boilers}$ | Thermal energy produced at CHP and NG boilers           | $MWh_{th}$    | 371,574         | 278,506         | 365,661         |
| $P_{CHP}$                 | Electric energy produced and delivered to the grid      | $MWh_e$       | 2,700           | 27,000          | 30,000          |
| $Q_{DH}$                  | Total district heating production                       | $MWh_{th}$    | 4,067,000       | 3,459,000       | 3,580,000       |

**Table 6:** 9GOe demo-Input data for KPI calculation

- Economic parameters: assumed tariffs (T) are reported in table below for the years of interest.

|          |                     | 2010  | 2011  | 2012  | Comments and references |
|----------|---------------------|-------|-------|-------|-------------------------|
| $T_{el}$ | €/kWh <sub>e</sub>  | 0.075 | 0.059 | 0.043 | [9]                     |
| $T_{DH}$ | €/kWh <sub>th</sub> | 0.057 | 0.061 | 0.061 | [9]                     |

**Table 7:** 9GOe demo-Assumed economic parameters

- Environmental parameters:
  - Emissions to air calculation: reference values for HP3 generator in current situation have been provided by GOTE (Yearly environmental reports from GOTE: [10], [11] and [12])

| Emissions to air | Unit of measurement | 2010 | 2011 | 2012 |
|------------------|---------------------|------|------|------|
| NO <sub>x</sub>  | t                   | 67.7 | 61.7 | 81.8 |
| SO <sub>2</sub>  | t                   | 0.8  | 0.8  | 1.0  |
| CO <sub>2</sub>  | kt                  | 19.1 | 10.1 | 15.4 |
| PM               | t                   | 2    | 1    | 0.4  |
| NH <sub>3</sub>  | t                   | 2.7  | 11.6 | 2.2  |

**Table 8:** 9GOe demo-Emissions to air

- Primary energy calculation: the assumed Primary Energy Factor (PEF) both for biomass and natural gas is reported in the table below.

| Parameter              | Unit of meas. | Value | Comments and references |
|------------------------|---------------|-------|-------------------------|
| PEF <sub>NG</sub>      | -             | 1.1   | [13]                    |
| PEF <sub>biomass</sub> | -             | 1.1   | [5]                     |

**Table 9:** 9GOe demo-Assumed Primary Energy Factors (PEF)

- Social parameters: in order to calculate the number of users benefitting of the 9GOe demonstrator, the fraction of thermal energy produced by the demo plant has been multiplied for the total number of customers of district heating network, reported in the following table [14]. See social general KPIs in table 15.

|       | Total housing units in Gothenburg | Residents per dwelling (no. of people) | Residents in Gothenburg (no. of people) |                 | Percentage of Gothenburg residents with DH |
|-------|-----------------------------------|----------------------------------------|-----------------------------------------|-----------------|--------------------------------------------|
|       |                                   |                                        | Total                                   | Connected to DH |                                            |
| Flat  | 197,296                           | 1.6                                    | 315,674                                 | 284,000         | 90%                                        |
| House | 52,866                            | 3.4                                    | 179,744                                 | 35,000          | 19%                                        |
| Total | 250,162                           | 1.9                                    | 495,418                                 | 319,000         | 64%                                        |

**Table 10:** 9GOe- Social parameters

#### 4.1.2.1 Demo-specific KPI

In the following table demo-specific KPIs are presented.

| ID     | KPI                                                                                          | Unit of Measurement | Formula                                          | 2010                | 2011                | 2012                |
|--------|----------------------------------------------------------------------------------------------|---------------------|--------------------------------------------------|---------------------|---------------------|---------------------|
| 9GOeT1 | Yearly thermal energy production                                                             | GWh/ye<br>ar        | $\sum_{year} Q_{tot}$                            | 371,574             | 278,506             | 365,661             |
| 9GOeT3 | Yearly electric energy production                                                            | GWh/ye<br>ar        | $\sum_{year} P_{CHP}$                            | 2,700               | 27,000              | 30,000              |
| 9GOeT4 | Share of thermal energy provided by this demonstrator to the Gothenburg district heating mix | %                   | $\frac{\sum_{year} Q_{CHP}}{\sum_{year} Q_{DH}}$ | 9                   | 8                   | 10                  |
| 9GOeT5 | District heating supply temperature (yearly average, summer average and winter average)      | °C                  | $\frac{\sum_{period} T_{e,DH}}{period}$          | Annual average 94°C | Annual average 95°C | Annual average 97°C |
|        |                                                                                              |                     |                                                  | Winter average 96°C | Winter average 96°C | Winter average 97°C |
|        |                                                                                              |                     |                                                  | Summer average 93°C | Summer average 94°C | Summer average 96°C |
| 9GOeT6 | District heating return temperature (yearly average, summer average and winter average)      | °C                  | $\frac{\sum_{period} T_{r,DH}}{period}$          | Annual average 50°C | Annual average 49°C | Annual average 47°C |
|        |                                                                                              |                     |                                                  | Winter average 48°C | Winter average 45°C | Winter average 43°C |
|        |                                                                                              |                     |                                                  | Summer average 51°C | Summer average 52°C | Summer average 50°C |
| 9GOeT7 | Power-to-heat ratio (ratio between electric and thermal energy production)                   | dimensionless       | $\frac{9GOeT3}{9GOeT1}$                          | 0.01                | 0.11                | 0.10                |

**Table 11:** Demo-specific KPIs – 9GOe

Additional indicators (rather than those included in D4.1, [3]) have been considered in order to include further information collected with reference to economical assessment of the demonstrator. In the following table, information related to the mobilized investments, revenues from energy sales and costs related to fuels and maintenance are reported.

#### *Investment*

The table below highlights the investments mobilized for upgrading the plant first in 2004 converting the original coal boiler into a biomass boiler and then in 2010 when a further conversion in a cogeneration plant has been carried out.

| Reference Year | Investment [€] |
|----------------|----------------|
| 2004           | 30,000,000     |
| 2010           | 16,000,000     |

**Table 12:** Investments for 9GOe

#### *Revenues*

The revenues gained from the sale of both thermal and electricity energy are presented in table below with reference to the period 2010-2012.

| Additional demo-specific KPI                                | Unif of meas. | 2010       | 2011       | 2012       |
|-------------------------------------------------------------|---------------|------------|------------|------------|
| <b>Electricity</b>                                          |               |            |            |            |
| Net energy sales revenues for electricity fed into the grid | [€/year]      | 210,089    | 1,597,549  | 1,346,463  |
| <b>Heating energy</b>                                       |               |            |            |            |
| Total revenues for heating energy                           | [€/year]      | 24,847,267 | 21,153,588 | 28,106,510 |

**Table 13:** Total revenues for 9GOe

#### *Costs*

The fuels and non operational costs are presented in table below with reference to the period 2010-2012.

| Additional demo-specific KPI                       | Unit of measurement | 2010      | 2011      | 2012      |
|----------------------------------------------------|---------------------|-----------|-----------|-----------|
| <b>Electricity</b>                                 |                     |           |           |           |
| Net energy costs for biomass                       | [€/year]            | 6,854,066 | 6,360,496 | 7,915,618 |
| Net energy costs for peak load energy carrier (NG) | [€/year]            | 3,977,016 | 2,218,562 | 3,225,647 |
| <b>Heating energy</b>                              |                     |           |           |           |
| Net non-energy requirement-related costs           | [€/year]            | 160,000   | 170,000   | 180,000   |
| Net operation-related costs                        | [€/year]            | 16,000    | 16,000    | 16,000    |

**Table 14:** Total costs for 9GOe

#### 4.1.2.2 General KPI

In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                     | UM                     | 9GOe | 2010                                                                                                       | 2011                                                                                                        | 2012                                                                                                         |
|---------------|------------------------------------------------------------------|------------------------|------|------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| ENERGETIC     | The yearly amount of thermal energy produced by the new system   | $MWh_{th}/year$        | x    | 371,574                                                                                                    | 278,506                                                                                                     | 365,661                                                                                                      |
|               | Saved primary energy in comparison with baseline situation       | $MWh/year$             | x    | 103,584                                                                                                    | 83,781                                                                                                      | 111,424                                                                                                      |
|               | Energy efficiency of the project                                 | %                      | x    | 90%                                                                                                        | 92%                                                                                                         | 93%                                                                                                          |
|               | Energy recovery from waste/renewable sources                     | $MWh_{th}/year$        | x    | 287,426                                                                                                    | 236,862                                                                                                     | 299,777                                                                                                      |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation     | %                      | x    | 81%                                                                                                        | 96%                                                                                                         | 95%                                                                                                          |
|               | Yearly GHG emissions related to the project                      | $kton CO_2e/year$      | x    | 39                                                                                                         | 28                                                                                                          | 40                                                                                                           |
|               | Yearly pollutant emissions related to the project                | $ton/year$             | x    | SO <sub>2</sub> :0.8<br>N <sub>2</sub> O: 68<br>CO <sub>2</sub> : 19,154<br>PM: 2<br>NH <sub>3</sub> : 2.7 | SO <sub>2</sub> :0.8<br>N <sub>2</sub> O: 62<br>CO <sub>2</sub> : 10,150<br>PM: 1<br>NH <sub>3</sub> : 11.6 | SO <sub>2</sub> :1.0<br>N <sub>2</sub> O: 82<br>CO <sub>2</sub> : 15,400<br>PM: 0.4<br>NH <sub>3</sub> : 2.2 |
|               | Yearly reduction of polluting emission in comparison to baseline | %                      | x    | SO <sub>2</sub> :92%<br>CO <sub>2</sub> :91%                                                               | SO <sub>2</sub> :92%<br>CO <sub>2</sub> :99%                                                                | SO <sub>2</sub> :92%<br>CO <sub>2</sub> :98%                                                                 |
|               | Carbon footprint                                                 | $ton CO_2e/year$ (LCA) | x    | 86,971                                                                                                     | 71,270                                                                                                      | 91,916                                                                                                       |
|               | Ecological footprint                                             | ha                     | x    | 19,528                                                                                                     | 16,035                                                                                                      | 20,681                                                                                                       |
| SOCIAL        | Number of residents/users benefitting of the new project         |                        | x    | 29,145                                                                                                     | 25,685                                                                                                      | 32,583                                                                                                       |

Table 15: General KPIs – 9GOe

#### 4.1.3 Gothenburg demonstrator 7GOe “Industrial waste heat recovery”

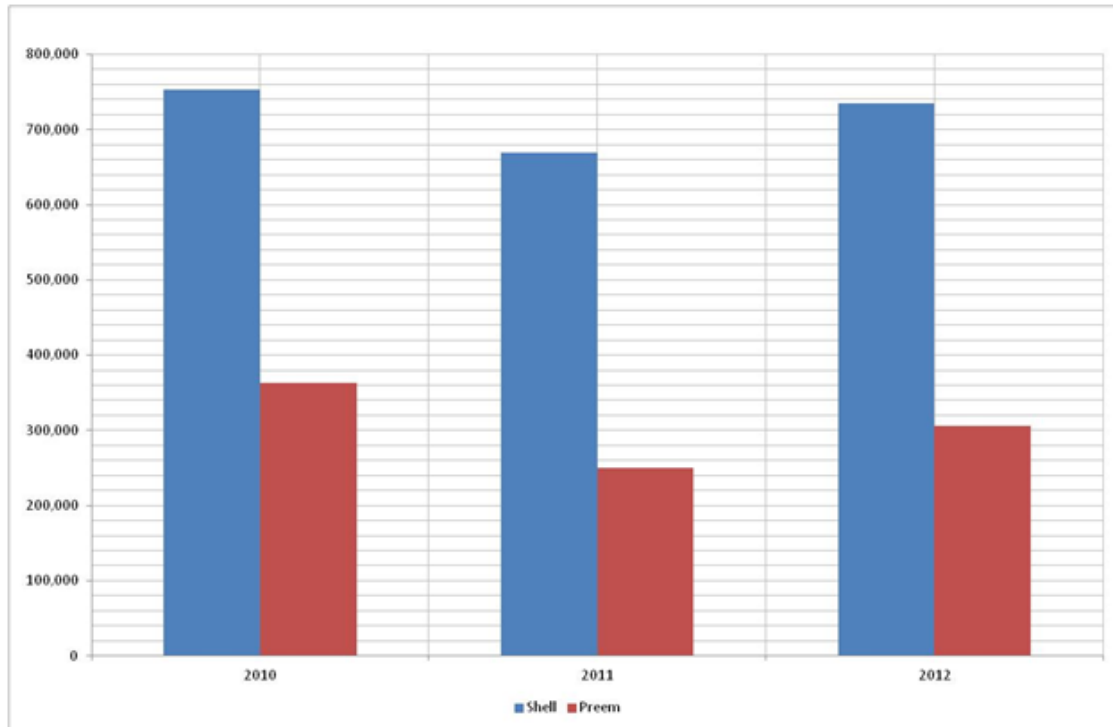
##### Demo description

The demonstrator includes two waste heat recovery facilities that are part of the Gothenburg district heating system. Waste heat from two oil refineries (Preem and Shell) are recovered and delivered to the district heating grid. Thanks to the implementation of this demonstrator, heat that would otherwise be lost to the environment is used to heat homes and produce domestic hot water. As a result, primary energy consumption at Göteborg Energi’s own facilities can be consequently reduced.

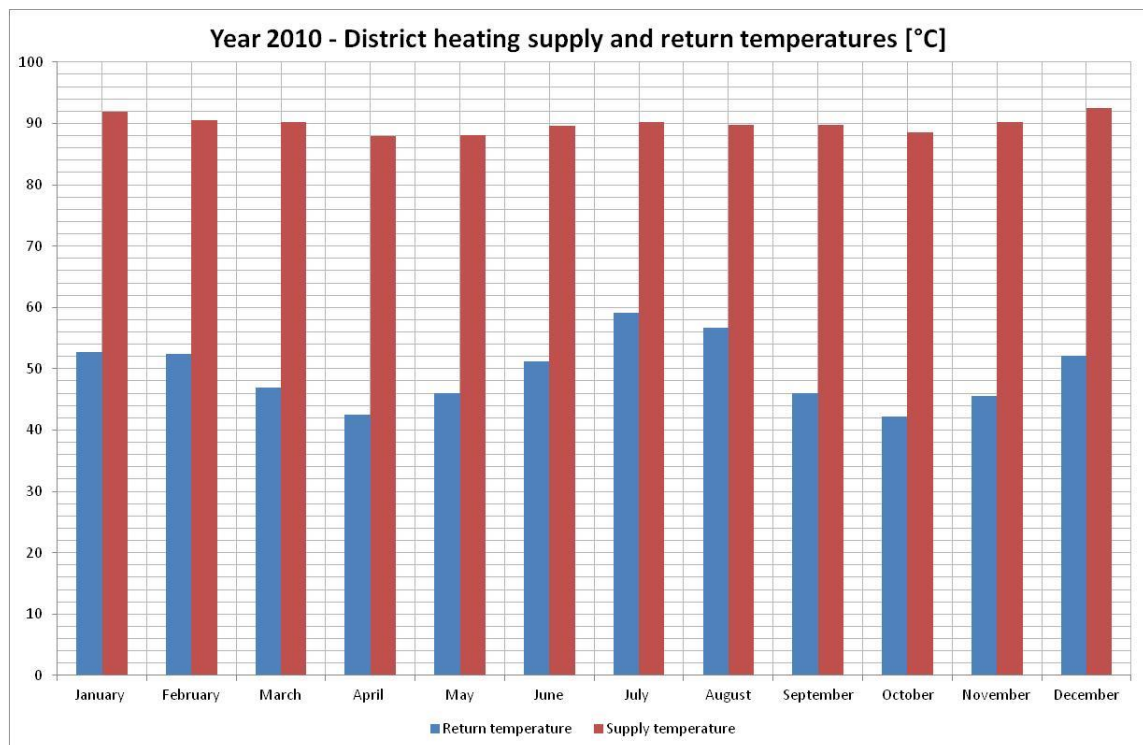
The monitored parameters available are presented in table below and cover the period 2010-2012.

| Technical parameters                        | Unit of measurement |
|---------------------------------------------|---------------------|
| Amount of waste heat recovered at each site | $[MWh_{th}]$        |
| District heating supply temperature         | [°C]                |
| District heating return temperature         | [°C]                |

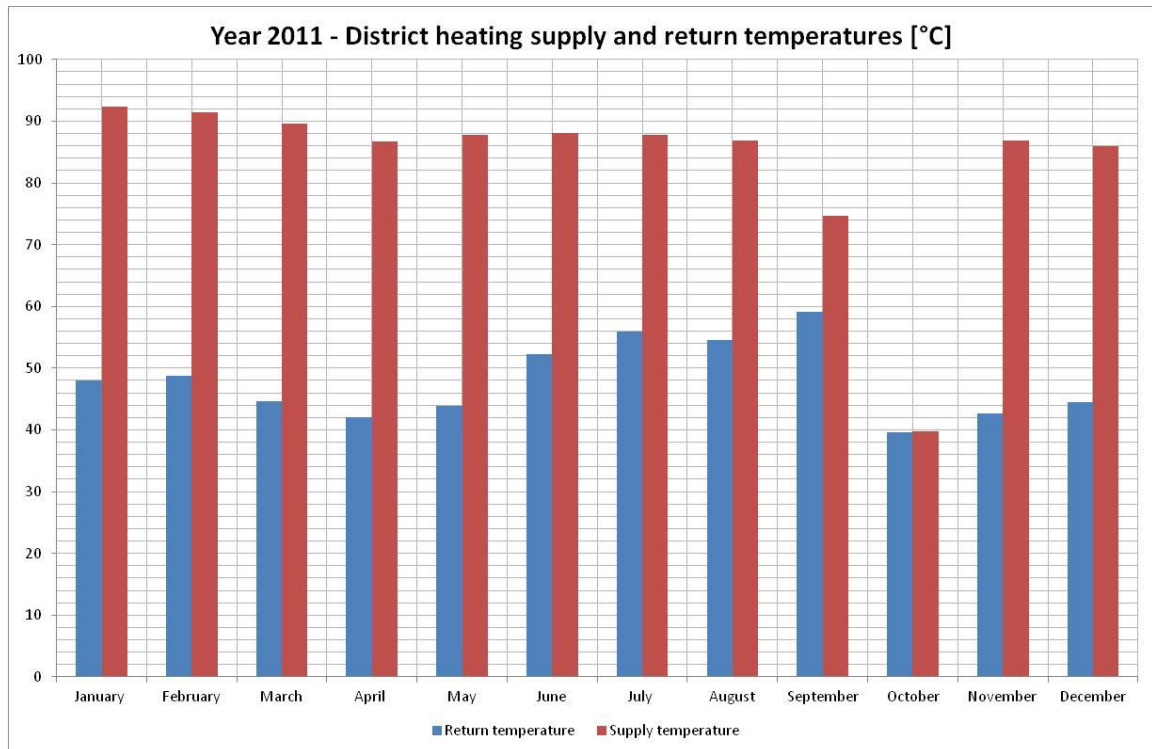
Table 16: 7GOe demo-Monitored parameters



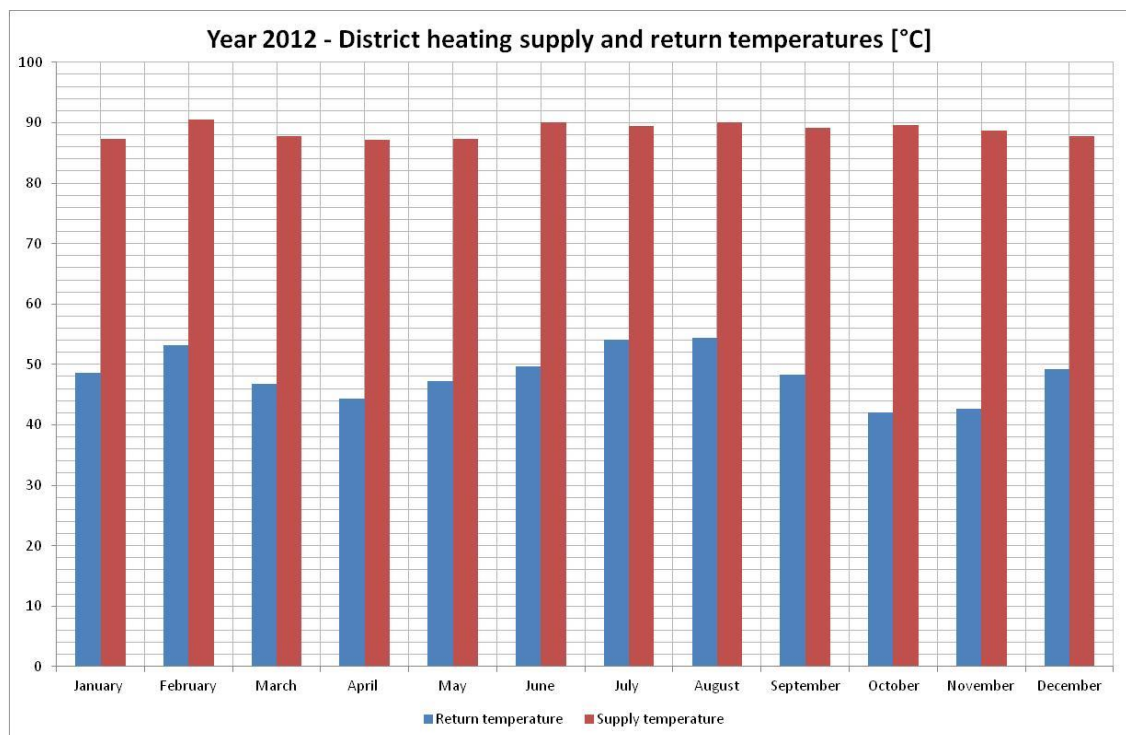
**Figure 12:** 7GOe- Annual amount of waste heat recovered [MWh<sub>th</sub>]



**Figure 13:** 7GOe- Monthly averaged supply and return temperatures [2010]



**Figure 14:** 7GOe- Monthly averaged supply and return temperatures [2011]



**Figure 15:** 7GOe- Monthly averaged supply and return temperatures [2012]

#### *Main assumptions for KPIs calculation*

- The baseline situation will be referred to the case of no waste heat recovering, consequently increasing the production of the natural gas fired boilers.

| Parameter                   | Unit of meas.   | Value | Comments and references |
|-----------------------------|-----------------|-------|-------------------------|
| $\eta_{NG \text{ boilers}}$ | -               | 0.9   | -                       |
| $PEF_{NG}$                  | -               | 1.1   | [13]                    |
| $E_{CO_2, NG}$              | $t_{CO_2e}/MWh$ | 0.202 | [6]                     |

**Table 17:** 7GOe – Baseline parameters

- The data used as reference for total thermal energy produced by GOTE DH network are data from the Sweden Energy Authority [9].

| ID       | Input parameters                  | Unit of meas. | Values |       |       |
|----------|-----------------------------------|---------------|--------|-------|-------|
|          |                                   |               | 2010   | 2011  | 2012  |
| $Q_{DH}$ | Total district heating production | $GWh_{th}$    | 4,067  | 3,459 | 3,580 |

**Table 18:** Gothenburg total DH production

- Environmental parameters:
  - Primary energy savings calculations: according to [13] primary energy factor from the use of waste industrial heat is to be considered equal 0.05.
  - Emissions to air calculation: it has been assumed to consider pollutants emissions related only to electric energy consumptions of the system's electricity-driven pumps since the demonstrator provides heat to the district heating network by means of recovering waste thermal energy from the two already existing oil refineries. Pump's electric energy consumptions shown in table 21 have been estimated on the basis of the parameters reported in the following table.

| Parameter     | Unit of meas. | Value | Comments and references                                                     |
|---------------|---------------|-------|-----------------------------------------------------------------------------|
| $\eta_{pump}$ | -             | 0.9   | -                                                                           |
| L             | km            | 1     | Assumed distance between the refineries and closest connection point to DHN |
| $\Delta p$    | $m_{H_2O}/km$ | 10    | -                                                                           |

**Table 19:** Assumed parameters for calculating pump's electricity consumptions

- Social parameters: in order to calculate the number of users benefitting of the 7GOe demonstrator, the fraction of thermal energy produced by the demo plant has been multiplied for the total number of customers of district heating network, reported in the following table [14]. See social KPIs in table 21.

|       | Total housing units in Gothenburg | Residents per dwelling (no. of people) | Residents in Gothenburg (no. of people) |                  | Percentage of Gothenburg residents with DH |
|-------|-----------------------------------|----------------------------------------|-----------------------------------------|------------------|--------------------------------------------|
|       |                                   |                                        | Total                                   | Connected to DHN |                                            |
| Flat  | 197,296                           | 1.6                                    | 315,674                                 | 284,000          | 90%                                        |
| House | 52,866                            | 3.4                                    | 179,744                                 | 35,000           | 19%                                        |
| Total | 250,162                           | 1.9                                    | 495,418                                 | 319,000          | 64%                                        |

**Table 20:** 7GOe – Social parameters

#### 4.1.3.1 Demo-specific KPI

In the following table demo-specific KPIs are presented.

| ID     | KPI                                                                         | Unit of Measurement | Formula                                                 | Comments                                          | 2010          | 2011          | 2012          |
|--------|-----------------------------------------------------------------------------|---------------------|---------------------------------------------------------|---------------------------------------------------|---------------|---------------|---------------|
| 7GOeT1 | Waste heat temperature, yearly average                                      | °C                  | $Te_{waste,average}$                                    | Values provided for each waste heat recovery site | Not available | Not available | Not available |
| 7GOeT2 | Share of Gothenburg district heating produced by this demonstrator          | %                   | $\frac{\sum_{year} Q_{rec,DH}}{\sum_{year} Q_{mix,DH}}$ |                                                   | 27%           | 27%           | 29%           |
| 7GOeT3 | District heating supply temperature (yearly, monthly and seasonal averages) | °C                  | $\frac{\sum_{period} Te_{s,DH}}{period}$                | <b>Preem</b> yearly average                       | 90°C          | 83°C          | 89°C          |
|        |                                                                             |                     |                                                         | Winter average                                    | 91°C          | 89°C          | 89°C          |
|        |                                                                             |                     |                                                         | Summer average                                    | 89°C          | 85°C          | 89°C          |
|        |                                                                             |                     |                                                         | <b>Shell</b> yearly average                       | 90°C          | 84°C          | 84°C          |
|        |                                                                             |                     |                                                         | Winter average                                    | 91°C          | 86°C          | 84°C          |
|        |                                                                             |                     |                                                         | Summer average                                    | 88°C          | 81°C          | 83°C          |
| 7GOeT4 | District heating return temperature (yearly, monthly and seasonal averages) | °C                  | $\frac{\sum_{period} Te_{r,DH}}{period}$                | <b>Preem</b> yearly average                       | 49°C          | 48°C          | 48°C          |
|        |                                                                             |                     |                                                         | Winter average                                    | 49°C          | 45°C          | 47°C          |
|        |                                                                             |                     |                                                         | Summer average                                    | 50°C          | 51°C          | 50°C          |
|        |                                                                             |                     |                                                         | <b>Shell</b> yearly average                       | 48°C          | 47°C          | 46°C          |
|        |                                                                             |                     |                                                         | Winter average                                    | 46°C          | 44°C          | 43°C          |
|        |                                                                             |                     |                                                         | Summer average                                    | 51°C          | 50°C          | 49°C          |
| 7GOeT5 | Electric energy consumption needed for recovering waste heat                | MWhe/year           | $\sum_{year} C_{tot}$                                   | Values provided for each waste heat recovery site | 727           | 598           | 677           |

**Table 21:** Demo-specific KPIs-7GOe

#### 4.1.3.2 General KPI

In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                 | UM                         | 7GOe | 2010                                     | 2011                                     | 2012                                     |
|---------------|--------------------------------------------------------------|----------------------------|------|------------------------------------------|------------------------------------------|------------------------------------------|
| ENERGETIC     | Saved primary energy in comparison with baseline situation   | MWh/year                   | x    | 1,049,172                                | 863,880                                  | 977,469                                  |
|               | Energy efficiency of the project                             | %                          | x    | 85% (estimated heat exchange efficiency) | 85% (estimated heat exchange efficiency) | 85% (estimated heat exchange efficiency) |
|               | Energy recovery from waste/renewable sources                 | MWh/year                   | x    | 1,116,135                                | 919,017                                  | 1,039,856                                |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation | %                          | x    | 95%                                      | 95%                                      | 95%                                      |
|               | Yearly GHG emissions related to the project                  | ton CO <sub>2</sub> e/year | x    | 17                                       | 14                                       | 16                                       |
|               | Carbon footprint                                             | ton C/year                 | x    | 57.4                                     | 47.2                                     | 53.5                                     |
|               | Ecological footprint                                         | ha                         | x    | 12.9                                     | 10.6                                     | 12.0                                     |
| SOCIAL        | Number of residents/users benefitting of the new project     |                            | x    | 87,545                                   | 84,755                                   | 92,658                                   |

**Table 22:** General KPIs-7GOe

#### 4.1.4 Gothenburg demonstrator 8GOe “Recovery of heat - waste incinerator”

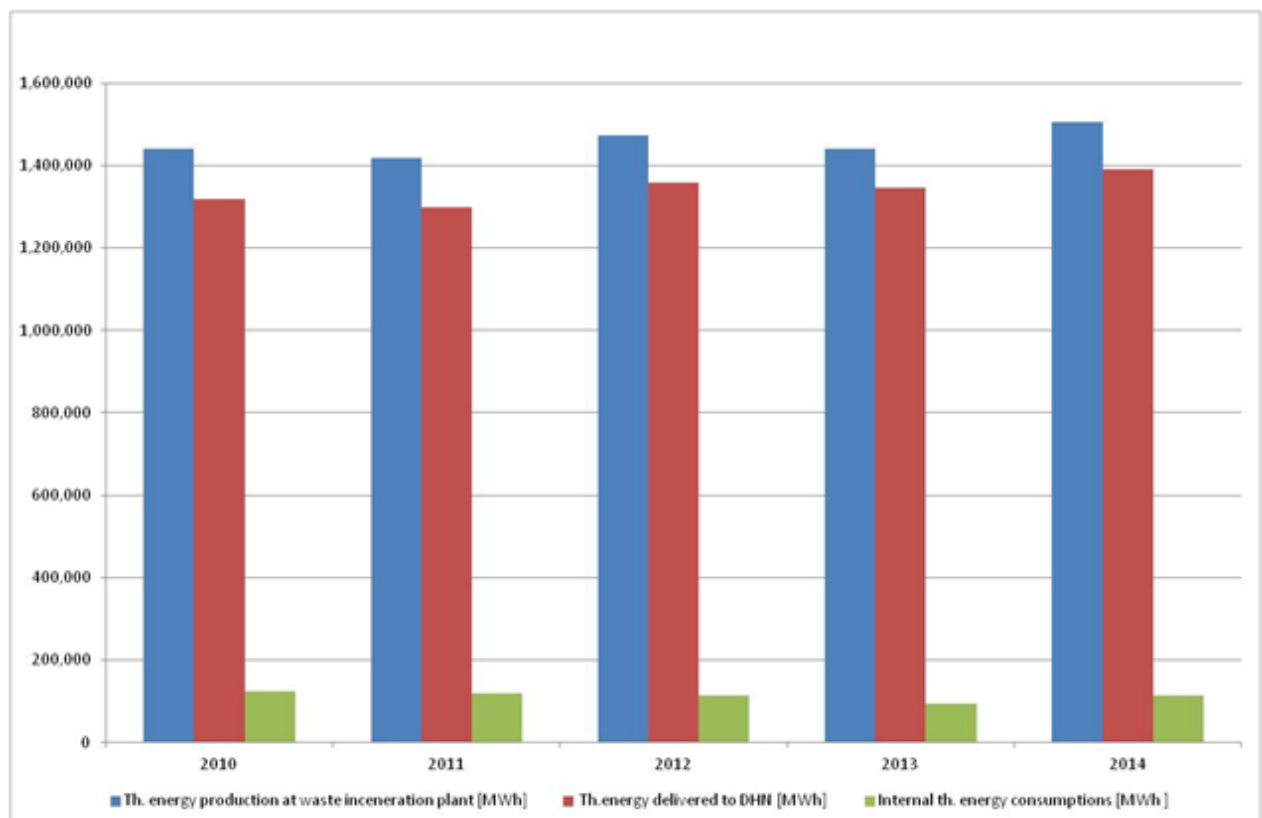
##### *Demo description*

The 8GOe demonstrator aims at recovering the waste heat from an incineration plant in Gothenburg, operated by Renova (a waste management and recycling company). The demonstrator consists of a combined heat and power plant that produces both electric and thermal energy. More in detail, the waste-fired boiler produces saturated steam that expands in a counter-pressure turbine to produce electricity. At the discharge of the turbine, the wet steam is condensed using district heating water and the transferred heat is delivered to the network. An additional source of hot water is heat recovered from flue gases.

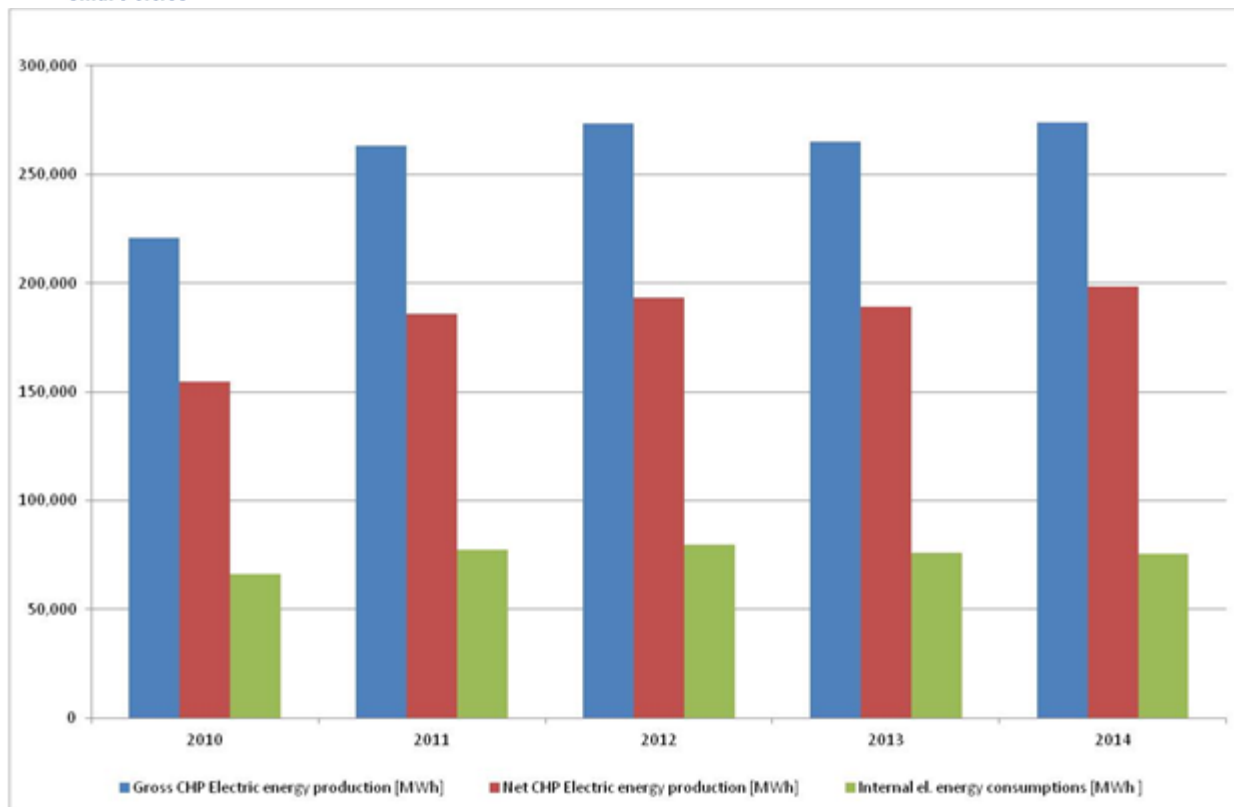
The monitored parameters available are presented in table below and cover the period 2010-2014 (RENOVA reports [15], [16], [17] and [18]).

| Technical parameters                                         | Unit of measurement  |
|--------------------------------------------------------------|----------------------|
| Heat produced at the waste incinerator plant                 | [MWh <sub>th</sub> ] |
| Heat recovered from the flue gases of the combustion chamber | [MWh <sub>th</sub> ] |
| Heat delivered to the district heating network               | [MWh <sub>th</sub> ] |
| CHP electric energy production (gross values)                | [MWh <sub>e</sub> ]  |
| Internal consumption of electric energy                      | [MWh <sub>e</sub> ]  |
| Amount of waste incinerated                                  | [tons]               |

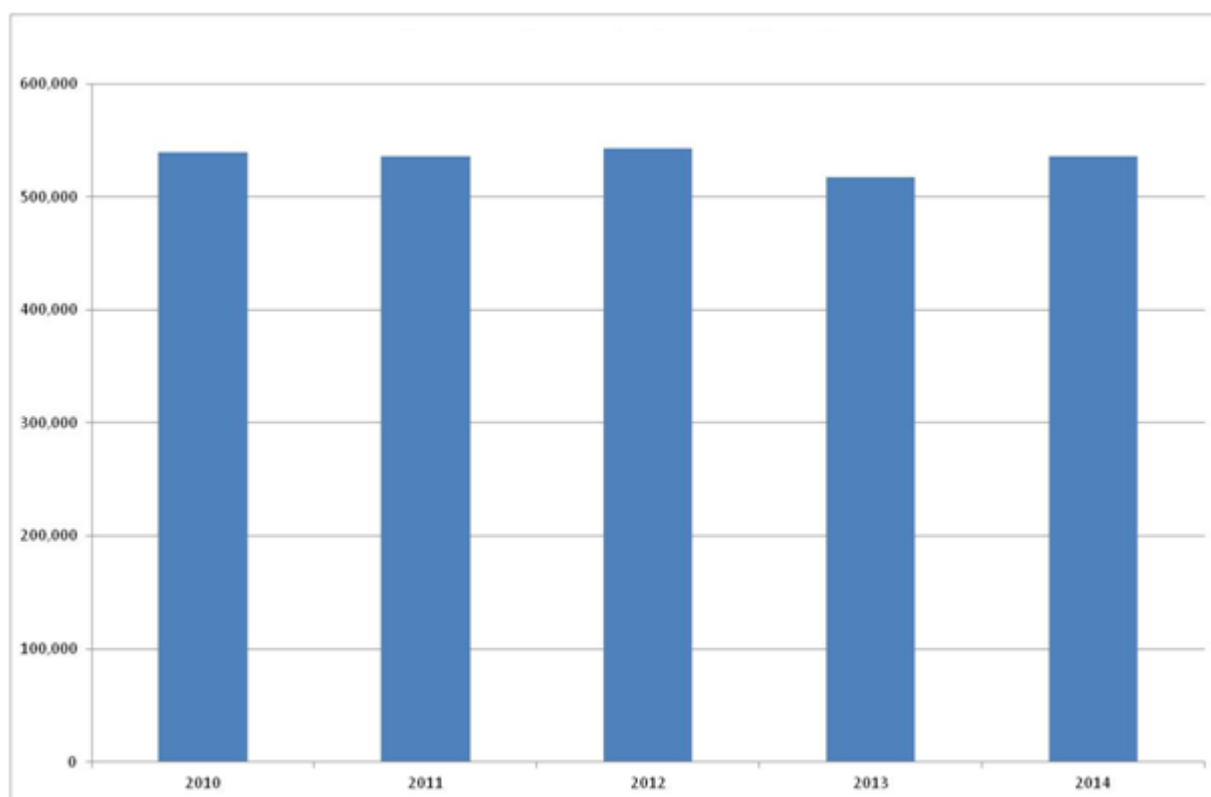
**Table 23:** 8GOe demo-Monitored parameters



**Figure 16:** 8GOe- Annual thermal energy production at the waste incinerator plant [MWh<sub>th</sub>]



**Figure 17:** 8GOe- Annual electric energy production at the CHP [MWh<sub>e</sub>]



**Figure 18:** 8GOe- Annual amount of incinerated waste [tons]

### Main assumptions for KPIs calculation

- The baseline situation is referred to the case of no waste heat recovery, resulting in a consequent increase of the production of both natural gas boilers for thermal energy production and natural gas-fired turbines for electric energy production.

| Parameter                    | Unit of meas.   | Value | Comments and references |
|------------------------------|-----------------|-------|-------------------------|
| $\eta_{NG \text{ boilers}}$  | -               | 0.90  | -                       |
| $\eta_{NG \text{ turbines}}$ | -               | 0.40  | -                       |
| PEF, NG                      | -               | 1.10  | [13]                    |
| $E_{CO_2, NG}$               | $t_{CO_2e}/MWh$ | 0.202 | [6]                     |

**Table 24:** 8GOe- Baseline parameters

- The data used as reference for total thermal energy produced by GOTE district heating network are from the Sweden Energy Authority [9].

| ID       | Input parameters                  | Unit of meas. | Values |       |       |       |
|----------|-----------------------------------|---------------|--------|-------|-------|-------|
|          |                                   |               | 2010   | 2011  | 2012  | 2013  |
| $Q_{DH}$ | Total district heating production | $GWh_{th}$    | 4,067  | 3,459 | 3,580 | 3,774 |

**Table 25:** Gothenburg total DH production

- Environmental parameters:
  - Primary energy savings calculations: according to [13] primary energy factor from the use of waste as fuel for energy production is to be considered equal to zero.
  - Emissions to air calculation: it has been assumed to consider pollutants emissions related only to electric energy consumptions of the system's electricity-driven pumps, since the demonstrator provides heat to the district heating network by means of recovering waste thermal energy from the already existing waste incinerator. Pump's electric energy consumptions have been estimated on the basis of the parameters reported in the following table.

| Parameter     | Unit of meas. | Value | Comments and references                                                     |
|---------------|---------------|-------|-----------------------------------------------------------------------------|
| $\eta_{pump}$ | -             | 0.9   | -                                                                           |
| L             | km            | 1     | Assumed distance between the refineries and closest connection point to DHN |
| $\Delta p$    | $m_{H_2O}/km$ | 10    | -                                                                           |

**Table 26:** Assumed parameters for calculating electric energy consumption

- Social parameters: in order to calculate the number of users benefitting of the 8GOe demonstrator, the fraction of thermal energy produced by the demo plant has been multiplied for the total number of customers of district heating network, reported in the following table [14]. See social KPIs in table 27.

|              | Total housing units in Gothenburg | Residents per dwelling (no. of people) | Residents in Gothenburg (no. of people) |                  | Percentage of Gothenburg residents with DH |
|--------------|-----------------------------------|----------------------------------------|-----------------------------------------|------------------|--------------------------------------------|
|              |                                   |                                        | Total                                   | Connected to DHN |                                            |
| <b>Flat</b>  | 197,296                           | 1.6                                    | 315,674                                 | 284,000          | 90%                                        |
| <b>House</b> | 52,866                            | 3.4                                    | 179,744                                 | 35,000           | 19%                                        |
| <b>Total</b> | 250,162                           | 1.9                                    | 495,418                                 | 319,000          | 64%                                        |

**Table 27:** 8GOe – Social parameters

#### 4.1.4.1 Demo-specific KPI

In the following table demo-specific KPIs are presented.

| ID     | KPI                                                                        | Unit of Meas.   | Formula                                              | 2010    | 2011    | 2012    | 2013    |
|--------|----------------------------------------------------------------------------|-----------------|------------------------------------------------------|---------|---------|---------|---------|
| 8GOeT1 | Percentage of Gothenburg district heating produced by this demonstrator    | %               | $\frac{\sum_{year} Q_{inc}}{\sum_{year} Q_{DH,mix}}$ | 32%     | 38%     | 38%     | 36%     |
| 8GOeT2 | Yearly net electric energy production                                      | MWhe            | $\sum_{year} P_{inc} - \sum_{year} C_{inc}$          | 154,754 | 185,653 | 193,307 | 189,072 |
| 8GOeT3 | Power-to-heat ratio (ratio between electric and thermal energy production) | (dimensionless) | $\frac{8GOeT2}{\sum_{year} Q_{inc}}$                 | 0.12    | 0.14    | 0.14    | 0.14    |
| 8GOeT4 | Amount of incinerated waste (tons)                                         | tons/year       | $\sum_{year} V_{waste}$                              | 539,118 | 535,811 | 542,520 | 517,772 |

**Table 28:** Demo-specific KPIs-8GOe

#### 4.1.4.2 General KPI

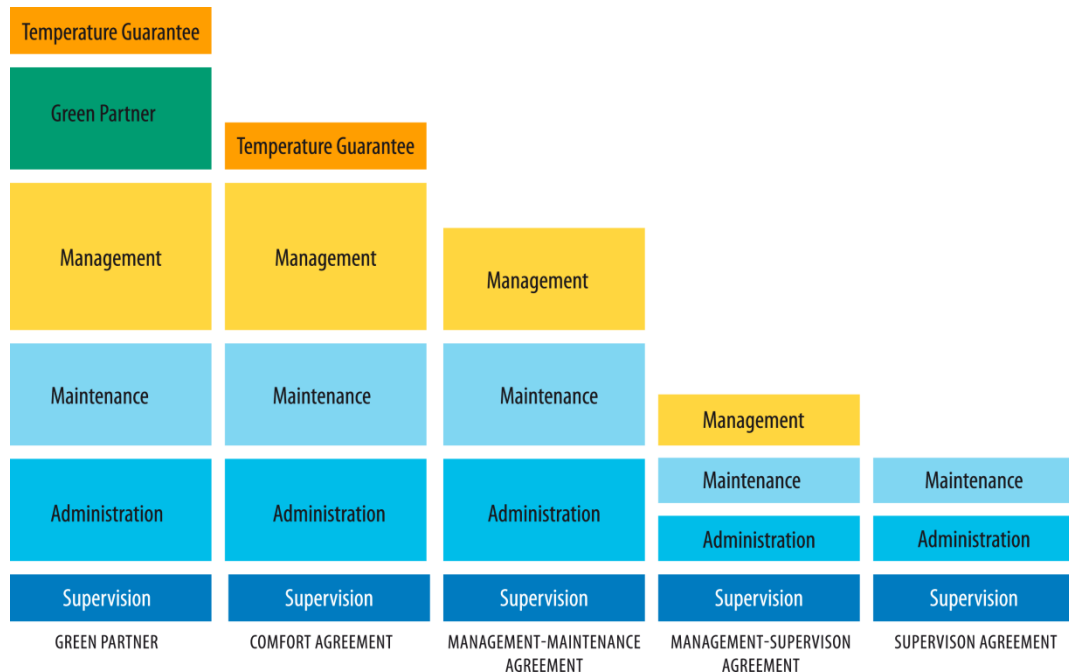
In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                   | UM                         | 8GOe | 2010      | 2011      | 2012      | 2013      |
|---------------|----------------------------------------------------------------|----------------------------|------|-----------|-----------|-----------|-----------|
| ENERGETIC     | The yearly amount of thermal energy provided by the new system | MWhth/year                 | x    | 1,440,620 | 1,419,300 | 1,472,253 | 1,439,466 |
|               | Saved primary energy in comparison with baseline situation     | MWh/year                   | x    | 2,366,619 | 2,457,040 | 2,549,113 | 2,486,116 |
|               | Energy efficiency of the project                               | %                          | x    | 89%       | 88%       | 89%       | 90%       |
|               | Energy recovery from waste/renewable sources                   | MWhth/year (TOTAL PR)      | x    | 1,661,547 | 1,682,574 | 1,745,496 | 1,745,496 |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation   | %                          | x    | 99%       | 99%       | 99%       | 99%       |
|               | Yearly GHG emissions related to the project                    | ton CO <sub>2</sub> e/year | x    | 22        | 21        | 22        | 22        |
|               | Carbon footprint                                               | ton C/year                 | x    | 74.1      | 73.0      | 75.7      | 74        |
|               | Ecological footprint                                           | ha                         | x    | 16.7      | 16.4      | 17.0      | 16.6      |
| SOCIAL        | Number of residents/users benefitting of the new project       |                            | x    | 103,320   | 119,823   | 121,019   | 113,768   |

**Table 29:** General KPIs-8GOe

#### 4.1.5 Gothenburg demonstrator 29GOe “Climate Agreement”

There are five energy service agreements offered by Göteborg Energi, and the Climate Agreement, also called Comfort Agreement, is only one of them that include services to customers (see picture below). Interviews to GOTE (carried out in the framework of WP5 by the involved partners) provided useful insights into the adopted strategy for approaching customers with the different types of agreements and were included in D5.2 [19].



**Figure 19:** The five energy service agreements that Göteborg Energi offers.

The overall aim of this demonstrator is to offer the customers a non-conventional energy contract (“Climate Agreement”) by providing a set indoor temperature (e.g. 21 °C) at a fixed cost, instead of a certain quantity of energy (kWh). The proposed agreement is offered either for a five or three years duration and by now has been undersigned by customers within different areas for a total extension of 3.6 million square meters. The energy company (GOTE) takes responsibility of the building energy system and by the agreement gets incentives to save energy as well as continuously maintain the system, providing also information to customers about their energy consumptions.

In the framework of current paragraph, the performance of one building in Gothenburg under Climate Agreement and monitored since 2011, is presented.

This property is heated by district heating and hydronic radiators and it is equipped with cooling distributed through the ventilation systems. The house has a solar power plant for electricity generation. The photovoltaic system consists of 78 modules for a total power of almost 13 kW.

The building has undergone different measures to improve energy efficient, and the diagrams below show the monthly heat consumptions. Figures below show the average value before and after the installation of the new control system.

#### Main assumptions for KPIs calculations

- The same building with standard energy contracts before signing the Climate Agreement has been considered as the baseline situation.
- The main features of Vingen building are presented in table below.

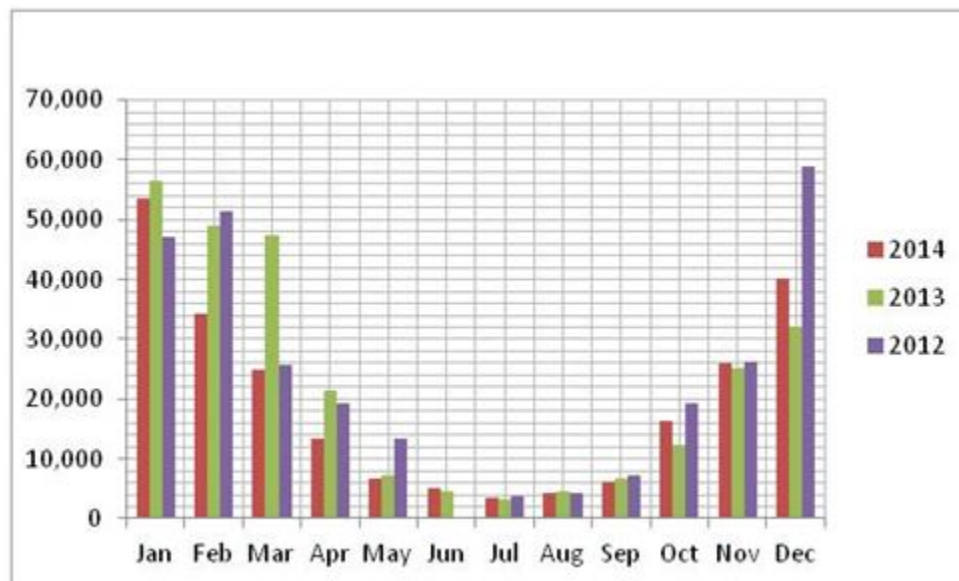
|                                 |                                            |
|---------------------------------|--------------------------------------------|
| <b>Building Name</b>            | Vingen                                     |
| <b>Number of floors</b>         | 5                                          |
| <b>Area</b>                     | 4800 m <sup>2</sup>                        |
| <b>Functional type</b>          | Offices and culture centre                 |
| <b>Energy efficient measure</b> | Kabona management system (since June 2011) |

**Table 30** Vingen building main features

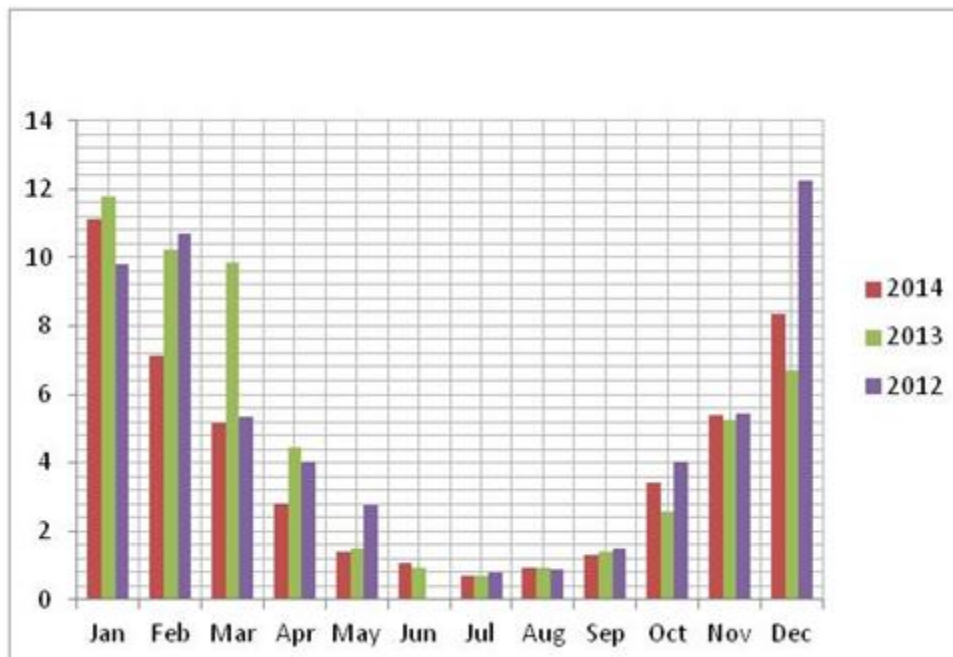
- The assumed tariff for thermal energy from district heating network is equal to 0.061€/kWh<sub>th</sub> [9]
- The monitored parameters available are presented in table and charts below and cover the period 2012-2014.

| <b>Technical parameters</b>                                               | <b>Unit of measurement</b> |
|---------------------------------------------------------------------------|----------------------------|
| Monthly thermal energy consumptions                                       | [kWh <sub>th</sub> ]       |
| Monthly total energy consumptions (including electricity, thermal energy) | [kWh]                      |
| Rooms temperatures                                                        | [°C]                       |

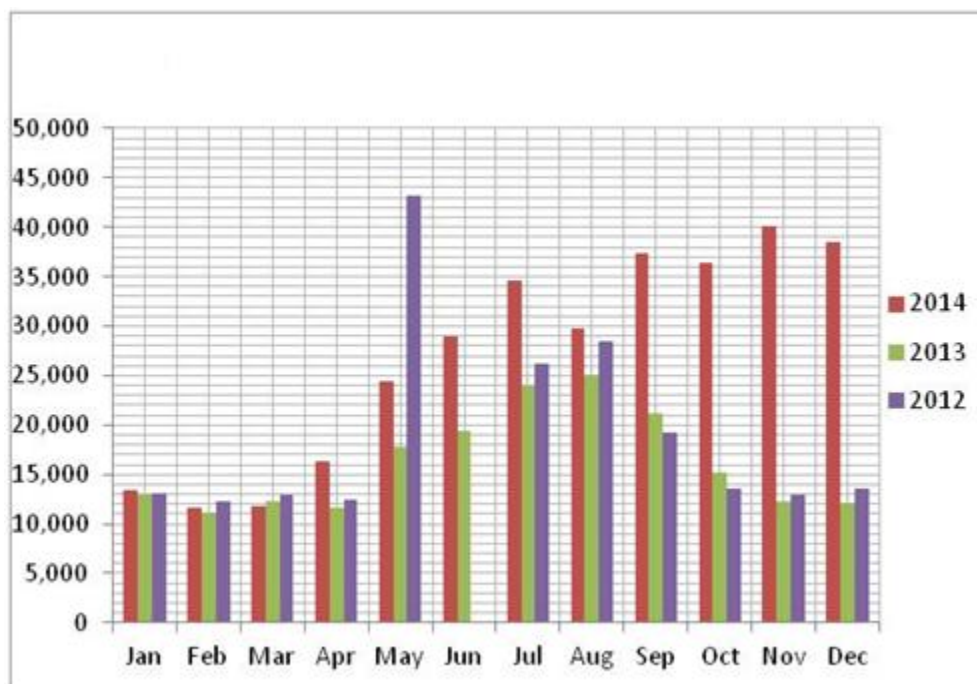
**Table 31:** 29GOe demo-Monitored parameters



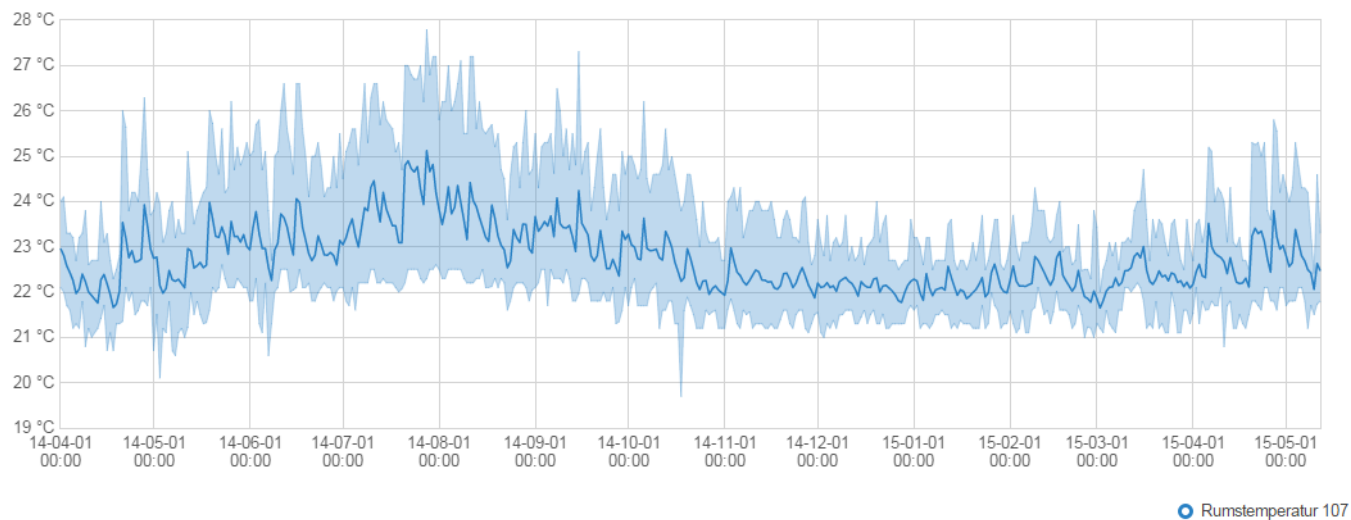
**Figure 20:** Vingen building-Monthly thermal energy consumptions [kWh<sub>th</sub>]



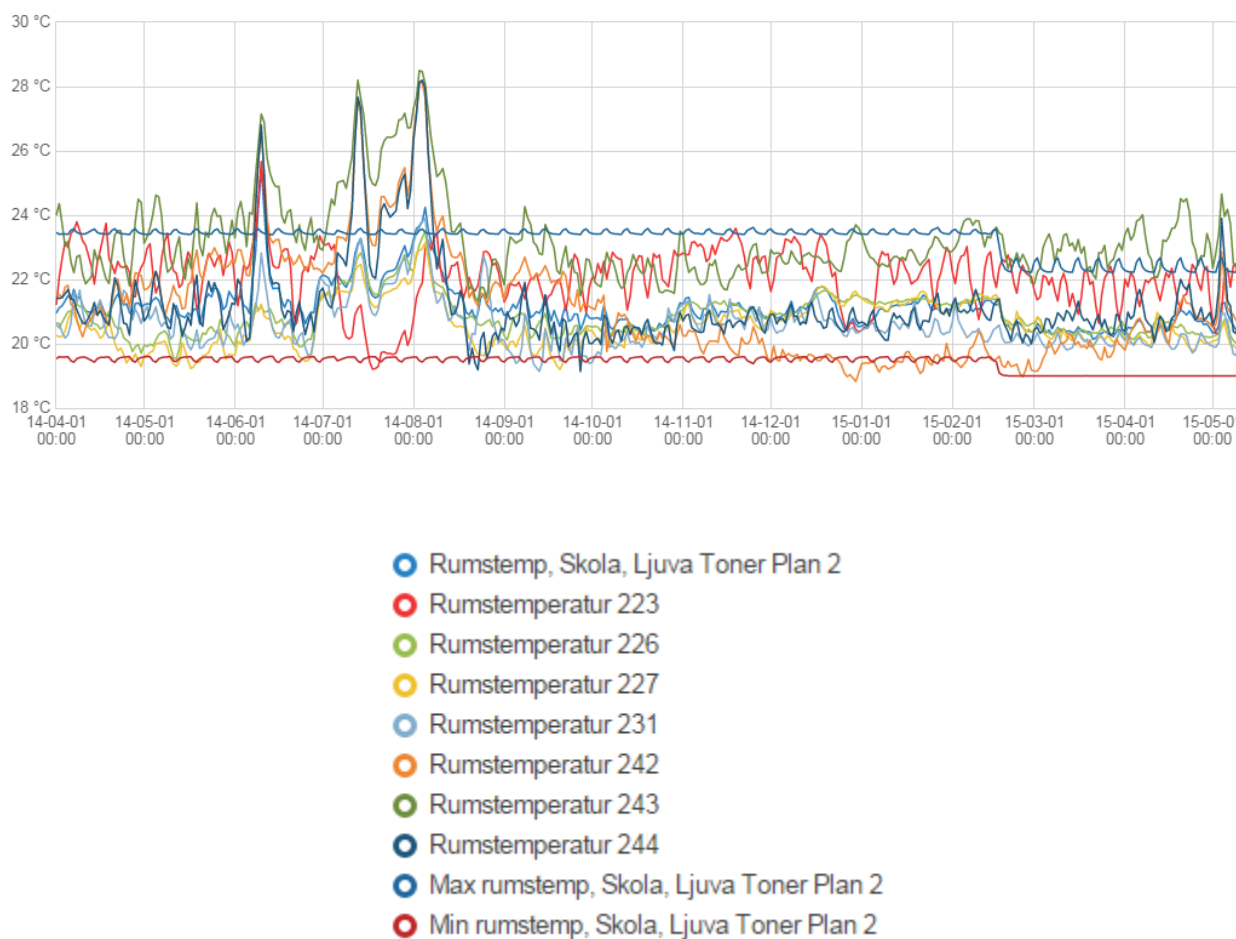
**Figure 21:** Vingen building- Specific monthly thermal energy consumptions [ $\text{kWh}_{\text{th}}/\text{m}^2$ ]



**Figure 22:** Vingen building- Monthly total energy consumptions [kWh]



**Figure 23:** Vingen building- Indoor temperature for one room [°C]-Year 2014



**Figure 24:** Vingen building- Indoor temperature all rooms [°C]-Year 2014

#### 4.1.5.1 Demo-specific KPI

In the following tables demo-specific KPIs are presented.

| ID      | KPI                                                                                                                            | Unit of Measurement                                 | Formula                                                                       | 2012                                                    | 2013                                                    | 2014                                                    |
|---------|--------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------|---------------------------------------------------------|---------------------------------------------------------|
| 29GOeT1 | Yearly thermal energy consumption in buildings with “climate agreement” (only Vingen building)                                 | MWhth/year                                          | $\sum_{year} Q_{agreement}$                                                   | 276.2                                                   | 270.2                                                   | 234.2                                                   |
| 29GOeT2 | Yearly thermal energy consumption per square meter of heated area in buildings with “climate agreement” (only Vingen building) | kWhth/m <sup>2</sup> year                           | $\frac{\sum_{year} Q_{agreement}}{A_{temp}}$                                  | 48.8                                                    | 56.3                                                    | 57.5                                                    |
| 29GOeT3 | Yearly reduction in thermal energy consumption in comparison with baseline situation (only Vingen building)                    | kWh/year and % with reference to baseline situation | $\frac{\sum_{year} (Q_{agreement} - Q_{baseline})}{\sum_{year} Q_{baseline}}$ | Estimated yearly average<br>23kWh/m <sup>2</sup><br>52% | Estimated yearly average<br>23kWh/m <sup>2</sup><br>59% | Estimated yearly average<br>23kWh/m <sup>2</sup><br>60% |

**Table 32-** Technical KPIs (29GOe)

| ID       | KPI                                            | Unit of Measurement | Formula                                                                                         | 2012  | 2013  | 2014  |
|----------|------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------|-------|-------|-------|
| 29GOeEc1 | Yearly savings for the end-user (one building) | €/year              | $T_{th,end-user,baseline} \sum_{year} Q_{baseline} - T_{th,end-user} \sum_{year} Q_{agreement}$ | 6,730 | 6,730 | 6,730 |

**Table 33-** Economic KPIs (29GOe)

#### 4.1.6 Gothenburg demonstrator 20GOe “Solar heat by district heating system”

##### Demo description

As presented in D4.1, the 20GOe demonstrator is a system of solar collectors placed on the roof of a multi-dwelling building in Gårdsten, Gothenburg. The building is connected to the district heating network and the installed system offsets the district heating demand of the building by supplying heat from a renewable source to heat spaces and to produce domestic hot water, by reducing the quantity of heat that has to be produced at Göteborg Energi’s production facilities.

The defined baseline situation refers to heat entirely supplied by the district heating system, i.e. the current production mix of the Gothenburg network will be compared to the solar heat system.

General information about the present demonstrators is listed below:

- Solar collector field: 12 modules of Arcon HT, total aperture area 150,72 m<sup>2</sup>;
- Azimuth: 0°;
- Collector tilt: 35°.

##### Main assumptions for KPIs calculation

- The original use of coal boiler is assumed as the baseline situation for estimating the performance of the demonstrator. Coal boiler efficiency is assumed equal to 85% [4]. The main parameters used as reference for KPI calculation are presented in table below. The evaluation with the baseline situation has been carried out considering both CHP and natural gas fired boilers (for peak loads) thermal productions.

| Parameter              | Unit of meas.                         | Value | Comments and references                                                                                      |
|------------------------|---------------------------------------|-------|--------------------------------------------------------------------------------------------------------------|
| PEF, DHN               | -                                     | 0.04  | Assuming the following energy production mix:<br>74% waste heat, 9% natural gas, 12% biofuel, 5% electricity |
| E, DHN                 | g CO <sub>2</sub> /kWh <sub>th</sub>  | 0.019 |                                                                                                              |
| η <sub>DHN</sub>       | -                                     | 0.92  | Calculated as the ratio between of thermal energy produced and delivered to customers [30]                   |
| PEF, current situation | -                                     | 1     | [5]                                                                                                          |
| E, current situation   | kg CO <sub>2</sub> /kWh <sub>th</sub> | 0     | Solar thermal plant                                                                                          |

**Table 34:** 20GOe-Baseline parameters

##### 4.1.6.1 Demo-specific KPI

The following technical KPI have been assessed:

- 20GOeT1, Specific heat output (kWh/(a·m<sup>2</sup>)) The plant has now been in operation for a few years (since 2011), and during this time some corrections and changes have been performed in order to enhance the energy output. To have the fairest evaluation for this report it is limited to the production of last year (2014).

|              | Real prod. 2014   | Real prod. 2014/m <sup>2</sup> |
|--------------|-------------------|--------------------------------|
| Jan          | 50                | 0.33                           |
| Feb          | 100               | 0.66                           |
| Mars         | 3,800             | 25.21                          |
| April        | 7,200             | 47.8                           |
| May          | 9,700             | 64.36                          |
| June         | 8,000             | 53.08                          |
| July         | 10,800            | 71.66                          |
| Aug          | 5,600             | 37.15                          |
| Sept         | 7,700             | 51.09                          |
| Okt          | 1,300             | 8.63                           |
| Nov          | 100               | 0.66                           |
| Dec          | 50                | 0.33                           |
| <b>Total</b> | <b>54,400 kWh</b> |                                |

**Table 35:** Thermal energy production (2014)-20GOe

- 20GOeT2, Temperature of delivered heat (yearly average)(C°)  
The temperature of the solar energy fed into to district heating system is constant, 80°C is what the control program demands of the temperature measured on the district heating side of the solar heat exchanger. Due to a very big district heating flow rate, the return temperature to the solar collector field varies a lot. This gives a big variation of the temperature from the solar collector.
- 20GOeT3, Period of the year with significant heat production (months). In comparison to the delivery of energy in the district heating system the solar energy is neglectable. The peak power of the solar thermal plant is in the range of 75 kW (sunny days June/July), whereas the domestic heat base load in July is 150 MW. Surplus energy is even dumped now and then during the summer, since the system is obliged to feed in waste heat from refineries and the Sävenäs waste heat power plant. Locally in the buildings on which the solar collectors are installed the contribution from solar is important during the summer months.

In the following table demo-specific KPIs are presented.

| ID      | KPI                                                              | Unit of Measurement                          | Values             | Comments                                                           |
|---------|------------------------------------------------------------------|----------------------------------------------|--------------------|--------------------------------------------------------------------|
| 20GOeT1 | Specific heat output                                             | <i>kWh/year m<sup>2</sup> collector area</i> | 54,400             | Delivered to the district heating system, not the total production |
| 20GOeT2 | Temperature of delivered heat (yearly average)                   | °C                                           | 80                 |                                                                    |
| 20GOeT3 | Period of the year with significant heat production              | <i>(months)</i>                              | March to September |                                                                    |
| 20GOeT4 | District heating supply temperature, yearly and monthly averages | °C                                           | 91                 |                                                                    |
| 20GOeT5 | District heating return temperature, yearly and monthly averages | °C                                           | 46                 |                                                                    |

**Table 36:** Demo- specific KPIs-20GOe

#### 4.1.7 Gothenburg demonstrator 11GOe “Cooling by river water”

##### *Demo description*

As presented in D4.1, the aim of this demonstrator, “Cooling by river water”, is to produce cooling energy for the district cooling network by means of using river water in heat exchangers used to cool water, i.e. free cooling. Total installed capacity is 15 MW and 43 GWh are produced yearly, corresponding to 35 % of the total district cooling production in Gothenburg.

##### *Main assumptions for KPIs calculation*

- Electric chillers used for cooling individual buildings are considered as the baseline situation of this specific case.

| Parameter               | Unit of meas. | Value | Comments and references |
|-------------------------|---------------|-------|-------------------------|
| SPF <sub>chillers</sub> | -             | 2     | [20]                    |

**Table 37:** 11GOe-Baseline parameters

- The reference year for KPI calculations is 2013

#### 4.1.7.1 Demo-specific KPI

In the following table demo-specific KPIs are presented.

| ID      | KPI                                                                                              | Unit of Measurement | Values                                                                                                                              | Comments                                                                                                               |
|---------|--------------------------------------------------------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|
| 11GOeT1 | Share of district cooling produced as free cooling by river water                                | %                   | 24                                                                                                                                  |                                                                                                                        |
| 11GOeT2 | Period of the year when river water can be used directly in district cooling                     | Date-date           | Free cooling 100 % of district cooling production December-March<br>Free cooling 0-100 % of district cooling production October-May |                                                                                                                        |
| 11GOeT3 | Seasonal performance factor                                                                      | -                   | 9.2                                                                                                                                 | Incl. distribution losses of 2 % and electricity in distribution pumps, i.e. factor for cooling delivered to customer. |
| 11GOeT4 | Yearly consumption of electric energy                                                            | MWhe/year           | 979                                                                                                                                 | Including production (587 MWh) and distribution                                                                        |
| 11GOeT5 | District cooling supply temperature (yearly average, summer average and winter average)          | °C                  | 6                                                                                                                                   |                                                                                                                        |
| 11GOeT6 | District cooling return temperature (yearly average)                                             | °C                  | 10.9                                                                                                                                |                                                                                                                        |
| 11GOeT7 | Temperature of river water to heat exchanger (yearly average, summer average and winter average) | °C                  | 9.8 (yearly average)<br>1.5 (average January-March)<br>18.4 (average June-August)                                                   |                                                                                                                        |
| 11GOeT8 | Temperature of water from heat exchanger back to the river (yearly average)                      | °C                  | 15                                                                                                                                  |                                                                                                                        |

**Table 38:-** Technical KPIs (11GOe)

| ID       | KPI                              | Unit of Measurement | Value                     | Comments                                                                                                                                         |
|----------|----------------------------------|---------------------|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| 11GOeEc1 | Pay-back time for energy company | Years               | <20 (for total DC system) | Based on investment costs for absorption chillers and district cooling network, operating costs, maintenance costs and revenues from sold energy |

**Table 39:-** Economic KPIs (11GOe)

#### 4.1.7.1 General KPI

|               | General KPIs                                                            | UM                             | 11GOe                              |
|---------------|-------------------------------------------------------------------------|--------------------------------|------------------------------------|
| ENERGETIC     | The yearly amount of thermal energy produced/provided by the new system | kWh/year                       | Produced<br>9,217,000              |
|               |                                                                         | kWh/year                       | Provided to customers<br>9,032,660 |
|               | Saved primary energy in comparison with baseline situation              | kWh/year                       | 6,155,749                          |
|               | Energy recovery from waste/renewable sources                            | kWh/year                       | 9,217,000                          |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation            | %<br>tonCO <sub>2</sub> e/year | 78%<br>344                         |
|               | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e/year     | 95                                 |
|               | Carbon footprint                                                        | ton C/year<br>(LCA)            | 77.3                               |
|               | Ecological footprint                                                    | ha                             | 17.4                               |

**Table 40:** General KPIs-11GOe

#### 4.1.8 Gothenburg demonstrator 19GOe “Absorption cooling”

##### *Demo description*

The aim of this demonstrator, “Absorption cooling”, is to produce energy for the district cooling network by means of absorption chillers. The thermodynamic cycle of the absorption chillers is driven by a heat source and, considering this demonstrator, thermal energy from district heating is used as heat source. Göteborg Energi has two district cooling networks and there are also smaller absorption chillers installed in “cooling islands” directly to major customers. Total installed capacity of absorption cooling is 30 MW and 45 GWh of cooling energy is produced annually. However, the following analyses are limited to the biggest cooling network, the central district cooling. Total annual production from absorption cooling in the central district cooling is 19 GWh (2013). Other production methods for district cooling in Gothenburg are free cooling from the river, see demonstrators 9GOe and GO4, and compressor cooling.

##### *Main assumptions for KPIs calculation*

Electric chillers used for cooling individual buildings are considered as the baseline situation of this specific case. This uses electricity which is assumed to correspond to average production in the Nordic countries and the seasonal performance factor, SPF, of the chillers is assumed to be 2. To calculate environmental data and primary energy, monthly production mix of district heating in Gothenburg district heating network has been applied. Environmental data from the Swedish district heating association are used<sup>1</sup>.

##### 4.1.8.1 Demo-specific KPI

In the following table demo-specific KPIs are presented.

| ID       | KPI                                                                      | Unit of Measurement | 2013                                     |
|----------|--------------------------------------------------------------------------|---------------------|------------------------------------------|
| 19GOeT1  | Share of district cooling produced by absorption chillers                | %                   | 51%                                      |
| 19GOeT2  | Period of the year when absorption chillers are used in district cooling | -                   | April-October                            |
| 19GOeT3  | Seasonal performance factor                                              | -                   | 0.68                                     |
| 19GOeT4  | Use of thermal energy from district heating (yearly average)             | MWh/year            | 27,100                                   |
| 19GOeT5  | Yearly electric energy consumption                                       | MWh/year            | 830                                      |
| 19GOeT6  | District cooling supply temperature (yearly average)                     | °C                  | 6.0                                      |
| 19GOeT7  | District cooling return temperature (yearly average)                     | °C                  | 10.9                                     |
| 19GOeT8  | District heating supply temperature (yearly average, summer average,)    | °C                  | Yearly average:<br>91                    |
|          |                                                                          |                     | Summer average:<br>91                    |
| 19GOeT9  | District heating return temperature (yearly average, summer average,)    | °C                  | Yearly average:<br>46                    |
|          |                                                                          |                     | Summer average:<br>51                    |
| 19GOeEc1 | Pay-back time for energy company                                         | Years               | Of total district cooling system:<br><20 |

**Table 41:** Demo-specific KPIs – 19GOe

<sup>1</sup> Svensk fjärrvärme (2014) “Miljövärden 2013”

#### 4.1.8.2 General KPI

In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                   | UM                 | 2013                                                                             |
|---------------|----------------------------------------------------------------|--------------------|----------------------------------------------------------------------------------|
| ENERGETIC     | The yearly amount of thermal energy produced by the new system | $MWh_{th}/year$    | Produced: 19,500<br>Provided to customer: 19,100                                 |
|               | Saved primary energy in comparison with baseline situation     | $MWh/year$         | 19,600                                                                           |
|               | Energy efficiency of the project                               | %                  | Delivered to customer /electricity and heat in production and distribution: 68 % |
|               |                                                                |                    | Delivered to customer /primary energy: 1150%                                     |
|               | Energy recovery from waste/renewable sources                   | $MWh_{th}/year$    | 18,300                                                                           |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation   | %                  | 52%                                                                              |
|               | Yearly GHG emissions related to the project                    | $kton CO_2 e/year$ | 1.2                                                                              |

**Table 42:** General KPIs – 19GOe

#### 4.1.9 Gothenburg demonstrator 2GOe “Integration of municipalities”

##### Demo description

The demonstrator 2GOe is “Integration of municipalities”. The district heating network in Gothenburg is connected to two neighboring municipal networks, Mölndal to the south and Kungälv to the north. The first connection was commissioned in 1982. In summer Gothenburg has an excess of heat from industries and from waste incineration, which is delivered to Mölndal and Kungälv. During spring and autumn Gothenburg buys heat from Mölndal based on biofuel in CHP when this is preferable to starting a more expensive production plant.



*Main assumptions for KPIs calculation*

The following table summarizes the flows of heat between the three networks in 2015.

| Municipalities involved | Thermal energy delivered [GWh/year] | Fuels/sources                                                                                                                                |
|-------------------------|-------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|
| Mölndal to Gothenburg   | 106                                 | Wood chips in CHP                                                                                                                            |
| Gothenburg to Mölndal   | 23                                  | 99 % renewable or recovered energy – assumes equal amounts of industrial waste heat and waste incineration.<br>1 % fossil – assumes gas CHP  |
| Gothenburg to Kungälv   | 78                                  | 87 % renewable or recovered energy – assumes equal amounts of industrial waste heat and waste incineration.<br>13 % fossil – assumes gas CHP |

**Table 43:** Purchased heat between the networks

The baseline refers to how heat would have been produced if there had been no exchange of heat in between the networks. This is difficult to find high quality information about. The following assumptions have been made.

| Municipality | Thermal energy produced [GWh/year] | Fuels/sources                           |
|--------------|------------------------------------|-----------------------------------------|
| Gothenburg   | 106                                | Natural gas in CHP                      |
| Mölnälv      | 23                                 | 99 % wood briquettes boiler<br>1 % oil  |
| Kungälv      | 78                                 | 87 % wood briquettes boiler<br>13 % oil |

**Table 44:** Baseline assumptions of heat production without integration of municipalities

#### 4.1.9.1 General KPI

In the following table general energetic, environmental and social KPIs are presented.

|               | General KPIs                                                                                                                      | UM                 | 2015    |
|---------------|-----------------------------------------------------------------------------------------------------------------------------------|--------------------|---------|
| ENERGETIC     | The yearly amount of thermal energy provided by the new system: Heat purchased across the municipalities, total in all directions | $MWh_{th}/year$    | 157,000 |
|               | Saved primary energy in comparison with baseline situation                                                                        | $MWh/year$         | 99,500  |
|               | Energy recovery from waste/renewable sources                                                                                      | $MWh_{th}/year$    | 153 000 |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation                                                                      | %                  | 91 %    |
|               | Yearly GHG emissions related to the project                                                                                       | $kton CO_2 e/year$ | 2.1     |

**Table 45:** General KPIs – 2GOe

#### 4.1.10 Cologne demonstrator 6COe “Geothermal heating plant”

##### *Demo description*

As presented in D4.1, besides the District Heating, RheinEnergie AG is promoting heat supply solutions in local areas in the city. In the 80 and 90s the heat production was gas based only. In the last years RheinEnergie extended the sources for the heat production trying to use environmentally sustainable sources. Up to 2013 several technical facilities of this type were brought into service:

- 9 bio-methane projects (6,000 kW heat, 80 GWh bio-methane);
- 10 geothermal heating (heating power between 8-70 kW);
- 4 wood pellet projects (100 – 850 kW; 600 t p.a.);
- 6 thermal solar heating systems (10 – 120 kW; collector surface 13 – 155 m<sup>2</sup>).

Thermal solar systems are used for water heating at RHEI local heat supply sites. They cover only a small part of the whole energy consumption at the sites. In reference to the main issue of CELSIUS – large scale systems for urban heating and cooling – it is relevant to report about a geothermal heating project in Herler Carre, in the Cologne district Buchheim, where several houses are built on a 20,000 m<sup>2</sup> plot. Three heat pumps are installed to use geothermal energy for heating. The residential complex will consist in its final state of about 250 apartments with underground parking spaces.

##### 4.1.10.1 Demo-specific KPI

Demo-specific KPI are presented in the table below.

| ID    | KPI                                                | Unit of Measurement    | Value  |
|-------|----------------------------------------------------|------------------------|--------|
| 6COe1 | Yearly thermal energy production of each heat pump | MWht/year              | 158,00 |
| 6COe2 | Gas and electricity consumption of each heat pump  | MWh/year and MWhe/year | 106,25 |
| 6COe3 | COP of each heat pump                              |                        | 1,49   |

**Table 46:** Demo-specific KPIs-6COe

#### 4.1.11 Rotterdam demonstrator: 16ROe “Aquifer storage”

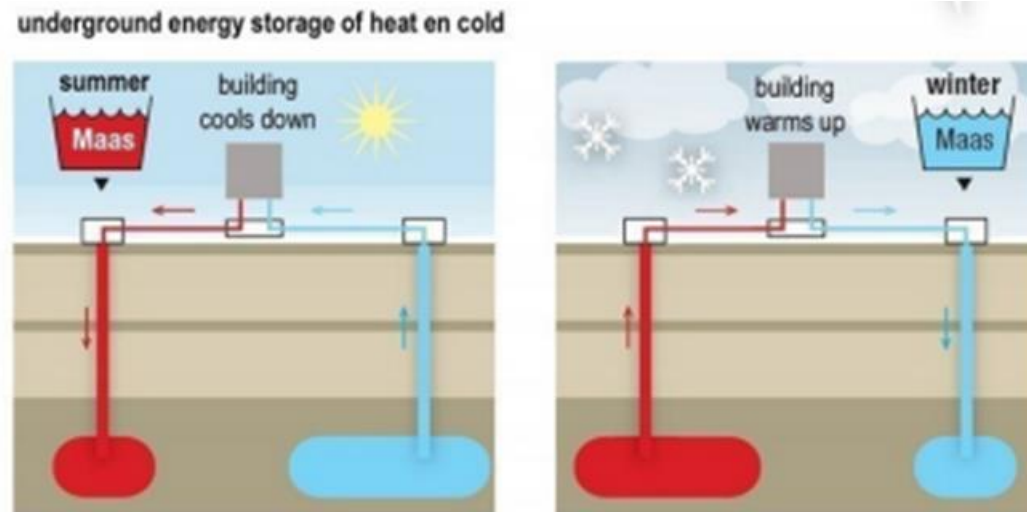
##### *Demo description*

With the construction of the Maastoren, the Rotterdam skyline gained a new icon. Erected in the Kop van Zuid area, the Maastoren has a height of 165 m, making it the tallest building in the Netherlands. Its floor space is approximately 57,000 m<sup>2</sup>, of which approximately 35,000 m<sup>2</sup> is reserved for office space, 17,000 m<sup>2</sup> for parking (both underground and street level), 4,000 m<sup>2</sup> is reserved for the entrance and facilities and 700 m<sup>2</sup> for technical space.

The project is characterised by an extremely sustainable energy concept that in 2007 earned Techniplan Adviseurs the engineering award De Vernufteling. One of the most interesting aspects of this concept is that the water of the nearby Maas River is used – complementary to the other sources of aquifer thermal energy storage – to generate heating and cooling energy in the building as well as supply the sprinkler system. This has allowed the designers to reduce the sources to half their original size, which means that the building did not have to be connected to the district heating system and furthermore cuts CO<sub>2</sub> emissions by half.

The design has an Energy Performance (EPC) that is 35% lower than legally required, within the strict financial framework that applies to commercial utility architecture. Measures taken to ensure

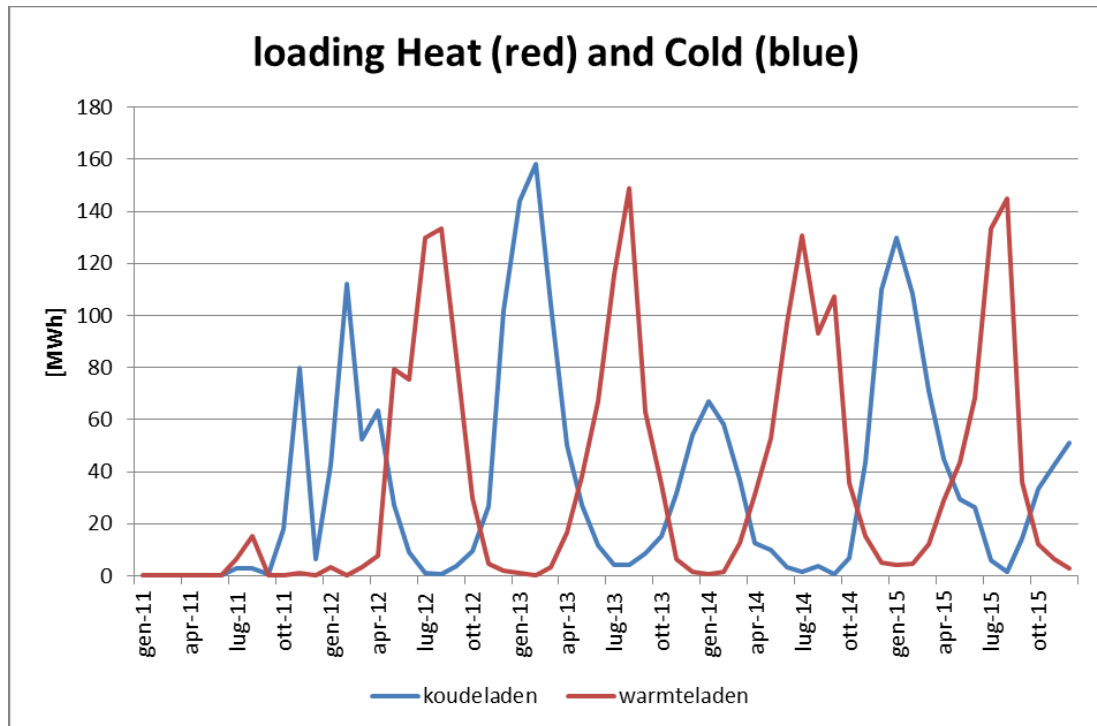
this energy performance include; intelligent installation measures in the area of occupancy detection, maximum daylight utilisation along with space and energy-saving lift traction systems. Other measures include heat recovery from ventilation air and optimum building-physical measures aimed at reducing the installation size. In addition, thanks to the intelligent elevator concept, the space reserved for the installation core throughout the entire building can be reduced by some 800 m<sup>2</sup>: space savings that have been directly added to the rentable floor space. The demo concept is summarized in Figure 25, where the use of the aquifer storage in winter and in summer can be noted.



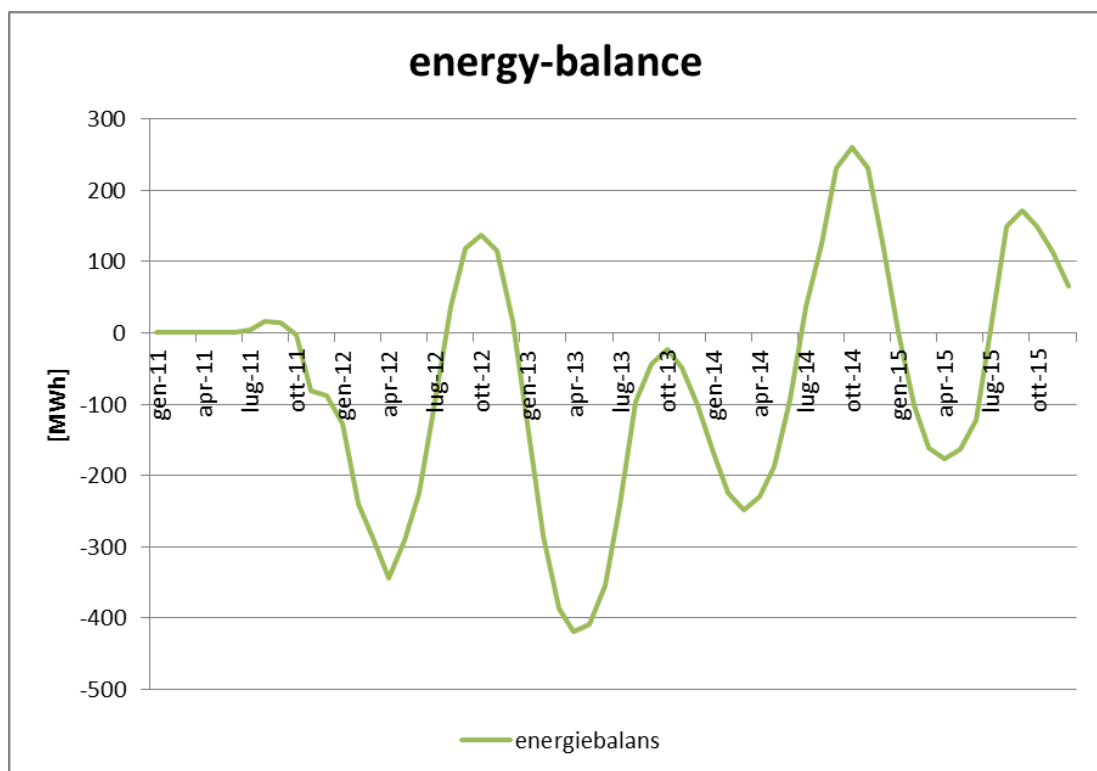
**Figure 25:** 14ROe demo concept

#### *Monitored parameters*

The monitored parameters include the temperature of injection/withdrawal of water from the storage and the volume of water injected/withdrawn; the availability of these data makes possible the calculation of the amount of heat stored in the storage as hot or cold water. Figure 26 shows the monthly trend of stored hot/cold water over the period January 2011 – December 2015, whereas Figure 27 presents the cumulated trend of injections and withdrawals, which indicates the energy balance of the overall aquifer storage, on a monthly basis and for the same period.



**Figure 26:** Monthly trend of stored hot/cold water, 2011-2015



**Figure 27:** Monthly energy balance of the aquifer storage, 2011-2015

#### *Main assumptions for KPI calculation*

The baseline situation for the calculation of the KPIs is constituted by the use of a reversible heat pump characterized by a sufficiently high efficiency (i.e., COP 3.5) for the production of the same amount of hot and cold water stored and consequently supplied by the system. More in detail, the electricity consumptions of the heat pump are considered, whereas those of the circulation pumps

as well as those of the pumps for the injection and withdrawal of water from the aquifer storage are neglected.

The following Table 47 summarizes the emission factors and primary energy factors for the baseline situation.

| Parameter  | Unit of meas. | Value | Comments and references |
|------------|---------------|-------|-------------------------|
| $E_{el}$   | t/MWh         | 0.435 | [7]                     |
| $PEF_{el}$ | -             | 2.78  | IEA Statistics          |

**Table 47:** RO1-Baseline Parameters

The assessment of the annual performance of the demonstrator was performed on the basis of the available monitored data covering the years 2012 to 2015.

#### 4.1.11.1 Demo-specific KPI

The demo-specific KPI calculated for the 14ROe demonstrator are shown in Table 48 for the years 2012 to 2015.

| ID     | KPI                                         | Unit of Measurement | 2012 | 2013 | 2014 | 2015 |
|--------|---------------------------------------------|---------------------|------|------|------|------|
| 14ROe1 | Hot water injection average temperature     | °C                  | 14.2 | 13.7 | 14.6 | 14.1 |
| 14ROe2 | Cold water injection average temperature    | °C                  | 9.6  | 8.8  | 8.8  | 8.8  |
| 14ROe3 | Amount of heat stored in form of hot water  | MWh                 | 554  | 497  | 583  | 497  |
| 14ROe4 | Amount of heat stored in form of cold water | MWh                 | 450  | 614  | 355  | 559  |

**Table 48:** Demo-specific KPIs-6COe

#### 4.1.11.2 General KPI

In the following Table 49 the general KPIs related to energy and environmental aspects of 14ROe demonstrator are presented for the years 2012 to 2015.

|           | General KPIs                                                            | UM       | 14ROe | 2012  | 2013  | 2014 | 2015  |
|-----------|-------------------------------------------------------------------------|----------|-------|-------|-------|------|-------|
| ENERGETIC | The yearly amount of thermal energy produced/provided by the new system | MWh/year | x     | 1,005 | 1,111 | 938  | 1,056 |
|           | Saved primary energy in comparison with baseline situation              | MWh/year | x     | 798   | 882   | 745  | 839   |
| ENV       | Yearly GHG savings in comparison with the baseline situation            | %        | x     | 125   | 138   | 117  | 131   |

**Table 49:** 14ROe-General KPIs

#### 4.1.12 Rotterdam demonstrator: 15ROe “Vertical city”

##### Demo description

The “Vertical city” demonstrator is the largest building in the Netherlands (floor space 160.000 m<sup>2</sup>, height 150) completed in 2013. It consists of three towers with different functions: offices, apartments, hotels, retail, restaurants, theatre, museum, parking, etc. The building is constructed as a city on its own and has a total floor space of 160.000 m<sup>2</sup> realized on a very small footprint of only 5.500 m<sup>2</sup> (one soccer field). It's the

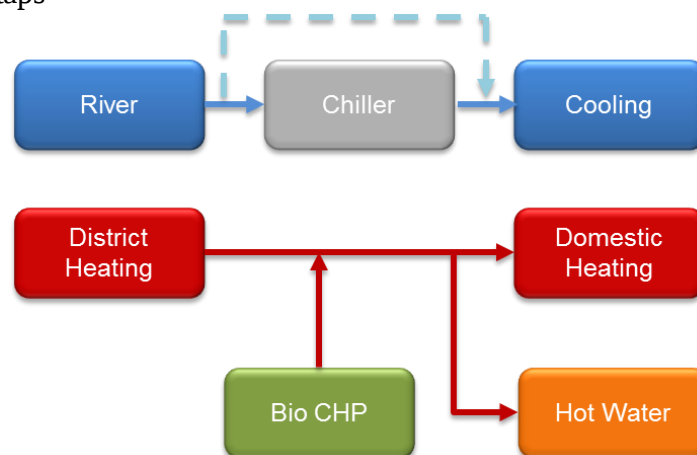


most densely built part of the Netherlands with a floor space index of 32. It consists of 240 apartments, 60.000 m<sup>2</sup> offices, 1.500 m<sup>2</sup> for restaurants and cafés, 278 hotel rooms, cultural institutions, 5.000 m<sup>2</sup> shops, 2.500 m<sup>2</sup> fitness-area and 670 parking-spots. The building has a mixture of functions that require both heating and cooling to sustain a good indoor climate. The total building has a good score on sustainability: a GreenCalc+ score of 235 points (A+) and is built 7 to 48 percent better than the Energy Performance Building Directive (EPBD), requirements, depending on the function. The building energy systems, schematized in Figure 28, consist of

- heating: combination of district heating and biofuel cogeneration
- cooling: compression system with use of cold river water
- electricity: combination of net-power and bio fuel cogeneration

Other energy or water saving measures implemented in the building are:

- high efficiency lighting
- automatic daylight control and presence sensing devices
- ventilation with heat recovery and speed control
- reuse of brake energy elevators
- water saving taps

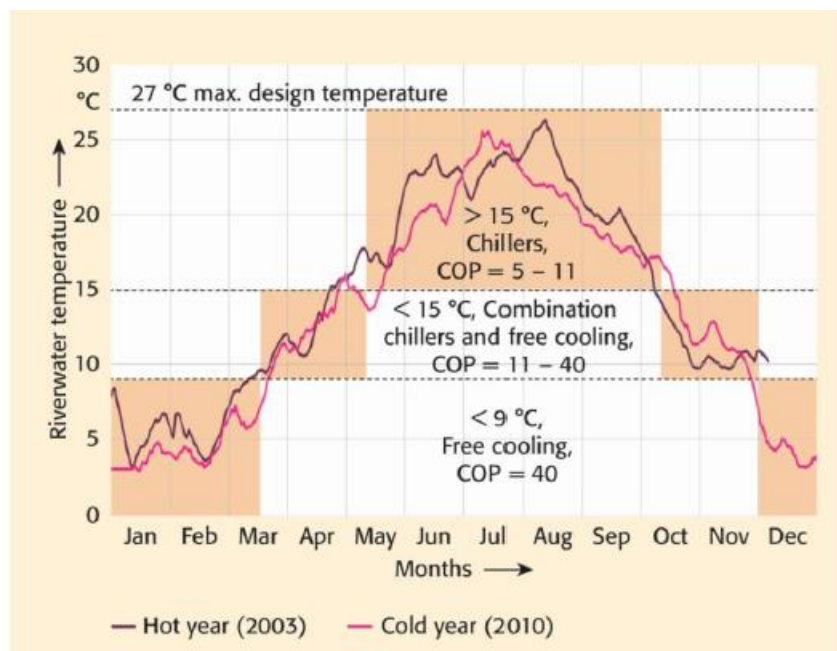


**Figure 28:** Integrated Energy Systems for Vertical City

More in detail, the cooling systems of the building are entirely based on river water, either used as free cooling source or as a heat sink for electric chillers, and in particular:

- when the river temperature is below 9°C, buildings are cooled with free cooling only;
- when the river temperature is between 9°C and 15°C, a combination of free cooling supplemented with compression chillers are used;
- when the river temperature is higher than 15°C, only compression chillers are used to cover the cooling demand of the buildings.

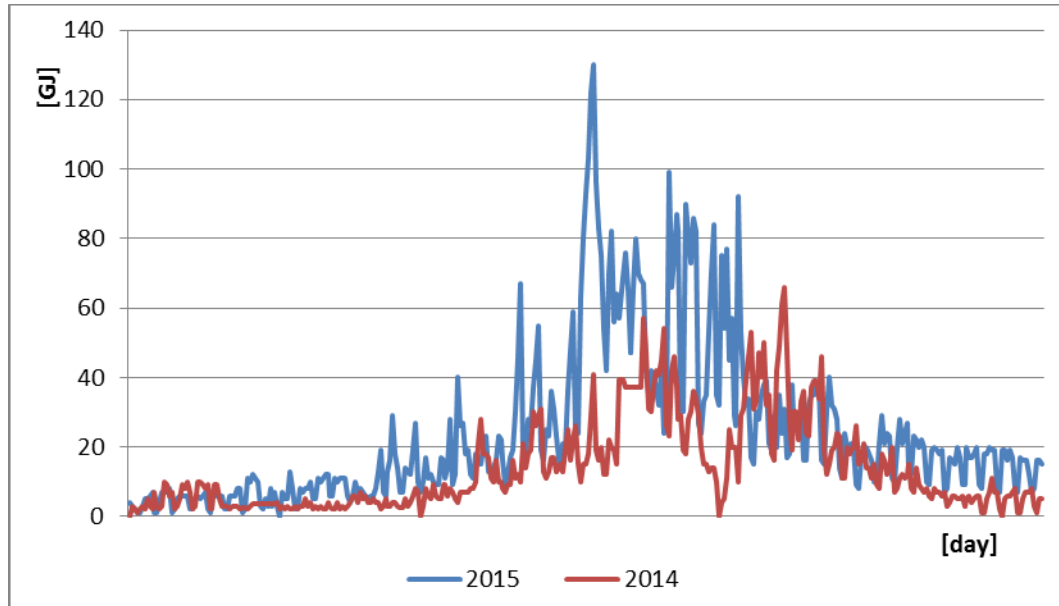
The COP for chill production is always higher than 5, and in particular between 5 and 11 when only compression chillers are used, between 11 and 40 when the combined solution is applied and higher than 40 when only free cooling is exploited. The applied cooling strategy is presented in Figure 29.



**Figure 29:** Cooling Strategy for Vertical City

A comprehensive set of data was made available regarding the Vertical City for the whole years 2014 and 2015 and for the first three months of 2016, with a data resolution of 5-8 minutes. The monitored data are particularly focused on the efficient production of chill, thus including the temperature of the cold source, the river water flow, the electricity consumption for pumping and electric chillers, the chill production.

For example, the daily amount of cooling for the years 2014 and 2015 is shown in Figure 30.



**Figure 30:** Daily Chill Production from River Cooling, 2014-2015

### *Main assumption for KPI calculation*

For this demonstrator, the baseline situation is constituted by the use of air cooled electric chillers, with an average efficiency of 4, which means that every 1 kWh of electricity consumption leads to a chill production of 4 kWh.

In the project scenario, indeed, the efficiency of the chillers working with river water is very high, around 10; according to the provided data, the actual average values of COP were of 6.8 in 2014 and of 12.2 in 2015. On the other hand, for the fraction of the chill demand covered with river water, an unchanged COP of 3 is considered.

The monitored parameters that have been elaborated and used as input data for the calculation of KPIs are those reported in Table 50.

| Parameter                       | Unit of meas. | 2014  | 2015  | Comments and references |
|---------------------------------|---------------|-------|-------|-------------------------|
| Cooling energy from river water | MWh           | 5,020 | 8,703 | -                       |
| Electricity consumption         | MWh           | 741   | 714   | -                       |
| Average COP                     | -             | 6.78  | 12.19 | -                       |

**Table 50:** 15ROe-Input Data

Among the energy and environmental parameters, the assumed Primary Energy and GHG Emission Factors for electricity are shown in Table 51 with the related references.

| Parameter  | Unit of meas. | Value | Comments and references |
|------------|---------------|-------|-------------------------|
| $E_{el}$   | t/MWh         | 0.435 | [7]                     |
| $PEF_{el}$ | -             | 2.78  | IEA Statistics          |

**Table 51:** 15ROe-Assumed Environmental Parameters

### *General KPI*

Table 52 presents the general KPIs on energy and environmental aspects for the cooling-by-river-water demo, referred to the whole year 2016.

|               | General KPIs                                                            | UM                    | 2014  | 2015  |
|---------------|-------------------------------------------------------------------------|-----------------------|-------|-------|
| ENERGETIC     | The yearly amount of thermal energy produced/provided by the new system | MWh                   | 5,020 | 8,703 |
|               | Saved primary energy in comparison with baseline situation              | MWh                   | 1,429 | 4,063 |
|               | Energy efficiency of the project                                        | -                     | 6.78  | 12.19 |
|               | Energy recovery from waste/renewable sources                            | MW                    | 5,020 | 8,703 |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation            | %                     | 41.0% | 67.2% |
|               | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e | 322.3 | 310.7 |
|               | Carbon footprint                                                        | ton C                 | 530.6 | 511.2 |
|               | Ecological footprint                                                    | ha                    | 119.4 | 115.0 |

Table 52: 15ROe- General KPIs

#### 4.1.13 Rotterdam demonstrator: 32ROe/33ROe “Datacenters”

The efficient solutions for cooling of datacenters are implemented in two demonstration sites in Rotterdam: Datacenter Rotterdam and BT Datacenter.

Datacenter Rotterdam is a 900 m<sup>2</sup> facility located in the “Spaanse Kubus” building in Rotterdam, hosting servers on behalf of private companies and public institutions. The datacenter, built in 2007, applies highly efficient cooling techniques to guarantee ambient conditions around 25°C of temperature and 45% of relative humidity. In particular, the ventilation system is based on rotary heat exchangers that allow cooling the internal air, which is recirculated, using cold air from outside; during the winter, cooling is also achieved adiabatically, by humidifying dry air, whereas electric chillers are used only during the hottest periods of summer. In 2013, the electricity consumption of Datacenter Rotterdam was of 440 MWh<sub>e</sub>, whereof only 90 MWh is used for non-IT equipment, therefore its average Power Usage Efficiency (PUE) is 1.2.

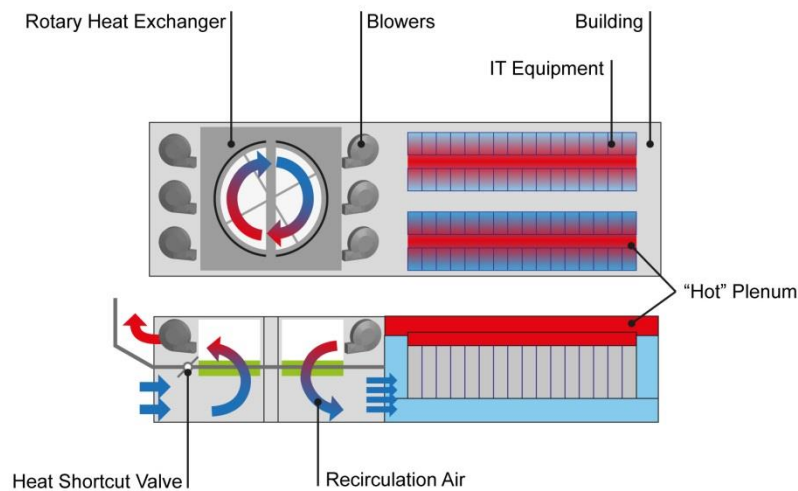
Indeed, PUE is calculated as the ratio between the energy consumed by the whole datacenter and that of the IT equipment only, thus in the ideal case of absence of power losses and zero additional power required for cooling, lighting, etc., the PUE would be 1.0, whereas a PUE of 1.2 means that for 1 W used by IT equipment, only 0.2 W is used by non-IT equipment.

Datacenter Rotterdam is equipped with a 600 kW chiller in the first floor and with a 200 kW chiller in the second floor; in the same floors, the total installed power for IT equipment is of 450 kW and 120 kW respectively.

On the other hand, BT Datacenter was completed in 2014, has a total surface of 800 m<sup>2</sup> for 96 racks and was designed to achieve a high level of energy efficiency. In order to save energy, the design value of the air temperature ranges between 25 and 35°C and ventilation is managed so that air moves only when needed. During the largest part of the year, air can be cooled adiabatically and the chillers are activated only in case of failure or during peak times in the summer.

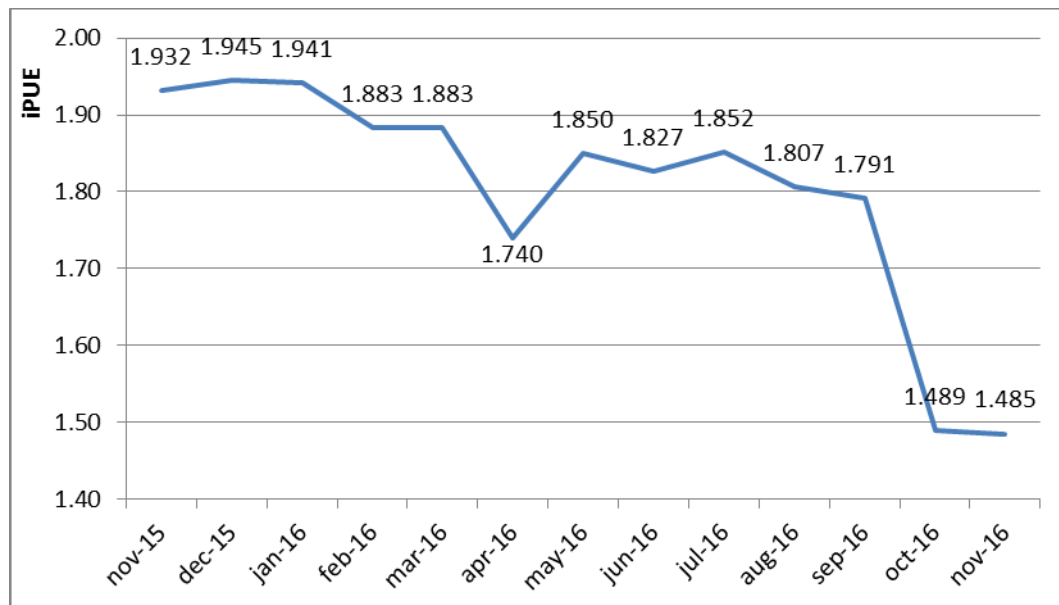
The offices in the building are heated with heat recovered by the datacenters according to the layout presented in **Error! Reference source not found.** and, only when necessary, using a high efficiency heat pump.

The BT Datacenter is equipped with 2 electric chillers, 159 kW<sub>e</sub> each, having an EER of 2.88 and an ESEER of 4.06, but runs for most of the year with an adiabatic chiller that has 600 kW of cooling power but only 24 kW of power absorption (corresponding to a COP of 25).



**Figure 31: Layout of the Efficient Cooling of Datacenters Demonstrator**

The BT Datacenter performs a monthly monitoring of the iPUE index, which is the input power divided by the IT load (UPS load minus energy use of CRACs and control units); the trend of iPUE for the months between November 2015 and November 2016 is shown in Figure 32; a decreasing trend can be noticed, with the declared objective of achieving values below 1.3.



**Figure 32: iPUE for BT Datacenter in Rotterdam**

*More detailed KPIs calculations will be included in the final version of current deliverable (foreseen at M57) when consolidated monitored data will be available.*

## 4.2 New demonstrators

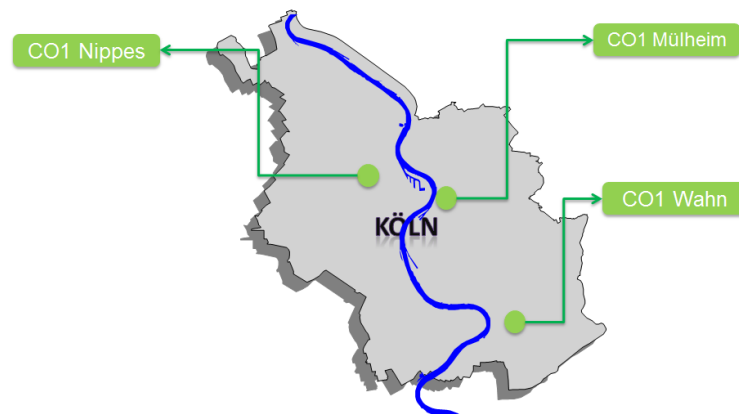
Considering new demonstrators, monitored parameters and preliminary KPIs calculation are hereinafter presented with regards to the following demos:

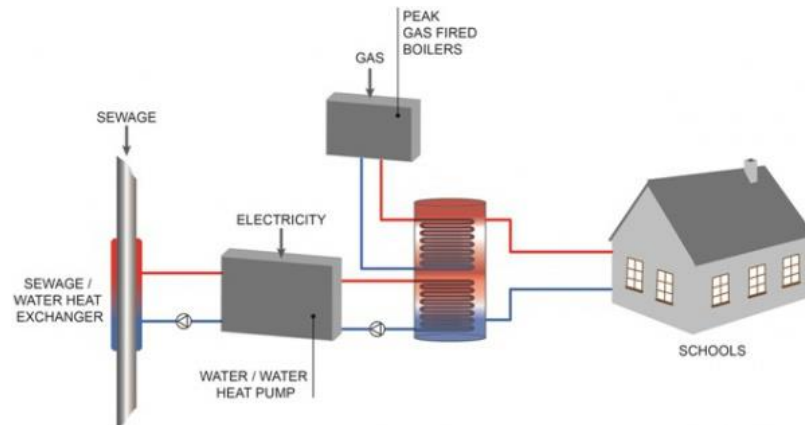
- CO1-SET1: Heat recovery from sewage water;
- RO1: The heat hub;
- GO1: Short term storage;
- GO2: DH to white goods;
- GO3: DH to ships;
- GO4: River cooling;
- LO1: Active network management and Demand Response;
- LO2-LO3: Capture of identified sources of waste heat and integration of thermal store & Extension of the Bunhill seed heating system;
- GE1: Energy recovery from the natural gas distribution network.

### 4.2.1 Cologne demonstrator: CO1-SET 1 “Heat recovery from sewage water”

#### *Demo description*

The main objective of this demonstrator is to overcome technical and economic barriers to recover heat from sewage network and use it in decentralized local heating network by supplying heat to local school buildings. The demonstrator foresees the application of this technology in three different spots in Cologne (Porz-Wahn, Mülheim and Nippes sites), with different conditions of the supply side on one hand and similar end-users (school buildings) on the other side.

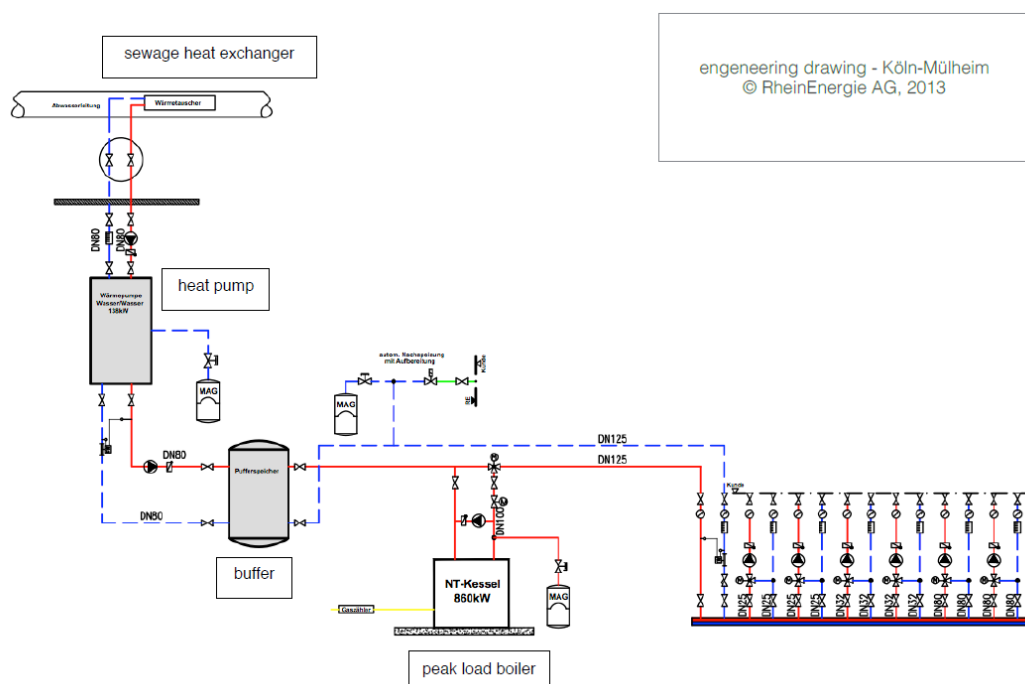




**Figure 33:** Cologne demonstrator – General layout

The *Porz-Wahn demonstrator* uses a 200kW heat pump, a 1MW boiler and a ca. 4m<sup>3</sup> buffer tank to provide the whole amount of heat required by the school “Otto Lilienthal Realschule”.

The *demonstrator in Mülheim* is one of the three different heat generation plants recovering heat from the sewage. The three of them uses similar technologies to recover heat from the sewage and supply the heat demand of some school buildings. The gas boiler used in Mülheim uses a special technology that allows to recover the heating flue gases and to use them again in the process of heating. This technology permits the gas boiler to achieve efficiencies up to 110%. Its heat capacity is 860 kW. The heat pump in the Mülheim site has a heat capacity of 138 kW. In comparison with the demonstrator site in Köln Wahn, only the heat pump can store the heat produced in a buffer tank. When high water temperatures are necessary, the gas boiler receives the preheated water coming from the buffer tank and heats up the water to supply the demanded heat. When no peak temperatures are needed the school is supplied with heated water coming from the buffer tank.



**Figure 34** Engineering drawing of CO1-Mülheim

At *Nippes site* RHEI is testing and demonstrating the most innovative technology among the Cologne demos for heat recovery from sewage being the first plant with a direct flowrate of sewage water and particles. The heat is recovered by a 400 kW evaporator which transfers the heat of the sewage directly to the heating circuit of the schools. Contrary to current practice for similar plants in Germany, at Nippes plant there is no transmission medium. There are just three other evaporators running in Germany. The biggest one has a thermal output of 71 kW and the all are running with process water or grey water.

### *Status description*

The systems were started up in different times

- Porz-Wahn site: in operation since Q4-2013 and monitored since Q1-2014.
- Mulheim site: in operation since November 2014 and monitored Q1- 2015;
- Nippes site: in operation since Q1-2015 but monitored data not available yet.

In the following paragraphs information about the performance of Porz-Wahn and Mulheim sites are reported, while operation at Nippes demonstrator is still under optimization.

For Porz-Wahn and Mulheim demonstrator sites, monitoring parameters are being measured. The main parameters used for the KPI's calculation are: gas consumption, electricity consumption, heat supplied by boiler and heat supplied by the heat pump.

Table 53 and Table 54 show the available parameters being monitored at the CO1 demo sites (Porz-Wahn and Mulheim site).

| Technical parameters                                                | Unit of measurement |
|---------------------------------------------------------------------|---------------------|
| Electric energy consumption of the heat pumping system              | kWh <sub>e</sub>    |
| Electric energy consumption of the wastewater pumping system        | kWh <sub>e</sub>    |
| Inlet wastewater temperature                                        | °C                  |
| Outlet wastewater temperature                                       | °C                  |
| Thermal energy at the heat pump                                     | kWh <sub>th</sub>   |
| Thermal energy between the storage system and the distribution mine | kWh <sub>th</sub>   |
| Gas consumption                                                     | Nm <sup>3</sup> /h  |

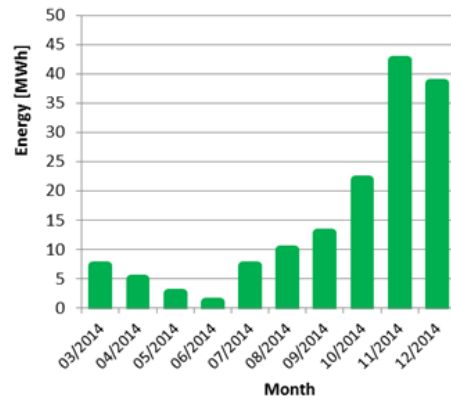
**Table 53:** CO1- Monitored parameters available at Porz-Wahn site

| Technical parameters                                   | Unit of measurement |
|--------------------------------------------------------|---------------------|
| Electric energy consumption of the heat pumping system | kWh <sub>e</sub>    |
| Thermal Energy at the boiler                           | kWh <sub>e</sub>    |
| Thermal energy at the heat pump                        | Nm <sup>3</sup> /h  |
| Output and return temperatures of the buffer tank      | °C                  |
| Gas consumption                                        | °C                  |
| Temperatures at the buffer tank                        | kWh <sub>th</sub>   |

**Table 54:** CO1- Monitored parameters available at Mulheim site

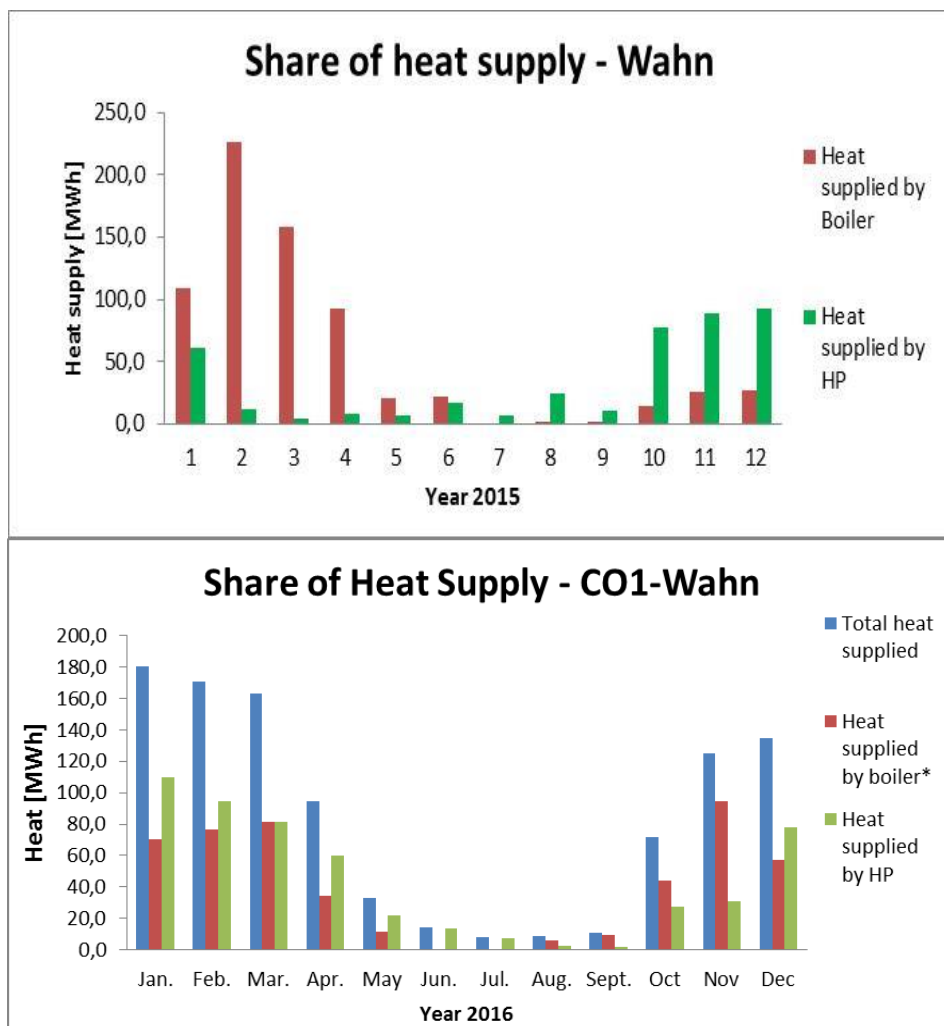
### **Wahn – Demonstrator**

Being Wahn demonstrator in operation since 2014, monitored data are available for the period March 2014- December 2016. The operation 2014 was nevertheless characterized by inefficiencies considering that the operation control system did not work properly. Monthly thermal energy production for 2014 is presented in the chart below, and clearly is not representative of the steady state operation, as the average COP for the pump in 2014 was approximately 1.97.



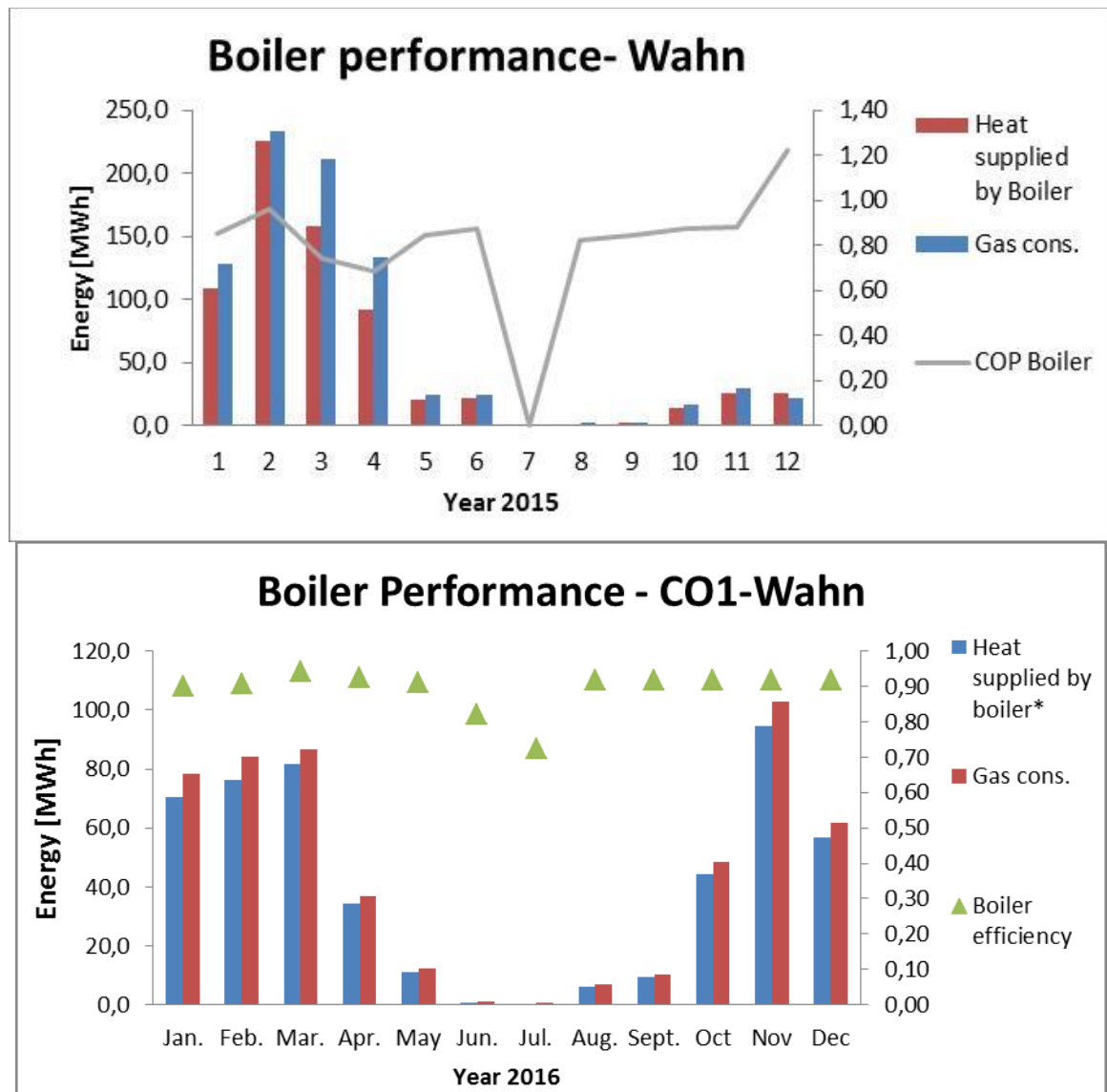
**Figure 35:** Wahn site thermal energy production – 2014

Steady operation started at mid 2015 as presented in the following sections. The charts below compare the monthly heat production at Wahn site (heat pump and gas-fired boiler) in 2015 and 2016. The total amount of heat supplied by the system in 2016 was 1011 MWh, 3 MWh more than in 2015. The heat pump supplied 15 % more heat than in 2015, making a total share of 52% of the total heat supply. This variation in the heat supply by the heat pump is mainly due to the control improvement carried out during the summer of 2015. As a consequence, less primary energy is used.



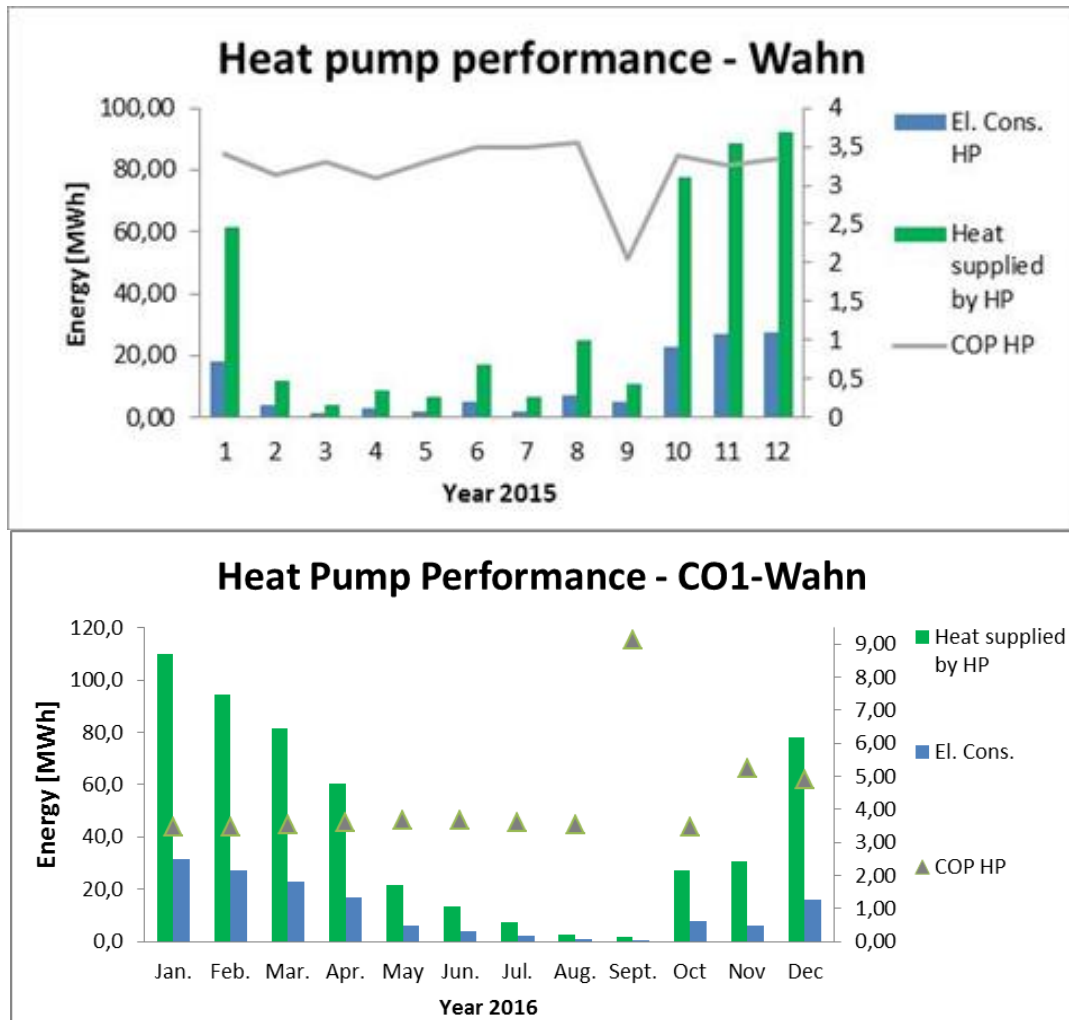
**Figure 36:** Monthly heat supplied by heat generators at Wahn site – 2015 and 2016

The boiler performance together with heat supply in 2015 and 2016 are shown in figure below. The average monthly efficiency of the boiler in 2015 is approximately 0.88 whereas it reached 0.91 in 2016. In 2016, the boiler supplied 48% of the total heat demand. Only in October and November the gas boiler supplied more heat than the heat pump, while during the summer months barely operated. The gas consumption measuring device did not operated correctly during the second semester, therefore the consumption values from August to December were calculated according the heat supplied and the efficiency of the boiler during the first semester.



**Figure 37:** Monthly performance of the gas fired boiler in CO1 Wahn – 2015 and 2016 (electricity consumptions of the circulation pumps are not included)

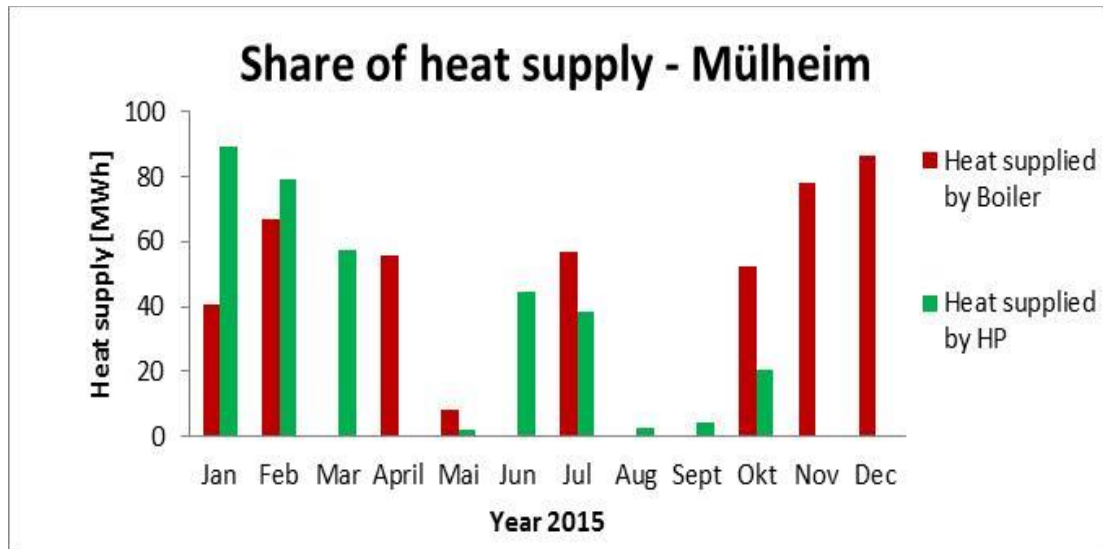
The heat pump performance together with heat supply in 2015 and 2016 are shown in figure below. The average COP for the pump in 2015 was approximately 3.24 whereas in 2016 provided 529 MWh of heat and consumed 141 MWh of electricity. The COP of the heat pump was 3.75 only taking into account the electricity consumed by the heat pump. The SCOP (seasonal coefficient of performance) in 2016 was 3.34, which includes the electricity consumption of the circulation pumps.



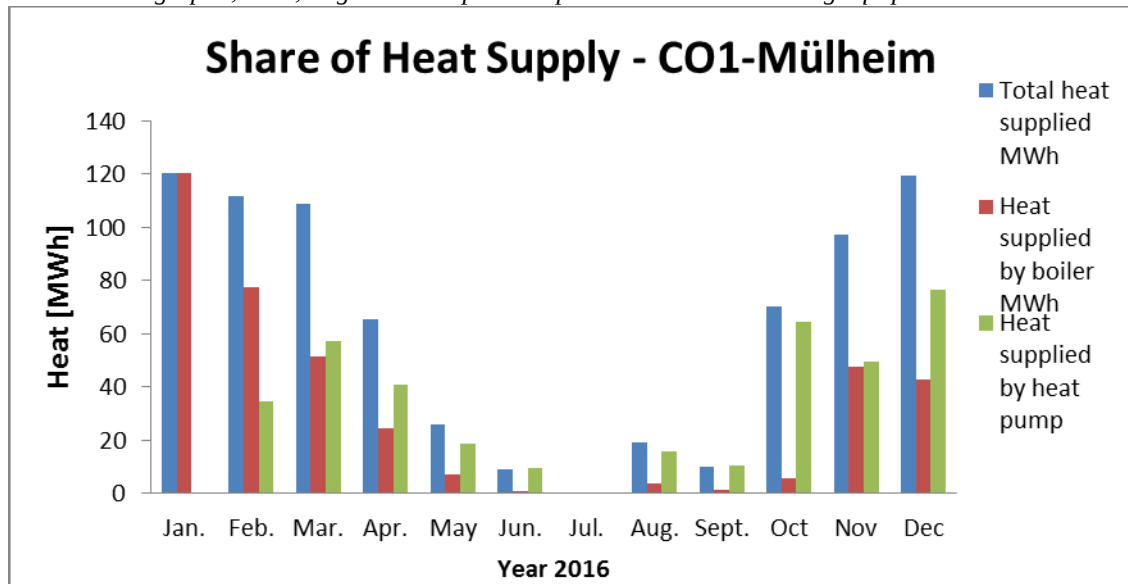
**Figure 38:** Monthly performance of the heat pump in CO1 Wahn – 2015 and 2016

### Mulheim – Demonstrator

This section presents the main monitored parameters at Mülheim demonstrator. In 2015, the share of heat delivered by the heat pump (approx. 47%) was bigger than in Cologne Wahn (approx. 37%). For a technical problem to the sewage heat exchanger, the heat pump was not in operation until February 2016 when started operating again in a regularly basis. As it is shown in the following figure, the boiler covered the majority of the heat demand in this year (almost 60% of the heat demand). During the summer months, the heat demand decreases significantly, forcing even the generators to go completely offline in the month of July 2016. The total amount of heat supplied by the system in 2016 was 760 MWh, 41 MWh more than in 2015. The heat pump supplied a total of 379 MWh of heat more than in 2015. Despite the no operation time in January and February, the heat pump supplied 50 % of the total heat demand.

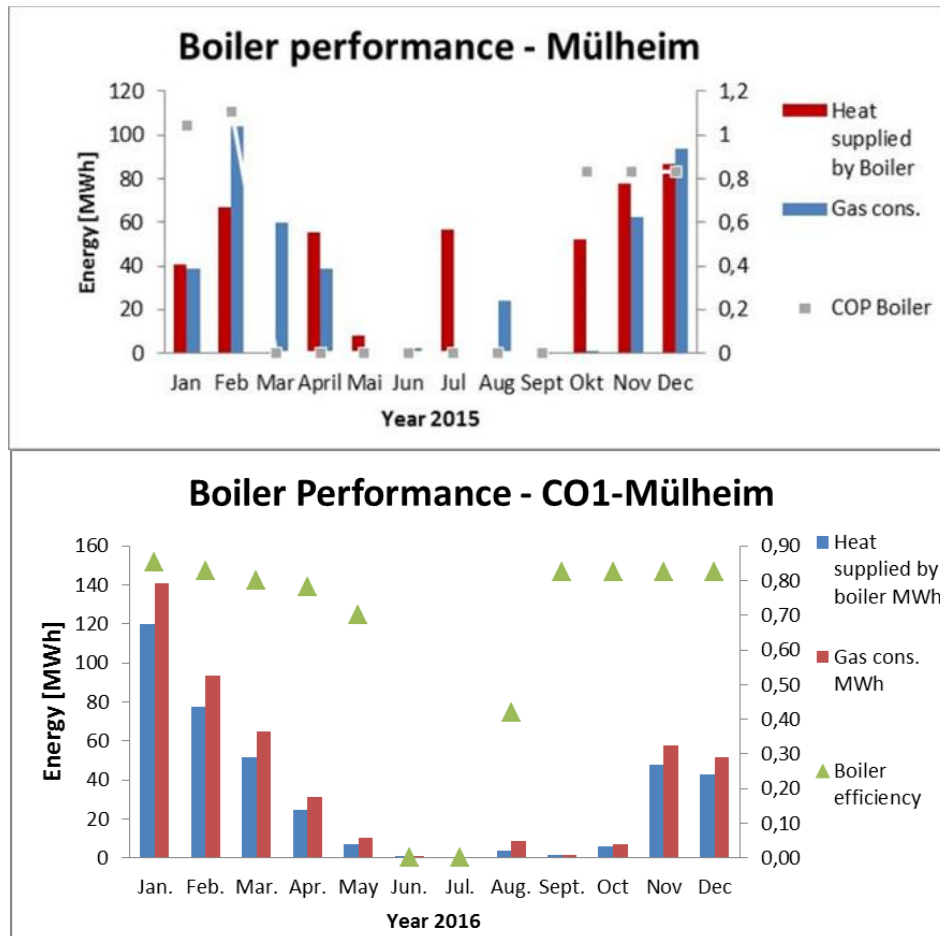


*During April, June, August and September problems with monitoring equipment occurred*



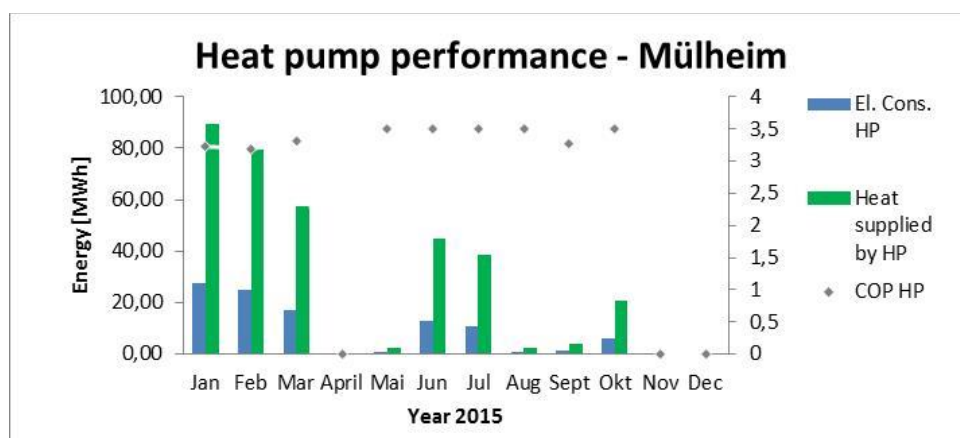
**Figure 39:** Monthly performance of the heat pump in CO1 Mülheim – 2015 and 2016

The boiler performance together with heat supply in 2015 and 2016 are shown in figure below. The average monthly efficiency of the boiler in 2015 is approximately 0.93. In 2016, The boiler supplied a little bit more heat than the heat pump but this is mostly because of the time the heat pump was offline. From January to May the boiler showed an efficiency of 82 %. Due to a failure in the gas consumption measuring device in the second semester of the year, the consumption of the months October, November and December was calculated by dividing the heat supplied by the efficiency presented in the first semester.

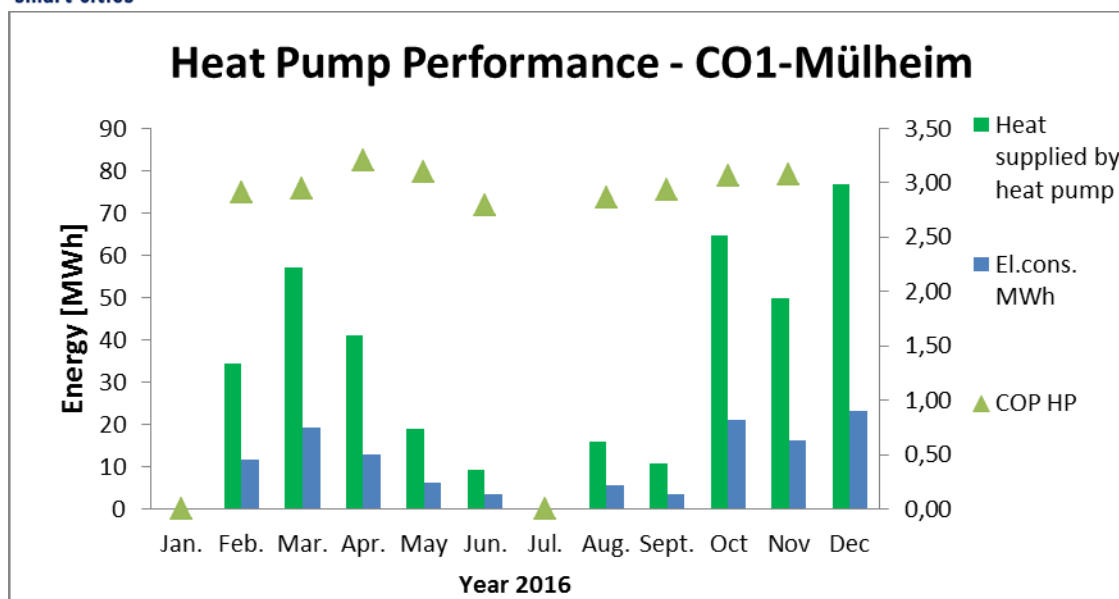


**Figure 40:** Monthly performance of the gas fired boiler in CO1 Mülheim – 2015 and 2016

The heat pump performance together with heat supply in 2015 and 2016 are shown in figure below. The average COP for the pump in 2015 was approximately 3.39. In 2016, Despite the offline period, the heat pump provided 379 MWh of heat, which is more than in 2015. The electricity consumed by the heat pump in 2016 was 123 MWh. The share of heat supply by the heat pump is 50% of the total heat, but if January were not taking into account, then the share of heat supply by the heat pump goes up to 59%. The COP of the heat pump in 2016 is 3.1 (see figure 7 for the monthly COP) and the SCOP of the year is 3.0.



From Nov. 2015 to Feb. 2016 the HP was out of operation due to a problem to the heat exchanger into the sewage.



**Figure 41:** Monthly performance of the heat pump in CO1 Mülheim – 2015 and 2016 (electricity consumptions of the circulation pumps are not included)

Using these monthly parameters presented above, the KPIs of both sites Wahn and Mülheim were calculated for 2015 and 2016 and they are presented within the next pages.

#### *Main assumptions for KPIs calculation*

The baseline situation to which comparisons are made corresponds with the use of gas-fired condensing boilers as the sole equipment for heating the same schools. The main parameters used as reference for the calculation of KPIs are presented in table below.

| Parameter                         | Unit of meas.      | Value  | Comments and references                                                                      |
|-----------------------------------|--------------------|--------|----------------------------------------------------------------------------------------------|
| PEF <sub>natural gas</sub>        | -                  | 1.1    | [21]                                                                                         |
| PEF <sub>el grid</sub>            | -                  | 2.4    | [21]                                                                                         |
| E <sub>CO2 natural gas</sub>      |                    | 0.2016 | [22]                                                                                         |
| E <sub>el grid</sub>              |                    | 0.511  | [22]                                                                                         |
| E <sub>SO2 natural gas</sub>      | mg/m³              | 140    | [23]                                                                                         |
| E <sub>NOx, natural gas</sub>     | mg/m³              | 2,020  | [23]                                                                                         |
| E <sub>PM, natural gas</sub>      | mg/m³              | 80     | [23]                                                                                         |
| E Factor /TJ for carbon footprint | kg CO <sub>2</sub> | 56,000 | The factor 56.000kg CO <sub>2</sub> /TJ is coming from the federal environmental agency [24] |

**Table 55:** CO1-Baseline parameters

The total heat supply of the baseline situation is equal to the real total heat supplied. In order to calculate the energy used to produce this amount of heat, the efficiencies of the previous gas boilers in 2012 were taken. For the case of CO1 Wahn COP is assumed equal to 0.81 and for the case of CO1 Mülheim equal to 0.85. The resulting values are compared with the real measured data.

#### 4.2.1.5 Demo-specific KPI

The following tables show the demo specific KPI of both sites. The period covered is 2014-2016 for Wahn site and 2015-2016 for Mulheim site. Nevertheless, concerning Wahn, site demo's operation control system started working properly only since June 2015 thus as already mentioned in previous submissions of the present deliverable KPI calculated for Wahn site for 2014 cannot be considered a picture of the situation at steady state operation.

| ID    | KPI                                                                                | Unit of Measurement | Wahn              |         |         | Mulheim |       |
|-------|------------------------------------------------------------------------------------|---------------------|-------------------|---------|---------|---------|-------|
|       |                                                                                    |                     | 2014<br>(Mar-Dec) | 2015    | 2016    | 2015    | 2016  |
| CO1T1 | Energy efficiency at each spot                                                     | -                   | 1.10              | 1.16    | 1.48    | 1.36    | 1.28  |
| CO1T2 | Seasonal COP for each heat pump system                                             | -                   | 1.97              | 3.30    | 3.3     | 3.32    | 3.00  |
| CO1T3 | Variation of primary energy in comparison with the baseline situation at each spot | MWh/year            | 118               | 289     | 411     | 216     | 166   |
| CO1T4 | Energy efficiency variation in comparison with the baseline situation at each spot | %                   | 12 %              | 19.27 % | 30.00 % | 23.22%  | 17.0% |

**Table 56:** CO1 Wahn and Mulheim - Technical KPI – 2014 (only Wahn), 2015 and 2016

| ID     | KPI                                                                                    | Unit of Measurement                 | Wahn              |       |       | Mülheim |       |
|--------|----------------------------------------------------------------------------------------|-------------------------------------|-------------------|-------|-------|---------|-------|
|        |                                                                                        |                                     | 2014<br>(Mar-Dec) | 2015  | 2016  | 2015    | 2016  |
| CO1En1 | Variation of pollutant emissions with reference to the baseline situation at each spot | kg/year of saved SO <sub>2</sub>    | 4                 | 8     | 10    | 6       | 6     |
| CO1En2 | Variation of pollutant emissions with reference to the baseline situation at each spot | kg/year of saved NO <sub>x</sub>    | 65                | 109   | 147   | 86      | 87    |
| CO1En3 | Variation of pollutant emissions with reference to the baseline situation at each spot | kg/year of saved particulates       | 2.6               | 4     | 6     | 3       | 3     |
| CO1En4 | Yearly GHG savings at each spot                                                        | ton/year of saved CO <sub>2</sub> e | 8                 | 33.34 | 49.50 | 23.86   | 12.84 |

**Table 57:** CO1 Wahn and Mulheim Environmental KPI – 2014 (only Wahn), 2015 and 2016

Due to the higher reduction of fuel used in Cologne Wahn, the emission reductions were higher in this site.

| ID     | KPI                                                                                                  | Unit of Measurement   | Wahn              |       |       | Mülheim |       |
|--------|------------------------------------------------------------------------------------------------------|-----------------------|-------------------|-------|-------|---------|-------|
|        |                                                                                                      |                       | 2014<br>(Mar-Dec) | 2015  | 2016  | 2015    | 2016  |
| CO1Ec1 | Yearly depreciation costs per saved ton of CO <sub>2</sub> at each spot                              | €/ton CO <sub>2</sub> | 5,030             | 1,238 | 833   | 1,438   | 2,672 |
| CO1Ec2 | Yearly operation costs per saved ton of CO <sub>2</sub> e at each spot                               | €/ton CO <sub>2</sub> | 1,772             | 436   | 294   | 480     | 893   |
| CO1Ec3 | Total cost (operating costs and yearly depreciation) per saved ton of CO <sub>2</sub> e at each spot | €/ton CO <sub>2</sub> | 6,803             | 1,674 | 1,127 | 1,918   | 3,565 |

**Table 58:** CO1 Wahn and Mulheim Economic KPI – 2014 (only Wahn), 2015 and 2016

The social KPIs remain the same as in the previous monitoring period.

| ID    | KPI                                                                              | Unit of Measurement | Wahn   | Mülheim |
|-------|----------------------------------------------------------------------------------|---------------------|--------|---------|
| CO1S1 | Number of working hours used for running and maintaining the system at each spot | hours/year          | 130    | 60      |
| CO1S2 | Number and type of possible complaints                                           | -                   | No     | No      |
| CO1S3 | Internal floor area served by the new system at each spot                        | m <sup>2</sup>      | 20,650 | 11,199  |
| CO1S4 | Number of end-users benefitting of the new system at each spot                   | -                   | 1,310  | 735     |

**Table 59:** CO1 Wahn and Mulheim Social KPI – 2014 (only Wahn), 2015 and 2016

#### 4.2.1.1 General KPI

In the following table general KPIs for both demonstrator sites are shown.

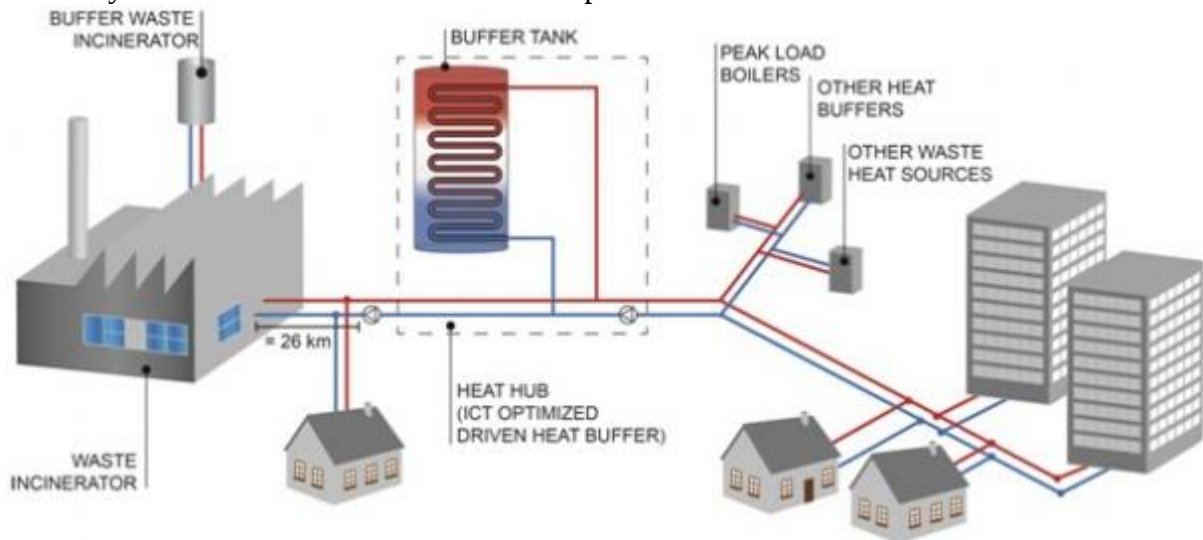
|               | General KPIs                                                                                                   | UM                         | Wahn                                                  |                                                        |                                                        | Mülheim                                              |                                                        |
|---------------|----------------------------------------------------------------------------------------------------------------|----------------------------|-------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|--------------------------------------------------------|
|               |                                                                                                                |                            | 2014<br>(Mar-Dec)                                     | 2015                                                   | 2016                                                   | 2015                                                 | 2016                                                   |
| Energetic     | The yearly amount of thermal energy produced/provided by the new system                                        | MWh/year                   | 704                                                   | 1,109                                                  | 1,015                                                  | 719                                                  | 762                                                    |
|               | Saved primary energy in comparison with baseline situation                                                     | MWh/year                   | 118                                                   | 289                                                    | 411                                                    | 216                                                  | 166                                                    |
|               | Energy efficiency of the project                                                                               | -                          | -                                                     | 1.16                                                   | 1.48                                                   | 1.36                                                 | 1.28                                                   |
|               | Energy recovery from waste/renewable sources                                                                   | MWh/year                   | 95                                                    | 286                                                    | 371                                                    | 237                                                  | 252                                                    |
| Environmental | Yearly GHG savings in comparison with the baseline situation                                                   | %                          | 5.2                                                   | 13.48                                                  | 21.90                                                  | 15.56                                                | 7.90                                                   |
|               | Yearly GHG emissions related to the project                                                                    | ton CO <sub>2</sub> e/year | 149                                                   | 214                                                    | 177                                                    | 130                                                  | 150                                                    |
|               | Yearly pollutant emissions related to the project                                                              | kg/year                    | SO <sub>2</sub> : 8<br>NO <sub>x</sub> : 111<br>PM: 4 | SO <sub>2</sub> : 12<br>NO <sub>x</sub> : 169<br>PM: 7 | SO <sub>2</sub> : 7<br>NO <sub>x</sub> : 108<br>PM: 4  | SO <sub>2</sub> : 6<br>NO <sub>x</sub> : 87<br>PM: 3 | SO <sub>2</sub> : 7<br>NO <sub>x</sub> : 96<br>PM: 4   |
|               | Yearly reduction of polluting emission in comparison to baseline                                               | kg/year                    | SO <sub>2</sub> : 5<br>NO <sub>x</sub> : 65<br>PM: 3  | SO <sub>2</sub> : 8<br>NO <sub>x</sub> : 109<br>PM: 4  | SO <sub>2</sub> : 10<br>NO <sub>x</sub> : 147<br>PM: 6 | SO <sub>2</sub> : 6<br>NO <sub>x</sub> : 85<br>PM: 3 | SO <sub>2</sub> : 6<br>NO <sub>x</sub> : 87.3<br>PM: 3 |
|               | Carbon footprint                                                                                               | ton C/year                 | -                                                     | 293                                                    | 250                                                    | 275                                                  | 200                                                    |
|               | Ecological footprint                                                                                           | ha                         | -                                                     | 66                                                     | 56                                                     | 72                                                   | 45                                                     |
| Economic      | Yearly depreciation rate per kWh of saved primary energy                                                       | €/kWh                      | 0.35                                                  | 0                                                      | 0.10                                                   | 0.16                                                 | 0.21                                                   |
|               | Yearly depreciation rate per ton of saved CO <sub>2</sub> e                                                    | €/t CO <sub>2</sub> e      | 5,030                                                 | 1,238                                                  | 833                                                    | 1,438                                                | 2,672                                                  |
|               | Total cost (yearly depreciation rate + OPEX) per kWh of saved primary energy                                   | €/kWh                      | 0.47                                                  | 0                                                      | 0.14                                                   | 0.21                                                 | 0.28                                                   |
|               | Total cost (yearly depreciation + OPEX) per ton of saved CO <sub>2</sub> e                                     | €/t CO <sub>2</sub> e      | 6,083                                                 | 1,675                                                  | 1,127                                                  | 1,918                                                | 3,565                                                  |
| Social        | Number of residents/users benefitting of the new project                                                       | -                          | 1,310                                                 |                                                        |                                                        | 735                                                  |                                                        |
|               | Reduction/increase of complaints due to the implementation of new system in comparison with baseline situation | -                          | 0                                                     |                                                        |                                                        | 0                                                    |                                                        |
|               | The internal floor area served by the new system                                                               | m <sup>2</sup>             | 20,650                                                |                                                        |                                                        | 11,199                                               |                                                        |

**Table 60:** CO1-General KPIs 2015 and 2016

#### 4.2.2 Rotterdam demonstrator: RO1 “The heat hub”

##### Demo description

The RO1 demonstrator or “The Heat Hub” is aimed at increasing the effectiveness of the waste heat distribution network of WARM through buffering, heat balancing, smart ICT and forecasting tools. Its implementation allows increasing the total heat delivery in the waste heat network, without any additional investments in new transport infrastructures or additional heat sources.



**Figure 42:** RO1- General Layout

##### Status description

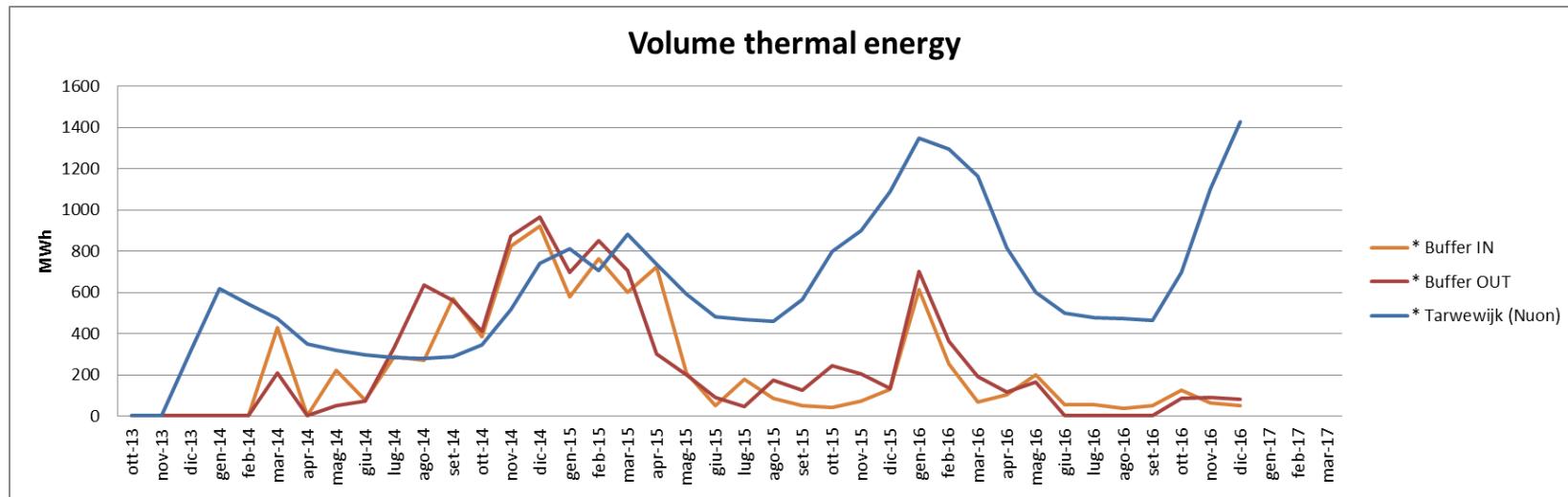
The demonstrator was started up in April 2014 and no deviation with respect to the initial schedule is foreseen. “The Heat Hub” is currently in operation and its performance is monitored in accordance to the protocol defined in D4.2. Monitored data and parameters are provided regularly every three months and the calculation of KPIs according to D4.1 is presented in the current deliverable with reference to 2014, 2015 and 2016.

The technical parameters monitored are shown in Table 61.

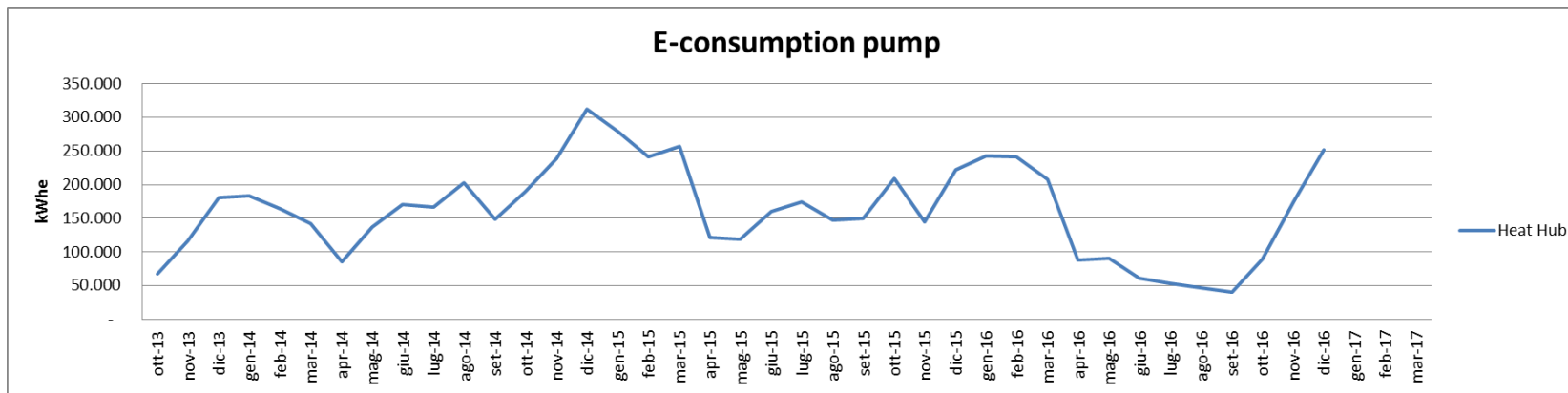
| Technical parameters           | Unit of measurement |
|--------------------------------|---------------------|
| Volume of heat delivered       | [MWht]              |
| Pumps electricity consumptions | [kWhe]              |
| Temperature (Supply&Return)    | [°C]                |

**Table 61:** RO1-Monitored parameters

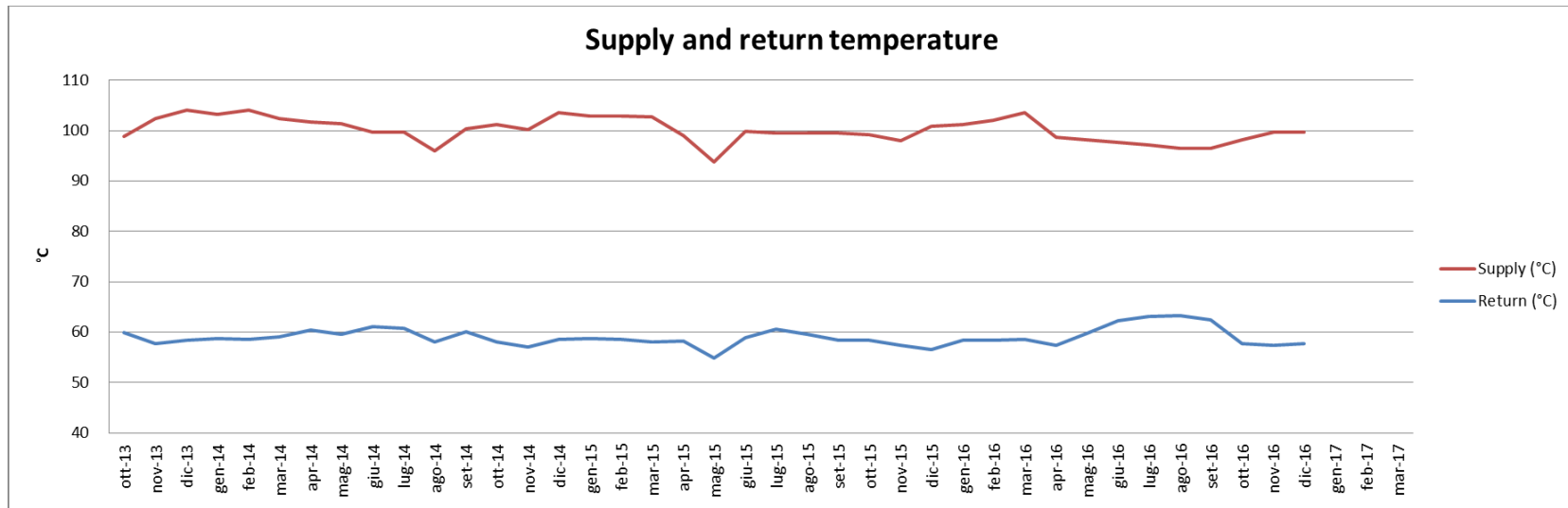
The distributions of the aforementioned parameters are graphically presented in the following charts with reference to the years 2014, 2015 and 2016. It can be noticed that the pumps electricity consumption is mainly related to the amount of heat stored in and delivered by the Heat Hub, whereas the water supply and return temperature is almost constant during the year.



**Figure 43:** RO1-Delivered Thermal Energy [MWh]



**Figure 44:** RO1- Electricity Consumptions [kWh] of Heat Hub Pumps



**Figure 45:** RO1-Supply and Return Temperatures [°C] at the Heat Hub

### Main assumptions for KPIs calculation

The current situation, where the Heat Hub recovers part of the waste heat coming from the AVR incinerator improving the efficiency of Warm district heating network, has been compared to a baseline situation where the same amount of recovered heat is produced by means of a big centralized gas boiler connected to the district heating network. As for the current situation, electric energy consumptions related to AVR incinerator, DHN pumps and pressure control stations have been considered in the baseline situation. On the contrary, electric energy consumptions related to the pumps at AVR incinerator have not been taken into account.

In the following Table 62, the emission factors and primary energy factors for the baseline situation are presented.

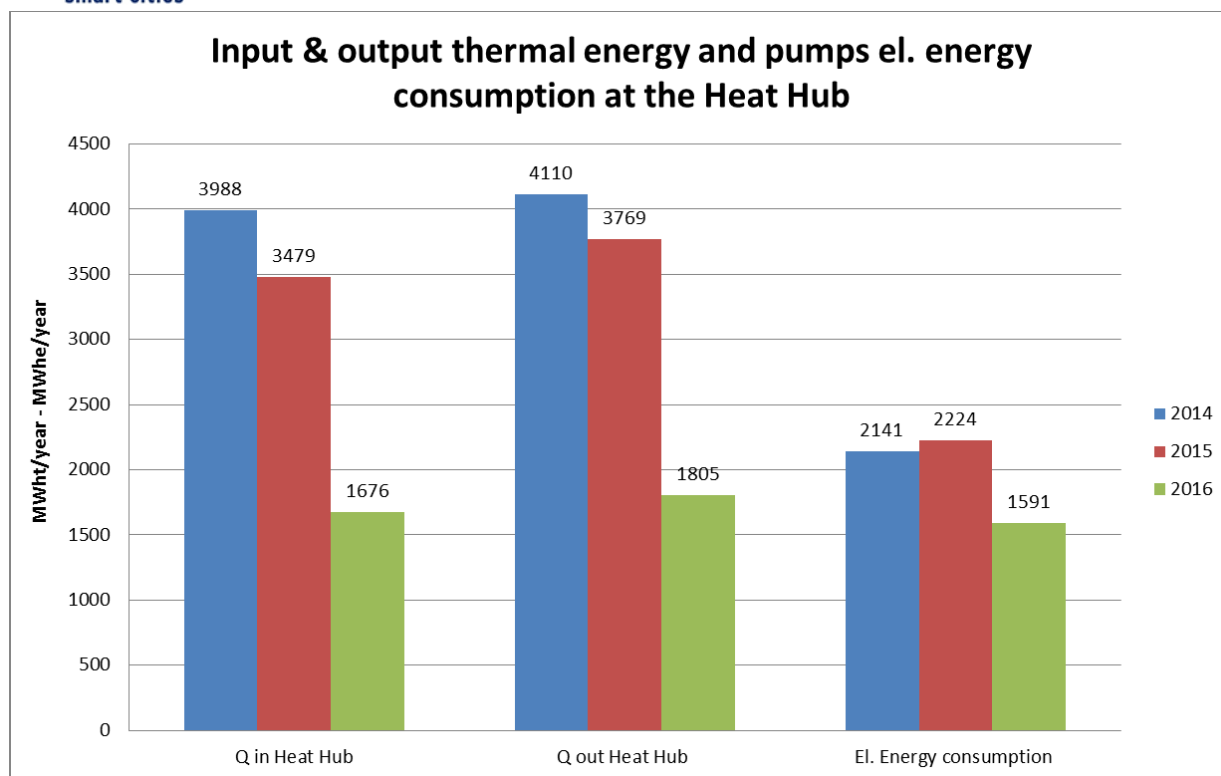
| Parameter        | Unit of meas. | Value   | Comments and references                                                   |
|------------------|---------------|---------|---------------------------------------------------------------------------|
| $E_{th\ prod}$   | t/MWh         | 0.202   | Assuming thermal energy supplied by a big centralized NG fired boiler [6] |
| $PEF_{th\ prod}$ | -             | 1.1     | [5]                                                                       |
| $NOx_{th\ prod}$ | -             | 3.4e-07 | $NOx=N_2O$ [6]                                                            |

**Table 62:** RO1-Baseline Parameters

The assessment of the annual performance of the demonstrators was performed on the basis of the available monitored data covering the period April-December 2014, January-December 2015 and January- December 2016. The monitored parameters have been elaborated and used as input data for KPI calculation, as reported in Table 63.

| Input parameters             |                                                                                                                                | Unit of measurement | Apr-Dec 2014 | Jan-Dec 2015 | Jan-Dec 2016 |
|------------------------------|--------------------------------------------------------------------------------------------------------------------------------|---------------------|--------------|--------------|--------------|
| $Q_{in}$                     | Incoming thermal energy                                                                                                        | [MWh]               | 3,988        | 3,479        | 1,676        |
| $Q_{out}$                    | Outcoming thermal energy                                                                                                       | [MWh]               | 4,110        | 3,769        | 1,805        |
| $C_{pump\ heat\ hub}$        | Electric energy consumption of pumps at heat hub                                                                               | [MWh]               | 2,140        | 2,223        | 1,591        |
| $C_{pump\ AVR}$              | Estimation of electric energy consumption of, DHN pumps from AVR incinerator to heat hub (1% of total el. energy consumptions) | [MWh]               | 58           | 66           | 50           |
| $C_{pump\ control\ station}$ | Electric energy consumption of pumps at pressure control stations)                                                             | [MWh]               | 765          | 1,295        | 1,602        |
| $C_{pump\ total}$            |                                                                                                                                | [MWh]               | 2,965        | 3,586        | 3,242        |
| $Q_{buffer}$                 | Thermal energy in and out of the buffer                                                                                        | [MWh]               | 8,098        | 7,248        | 3,482        |

**Table 63:** RO1-Input Data for KPIs Calculation



**Figure 46:** Monitored parameters at the Heat Hub aggregated on annual basis - 2014, 2015 and 2016

Considering that RO1 demonstrator is supplied with heat recovered from the already existing waste incinerator, no additional emissions to atmosphere have been considered. In addition, with regard to the environmental parameters, Emission Factors (E) related to electric energy are assumed equal to zero as WARM sources electricity from certified renewable sources and specifically from wind power.

| Parameter                                | Unit of meas. | Value | Comments and references                                                                    |
|------------------------------------------|---------------|-------|--------------------------------------------------------------------------------------------|
| E <sub>CO<sub>2</sub>, incinerator</sub> | t/MWhe        | 0     | Thermal energy recovered from the incinerator                                              |
| E <sub>CO<sub>2</sub>, el grid</sub>     | t/MWhth       | 0     | WARM sources electricity from certified renewable sources and specifically from wind power |
| E <sub>NO<sub>x</sub>, el grid</sub>     | t/MWhth       | 0     | WARM sources electricity from certified renewable sources and specifically from wind power |

**Table 64:** RO1-Assumed Environmental Parameters

Finally, the assumed Primary Energy Factor (PEF) both for electricity and thermal energy are reported in Table 65 with the corresponding references.

| Parameter                  | Unit of meas. | Value | Comments and references                                                                        |
|----------------------------|---------------|-------|------------------------------------------------------------------------------------------------|
| PEF <sub>incinerator</sub> | -             | 0.05  | Thermal energy recovered from the incinerator [13]                                             |
| PEF <sub>el.grid</sub>     | -             | 1.00  | WARM sources electricity from certified renewable sources and specifically from wind power [5] |

**Table 65:** RO1-Assumed Primary Energy Factors (PEF)

#### 4.2.2.1 Demo-specific KPI

Following the specific analysis performed on each demonstrator, a list of specific KPIs has been defined in D4.1 [3] in order to evaluate the performance and the impact of each demonstrator from the technical, economic, social and environmental point of view.

The following tables present the demo-specific KPIs for RO1 demonstrator, with reference to the periods April-December 2014, January-December 2015 and January-December 2016: more in detail, Table 66 shows the technical KPIs and Table 67 the environmental ones.

| ID    | KPI                                                                                                                      | Unit of Measurement   | Formula                                   | Apr-Dec 2014 | Jan-Dec 2015 | Jan-Feb 2016 |
|-------|--------------------------------------------------------------------------------------------------------------------------|-----------------------|-------------------------------------------|--------------|--------------|--------------|
| RO1T1 | Yearly amount of waste energy recovered by the heat hub                                                                  | MWh/year              | $\sum_{year} Q_{in}$                      | 3,988        | 3,479        | 1,436        |
| RO1T2 | Yearly electric energy consumption of the buffer pump versus the yearly thermal energy loading and unloading buffer tank | MWh/year and MWh/year | $\sum_{year} \frac{C_{pump}}{Q_{buffer}}$ | 0.366        | 0.495        | 0.556        |

**Table 66:** RO1-Technical KPIs

| ID     | KPI                               | Unit of Measurement | Formula | Apr-Dec 2014 | Jan-Dec 2015 | Jan-Feb 2016 |
|--------|-----------------------------------|---------------------|---------|--------------|--------------|--------------|
| RO1En1 | Yearly savings of CO <sub>2</sub> | ton/year            | -       | 874          | 801          | 329          |
| RO1En2 | Yearly savings of NO <sub>x</sub> | ton/year            | -       | 6.23*        | 7.13*        | 3.23*        |

**Table 67:** RO1-Environmental KPIs

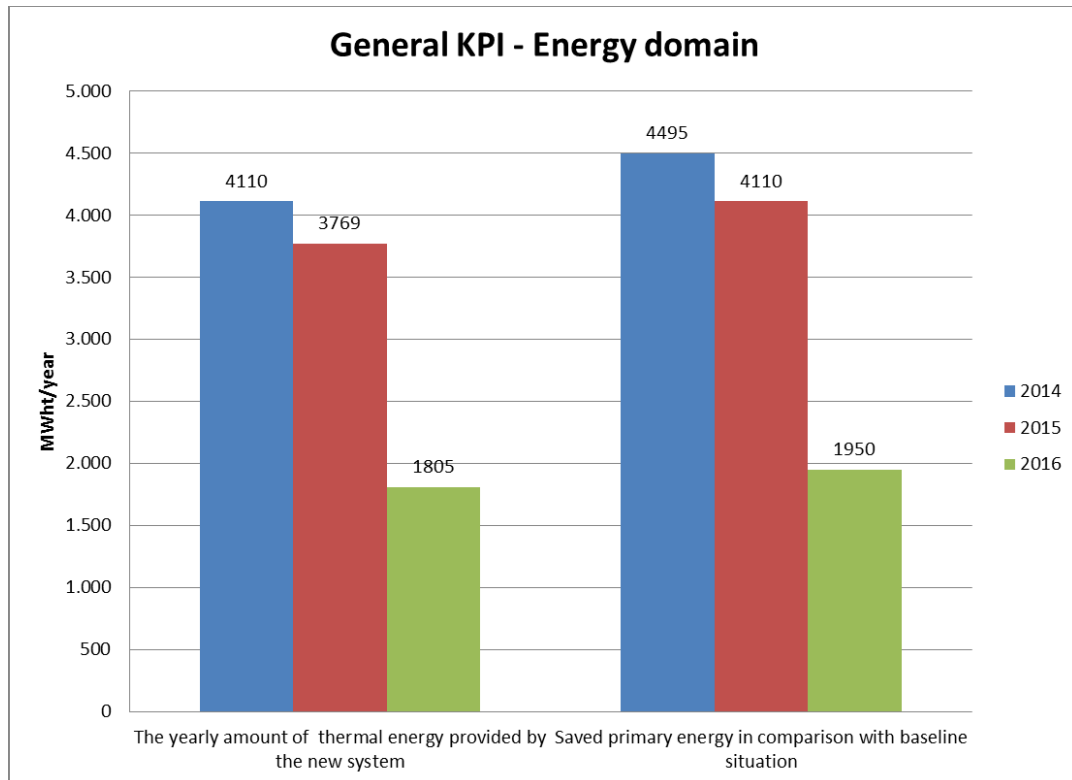
\*NO<sub>x</sub> savings are calculated considering as baseline situation for the electricity production the following national production mix: 55% natural gas, 27% coal and 18% renewables [25].

#### 4.2.2.2 General KPI

In the following Table 68 the general KPIs related to energy and environmental aspects of RO1 demonstrator are presented for the years 2014, 2015 and 2016.

|           | General KPIs                                                            | UM                         | RO1                  | Apr-Dec 2014 | Jan-Dec 2015 | Jan-Dec 2016 |
|-----------|-------------------------------------------------------------------------|----------------------------|----------------------|--------------|--------------|--------------|
| ENERGETIC | The yearly amount of thermal energy produced/provided by the new system | MWh/year                   | x                    | 4,110        | 3,186        | 1,805        |
|           | Saved primary energy in comparison with baseline situation              | MWh/year                   | x                    | 4,495        | 4,110        | 1,950        |
| ENV       | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e/year | x                    | 0            | 0            | 0            |
|           | Yearly pollutant emissions related to the project                       | kg/year                    | Only NO <sub>x</sub> | 0            | 0            | 0            |

**Table 68:** RO1-General KPIs



**Figure 47: RO1- General KPI for the energy domain**

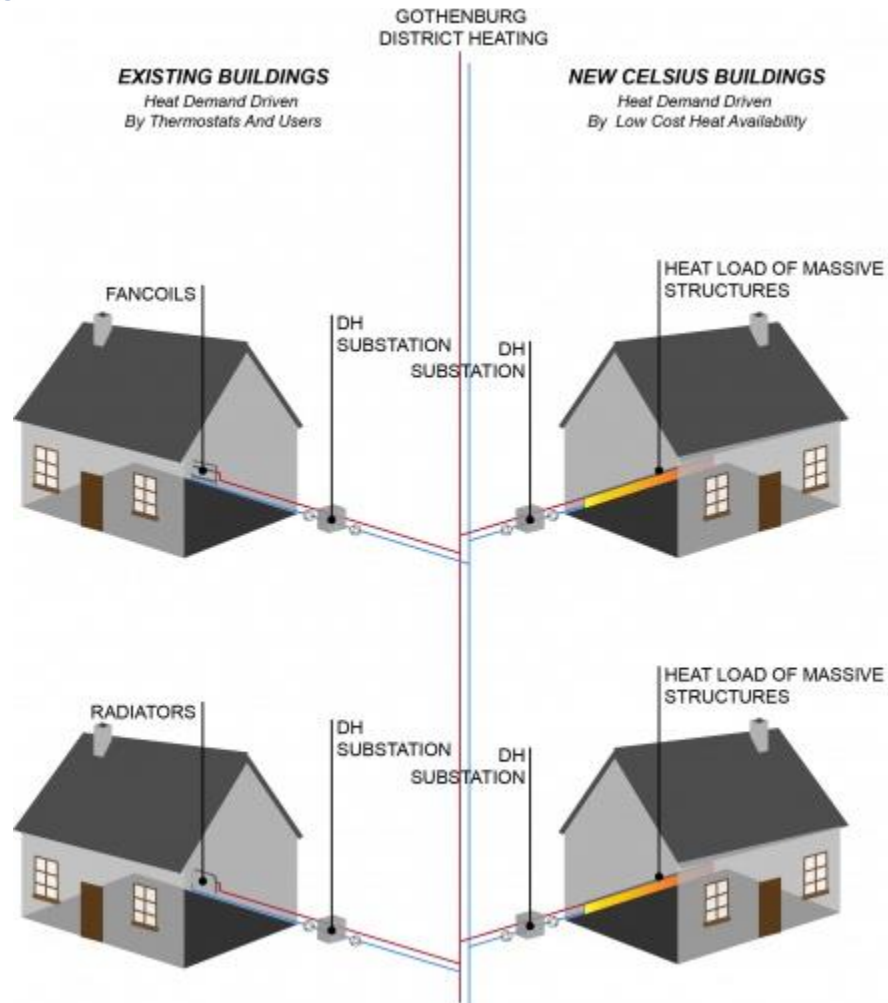
The yearly amount of thermal energy provided by the system in 2014 and 2015 is comparable, whereas it is lower for 2016, due to a lower heat recovery from the incinerator. Moreover, according to the calculations performed, the environmental benefits resulting from the installation and operation of the Heat Hub are significant being current primary energy consumptions equal to 59%, 52% and 37% of the baseline consumptions. As mentioned above the effects of the demonstration operation from an environmental perspective are null as WARM sources electricity from certified renewable sources (i.e. wind power).

#### **4.2.3 Gothenburg demonstrator: GO1 “Using buildings as short term storage”**

##### *Demo description*

The idea underlying the GO1 demonstrator (“Using building as short term storage”) is to exploit the thermal capacity of buildings’ structural elements (e.g.: floors, ceilings and walls) for heat storage and enhanced heat control purposes.

Indeed, on the basis of weather forecasts, in case severe weather conditions are foreseen, the demo technology would allow to “load” the building with thermal energy in advance with respect to the achievement of the most critical external conditions. Then, the building heating system would be switched off in order to prevent peak loads at the heat production facilities, but without creating any comfort problems to the customers, since the building would be warmed up by means of the heat stored in the building components/materials (in a sort of “unloading” phase of the building).

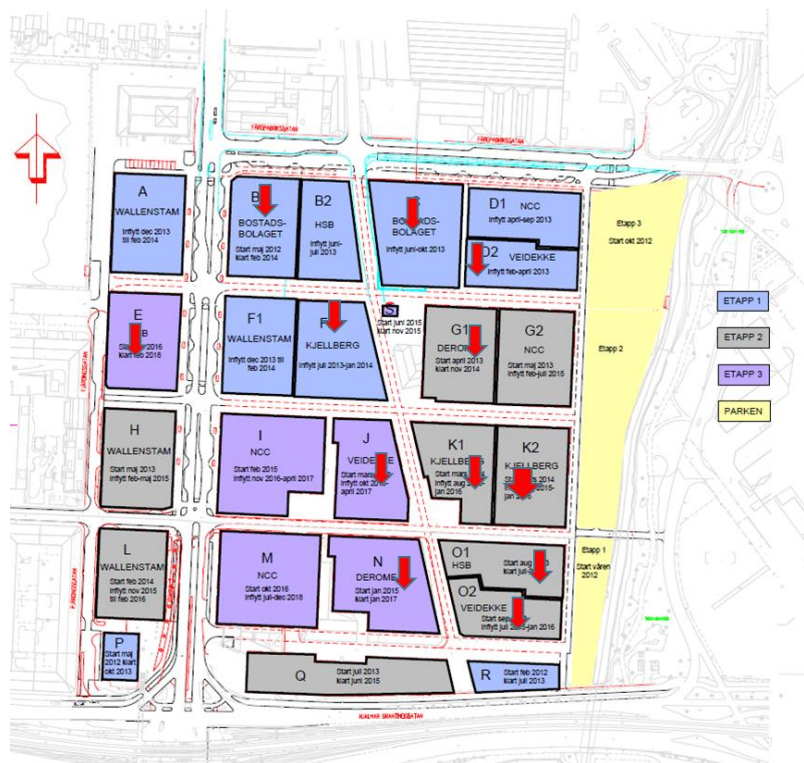


**Figure 48:** GO1 concept layout

### *Status description*

Short term storage” technology is currently applied to 12 buildings in Gothenburg (Kvillebacken district), among which 4 buildings have been monitored since the winter season 2015/2016 and for which the analysis of the monitored data made available is presented in the following section.





↓ Installed test and reports from buildings winter 2016 and spring 2017

Figure 49: GO1 Status of installation

### Monitored parameters

As mentioned above, the short term storage technology is expected to contribute to shave peaks in thermal energy demand at energy production facilities without impacting on buildings tenants and specifically on indoor temperature. Considering the limited number of buildings where the GO1 technology is installed, it is not possible to clearly show the effect of this demonstrator at energy production facilities yet; GOTE informs that 165 buildings provided with GO1 technology and concentrated in one area served by the same thermal energy production facility would be needed to produce an effect on it. On the contrary, it is possible to put in evidence the effects from end-users perspective (i.e. building tenants). As a matter of fact, running GO1 demonstrator for a ten-day period in March 2016 resulted in no variations in indoor temperature.

Such an effect is shown in the following chart where different information is included:

- Indoor temperature in one room (°C - black line)
- Outdoor temperature (°C - blue line)
- Solar irradiance (W/m<sup>2</sup> - red line)
- Thermal energy upload and download in buildings elements (green line)

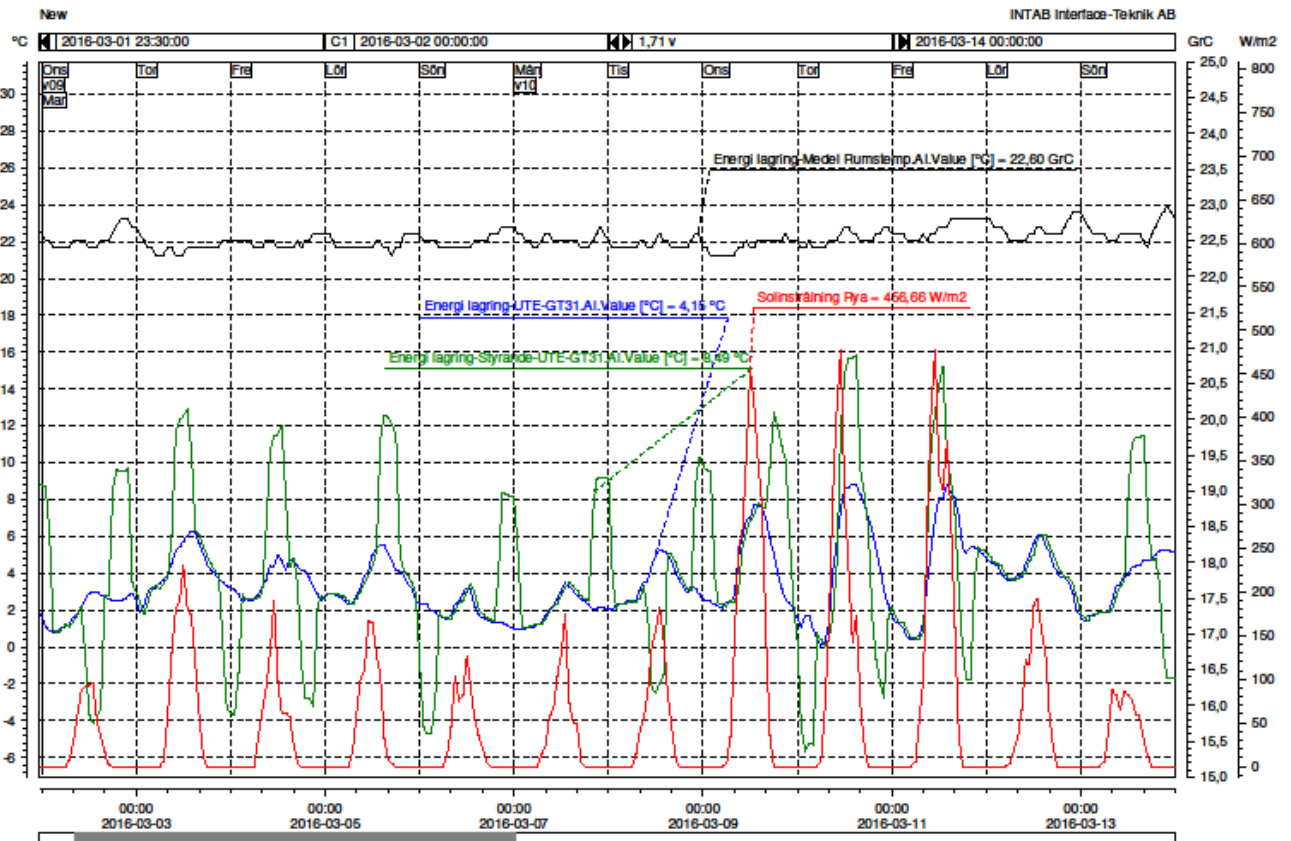
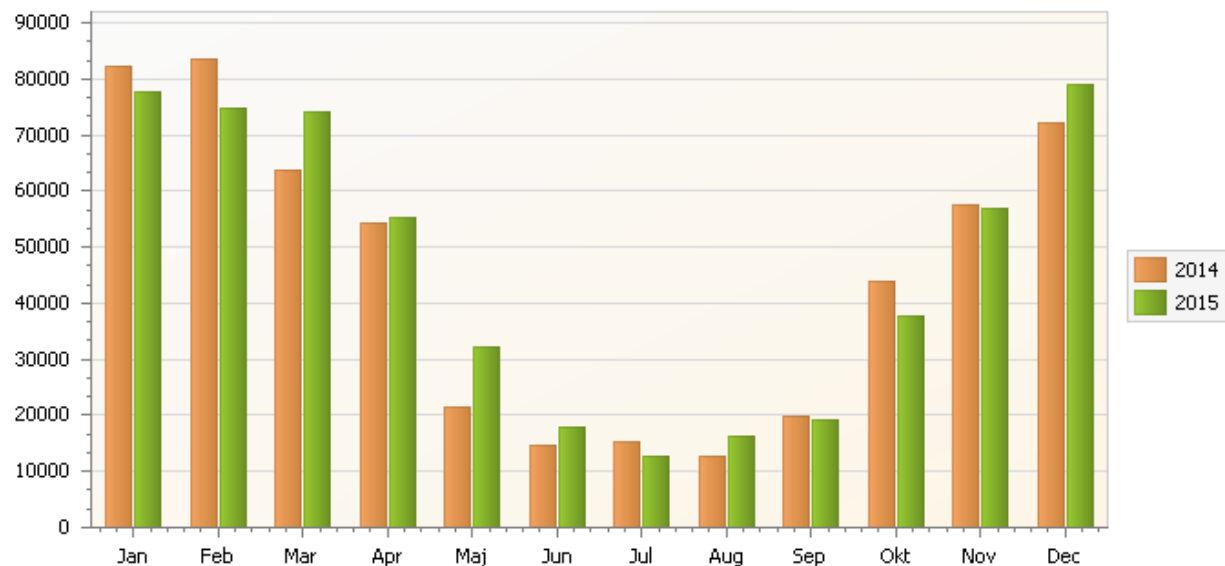


Figure 50: GO1 – Example of monitored parameters

GOTE has made available a complete set of data, referring to the period 2012-2015, for the baseline situation, which in this case is constituted by the same buildings without the implementation of the active heat load control technology (GO1 activated since November 2015).

## Building's energy consumptions 2012-2016

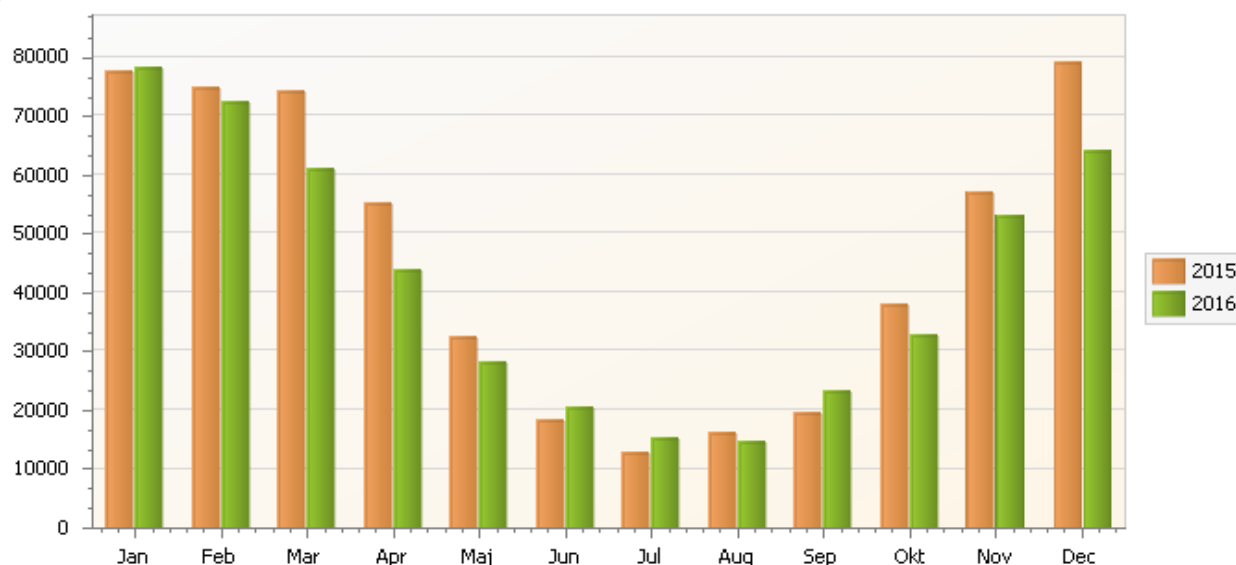
| Rubrik                            | Enhet  | 2012 | 2013  | 2014   | 2015   | 14/15 |
|-----------------------------------|--------|------|-------|--------|--------|-------|
| Värmeanvändning                   | MWh    | -    | 73,70 | 477,20 | 506,87 | 6,2 % |
| Graddagar                         | GD     | 3430 | 3328  | 2829   | 3019   | 6,7 % |
| Korrigerad värmeanvändning        | MWh    | -    | 91,23 | 541,40 | 553,76 | 2,3 % |
| Korrigerad värmeanvändning per m² | kWh/m² | -    | 2 919 | 17 325 | 17 720 | 2,3 % |



| Månad   | Graddagar |      |      | Användning Värme |          |                              |          |         | Budgeterad användning |       |
|---------|-----------|------|------|------------------|----------|------------------------------|----------|---------|-----------------------|-------|
|         | Norm      | 2014 | 2015 | Verklig 2014 MWh | 2015 MWh | Normalårskorrigerad 2014 MWh | 2015 MWh | Diff    | 2015 MWh              | Diff  |
| Jan     | 528       | 527  | 451  | 82,00            | 68,20    | 82,13                        | 77,57    | -5,6 %  | -                     | -     |
| Feb     | 484       | 385  | 430  | 69,70            | 68,00    | 83,65                        | 74,81    | -10,6 % | -                     | -     |
| Mar     | 464       | 360  | 395  | 52,30            | 65,10    | 63,88                        | 74,00    | 15,8 %  | -                     | -     |
| Apr     | 322       | 254  | 307  | 45,80            | 53,20    | 54,37                        | 55,12    | 1,4 %   | -                     | -     |
| Maj     | 176       | 158  | 221  | 20,00            | 37,40    | 21,35                        | 32,31    | 51,4 %  | -                     | -     |
| Jun     | 83        | 53   | 119  | 12,30            | 21,40    | 14,57                        | 18,03    | 23,7 %  | -                     | -     |
| Jul     | 27        | 4    | 55   | 12,60            | 15,10    | 15,15                        | 12,53    | -17,3 % | -                     | -     |
| Aug     | 38        | 47   | 14   | 13,50            | 13,50    | 12,72                        | 16,12    | 26,7 %  | -                     | -     |
| Sep     | 126       | 95   | 114  | 17,30            | 18,30    | 19,92                        | 19,28    | -3,2 %  | -                     | -     |
| Okt     | 260       | 185  | 252  | 34,90            | 37,00    | 43,79                        | 37,82    | -13,6 % | -                     | -     |
| Nov     | 382       | 318  | 304  | 50,20            | 47,97    | 57,72                        | 57,02    | -1,2 %  | -                     | -     |
| Dec     | 489       | 443  | 357  | 66,60            | 61,70    | 72,14                        | 79,16    | 9,7 %   | -                     | -     |
| Jan-Mar | 1476      | 1272 | 1276 | 204,00           | 201,30   | 229,67                       | 226,38   | -1,4 %  | -                     | 0,0 % |
| Tot:    | 3379      | 2829 | 3019 | 477,20           | 506,87   | 541,40                       | 553,76   | 2,3 %   | -                     | 0,0 % |

Figure 51: GO1 – Buildings' energy consumptions, 2014-2015

| Rubrik                                        | Enhet              | 2013  | 2014   | 2015   | 2016   | 15/16  |
|-----------------------------------------------|--------------------|-------|--------|--------|--------|--------|
| Värmeanvändning                               | MWh                | 73.70 | 477.20 | 506.87 | 482.62 | -4,8 % |
| Graddagar                                     | GD                 | 3328  | 2829   | 3019   | 3151   | 4,4 %  |
| Korrigerad värmeanvändning                    | MWh                | 9123  | 54140  | 553.76 | 505.57 | -8,7 % |
| Korrigerad värmeanvändning per m <sup>2</sup> | kWh/m <sup>2</sup> | 2919  | 17325  | 17720  | 16178  | -8,7 % |



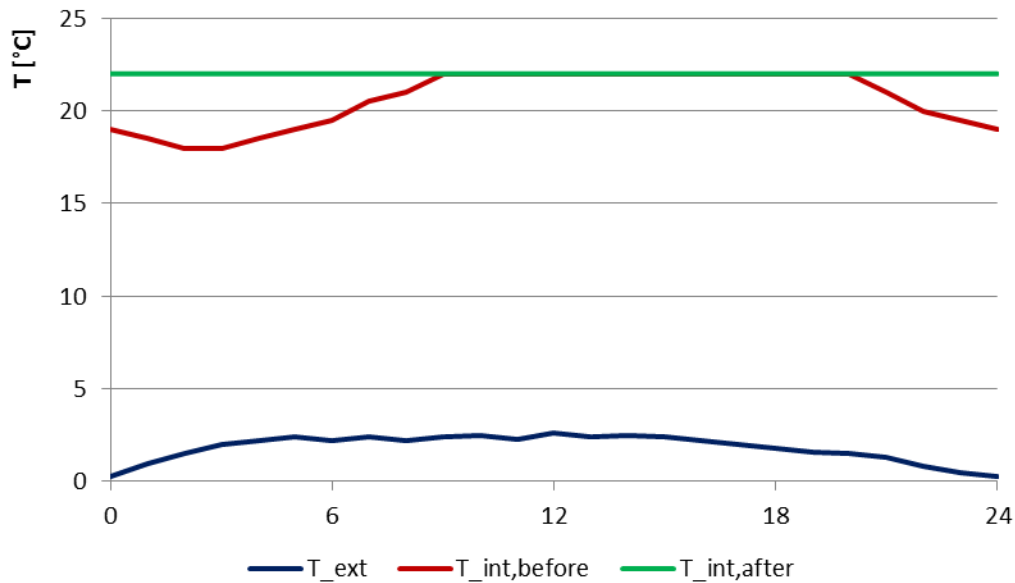
| Månad   | Graddagar |      |      | Användning Värme |          |                              |          |         | Budgeterad användning |       |
|---------|-----------|------|------|------------------|----------|------------------------------|----------|---------|-----------------------|-------|
|         | Norm      | 2015 | 2016 | Verklig 2015 MWh | 2016 MWh | Normalårskorrigerad 2015 MWh | 2016 MWh | Diff    | 2016 MWh              | Diff  |
| Jan     | 528       | 451  | 590  | 68.2             | 85.6     | 77.57                        | 78.01    | 0,6 %   | -                     | -     |
| Feb     | 484       | 430  | 462  | 68               | 69.55    | 74.81                        | 72.23    | -3,4 %  | -                     | -     |
| Mar     | 464       | 395  | 422  | 65.1             | 56.51    | 74                           | 60.98    | -17,6 % | -                     | -     |
| Apr     | 322       | 307  | 311  | 53.2             | 42.64    | 55.12                        | 43.76    | -20,6 % | -                     | -     |
| Maj     | 176       | 221  | 125  | 37.4             | 22.99    | 32.31                        | 27.99    | -13,4 % | -                     | -     |
| Jun     | 83        | 119  | 36   | 21.4             | 15.4     | 18.03                        | 20.37    | 13,0 %  | -                     | -     |
| Jul     | 27        | 55   | 22   | 15.1             | 14.61    | 12.53                        | 15.17    | 21,0 %  | -                     | -     |
| Aug     | 38        | 14   | 39   | 13.5             | 14.59    | 16.12                        | 14.49    | -10,1 % | -                     | -     |
| Sep     | 126       | 114  | 43   | 18.3             | 15       | 19.28                        | 23.16    | 20,1 %  | -                     | -     |
| Okt     | 260       | 252  | 285  | 37               | 34.71    | 37.82                        | 32.51    | -14,0 % | -                     | -     |
| Nov     | 382       | 304  | 411  | 47.97            | 55.9     | 57.02                        | 52.79    | -7,4 %  | -                     | -     |
| Dec     | 489       | 357  | 405  | 61.7             | 55.12    | 79.16                        | 64.12    | -19,0 % | -                     | -     |
| Jan-Jan | 0         | 0    | 0    | -                | -        | -                            | -        | 0,0 %   | -                     | 0,0 % |
| Tot:    | 3379      | 3019 | 3151 | 506.87           | 482.62   | 553.76                       | 505.57   | -8,7 %  | -                     | 0,0 % |

Figure 52: GO1 – Buildings' energy consumptions, 2015-2016

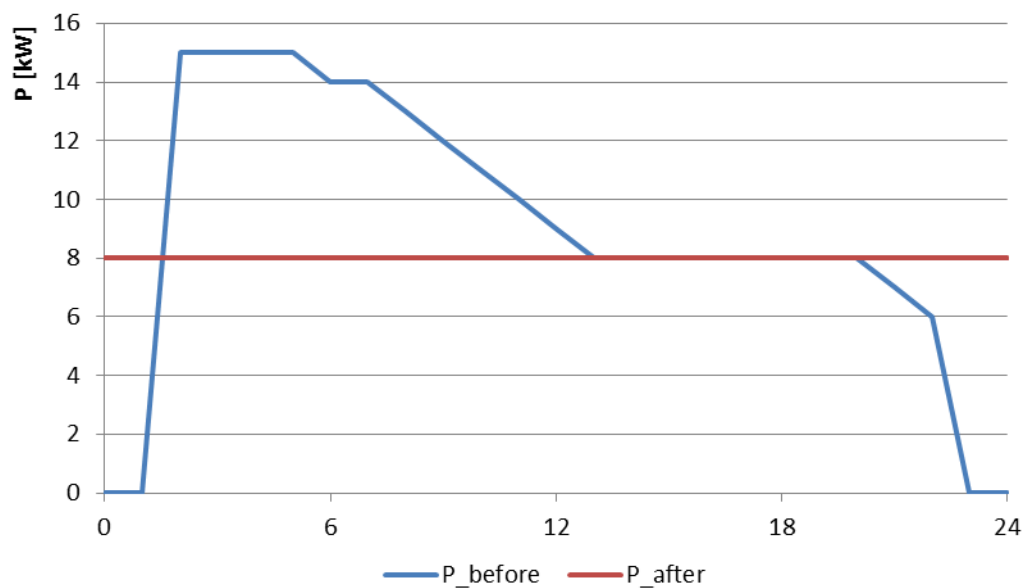
As stated above, not enough data are available for determining the impact of the implementation of the GO1 demo on the DH system. This is mainly due both the low number of buildings involved in the demonstration.

In a previous release of the D4.3, a very simplified simulation was performed in order to achieve a rough estimate of the impact of the demo implementation, by analysing a hypothetical 100 m<sup>2</sup> flat in Gothenburg. Figure 53 shows the considered trend for the external temperature (corresponding to a typical day of January) and for the internal temperature in two cases: with a standard use of district heating and with a new use aimed at keeping constant the internal temperature without any attenuation during the night. The corresponding estimated trend for the withdrawn thermal power in the two cases is shown in Figure 54, where two main effects can be noted: the morning peak is decreased by 7 kW, whereas the overall daily energy load is reduced by almost 10%.

Based on this simplified evaluation and multiplying the amplitude of the estimated peak shaving for the number of buildings that would be involved (165), an overall peak shaving effect of more than 1,100 kW can be calculated for the whole system.



**Figure 53:** GO1 – Estimated trends for internal and external temperatures, baseline vs. project scenario

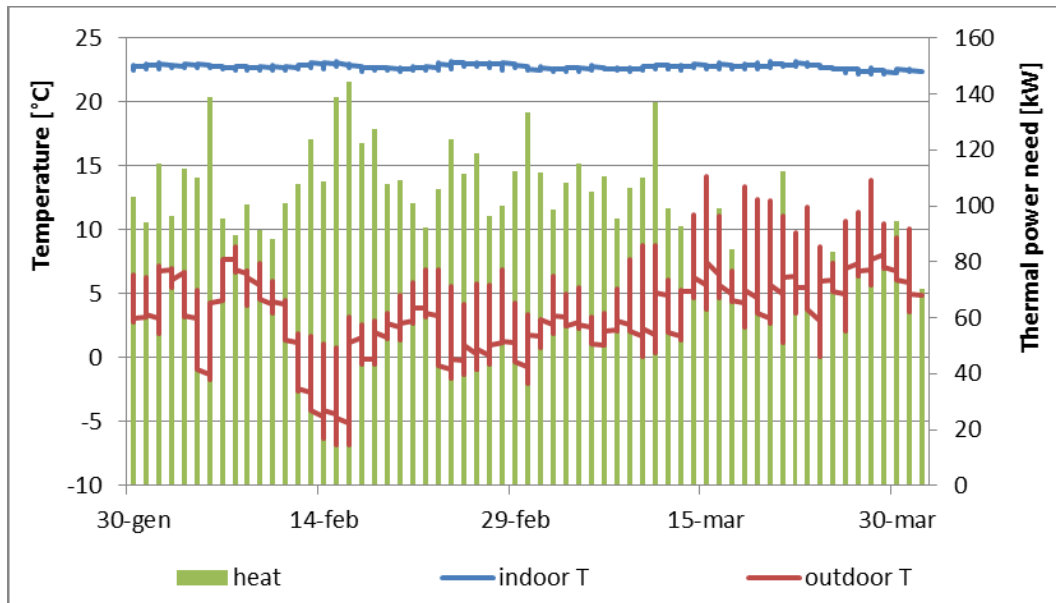


**Figure 54:** GO1 – Estimated trends for thermal power, baseline vs. project scenario

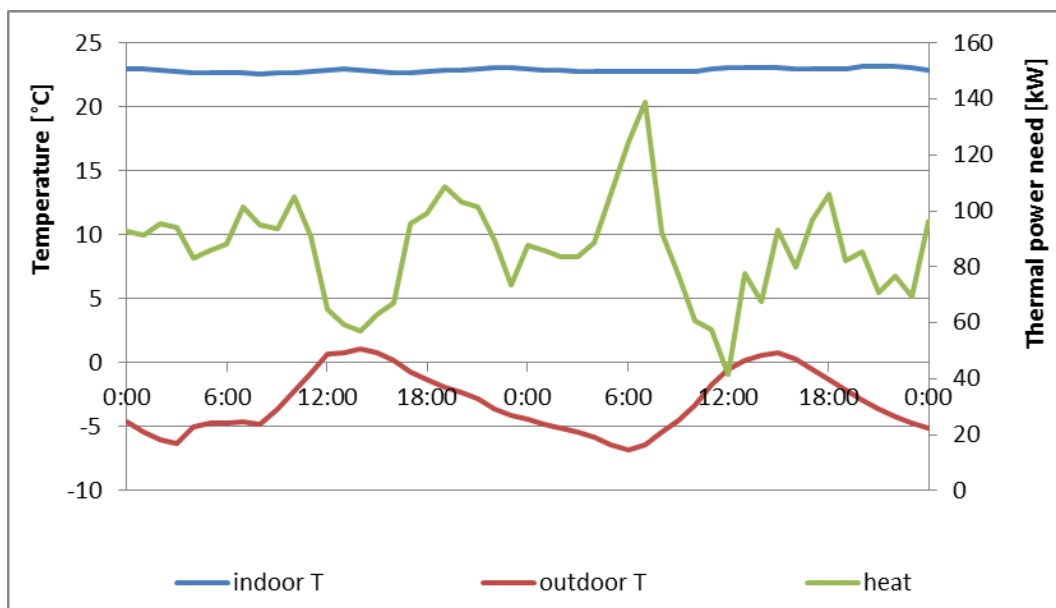
In addition to the above presented simulation, the following charts show the measured hourly trend of indoor and outdoor temperature in one of the multi-apartment buildings provided with the demo technology. More in detail, Figure 55 shows the trend for the whole considered months (February and March 2016), whereas in Figure 56 the same values are plotted for two of the coldest days (February 14<sup>th</sup> and 15<sup>th</sup>, 2016) and in Figure 63 for the warmest days of the winter (March 14<sup>th</sup> and 15<sup>th</sup>, 2016).

From the analysis of the presented data, it can be noticed that, as expected, the building's thermal power need shows an inverse trend to the outdoor temperature, thus reaching the highest values in the coldest periods. As regards the peak shaving effect, unfortunately it is not possible to give a numerical comparison with the previous situation since hourly values are not available for the baseline case, but it can be noticed that the elasticity of the heat demand, i.e. the ratio between the highest and the lowest hourly average thermal power is around 3 for the coldest days of the year,

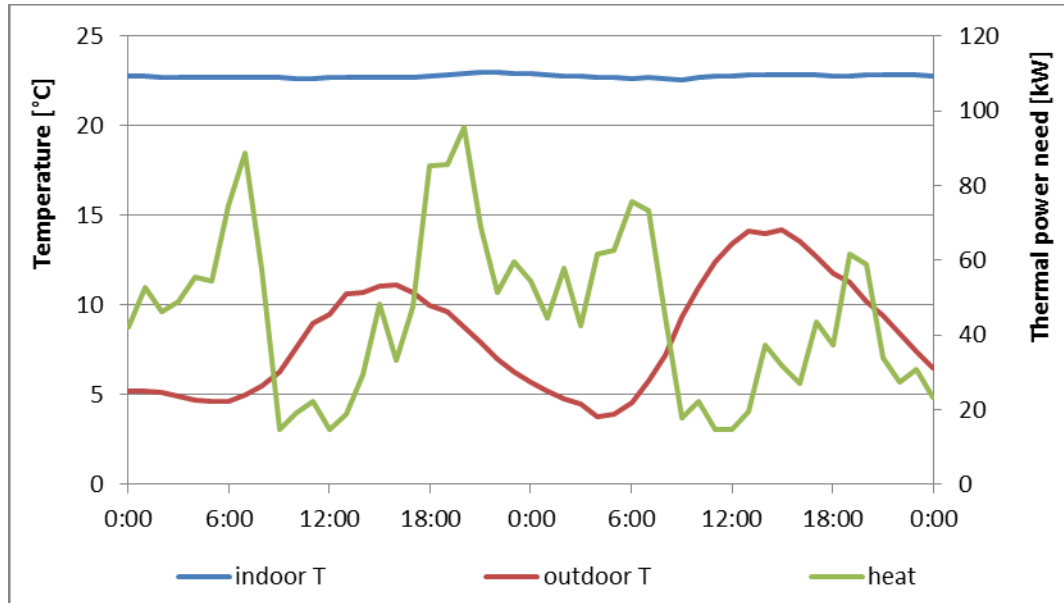
which indicates a smooth load trend that would not have been possible without the application of the short term storage technology.



**Figure 55:** GO1 – Indoor/Outdoor temperature and thermal power, project scenario (two months)



**Figure 56:** GO1 – Indoor/Outdoor temperature and thermal power, project scenario (coldest days)



**Figure 57: GO1 – Indoor/Outdoor temperature and thermal power, project scenario (warmest days)**

*More detailed KPIs calculations will be included in the final version of current deliverable (foreseen at M57) when consolidated monitored data will be available.*

#### 4.2.4 Gothenburg demonstrator: GO2 “District heating to white goods”

##### Demo description

The overall objective of GO2 Demonstrator is to install, operate and monitor performances of white goods (e.g. dishwashers, washing machines and dryers) able to use district heating hot water to cover heat demand instead of currently dominating electric resistances-based ones. The proposed machines use electricity only for motors and in rare cases of high peak heat demand.

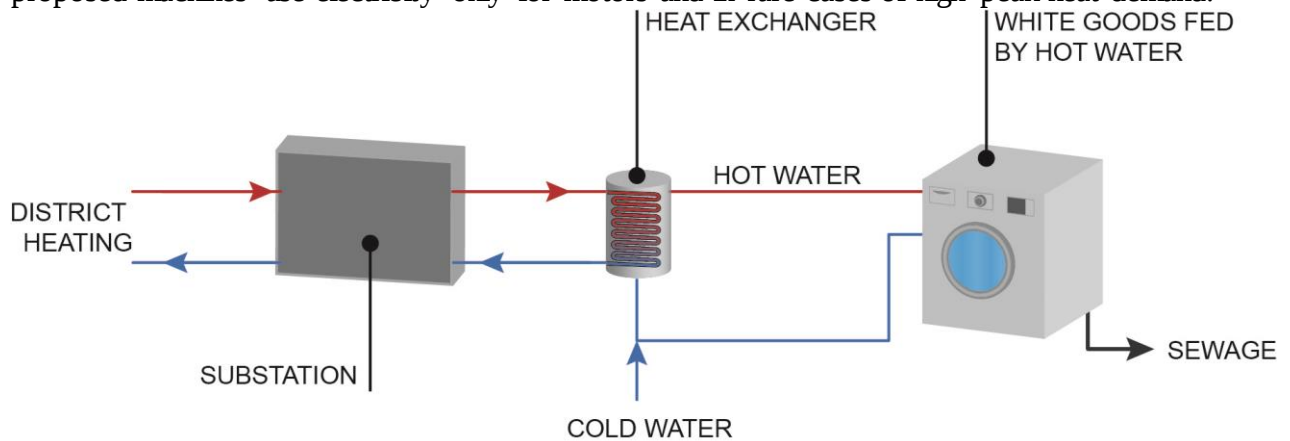


Figure 58

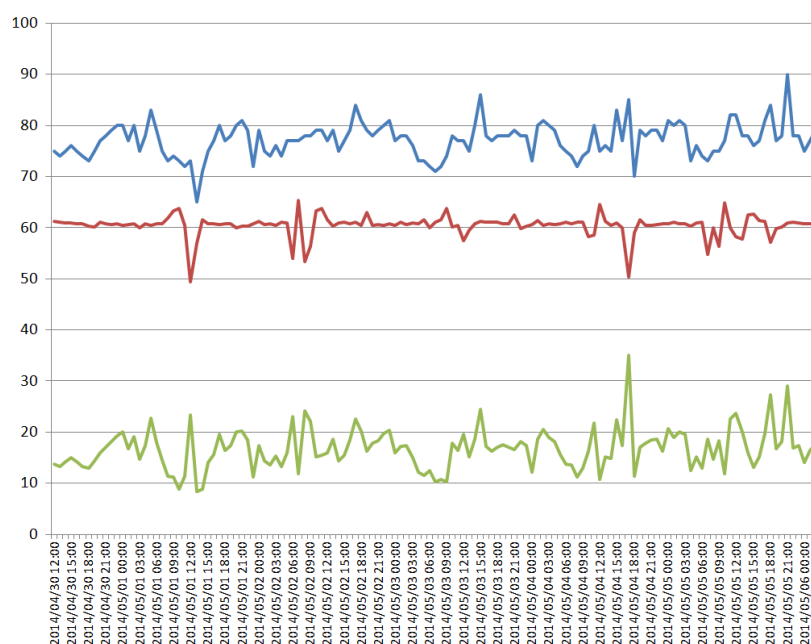
##### Status description

Currently (M42), 10 machines are in operation and 204 have been sold and are in the installation phase. The operating machines (i.e. 5 washers and 5 dryers) were installed and started up in July 2014 in a football club. Since then, monitored data and parameters are provided regularly, every three months and with an hourly frequency. In the present deliverable, the calculation of KPI according to D4.1 and data availability is presented, with reference to years 2014, 2015 and 2016 and in comparison with the defined baseline situation.

Table 69 summarizes the technical parameters monitored at GO2 demonstrator.

| Technical parameters                    | Unit of measurement   |
|-----------------------------------------|-----------------------|
| Thermal energy delivered to white goods | [Wh per laundry room] |
| Supply temperature                      | [°C per laundry room] |
| Return temperature                      | [°C per laundry room] |
| Electric energy use of white goods      | [Wh per machine]      |

Table 69: GO2-Monitored Parameters



**Figure 59:** GO2- Example of Monitored Temperatures - Supply (blue), return (red),  $\Delta T$  (green) [°C]

#### Main assumptions for KPIs calculation

In this case, the baseline situation is constituted by the same type of laundry rooms, equipped with standard new white goods, using only electricity (thus, also for heating purposes) as energy vector. The electricity consumptions of a traditional machine have been estimated, for comparison purposes, as the sum of the energy consumptions (i.e. heat and electricity) of the new machines.

The assessment of the annual performance of the demonstrators has been performed on the basis of the available monitored data covering the periods July-December 2014, January-December 2015 and January 1<sup>st</sup> - December 31<sup>st</sup> 2016.

The monitored parameters that have been elaborated and used as input data for the calculation of KPIs are those reported in the table below.

| Input parameters  |                                                                    | Unit of measurements    | Jul.-Dec 2014 | Jan.-Dec. 2015 | Jan.-Dec. 2016 |
|-------------------|--------------------------------------------------------------------|-------------------------|---------------|----------------|----------------|
| $Q_{wg}$          | Heat delivered to white goods                                      | [kWht per laundry room] | 4,295         | 6,811          | 6,815          |
| $C_{wg}$          | Electricity use of white goods                                     | [kWhe per laundry room] | 2,334         | 8,076          | 8,030          |
| $C_{wg-baseline}$ | Electric energy consumption for machines in the baseline situation | [kWhe per laundry room] | 6,855         | 14,883         | 14,751         |
| $N_w$             | Number of washing cycles                                           | [per laundry room]      | 6,958         | 17,013         | 17,020*        |

\* Values for 2016 are assumed according to 2015 records as those data have not been reported for 2016

**Table 70:** GO2-Input Data for KPIs Calculation

As regards the economic parameters, the assumed tariffs both for electricity and thermal energy are reported, with the related references, in Table 71.

| Parameter | Unit of meas. | Value | Comments and references |
|-----------|---------------|-------|-------------------------|
| $T_{el}$  | €/kWhe        | 0.21  | [26]                    |

| Parameter | Unit of meas. | Value | Comments and references                                                                                                 |
|-----------|---------------|-------|-------------------------------------------------------------------------------------------------------------------------|
| $T_{DHN}$ | €/kWhth       | 0.06  | Indirectly calculated considering total revenues from heat sold by GOTE in 2013 and thermal energy total production [9] |

**Table 71:** GO2-Assumed Economic Parameters

Among the environmental parameters, the assumed Emission Factors for both electricity and thermal energy are shown in Table 72 with the related references.

| Parameter      | Unit of meas. | Value | Comments and references                                                                                                                  |
|----------------|---------------|-------|------------------------------------------------------------------------------------------------------------------------------------------|
| $E_{el\ grid}$ | t/MWhe        | 0.023 | [7]                                                                                                                                      |
| $E_{DHN}$      | t/MWhth       | 0.019 | Calculated referring to the Gothenburg DH production mix: 74% waste heat, 9% natural gas, 12% biofuel, 5% electricity (provided by GOTE) |

**Table 72:** GO2-Assumed Environmental Parameters

Finally, the considered Primary Energy Factor (PEF) for electricity and heat is shown in Table 73 with the corresponding references.

| Parameter    | Unit of meas. | Value | Comments and references                                                                                                                  |
|--------------|---------------|-------|------------------------------------------------------------------------------------------------------------------------------------------|
| $PEF_{el}$   | -             | 1.8   | Assuming the following energy production mix: 70% renewable (PEF=1), 30% fossil fuels (PEF=3)                                            |
| $PEF_{DHN}$  | -             | 0.04  | Calculated referring to the Gothenburg DH production mix: 74% waste heat, 9% natural gas, 12% biofuel, 5% electricity (provided by GOTE) |
| $\eta_{DHN}$ | -             | 0.92  | Calculated as the ratio between of thermal energy produced and delivered to customers [30]                                               |

**Table 73:** GO2-Assumed Primary Energy Factors (PEF)

#### 4.2.4.1 Demo-specific KPIs

Following the specific analysis performed on each demonstrator, a list of specific KPIs has been defined in D4.1 in order to assess the performance and the impact of each demonstrator from the technical, economic, social and environmental point of view. The following tables present the values of demo-specific KPIs for GO2 demonstrator, with reference to the periods July-December 2014, January-December 2015 and January 1<sup>st</sup>-December 31<sup>st</sup>, 2016.

| ID    | KPI                                                                            | Unit of Measurement    | Formula                                                              | Jul.-Dec. 2014 | 2015  | 2016  |
|-------|--------------------------------------------------------------------------------|------------------------|----------------------------------------------------------------------|----------------|-------|-------|
| GO2T1 | Yearly heat demand per laundry room                                            | kWh/year laundry room  | $\sum_{year} \sum_i Q_{wg,i}$                                        | 4,295          | 6,811 | 6,815 |
| GO2T2 | Yearly electric energy savings per laundry room                                | kWhe/year laundry room | $\sum_{year} \sum_i C_{wg,i} - \sum_{year} \sum_i C_{wg,i-baseline}$ | 4,521          | 7,169 | 7,951 |
| GO2T3 | Percentage of substituted electric energy with reference to baseline situation | %                      | $\frac{C_{wg,i-baseline} - C_{wg,i}}{C_{wg,i-baseline}}$             | 66%            | 47%   | 47%   |

| ID    | KPI                                                  | Unit of Measurement | Formula                                | Jul.-Dec. 2014 | 2015 | 2016 |
|-------|------------------------------------------------------|---------------------|----------------------------------------|----------------|------|------|
| GO2T4 | Heat demand per washing and drying cycle             | kWh/wash            | $\frac{GO2T1}{\sum_{year} \sum_i N_i}$ | 0.64           | 0.44 | 0.44 |
| GO2T5 | Electric energy savings per washing and drying cycle | kWh/wash            | $\frac{GO2T2}{\sum_{year} \sum_i N_i}$ | 0.62           | 0.42 | 0.42 |

**Table 74: GO2- Technical KPIs**

| ID     | KPI                                                                                                                                        | Unit of Measurement                             | Formula                                           | Jul.-Dec. 2014 | 2015  | 2016  |
|--------|--------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|---------------------------------------------------|----------------|-------|-------|
| GO2En1 | Yearly pollutant emissions and GHG savings due to the reduction of electric energy consumption in comparison with the baseline situation   | kg/year of saved CO <sub>2</sub> e laundry room | $E_{el.grid} \cdot GO2T2 - E_{DHmix} \cdot GO2T1$ | 14             | 22    | 22    |
| GO2En2 | Pollutant emissions and GHG savings per wash due to the reduction of electric energy consumption in comparison with the baseline situation | kg of saved CO <sub>2</sub> e/wash              | $E_{el.grid} \cdot GO2T5 - E_{DHmix} \cdot GO2T1$ | 0.002          | 0.001 | 0.001 |

**Table 75: GO2- Environmental KPIs**

| ID     | KPI                                | Unit of Measurement | Formula                                                                                   | Jul.-Dec. 2014 | 2015          | 2016          |
|--------|------------------------------------|---------------------|-------------------------------------------------------------------------------------------|----------------|---------------|---------------|
| GO2Ec1 | Economic savings per washing cycle | €/wash              | $GO2T5 \cdot T_{el,end-user} - GO2T4 \cdot T_{th,end-user}$                               | 0.092          | 0.062         | 0.062         |
| GO2Ec2 | Economic savings per year          | €/ref period        | $\sum_{year} Q_{wg,i} \cdot T_{el,end-user} - \sum_{year} Q_{wg,i} \cdot T_{th,end-user}$ | 669            | 1061          | 1062          |
| GO2Ec3 | Payback of the extra investment    | Years               | -                                                                                         | Not available  | Not available | Not available |

**Table 76: GO2- Economic KPIs**

The economic values provided by GOTE about the purchase and installation costs both for a standard and a “Celsius” washing machine (washers and driers) are shown in Table 77.

| Costs                     | Standard machine |       | CELSIUS machine |         |
|---------------------------|------------------|-------|-----------------|---------|
|                           | Washer           | Dryer | Washer          | Dryer   |
| Machine costs [Euro]      | 2500             | 2000  | 1600            | 900     |
| Installation costs [Euro] | 500              | 500   | ca 1500         | ca 1500 |
| Total Costs [Euro]        | 3000             | 2500  | 3100            | 2400    |

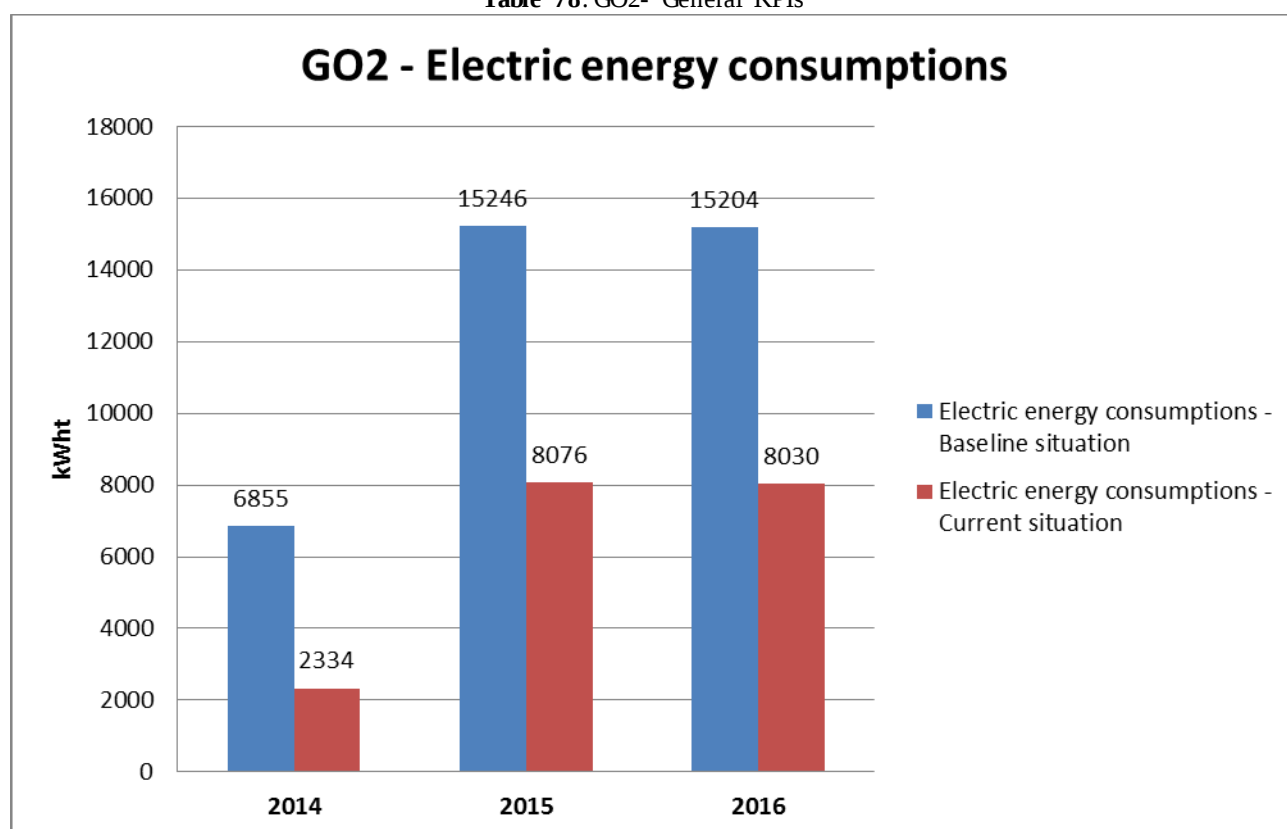
**Table 77:** GO2- Economic parameters

#### 4.2.4.2 General KPI

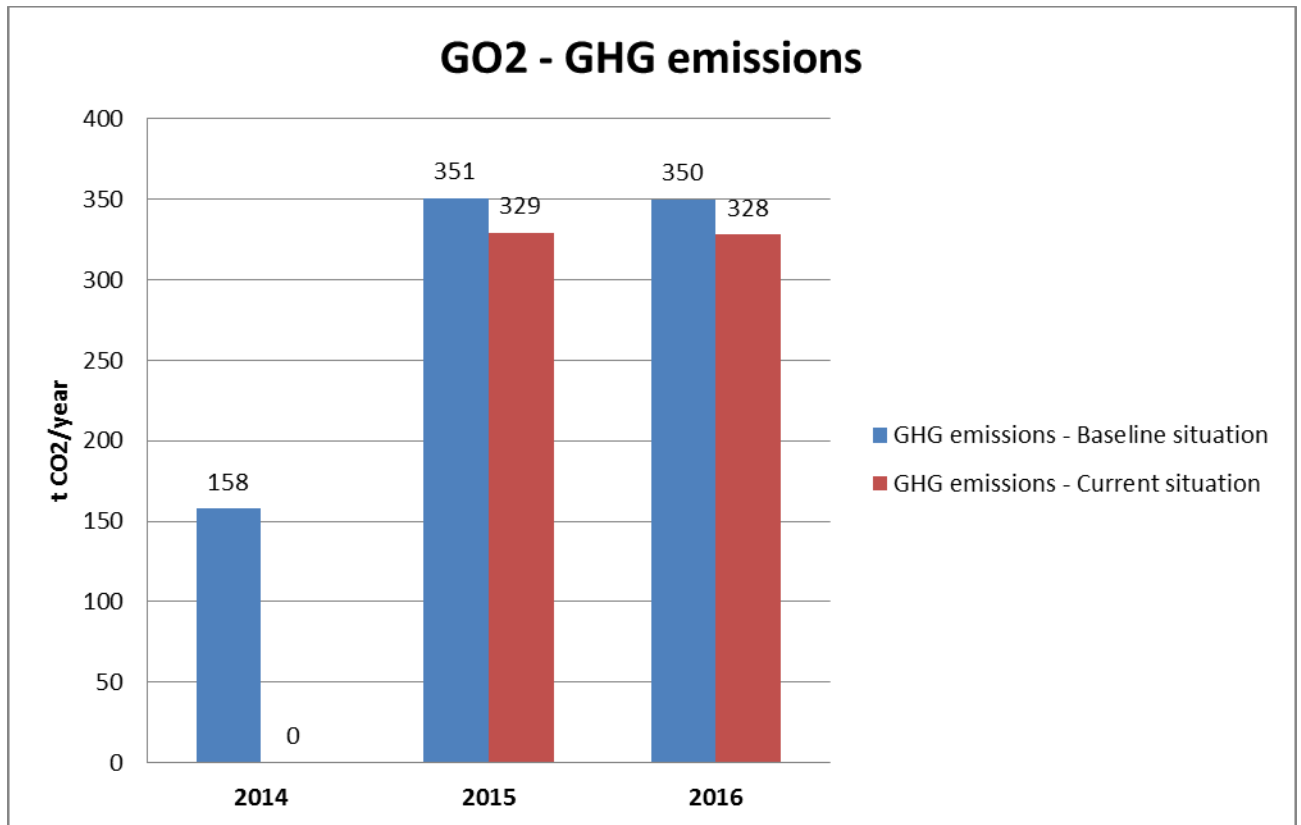
Table 78 presents the general KPIs on energy and environmental aspects.

|             | General KPIs                                                            | UM                   | GO2      | Jul.-Dec. 2014 | 2015   | 2016   |
|-------------|-------------------------------------------------------------------------|----------------------|----------|----------------|--------|--------|
| ENERGETI    | The yearly amount of thermal energy produced/provided by the new system | kWh                  | x        | 4,295          | 6,811  | 6,815  |
|             | Saved primary energy in comparison with baseline situation              | kWh                  | x        | 7,951          | 12,609 | 12,616 |
|             | Energy recovery from waste/renewable sources                            | kWh                  | indirect | 3,694          | 5,857  | 5,861  |
| ENVIRONMENT | Yearly GHG savings in comparison with the baseline situation            | %                    | x        | 8%             | 6%     | 6%     |
|             | Yearly GHG emissions related to the project                             | ton CO <sub>2e</sub> | x        | 144            | 329    | 328    |
|             | Carbon footprint                                                        | ton C                | x        | 335            | 732    | 732    |
|             | Ecological footprint                                                    | ha                   | x        | 75             | 164    | 164    |

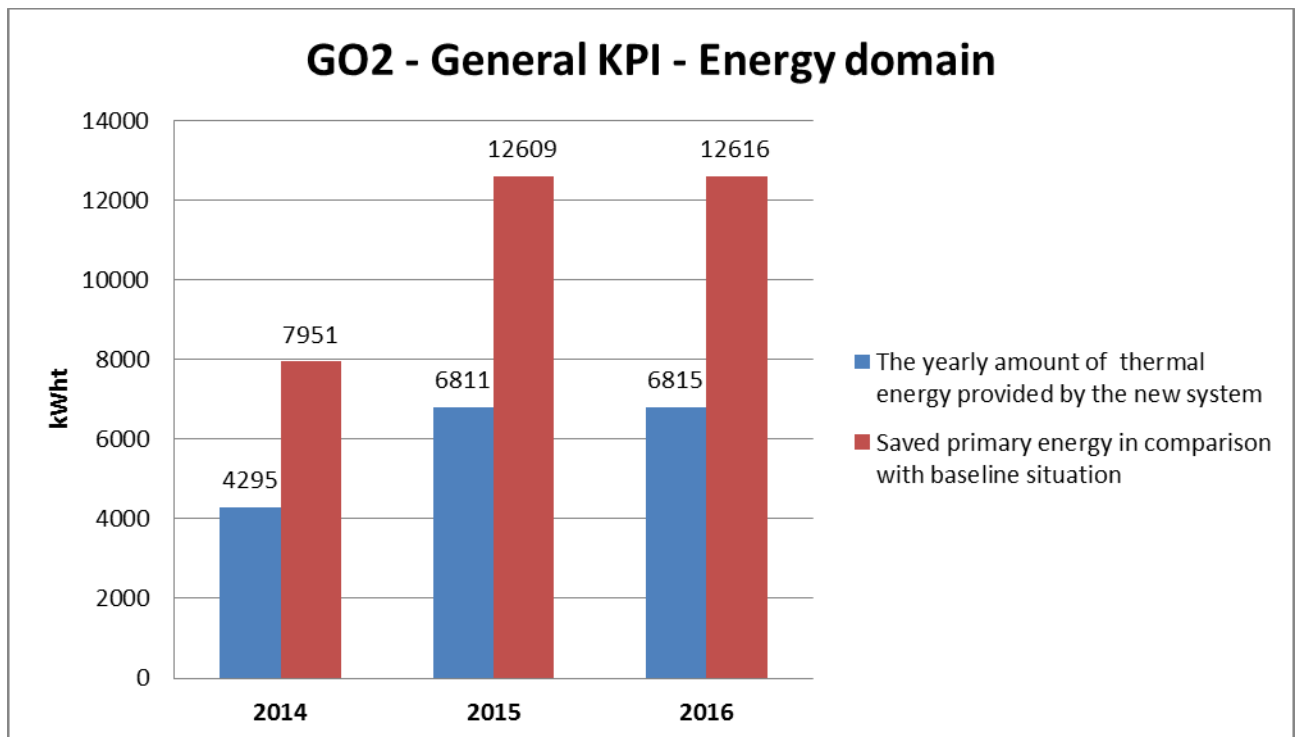
**Table 78:** GO2- General KPIs



**Figure 60** GO2– Electric energy consumption [kWh] Baseline vs. Current situation – 2014, 2015 and 2016



**Figure 61** GO2– GHG emissions [ton CO<sub>2</sub>/year] Baseline vs. Current situation – 2014, 2015 and 2016



**Figure 62:** GO2 General KPI – Energy domain [kWh/t] – 2014, 2015 and 2016

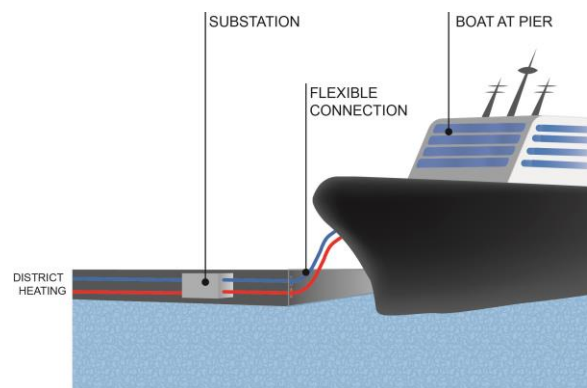
As shown, the effects of the demonstrator are translated into a reduction of the consumption of electric energy (replaced by thermal energy consumption from DHN) by white goods consequently into a decrease of the emissions to environment and primary energy consumptions.

#### 4.2.5 Gothenburg demonstrator: GO3 “District heating to ships”

##### *Demo description*

The objective of the GO3 demonstrator is to connect ships at quay in Gothenburg to the district heating network to cover their space heating needs when the ship is at quay. This is the first time a ship in regular service has been connected to a district heating network. The ship used for demonstration purposes is one of the ferries of the STENA Company. It is in regular service everyday between Gothenburg and Fredrikshamn (Denmark), stopping at quay at the Gothenburg’s harbor approximately 6 hours per night. It was built in 1983 with a capacity for up to 2300 passengers and 500 cars. The ship is already connected to the electricity grid (through the so-called cold ironing process), thus the connection with the DHN allows switching completely off the on-board diesel oil-fired engines and boilers, with the effect of avoiding pollutant and noise emissions in the harbor area. The ship has been provided with heat exchangers and connectors to enable connection to the district heating network while the required installations at quay have been encapsulated into a movable container allowing a flexible connection at quay.

More in detail, the baseline situation at quay was constituted by the production of steam by a diesel-fired boiler (heat recovery steam generators using the exhausts from the engines were used only during navigation). Steam was produced at a pressure of 7 bar and a temperature of 170°C and then distributed within the ship to feed different users, including space heaters that require hot water at 70°C. The thermal output required for space heating was calculated as 740 kW<sub>th</sub> from the analysis of the diesel consumption of the ship during the periods at quay, but in order to cover also the engines’ preheating, a pipe able to feed up to 1.18 MW<sub>th</sub> to the ship was installed.





**Figure 63: GO3 installation at Stena ship**

#### *Status description*

The “District heating to ships” demonstrator has been started up in December 2014 and is currently in operation. The performance monitoring system is active since January 2015, and the monitored parameters are available for the period January-November 2015. Between Dec 2015 and September 2016 the demonstrator operation was stopped for reparation as a consequence of an accidental collision between the ship and the quay that damaged the ship connection point to the district heating network. It is regularly in operation since October 2016.

#### *Monitored parameters*

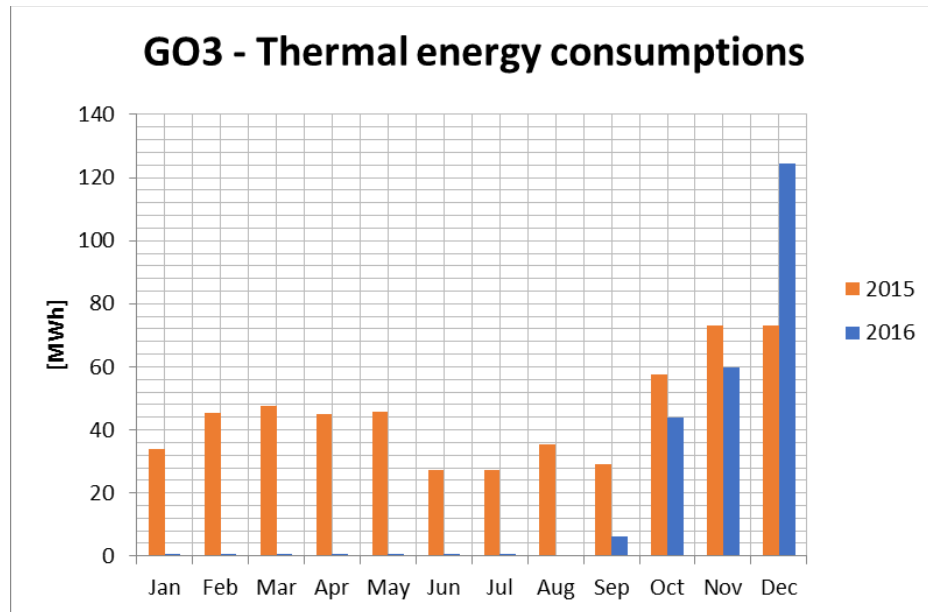
In the following Table 79 the thermal energy form DH delivered to STENA’s ship is presented for 2015 and nine months of 2016, clearly showing operation stop until October 2016.

| Month      | Degree Day  |             |             | Used thermal energy |              |                             |               |
|------------|-------------|-------------|-------------|---------------------|--------------|-----------------------------|---------------|
|            | Norm        | 2015        | 2016        | Actual values       |              | Degree Day corrected Values |               |
|            |             |             |             | 2015 [MWh]          | 2016 [MWh]   | 2015 [MWh]                  | 2016 [MWh]    |
| Jan        | 528         | 451         | 590         | 29.8                | 0.7          | 33.89                       | 0.64          |
| Feb        | 484         | 430         | 484         | 4.4                 | 0.5          | 45.54                       | 0.52          |
| Mar        | 464         | 395         | 464         | 41.8                | 0.6          | 47.52                       | 0.65          |
| Apr        | 322         | 307         | 322         | 43.3                | 0.8          | 44.86                       | 0.82          |
| May        | 176         | 221         | 176         | 52.9                | 0.5          | 45.7                        | 0.61          |
| Jun        | 83          | 119         | 83          | 32.4                | 0.4          | 27.3                        | 0.53          |
| Jul        | 27          | 55          | 27          | -                   | 0.5          | -                           | 0.52          |
| Aug        | 38          | 14          | 38          | 29.5                | 0.4          | 35.23                       | 0.40          |
| Sep        | 126         | 114         | 126         | 27.7                | 4.0          | 29.19                       | 6.18          |
| Oct        | 260         | 252         | 260         | 56.4                | 47           | 57.65                       | 44.02         |
| Nov        | 382         | 304         | 382         | 61.4                | 63.4         | 72.98                       | 59.87         |
| Dec        | 489         | 357         | 489         | 0.6                 | 107.1        | 0.77                        | 124.59        |
| <b>Tot</b> | <b>3379</b> | <b>3019</b> | <b>3341</b> | <b>417.2</b>        | <b>225.9</b> | <b>440.63</b>               | <b>239.33</b> |

**Table 79: GO3-Thermal energy consumptions**

#### *Main assumptions for KPIs calculation*

- To assess demonstrator performance over a one-year period (2015) it has been assumed that thermal energy consumptions in July 2015 (when problems occurred to the monitoring equipment) are equal to June 2015 and, similarly, consumptions for December 2015 (when the aforementioned incident occurred to Stena ship) are equal to November 2015, as presented in the following chart. For 2016, data availability is limited to the period October-December.



**Figure 64:** GO3-Used Thermal Energy [MWh] with corrections in July and December

- As baseline situation the same ship, using standard oil fired boilers for heating purposes at quay, will be considered in order to evaluate the impact of the demonstrator in comparison with the conventional situation. It is supposed to have the ship at quay 42h per week. The following parameters have been considered as reference:

| Parameter                       | Unit of meas.      | Value | Comments and references |
|---------------------------------|--------------------|-------|-------------------------|
| LHV, oil                        | MJ/kg              | 41.93 | [27]                    |
| Density                         | kg/dm <sup>3</sup> | 0.91  | [27]                    |
| Oil price                       | €/l                | 1.198 | EU average 2015 [28]    |
| E <sub>CO<sub>2</sub>,oil</sub> | g/kWh              | 267   | [29]                    |
| E <sub>NO<sub>x</sub>,oil</sub> | g/kWh              | 13.2  | [27]                    |
| E <sub>SO<sub>2</sub>,oil</sub> | g/kWh              | 6.8   | [27]                    |
| E <sub>HC,oil</sub>             | g/kWh              | 0.6   | [27]                    |
| E <sub>PM,oil</sub>             | g/kWh              | 0.7   | [27]                    |

**Table 80:** GO3-Baseline Parameters

- With regard to current situation and specifically to the usage of thermal energy from district heating network, energetic, environmental and economic parameters used for KPI calculation with the related references, in Table 81.

| Parameter          | Unit of meas. | Value | Comments and references                                                                                                                  |
|--------------------|---------------|-------|------------------------------------------------------------------------------------------------------------------------------------------|
| PEF <sub>DHN</sub> | -             | 0.04  | Calculated referring to the Gothenburg DH production mix: 74% waste heat, 9% natural gas, 12% biofuel, 5% electricity (provided by GOTE) |
| E <sub>DHN</sub>   | t/MWht        | 0.019 |                                                                                                                                          |
| η <sub>DHN</sub>   | -             | 0.92  | Calculated as the ratio between of thermal energy produced and delivered to customers [30]                                               |
| T <sub>DHN</sub>   | €/kWht        | 0.06  | Indirectly calculated considering total revenues from heat sold by GOTE in 2013 and thermal energy total production [9]                  |

**Table 81:** GO3-Assumed energetic, environmental and economic parameters

#### 4.2.5.1 Demo-specific KPI

The overall performance of the demonstrator is presented in the following tables in terms of KPI. As shown, the effects of the demonstrator are translated into a reduction of the consumption of

bunker fuel oils by the STENA ship and consequently into a decrease of the emissions to environment and primary energy consumptions.

| ID    | KPI                                                                           | Unit of Measurement | Formula              | 2015   | 2016 (Oct-Dec) |
|-------|-------------------------------------------------------------------------------|---------------------|----------------------|--------|----------------|
| GO3T1 | Yearly thermal energy delivered to ship in harbour                            | <i>MWh/year</i>     | $\sum_{year} Q_{sh}$ | 540    | 239            |
| GO3T2 | Change in yearly use of oil at quay in comparison with the baseline situation | <i>lt/year</i>      | -                    | 60,237 | 26,692         |

**Table 82-** Technical KPIs (GO3)

In addition, economic savings for the STENA Company have been calculated as well comparing average tariffs for thermal energy from Goteborg's DHN and average prices of bunker oil. The total investment for this demonstrator is approximately €390,000.

| ID     | KPI                                                           | Unit of Measurement | Formula                                                                            | 2015   | 2016 (Oct-Dec) |
|--------|---------------------------------------------------------------|---------------------|------------------------------------------------------------------------------------|--------|----------------|
| GO3Ec1 | Economic savings per year due to reduction of oil consumption | €/year              | $\sum_{year} (V_{oil,baseline} - V_{oil}) \cdot T_{oil} - GO3T1 \cdot T_{th,2015}$ | 32,000 | 31,978         |

**Table 83-** Economic KPIs (GO3)

It can be stated that the demonstrator contributes to the improvement of the quality of air in the city of Goteborg, especially for the inhabitants of the area surrounding STENA's quay. The demonstrator is particularly interesting for cities with harbours and need for actions to provide cleaner air as well as efficient heating.

| ID     | KPI                                                                                                                                                                                        | Unit of Measurement | Formula                                                                                 | 2015                                                                                              | 2016 (Oct-Dec)                                                                                   |
|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| GO3En1 | kg/year of saved PM <sub>10</sub> , PM <sub>2.5</sub> , TSP, NO <sub>x</sub> , SO <sub>x</sub> , CO, CO <sub>2</sub> with reference to the baseline situation                              | kg/year             | $\sum_{year} (V_{oil,baseline} - V_{oil}) \cdot E_{oil-boiler} - GO3T1 \cdot E_{DHmix}$ | NO <sub>x</sub> :7022<br>SO <sub>2</sub> : 3673<br>CO <sub>2</sub> : 144217<br>HC: 324<br>PM: 378 | NO <sub>x</sub> :3112<br>SO <sub>2</sub> : 1628<br>CO <sub>2</sub> : 63906<br>HC: 144<br>PM: 168 |
| GO3En2 | GHG savings connected to the reduction of oil use with reference to the baseline situation (kg/year of saved CO <sub>2</sub> e and ratio between the reduction and the baseline emissions) | t/year              | -                                                                                       | 156                                                                                               | 69                                                                                               |

**Table 84-** Environmental KPIs (GO3)

| ID    | KPI                                                                     | Unit of Measurement | 2015                                                                                                            |
|-------|-------------------------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------|
| GO3S1 | Reduction of complaints for noise with reference to baseline situation  | -                   | Interviews to people living in the harbour area confirm a higher quality of life (less noise and air pollution) |
| GO3S2 | The number of working hours used for running and maintaining the system | hours/year          | -                                                                                                               |

**Table 85-** Social KPIs (GO3)

#### 4.2.5.2 General KPI

In the following table general KPIs for GO3demonstrator sites are shown.

|               | General KPIs                                                            | UM                          | 2015                                                                                               | 2016 (Oct-Dec)                                                                                   |
|---------------|-------------------------------------------------------------------------|-----------------------------|----------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| ENERGETIC     | The yearly amount of thermal energy produced/provided by the new system | MWh/year                    | 540                                                                                                | 239                                                                                              |
|               | Saved primary energy in comparison with baseline situation              | MWh/year                    | 733                                                                                                | 325                                                                                              |
|               | Energy recovery from waste/renewable sources                            | MWh/year                    | 465                                                                                                | 206                                                                                              |
|               | Energy efficiency of the project (DHN efficiency)                       | -                           | 0.92                                                                                               | 0.92                                                                                             |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation            | %                           | 97%                                                                                                | 97%                                                                                              |
|               | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e /year | 11                                                                                                 | 5                                                                                                |
|               | Yearly reduction of polluting emission in comparison to baseline        | kg/year                     | NO <sub>x</sub> :7022<br>SO <sub>2</sub> : 3673<br>CO <sub>2</sub> : 144,217<br>HC: 324<br>PM: 378 | NO <sub>x</sub> :3112<br>SO <sub>2</sub> : 1628<br>CO <sub>2</sub> : 63906<br>HC: 144<br>PM: 168 |
|               | Carbon footprint                                                        | ton C/year                  | 27                                                                                                 | 12                                                                                               |
|               | Ecological footprint                                                    | ha                          | 6                                                                                                  | 3                                                                                                |

Table 86- GO3-General KPIs

#### 4.2.6 Gothenburg demonstrator: GO4 “River cooling”

##### Demo description

Cooling from the river Rosenlund was rebuilt in 2007 for production of cooling as well. An old boiler was taken out and a system for free cooling was installed instead. Free cooling entails that 6–10-degree water is pumped in from the Göta Älv River and then conveyed in pipes directly to the customer’s air conditioning system into the city centre as well as to Sahlgrenska University Hospital. During the summer, when the river water is too warm, the cooling is produced by absorption chillers, which are driven by waste heat.

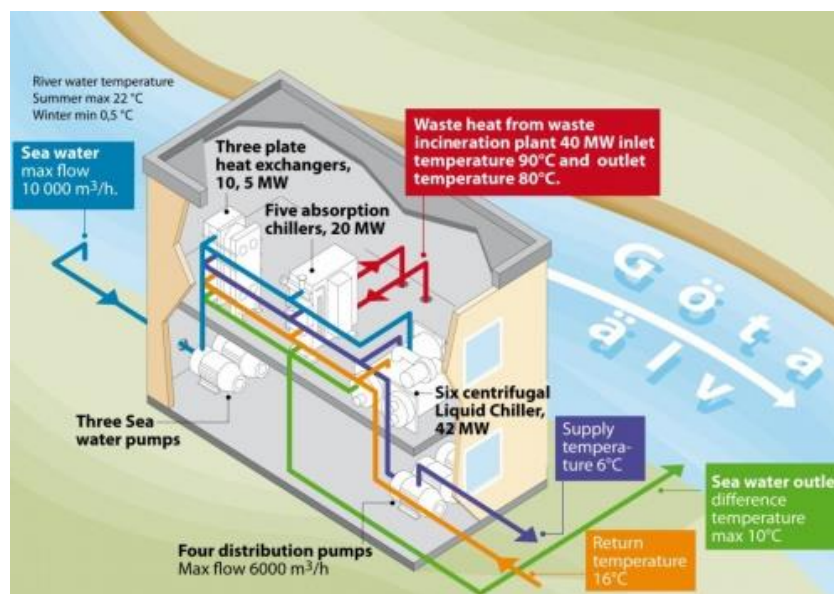


Figure 65: GO4 demonstrator layout

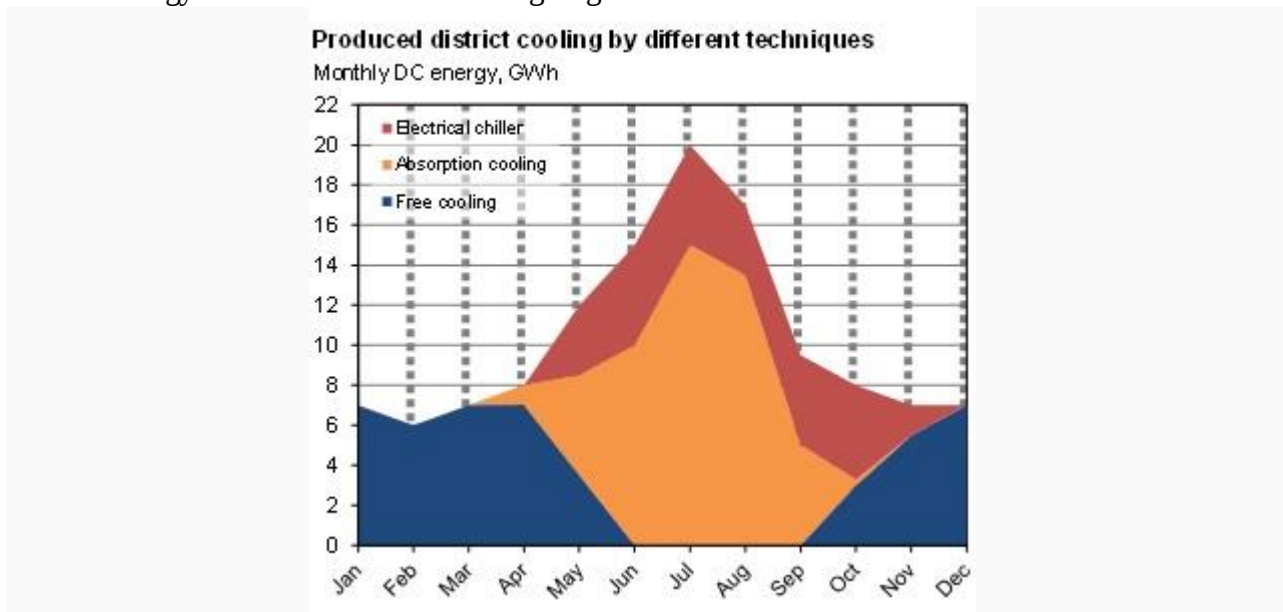
The overall objective with this demonstrator is to enhance the free cooling production facility in Roselund, already provided with absorption chillers to recover waste heat from the nearby incinerator, by installing 4 new heat exchangers and therefore upgrading the total installed capacity from 20 MW to 30 MW.

#### *Status description*

The “river cooling” demonstrator has been included among the CELSIUS demonstrators, as a consequence of the occurred deviations at some demonstrators (in Cologne and Rotterdam) in 2015, as extensively reported in the previous submission of deliverable D4.4 (Nov 2015). One of the corrective measures proposed to overcome those deviations consisted in downsizing RO2-RO3 and RO4 demo projects (affected by critical issues) re-allocating the remaining budget to new demonstrators to identify on the basis of precise criteria: already installed, provided with monitoring equipment and, preferably, a cooling solutions. On the basis of an accurate analysis carried out by the PMO in the monitoring period M30-M36, GO4 was chosen as compliant to the established selection criteria.

#### *Main assumption for KPI calculation*

An efficient strategy for district cooling is that implemented in Göteborg for chilled water production: free cooling is primarily exploited (i.e.: cold water from the river Göta Älv and outdoor air), then absorption heat pumps are used as a second option and electrical chillers are switched on only when none of the other techniques are sufficient to cover the load. The results of such a strategy are shown in the following Figure 66.



**Figure 66:** Cooling Sources in Gothenburg

For this demonstrator, the baseline situation is constituted by the use of a combination of electric chillers and absorption chillers fed with water from the DH network; the average efficiency assumed for this kind of chill production mix is assumed to be 4, which means that every 1 kWh of electricity consumption leads to a chill production of 4 kWh.

In the project scenario, the electricity consumptions associated to the river water cooling systems are very low, i.e. limited to those for water pumping; on the other hand, the part of the cooling load that is not covered by free cooling sources is provided by the same systems used in the baseline case, with unchanged efficiency.

**The monitored parameters that have been elaborated and used as input data for the calculation of KPIs are KPIs are those reported in Table 87, whereas the monthly trend of energy provided by the demo, broken**

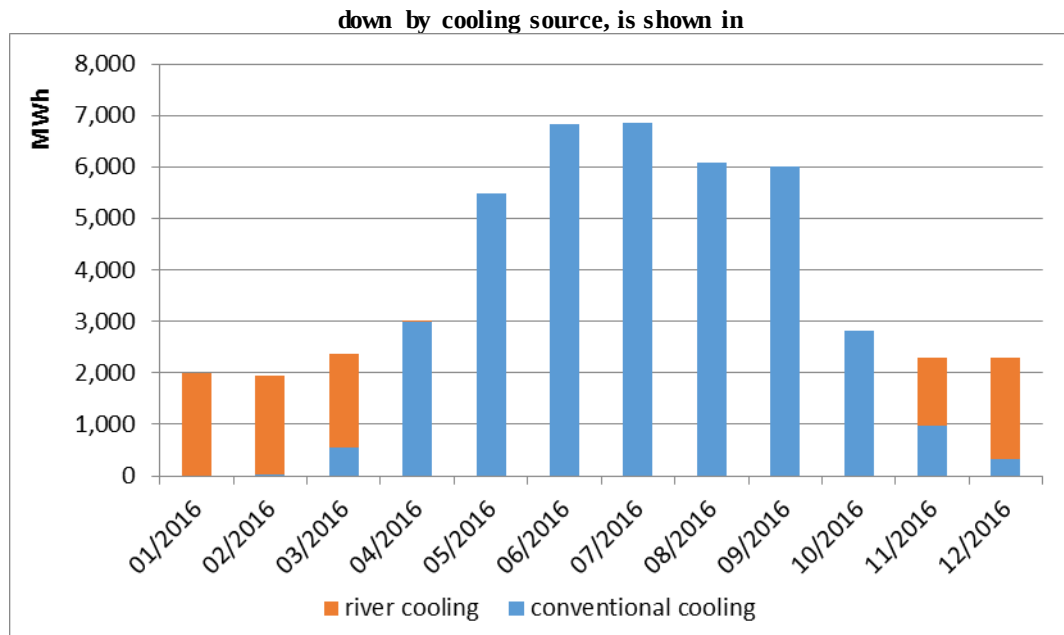
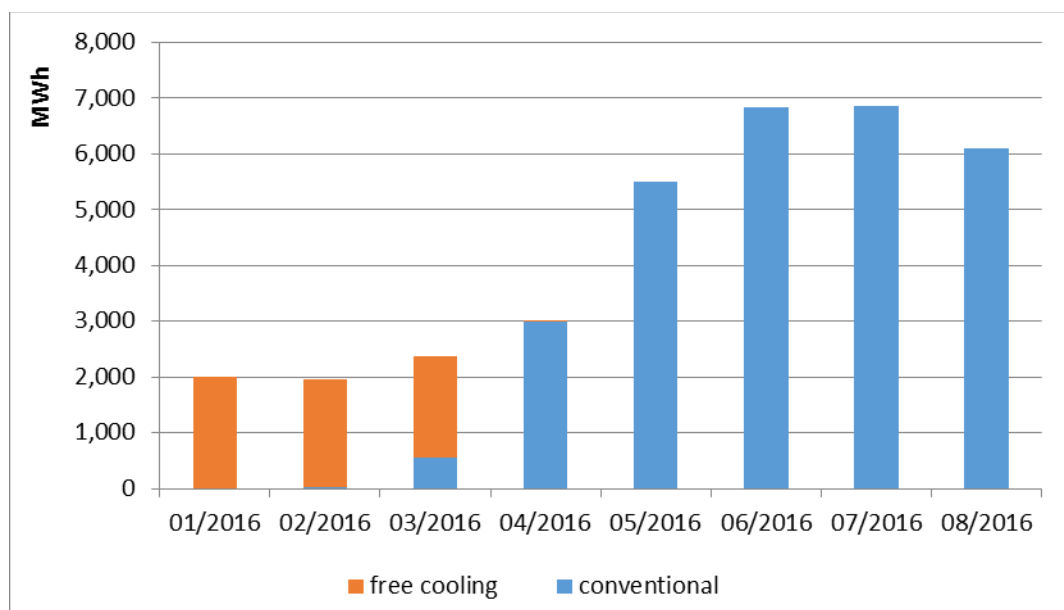
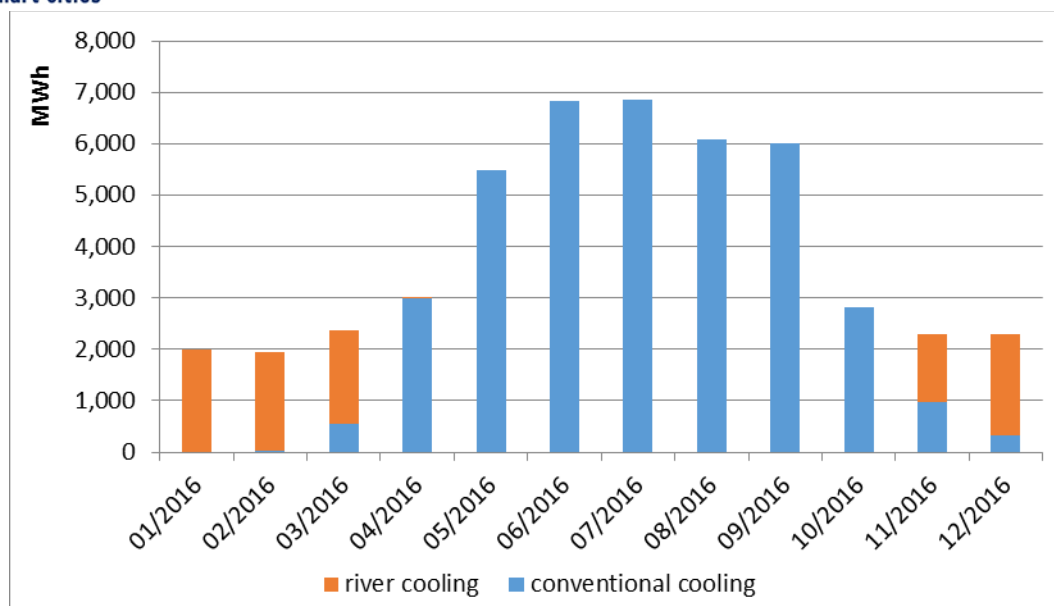


Figure 67.

| Parameter                                | Unit of meas. | Value  | Comments and references |
|------------------------------------------|---------------|--------|-------------------------|
| Cooling energy from conventional system  | MWh           | 38,800 | -                       |
| Cooling energy from free cooling (river) | MWh           | 9,093  | -                       |
| Electricity consumption (water pumping)  | MWh           | 797    | -                       |

Table 87: GO4-Input Data





**Figure 67:** GO4 – Monthly trend by cooling source

Among the energy and environmental parameters, the assumed Primary Energy and GHG Emission Factors for electricity are shown in Table 88 with the related references.

| Parameter      | Unit of meas. | Value | Comments and references                                                                                  |
|----------------|---------------|-------|----------------------------------------------------------------------------------------------------------|
| $E_{el, grid}$ | t/MWhe        | 0.023 | [7]                                                                                                      |
| $PEF_{el}$     | -             | 1.8   | Assuming the following energy production mix:<br>70% renewable ( $PEF=1$ ), 30% fossil fuels ( $PEF=3$ ) |

**Table 88:** GO4-Assumed Environmental Parameters

### General KPI

Table 78 presents the general KPIs on energy and environmental aspects for the cooling-by-river-water demo, referred to the whole year 2016.

|               | General KPIs                                                            | UM                    | Jan-Dec 2016 |
|---------------|-------------------------------------------------------------------------|-----------------------|--------------|
| ENERGETIC     | The yearly amount of thermal energy produced/provided by the new system | MWh                   | 47,893       |
|               | Saved primary energy in comparison with baseline situation              | MWh                   | 2,657        |
|               | Energy efficiency of the project                                        | -                     | 4.56         |
|               | Energy recovery from waste/renewable sources                            | MW                    | 9,093        |
| ENVIRONMENTAL | Yearly GHG savings in comparison with the baseline situation            | %                     | 14.1%        |
|               | Yearly GHG emissions related to the project                             | ton CO <sub>2</sub> e | 241.4        |
|               | Carbon footprint                                                        | ton C                 | 945.9        |
|               | Ecological footprint                                                    | ha                    | 212.8        |

**Table 89:** GO4- General KPIs

#### 4.2.7 London demonstrator: LO1 “Active network management and Demand Response”

##### *Demo description*

The LO1 demonstrator represents the first autonomous dispatch system in which a CHP is used to provide ancillary electrical supply in case it is required by the Distribution Network Operator, for example due to a black-out or another kind of unexpected interruption in the power supply from the electrical grid.

##### *Status description*

The only trials performed on the demonstrator are those carried out in October 2014 and all the data made available are presented in the present deliverable.

##### *Monitored parameters*

Table 90 presents a summary of the parameters monitored during the trial. It can be noted that the trials had a total duration of almost five hours in five days, and that the CHP was able to provide up to 89% of its nominal capacity (which is of 1.95 MW) when requested.

It is worth highlighting that the implementation of the demonstrator requested significant changes to the control algorithms which rule the normal operation of the CHP (which is normally heat-led from thermal store capacity), in order to allow a dispatch signal to be received and acted upon. This signal was sent on breach of substation load, directly to the CHP BMS where upon, if there was significant capacity in the thermal store, the CHP would start.

Due to commercial constraints, the CHP could not be dispatched before 1000hrs of operation. Once this time was reached, the trials started and the dispatch followed the normal operation during the first three days of the trial period. For the remaining two days, the parameters within the ANM (Active Network Management) system were changed in order to allow events to be dispatched at different times. These changes were made to test the dispatch scenario under different timings.

| Day       | Dispatch time | Engine start | Engine stop | MW delivered (1.95MW expected) | Electricity produced (MWh) | Notes                                                                 |
|-----------|---------------|--------------|-------------|--------------------------------|----------------------------|-----------------------------------------------------------------------|
| Monday    | 1000          | 1001         | 1048        | 1.39MW<br>72%                  | 1.08                       | 47 min duration                                                       |
| Tuesday   | 1000          | 1004         | 1052        | 1.38MW<br>71%                  | 1.10                       | 48 min duration                                                       |
| Wednesday | 1000          | 0950         | 1049        | 1.57MW<br>80%                  | 1.31                       | CHP already running on receipt dispatch signal<br><br>50 min duration |
| Thursday  | 1034          | 1038         | 1139        | 1.74MW<br>89%                  | 1.62                       | 56 min duration                                                       |
| Friday    | 1535          | 1539         | 1640        | 1.74MW<br>89%                  | 1.62                       | 56 min duration                                                       |
| Average   | -             | -            | -           | 1.3MW<br>80%                   | 1.11                       | 51.2 min duration                                                     |
| Total     | -             | -            | -           | -                              | 6.73                       | -                                                                     |

**Table 90:** LO1-Monitored Parameters during Trials

#### 4.2.8 London demonstrators: LO2-LO3 “Capture of identified sources of waste heat and integration of thermal store” & “Extension of the Bunhill seed heating system”

##### *Demo description*

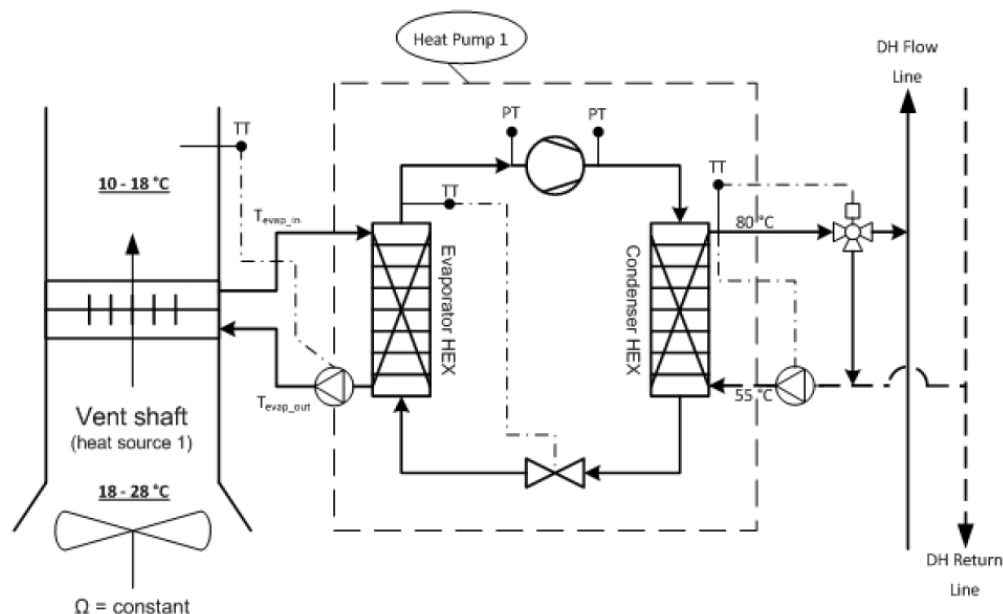
The aim of this demonstrator is to extend the district heating system already present in the Bunhill district in London, covering part of the load with waste heat from an underground ventilation shaft. The system is expected to cover about 15-18% of the total heat demand of the new Bunhill district heating network

As regards the former waste heat source, the monitoring campaigns carried out before the installation of the heat pump demonstrated that an air flow rate of approximately 30-32 m<sup>3</sup>/s at a temperature between 21°C (winter) and 27°C (summer). The exhaust vent is generally operated 24 hours per day but can be suspended in periods when the tube system is not in operation (e.g., night hours) to limit power consumption.

The layout of the installation at the underground ventilation system is shown in Figure 68. The heat exchanger installed in the ventilation shaft is a fin-coil air/water heat exchanger; this means that an intermediate water loop is used to transfer heat from the exhausts to the heat pump, in order to avoid the presence of refrigerant fluid in the shaft. Moreover, the design of the heat exchange system has taken into consideration the possible formation of condensates on the air side (allowing an increase of the heat exchange coefficient but also the risk of ice formation in the coldest days), as well as the possible fouling of the surface on the air side due to the presence of contaminants in the extracted air.

As regards the heat pump, a two-stage model was selected with the aim to increase the output temperature up to levels that are compatible with the heat distribution in the district heating network; therefore, the operating temperatures at the inlet/outlet of the heat pump are of 55/80°C respectively.

Based on the available amount of waste heat, the selected heat pump has a thermal output of 506 kW and an electric input of 141 kW divided by two compressors, a 74 kW and a 67 kW one.



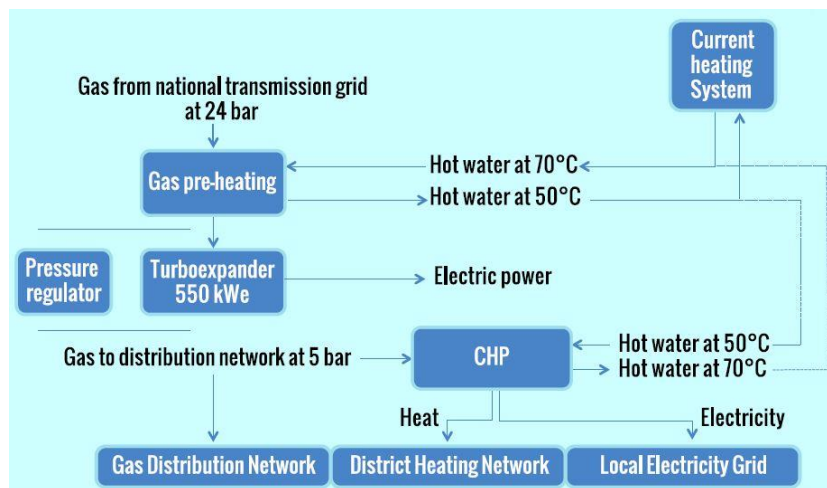
**Figure 68:** Underground ventilation heat recovery – layout of the installation

#### 4.2.9 Genoa demonstrator GE1-“Energy recovery from the natural gas distribution network”

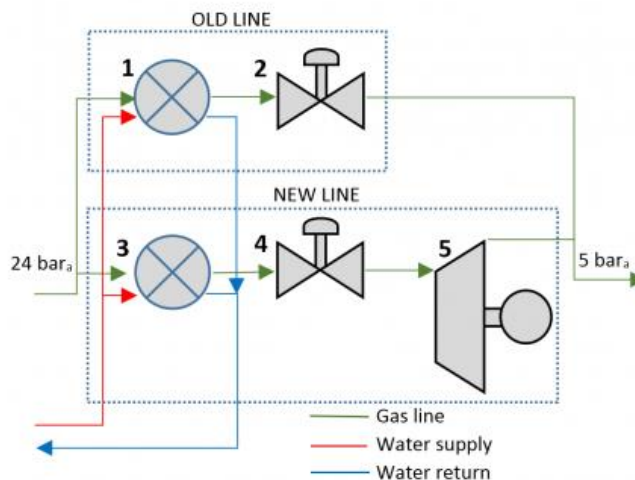
The demonstrator is located in the district of Gavette, in the North zone of Genova, selected for its high thermal and electrical demands from different type of users such as buildings and industrial processes.

The demonstrator is realized at a natural gas distribution station, where natural gas is taken from the national transmission network at a pressure of 25 bar(a), is processed in order to reduce its pressure to 6 bar(a) necessary for its distribution at the city level. Currently, the gas expansion is carried out in throttling valves (isenthalpic process), whereas the demo foresees the use of a turboexpander, producing electricity during the expansion process.

Since the expansion implies a strong reduction of the gas temperature, which could affect the safety of the plant, the gas needs to be heated before its expansion. The identified solution is to install a natural gas fired CHP plant, producing additional electricity to that coming from the turboexpander, and supplying heat to the natural gas before the expansion and additional heat to be used in a local district heating network.



**Figure 69:** Overall Layout of the Demonstrator



**Figure 70:** Detail of the natural gas expansion plant: 1) Throttling valves line gas preheater, 2) Throttling valve, 3) Turboexpander line preheater, 4) Flow regulation valve, 5) Turboexpander.

Figure 69 shows the overall layout of the system, whereas Figure 70 presents a detail of the natural gas lines, with the turboexpander installed in parallel to the current expansion valves.

The unit is sized to meet, at the steady state, the heat demand of the turboexpander line; in transient conditions the surplus heat produced by the CHP can be used by other users. On the other hand, the turboexpander was sized with the aim to maximize the energy production and minimize the payback time.

The installed turboexpander can produce a nominal power of 550 kWe using a maximum gas flow rate of about 22,500 Sm<sup>3</sup>/h; the minimum flow rate is about 3500 Sm<sup>3</sup>/h, which ensures that the machine operates also in the warm months when the gas demand of the city network is low.

The heat production plant, composed by the CHP and the two auxiliary boilers, is designed to supply heat to different users, with different power and temperature requirements:

- Gas preheating for the turboexpander line, about 600 kWth at 85°C;
- Gas preheating for the throttling valves line, about 200 kWth at a minimum temperature of 40°C;
- Building's district heating substations for the firestation, offices and workshops, for a max thermal power of 900 kWth.

The heat production system is formed by a CHP plant, which is a natural gas fired engine, equipped with systems for heat recovery from both the exhausts and the engine cooling circuit. More in detail, the selected CHP is an internal combustion engine fueled with natural gas capable of delivering, in nominal conditions, 550 kWe and to recover about 630 kWth from the engine coolant, the intercooling process and the exhaust.

Considering that the system operates for 5,000 hours/year, the expected electricity production is of 5,100 MWh/year (2,300 MWh/y from the CHP plant and 2,800 MWh/y from the turboexpander), which allow a reduction of GHG emissions of approximately 1,200 tCO<sub>2</sub>e/y compared to the baseline situation (purchase of electricity from the national grid and production of heat with natural gas fired boilers).

## 5. Technology replication potential and related impacts

As stated in the description of the methodology, the monitoring of the demonstrators is not limited to the assessment of their performance after their start-up, but covers also their design, permitting and realization phases. The objective of this section is to analyze the potential for replication of the selected demo technologies based on the results of the whole monitoring phase.

To this aim, seven criterion have been defined which assess the different aspects of the replicability of a technology, including availability of the exploited source, adaptation to different climate conditions, ease of authorization, implementation and operation, required investment cost. For each of the seven criteria, a score from 1 to 5 is assigned (from 1-low to 5-high); after the assignment of scores, an overall assessment is done, representing the potential for replication of the technology in Europe. The meaning of each score for every assessment criterion is presented in Table 91.

**Table 91:** Evaluation Matrix for the Replication Potential

| Criterion                           | 1                                                                               | 2                                                                                   | 3                                                                                                    | 4                                                                              | 5                                                                            |
|-------------------------------------|---------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Availability of required conditions | Need for conditions currently not available in Europe                           | Conditions available in a small part of Europe (< 20%)                              | Fair availability of required conditions (20-60% of Europe)                                          | Conditions available in a large part of Europe (60-90%)                        | Conditions available in all areas (> 90% of Europe)                          |
| Adaptability to different climates  | Solution not compatible with European climate conditions                        | Solution applicable only in a small part of European climate areas (< 20%)          | Solution fairly applicable to European climate areas (20-60% of Europe)                              | Solution applicable to climates of a large part of Europe (60-90%)             | Solution compatible with all climate areas in Europe (>90%)                  |
| Ease of authorization               | Lack of a normative framework                                                   | Long time needed for authorization (> 6 months)                                     | Medium time required for authorization (3-6 months)                                                  | Short time needed for authorization (< 3 months)                               | No need for specific authorization                                           |
| Ease of implementation              | Solution very difficult to be implemented in an existing heating/cooling system | Implementation of the technology requiring major adjustments to the existing system | Slight structural changes required to adapt the heating/cooling system to work with the new solution | Only minor adaptation required to make the system work with the new technology | Technology suitable to replace conventional alternatives without any changes |
| Ease of operation                   | Strong maintenance need and effort to guarantee operation                       | Significant time and effort needed for functioning                                  | Maintenance and operation effort in line with other suitable alternatives                            | Low effort required for technology operation                                   | Almost no need for maintenance and very limited effort for operation         |
| Integration of waste energy sources | Technology not allowing any recovery of waste energy sources                    | Solution allowing a limited waste energy recovery (<20%)                            | Technology relying on a fair share of waste energy (20-50%)                                          | Solution exploiting a significant amount of waste energy (50-80%)              | Technology relying almost only on waste energy sources (>80%)                |

| Criterion              | 1                                                               | 2                                                                        | 3                                                                        | 4                                                              | 5                                                                                       |
|------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Low CAPEX requirements | CAPEX needs much higher than conventional alternatives (> +80%) | Capital investment slightly higher than conventional solutions (+20-80%) | Capital investment in line with conventional alternatives ( $\pm 20\%$ ) | Solution cheaper than conventional alternatives ( $-20-80\%$ ) | CAPEX requirements almost negligible compared to conventional alternatives ( $<-80\%$ ) |

The results of such an analysis are presented in Table 92 for five selected technologies among the CELSIUS demonstrators. It can be noticed that, out of the five selected demonstrators, in two cases the proposed solution foresees the creation of a synergy between the heating and the transport sector (WHR from tube ventilation, DH to ships), whereas two solutions concern the exploitation of further heat sources distributed within urban areas (sewage heat recovery, cooling by river water). This highlights the key role of heat mapping as a strategic tool for planning sustainable heating and cooling facilities in urban areas: the best available approach is to identify waste heat sources within urban areas in terms of location, available thermal output and time distribution, to overlap these data with a map of the heat demand in the same area and, finally, to identify the best technology to exploit the available source to cover the heat demand.

**Table 92: Assessment of the Replication Potential**

| Criterion                            | Sewage Heat Recovery | Datacenters Cooling | WHR from Tube Ventilation Shaft | Cooling by River Water | DH to Ships |
|--------------------------------------|----------------------|---------------------|---------------------------------|------------------------|-------------|
| Availability of required conditions  | 5                    | 4                   | 2                               | 3                      | 2           |
| Adaptability to different climates   | 4                    | 4                   | 3                               | 3                      | 2           |
| Ease of authorization                | 1                    | 5                   | 3                               | 2                      | 4           |
| Ease of implementation               | 3                    | 4                   | 3                               | 3                      | 4           |
| Ease of operation                    | 5                    | 5                   | 4                               | 3                      | 4           |
| Integration of waste energy sources  | 5                    | 3                   | 5                               | 2                      | 4           |
| Low CAPEX requirements               | 2                    | 4                   | 2                               | 4                      | 3           |
| <b>Overall replication potential</b> | <b>4</b>             | <b>5</b>            | <b>3</b>                        | <b>2</b>               | <b>3</b>    |

As regards the replication of the selected demonstrators, specific considerations and an estimate of the potential impact at European level based on the most recent available data are reported in the following paragraphs.

## 5.1 Heat recovery from sewage water

More than 84% of EU population is connected to a sewage network [31], share which increases if focusing the analysis on urban areas only; this means that the replication potential for the CO1 demonstrator is particularly high, also due to the adaptability to different climate conditions and the use of conventional technologies that are economically viable. According to the analyses carried out within other research projects (e.g.: Stratego), 5% of total heat demand could be covered with heat recovered from sewage systems in cities and towns with more than 10,000 inhabitants [32], which corresponds for Europe to an overall saving of about 150 TWh/y.

## 5.2 Efficient cooling of datacenters

The total energy consumption of datacenters in Europe was, in 2007, of 56 TWh/y and is expected to increase up to 104 TWh/y in 2020, with an average PUE around 1.8 [33]; assuming a linear growth over this period, an energy consumption of 90 TWh/y can be estimated for 2016. Should the average PUE of the existing datacenters be potentially reduced to 1.6 thanks to the implementation of the technologies applied in 32ROe/33ROe demonstrator, a potential saving of 10 TWh/y can be extrapolated for Europe.

## 5.3 Waste heat recovery from tube ventilation

In the world, underground metro systems are present in 148 cities, have a total extension of 11,000 km and transport 151 million passengers/day; Europe has a relevant share over the total, having 50 medium- and large-sized cities with metro systems, for a total length of 2,800 km and 31 million passengers/day [34]. Considering that the average distance between metro stations is of 1.0 km in Europe (the world level average is of 1.2 km), and the fact that all stations are located in urban areas where heat demand is significant, the replication of the LO2 demonstrator can potentially be done in 2,800 stations. Based on an average heat recovery of 1 MW per station, a total energy saving of 5 TWh/y can be estimated at European level.

## 5.4 Cooling by river water

The cooling demand in Europe was estimated in 2014 as 285 TWh/y, 1% of which is covered by DC systems [35]. In DC networks, free cooling with water from rivers, lakes and sea may cover a fraction of the total load between 20% and 80%, with values increasing from South to North [36]. Considering that, in average and conservatively, 30% of the district cooling load could be covered with river water, a total saving of 1 TWh/y can be extrapolated for this technology at European level. Additional savings of the same order of magnitude or even higher could also be achieved by realizing medium-sized river water cooling systems serving single buildings such as shopping malls, universities, hospitals, etc. Moreover, the possibility of exploiting free cooling sources may support the realization of further DC networks to the existing ones.

## 5.5 District heating to ships at quay

In 2014, European maritime transport systems carried more than 400 million passengers [31] through a network based on 329 main ports [37]. Although the impact of the GO3 demonstrator is high, both at global (primary energy savings, avoided GHG emissions) and at local (avoided pollutant emissions) level, its successful replication requires some specific conditions. Clearly, this technology is applicable only to cities with a harbor and a DH network, but even stricter requirements exist: indeed, the connection to DH is effective for ships stopping at quay for at least 5 hours/day, and for ports where it is possible to connect ships to the mainland electricity grid (in order to allow switching completely off the onboard engines and boilers during the stop at quay), which is currently available only in a few ports in northern Europe. This currently imposes a strong limit to the replication of this technology, which could be overcome by planning the simultaneous implementation also of facilities for the connection of ships to the electricity grid. However, based on the current situation, the potential impact of this solution at European level cannot be estimated within this work.

## **6. Demonstrators monitoring and SCIS initiative**

Monitoring activities are relevant not only in the CELSIUS framework to quantify the benefits lead by the project but also outside project boundaries to create knowledge and awareness on district heating and cooling systems as crucial systems towards the achievement of resource efficiency goals in cities. Sound performance data could facilitate replication and widespread of DH/DC solutions especially when those data are shared in easy-accessible database and platforms. The Smart Cities Information System (SCIS) initiative is currently working in order to create a platform to collect and visualize aggregated monitored data coming from European demonstrative co-funded projects on several topics: energy-efficiency in buildings, energy system integration, sustainable energy solutions on district level, smart cities and communities and strategic sustainable urban planning.

Collaboration between CELSIUS project and SCIS initiative started in 2015, being CELSIUS one the projects selected to provide relevant data. Several interactions and information exchanges have been necessary to fine-tune SCIS templates for data collection and properly take into account the peculiarities of the demonstrators developed in CELSIUS.

Currently SCIS has further developed those templates and is about to launch the so-called “self-reporting” procedure to collect data from all involved projects by directly accessing the on-line SCIS platform and uploading the required data.

A preliminary data exchange between the two projects was carried out, by sharing the measured/expected impact of the New CELSIUS demonstrators at city level. Three macro indicators are presented in the following sections: total investment, GHG savings and primary energy savings. Assumptions and estimations are presented for those demonstrators still under realization or for which monitored data are not available yet.

|            | Demo ID               | Demo name                                                                                | Primary Energy savings | CO2 savings           | Baseline and assumptions                                                                                                                                                                                                                                                                                                                             |
|------------|-----------------------|------------------------------------------------------------------------------------------|------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Rotterdam  | RO1                   | The heat hub                                                                             | 4,303 MWh/year         | 837.5 ton/year        | <b>Baseline</b><br>The same amount of recovered heat by the Heat Hub is produced by means of a big centralized gas boiler connected to the district heating network                                                                                                                                                                                  |
|            | RO2                   | Industrial ecology                                                                       | no data available yet  | no data available yet | <b>Baseline</b><br>For this specific case, the baseline situation will be referred to the situation prior to the implementation of the technical solution, where heat at Meneba grain processing plant is provided by conventional steam boilers also for low temperature requirements.                                                              |
|            | RO4                   | Integrated cooling solutions (Electric cooling chillers replaced by absorption chillers) | no data available yet  | no data available yet | <b>Baseline</b><br>Electric cooling chillers                                                                                                                                                                                                                                                                                                         |
| Gothenburg | GO1 <i>estimation</i> | Buildings as short term storage                                                          | 776 MWh/year           | 1,426 ton/year        | <b>Baseline</b><br>The same buildings without the implementation of the active heat load control technology<br><br><b>Assumptions:</b><br>12 buildings; 10% energy savings considering as baseline: building average consumption 500 MWh/year<br>PEF 1.1;<br>EF 0.202 (considering this demo optimizes the operation of natural gas driven facility) |
|            | GO2                   | DH to white goods                                                                        | 8 MWh/year             | 59 kg CO2eq/year      | <b>Baseline</b><br>The same type of laundry rooms, equipped with standard new white goods, using only electricity (thus, also for heating purposes) as energy vector                                                                                                                                                                                 |
|            | GO3                   | DH to ships                                                                              | 70 MWh/year            | 145 ton/year          | <b>Baseline</b><br>The same ship, using standard oil fired boilers for heating purposes at quay                                                                                                                                                                                                                                                      |

|               |                                 |                                                                 |                                                                            |                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------|---------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|               | <b>GO4</b><br><i>estimation</i> | River cooling                                                   | 54 MWh/year                                                                | 1 ton/year                                                                 | <b>Baseline</b><br>No free cooling<br><br><b>Assumptions</b><br>Free cooling production 45 MWh; 15MWh related to pumps consumptions--> energy savings compared to baseline 30 MWh<br>PEF=1.8 (Swedish electric grid)<br>EF 0,023                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Genoa</b>  | <b>GE1</b><br><i>estimation</i> | Waste energy recovery from the natural gas distribution network | 5,300 MWh/year                                                             | 1.090 ton/year                                                             | <b>Baseline</b><br>The baseline situation is referred to a standard lamination process where mechanical energy inherent in the pressurized gas (24 bar) is wasted and heat to the final end-users is supplied by means of independent gas-fired boilers. In particular, baseline situation can be detailed by referring to the two main implemented equipment (expansion turbine and CHP): <ul style="list-style-type: none"> <li>• without the realization of the expansion turbine, mechanical energy inherent in the pressurized natural is wasted within a standard lamination process; thus, electricity required by the district is generated by the traditional mix of Italian electric grid;</li> <li>• without the gas fired CHP plant and the related heating network foreseen for the surrounding Gavette district, heat from the gas expansion process is wasted and heat is supplied by means of independent gas-fired boilers.</li> </ul> |
| <b>London</b> | <b>LO2-LO3</b>                  | Waste heat recovery from Tube Ventilation Shaft                 | 17% (absolute numbers will be provided once the demo will be in operation) | 15% (absolute numbers will be provided once the demo will be in operation) | <b>Baseline</b><br>Baseline situation for LO2-3 project will be referred to the common mix of heating systems used in London, consisting of natural gas fired boilers, oil fired boilers, electric heaters and electric heat pumps. The reference and typical features of these systems will be a census of heating systems at city level or, better, at district level or, even better, a study done on the new loads to be connected to the district heating system during LO3 expansion.                                                                                                                                                                                                                                                                                                                                                                                                                                                             |

|         |     |                                               |                       |                            |                                                                                                                                                                                      |
|---------|-----|-----------------------------------------------|-----------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cologne | CO1 | Waste energy recovery from the sewage network | 289 MWh/year per site | 29 ton CO2eq/year per site | <b>Baseline</b><br>The baseline situation to which comparisons are made corresponds with the use of gas-fired condensing boilers as the sole equipment for heating the same schools. |
|---------|-----|-----------------------------------------------|-----------------------|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|



## Gothenburg demonstrators

### Gothenburg demonstrators

GO1- Using buildings as short term storage

GO2- District heating to white goods

GO3 –District heating to ships

GO4 – River cooling

|                        |                                  |
|------------------------|----------------------------------|
| Total investment       | 3,181,439 €                      |
| GHG savings            | 1,572 ton CO <sub>2</sub> e/year |
| Primary energy savings | 908 MWh/year                     |



## London demonstrators

### London demonstrators

LO1 Active network management

LO2 Capture of identified sources of waste heat and integration of thermal store

LO3 Extension of the Bunhill seed heating system”

|                        |                       |
|------------------------|-----------------------|
| Total investment       | 7,507,133 €           |
| GHG savings            | No data available yet |
| Primary energy savings | No data available yet |



## Genoa demonstrator

### Genoa demonstrator

GE1 Energy recovery from the natural gas distribution network

|                        |                                  |
|------------------------|----------------------------------|
| Total investment       | 2,683,260 €                      |
| GHG savings            | 1,090 ton CO <sub>2</sub> e/year |
| Primary energy savings | 5,300 MWh/year                   |



## Cologne demonstrators

### Cologne demonstrators

CO1-SET1 Sewage water- in school buildings

|                        |                               |
|------------------------|-------------------------------|
| Total investment       | 2,251,206 €                   |
| GHG savings            | 86 ton CO <sub>2</sub> e/year |
| Primary energy savings | 867 MWh/year                  |



## Rotterdam Demonstrators

|                                   |                                 |  |
|-----------------------------------|---------------------------------|--|
| Rotterdam demonstrators           |                                 |  |
| RO1 The Heat Hub                  |                                 |  |
| RO2 Industrial ecology            |                                 |  |
| RO4 Integration cooling solutions |                                 |  |
| Total investment                  | 2,088,628 €                     |  |
| GHG savings                       | 838 ton CO <sub>2</sub> e /year |  |
| Primary energy savings            | 4,303 MWh/year                  |  |

## 7. Conclusions

The present deliverable has presented both qualitative and quantitative information related to the Celsius demonstrators. With regards to the qualitative aspects, the status of the demonstrators under realization process has been presented highlighting main achievements, main conclusions, possible lesson learnt and foreseen next steps. Concerning quantitative aspects, information related to monitored data and calculated key performance indicators for those demonstrators already in operation have been presented. Information about the following demonstrators has been included:

- Already existing demonstrators: 6COe, 2GOe, 7GOe, 8GOe, 9GOe, 11GOe, 19GOe, 20GOe, 36GOe, 16ROe, 15ROe, 32ROe, 32ROe);
- New demonstrators: CO1-SET1, RO1, GO1, GO2, GO3, GO4, LO1.

An additional chapter has been dedicated to the analysis of the replication potential of some of the CELSIUS technologies. Further analyses will be included in the final version of the present deliverable. Moreover information about the established collaboration with the SCIS project is included.

*KPI calculations have been adapted to the current status of data availability at demo sites. In some cases, indicators presented in D4.1 have been slightly modified according to the system operation as well as to data availability. Updated calculations will be included in the final version of current deliverable, foreseen at M57.*

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