Flexible **H**eat and **P**ower, connecting heat and power networks by harnessing the complexity in distributed thermal flexibility

D4.4 Karlshamn validation

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Executive summary

The FHP concept is to use **distributed thermal flexibility**, such as provided by heat pumps in buildings, or large thermal storage solutions, such as the one provided by the Ecovat system, to make most effective use of available renewable energy, and to create the conditions to increase the amount of such renewable energy sources also at distribution system level.

The project has two demonstration sites, one in Uden, the Netherlands and one in Karlshamn, Sweden.

This report focuses on the pilot testing on the Karlshamn site, which consist of industrial and residential premises located in the electrical grid of the DSO Karlshamn Energi AB.

In general, a large effort was put into the following activities throughout the installation and test phases of the project:

- Understanding the set-up of the heating systems, including dialogues with building owners and external experts, with the objective to create checklists/guides that can be used by non-expert (with respect to building modelling) to determine whether a system can be retrofitted to offer flex services, and if so, where to install which sensors.
- Understanding the dynamics of the heating systems once installations had been performed and data was being collected and monitored. E.g. the actual dynamic thermal behaviour of the buildings, as well as the heatpump. Specifically the heatpump signature creation to enable indirect control through sensor override has proven to be a challenge.
- Deploying and validation a multi-agent system that:
    - connects buildings (via the NODA EnergyView platform) with the VITO DCM platform, implementing an Active Connected Buildings Flex Trading use case, where such buildings themselves create and communicate their own consumption plan as well as flexibility for those who need it (in the FHP context: the DCM), and where buildings actively engage with the DCM to achieve an optimal disaggregation of a flex request through a distributed optimization (ADMM)
    - connects the DCM with the DSO, where the DSO received an aggregated consumption plan as well as flexibility, enabling him to decide on an optimal flex dispatch himself, rather than only pointing out that there is a problem, and asking for – any – solution.
- Deploying and validation the webservices approach as an open and easy-to-use interface for the key functional blocks (Planner, Tracker, Forecaster, Shaper, Safer, Balancer) facilitating the integration of functionalities provided by 3rd parties.

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Authors:

Jens Brage, Martin Borgqvist (NODA)
Marcus Steen (KEAB)
Gowri Suryanarayana (VITO)
Mikel Fernandez Dominguez, Borja Tellado Laraudogoitia (TECNALIA)

Reviewers:

Chris Caerts (VITO)

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Glossary

Acronym	Full name
AGR	Aggregator
BRP	Balancing Responsible Party
DCM	Dynamic Coalition Manager (extension/specialization of Aggregator)
DM	Day ahead Market
DER	Distributed Energy Resource
DSO	Distribution System Operator
ISP	Imbalance Settlement Period
GSHP	Ground Source Heat Pump
HP	Heat Pump
PBC	Pluggable Business Component
P2H	Power To Heat
PTU	Program Time Unit
RES	Renewable Energy Source
TSO	Transmission System Operator
USEF	Universal Smart Energy Framework (www.usef.energy)

1 Introduction

1.1 About the FHP Project

The FHP project[2] – *Flexible Heat and Power: connecting Heat and Power networks by harnessing the complexity in distributed thermal flexibility* – was submitted under the call *LCE-01-2016-2017: Next generation innovative technologies enabling smart grids, storage and energy system integration with increasing share of renewables: distribution network*, more specifically under the *Synergies between Energy Networks* area.

1.2 Document structure

Chapter 2 in this document provides an overview of the tests performed in the pilot site in Karlshamn.

Chapter 3 describes the unit testing, i.e. validation of the equipment installed in the different buildings.

Chapter 4 describes the integration tests, i.e. combining the building installations with the NODA cloud-based EnergyView platform and the DCM-centric Multi-Agent prototype FHP-solution.

Chapter 5 provides learnings from the different tests with the pilot buildings.

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[2] See http://www.fhp-h2020.eu/ and http://cordis.europa.eu/programme/rcn/700614_en.html

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2 Pilot site description

This section provides a summary of the pilot site in Karlshamn. A detailed description is provided in ***D4.1 Pilot Definition***.

Table 1: Overview of premises in the demo site in Karlshamn

Premise	Short description
P1.1	Industrial premises, uses both HP and oil burner for heating.
P1.2	Industrial premises, uses air-to-air HP.
P2.1	Multi-apartment Residential premises, uses on/off GSHP (NIBE F1145) with UKV.
P2.2	Multi-apartment Residential premises, uses a (Mitsubishi) air-to-water heat pump, oil burner and electric heater for heating
P2.3	Multi-Apartment Residential premises, uses a frequency controlled GSHP (NIBE F1155)

2.1 Overall test plan

Table 2: Overall test plan

Phase	Test	Premises	Completed
Unit testing	Substation monitoring	Substation 1.1	2018-10-23
	Verification and validation of installed equipment	P1.2, P2.2, P2.1, P2.2, P2.3	2018-11-15
	Stress tests	P2.1, P2.2, P2.3	2019-02-25
	Generation and Evaluation of Thermal Models (VITO shaper)		January 2019
	TEC Shaper	P2.3	February 2019
Integration tests	VITO solution, Use case 1		March 2019
	TEC solution, Use case 1		

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3 Unit tests

This section describes the unit testing, which includes the following specific tests:

- Verification and validation of installed equipment. This process was conducted by NODA and KEAB.
- Generation and evaluation of thermal models. This process was conducted by [VITO/KU Leuven and TEC with support from NODA and RISE]

3.1 Verification and validation of installed equipment

3.1.1 Process

The general procedure for commissioning of NODAs services consist of audits, access, configuration, verification and validation. The procedure is described in short below.

Table 3: General procedure of for commissioning of NODAs services

Step	**Scope and purpose**
Audit	• Verify that the existing controller can be interfaced with NODAs access method. • Identify placements of indoor temperature sensors and their communication unit(s).
Access	• On-site installation of equipment to connect to the existing controller, existing outdoor temperature sensor and installation of pipe sensors on the radiator circuit(s). • Installation of indoor temperature sensors (normally performed by the building owner) and their communication units.
Configuration	• Configuration covers digital access to the premise. • Configure NODA EnergyView platform with a database corresponding to the installation, with accounts for the individuals that should have access to the data, and with appropriate reports tailored to the premise.
Verification (toggle)	• Confirm digital access and other operational capabilities, i.e., to establish a record of operational tests conducted over a number of successive days, and to confirm that the recorded behaviour falls within the expected behaviour.

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	- Toggling of the communication settings every few hours over about a week and recording the responses, and once the record is complete, evaluating the recorded behaviour.
Validation (response tests)	- Confirm the desired functionality, i.e., to establish a record of functional tests conducted over a number of successive days, and to confirm that the recorded behaviour measures up to the desired behaviour. - Repeating a pattern of standardized but realistic control signals over one week and recording the responses, and once the record is complete, evaluating the recorded behaviour.

The audit and access parts of the process described in Table 3 can be performed by an installer. In some cases, an electrician is required to install power outlets for the equipment, if this is not already available. No special competences e.g. regarding automation systems, energy systems or programming are required. The configuration, verification and validation parts of the process are managed by NODA via the cloud-based platform to which the installed equipment communicates.

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3.1.2 Summary of outcome

Table 4 below summarizes the outcome of the procedure to install, verify and validate equipment to access the building heating systems.

The details for each premise is described in sections 3.1.3 to 3.1.8.

Note that Premise 1.3 only was passively monitored (see 3.1.5).

Table 4: Summary of outcome from installation, verification and validation of equipment

Premise	**Audit**	**Access**	**Configuration**	**Verification (toggle)**	**Validation (response tests)**
1.1	Pass	Pass	Pass	Pass	Fail
1.2	Pass	Pass	Pass	Pass	Fail
1.3	Pass	Pass	Pass	N/A	N/A
2.1	Pass	Pass	Pass	Pass	Pass
2.2	Pass	Pass	Pass	Pass	Pass
2.3	Pass	Pass	Pass	Pass	Pass

3.1.3 Premise 1.1

Audit	Outcome: 2017, July: Audit for indoor temperature measurements. 2018, June: Audit for energy meter. 2018, July: Audit for NODA control equipment in substation. Details: During the initial discussions with the building owner and during the audit, an oil-burner was identified in the heating system. This was not regarded as a problem at the moment since it was assumed this was used for peak loads only (during the coldest winter days). The heating system was rather complex with different sub-systems (heat pump, oil burner etc.). At the start of the project this was regarded as a positive challenge. Learnings: The technical requirements regarding the experiments to be conducted in the project were unknown at the time of the audit. Thus, it was difficult to judge the suitability of the heating system for the intended purpose. The complexity of the heating system in the premise was underestimated.
Access	Outcome: 2017, July: Installation of 7 indoor sensors and 1 master unit. 2018, July: Installation of NODA control equipment: 5 pipe sensors, 1 NODA controller, 1 modem. 2018, August: Installation of 1 energy meter (electricity) Details: NODA performed the installations using the standard solution. Additional pipe sensors were installed to monitor expected points of interest of the heat pump and the oil burner. Learnings:

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	It was possible to use a standard NODA installation, however with additional pipe sensors compared to what is used in a traditional district heating substation.
Configuration	Outcome: 2017, July: Configuration of indoor sensors in NODAs web interface EnergyView. 2018, July: Configuration of control equipment in NODAs web interface EnergyView. 2018, August: Configuration of energy meter in NODAs web interface EnergyView. Details: The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners. Learnings: At this point, NODA normally also configures the relevant service to be provided. It required work internally at NODA to adapt the configuration to heat pumps (NODA normally work with district heating systems).
Verification (toggle)	Outcome: 2018, August: Operational tests performed. Details: The communication to the installations was confirmed.
Validation (response tests)	Outcome: In the end it was concluded that the premise was not suitable for the FHP-solution due to anomalies in the heating system, see details and learnings below. Details: In contrast to what was expected at the Audit time, during validation of the control functionality it was discovered that the oil burner was activated at mild outdoor temperatures and also

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	supplied space heating to the office part of the building, i.e. it was not used for peak loads. This required a larger effort to further investigate the heating system. Once we managed to locate a knowledgeable person working for the building owner, it turned out that the oil burner was the primary source of DHW, and that the excess heat was also used for space heating while at the same time overriding the use of the ground source heat pump. Why the latter hadn't been complemented with a corresponding hot water tank, which would allow reduction of oil use, was never revealed. Consequently, the oil burner was almost always active, making it very difficult to analyse the impact of the heat pump. Learnings: ● It was during installation and validation that the anomalies in the heating system was discovered. ● It was hard to find information and contact persons with know-how on the heating system in the premise. It was not possible to obtain knowledge on the complete picture of the heating system functionality, even through dialogue with the building owner. This was a challenge that was underestimated. Due to this we were not successful in identifying the anomalies in the heating system during the audit phase. ● The building owner could probably reduce oil use if the heating system was renovated and complemented with a hot water tank that could buffer heat from the heat pump. ● Heating systems in industrial facilities are sometimes re-constructed and retrofitted over a longer time period which can result in unexpected and contradictory solutions.

3.1.4 Premise 1.2

Audit	Outcome: 2017, July: Audit for indoor temperature measurements. 2018, June: Audit for NODA control equipment in substation (SHB). 2018, August: Audit for energy meter. Details: The 2018-06 Audit revealed the necessity to use 0-10 V to connect to the system to override the temperature sensors controlling the heat pumps and, moreover, the possibility to use this method to access the internal electricity meters. The NODA controller normally connects to a DHN substation controller as an outdoor temperature sensor, but it is also capable of connection through 0-10 V. This however requires programming of the controller in order to define how the 0-10 V signal should be interpreted.
Access	Outcome: 2017, July: Installation of 5 indoor sensors and 1 master unit. 2018, August: Installation of 4 indoor sensors for intake and supply temperatures (2 in hangar east and 2 in hangar west). 2018, August: Installation of NODA control equipment in substation for hangar east (SHB): 1 NODA controller, 1 modem. 2018, August: Installation of NODA control equipment in substation for hangar west (SHB): 1 NODA controller, 1 modem. 2018, August: Installation of 1 energy meter in hangar east and one energy meter in hangar west. Details: ● The purpose of the double setup of indoor sensors (CMa12W), modem (RUT900), NODA Integrated Energy Controller and NODA Energy Meter is to be able to control the two air handling units independently. Moreover, the 2018-08 addition of CMa12W serves the purpose to measure the air temperature of the intake and supply air

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	flow; pipe sensors (VFG54 LON) only applies to pipes of sufficiently small diameter. ● In the end, it was more cost effective to install separate electricity meters than accessing the internal electricity meters via 0-10 V. ● The integration via a 0-10 V signal (to enable controls via sensor override) required the support of an automation technician. This in turn resulted in additional lead time for the access phase. Learnings: The system uses air-to-air heat pumps. This requires temperature measurements in air flows instead of water in pipes. Therefore, a non-standard approach was required to measure the circuit temperatures. In the standard NODA-solution, media (circuit water) flowrate is collected via the heat meter. In the air-source system it was not possible to collect flow-rate data through a cost-effective solution.
Configuration	Outcome: 2017, July: Configuration of indoor sensors in NODAs web interface EnergyView. 2018, August: Configuration of substation equipment in NODAs web interface EnergyView. 2018, August: Configuration of energy meter in NODAs web interface EnergyView. Details: The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners.
Verification (toggle)	Outcome: 2018, August: Operational tests performed. Details: The communication to the installations was confirmed.

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Validation (response tests)	<u>Outcome:</u> The response tests failed and therefore it was not possible to use the premise in further testing. <u>Details:</u> ● A large effort was made to understand the system through its documentation. However, the system behaviour that was monitored in EnergyView (through collected data) was unexpected compared to the interpretation of the documentation. ● A complex behaviour with large fluctuations was observed in the monitored HP electricity consumption data (which was sub-metered). Thus, it was hard to identify the boundaries for modelling the system properly. ● Expertise from RISE and staff from VITO were engaged in the effort to understand the response of the hearing system. Specifically the modelling of the non-hydronic air-to-air HP was challenging. <u>Learnings:</u> There are different heat pump systems, where the heat pump is connected to different heat sources and sinks, e.g. ground-source heat pumps connected to hydronic space heating system and air-to-air heat pumps connected to ventilation systems. However, these two cases are not comparable, and technology developed for one kind of system (hydronic space heating) does not transfer to the other (ventilation).

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3.1.5 Premise 1.3

Audit	Outcome: 2017, July: Audit for indoor temperature measurements. Details: The audit concluded that the premise only had wall mounted air-source heat pumps. Learnings: The occupants were renting the building, but they were nevertheless keen to participate for sustainability reasons.
Access	Outcome: 2017, July: Installation of 3 indoor sensors and 1 master unit. Details: It was not possible to find a suitable interface to uses to integrate to these heat pumps. Therefore, it was decided to only monitor indoor temperature for modelling purposes.
Configuration	Outcome: 2017, July: Configuration of indoor sensors in NODAs web interface EnergyView. Details: The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners.
Verification (toggle)	Outcome: The premise was only be passively studied, and not controlled.
Validation (response tests)	Outcome: The premise was only passively studied, and not controlled.

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3.1.6 Premise 2.1

Audit	<u>Outcome:</u> 2018, October: Audit for indoor sensors, NODA equipment in the substation and energy meter. <u>Details:</u> It was hard to get hold of the building owner which resulted in a long lead time to get the audit done.
Access	<u>Outcome:</u> 2018, October: Installation of 3 indoor sensors and 1 master unit. 2018, October: Installation of NODA control equipment in substation: 1 NODA controller and 5 pipe sensors 2018, October: Installation of 1 energy meter.
Configuration	<u>Outcome:</u> 2018, October: Configuration of indoor sensors in NODAs web interface EnergyView. 2018, October: Configuration of substation equipment in NODAs web interface EnergyView. 2018, October: Configuration of energy meter in NODAs web interface EnergyView. <u>Details:</u> The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners.
Verification (toggle)	<u>Outcome:</u> 2018, October: Operational tests performed. <u>Details:</u> The communication to the installations was confirmed.

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Validation (response tests)	Outcome: It was possible to get a response on the HP electricity load from control actions. However, it was hard to determine the magnitude of the response. Details: The heat pump used is on/off controlled (i.e. not frequency controlled), it is either on or off. Due to this, it is hard to determine the magnitude of response on electricity use from control actions. This since it is necessary to evaluate mean electricity load over a few hours for an on/off heat pump (it will go on and off on a regular basis). And during these few hours, other conditions in the building and outdoor climate (ambient and social factors) can change and by so impacting heat use and corresponding electricity use. This makes comparison difficult and it is necessary to have a large statistical basis to correctly compensate for ambient and social factors.

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3.1.7 Premise 2.2

Audit	Outcome: 2018, February: Audit for indoor temperature measurements. 2018, February: Audit for NODA control equipment in substation (SHB). 2018, July: Audit for energy meter. Details: The 2018-06 Audit suggested the approach of measuring the combined energy consumption of the heat pump and the electric cartridge. The approach has the advantage of being truthful to the controllable energy consumption, however, in the end, it turned out that situation was better suited to only measure the electricity consumption of the heat pump. Moreover, initial studies suggested that the building consumes electricity in excess. The problem was traced back to the electric cartridge which, for unknown reasons, had been configured with no integration time. This has since then been acted upon by the building owners, and the electric cartridge should since then be used much more sparingly. Learnings: It was hard to get building owners on-board due to their prior experience of research projects.
Access	Outcome: 2018, March: Installation of 8 indoor sensors and 1 master unit 2018, March: Installation of NODA control equipment in substation: 1 NODA controller, 1 modem, 7 pipe sensors. 2018, June: Installation of 1 energy meter. Learnings: Once the indoor temperature sensors had been installed, it turned out that one apartment had about 30 °C, with the resident, who were working night, modulating the temperature during the day by opening windows. This in turn seems to be the main cause for the unexpectedly high electricity demand of

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	the heating system, though the overall cause and effect turned out to be much more intricate. In short, the outdated thermostats and a lack of knowledge about the building heating system caused the residents to work around the heating system, coming up with creative solutions of how to regulate their indoor climate.
Configuration	Outcome: 2018, March Configuration of indoor sensors in NODAs web interface EnergyView. 2018, March: Configuration of substation equipment in NODAs web interface EnergyView. 2018, July: Configuration of energy meter in NODAs web interface EnergyView. Details: The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners.
Verification (toggle)	Outcome: 2018, March: Operational tests performed. Details: The communication to the installations was confirmed.
Validation (response tests)	Outcome: It was possible to perform control actions and get a response from it. Details: ● The building had an unexpectedly large electricity use. ● One indoor temperature sensor gave strange reading. Upon closer inspection, it turned out that the outside of the wall housed a refrigerator, causing the strange readings. The sensor was moved and the problem was resolved.

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	Learnings: ● The high electricity use had probably to do with old thermostats that responded poorly and made the occupants come up with creative solutions, involving high temperature settings (on thermostats) and open windows. ● The above problems were obscured by a wrongly installed motorized vault, causing high frequent temperature oscillations in the heating system, by complex interaction with the overall pressure in the system, by unbalanced branches in the building heating system, and the fact that these anomalies were linked to the outdoor temperature and only available for analysis on irregular basis. ● It took a long time to sort out all the issues with the heating system, which also involved changing (correcting) the heating system, which in turn rendered the collected data useless for modelling purpose as the old data no longer reflected the corrected system. That said, the system responded very well to control actions, and the building owners, from being reluctant participants, we converted to be very enthusiastic about using digital tools for better understanding their building stock.

3.1.8 Premise 2.3

Audit	Outcome: 2018, July: Audit for indoor temperature measurements. 2018, July: Audit for NODA control equipment in substation (SHB). 2018, July: Audit for energy meter. Details: During the audit it was found the premise had a main building heated by radiators and an annex building that was heated by floor heating.
Access	Outcome: 2018, July: Installation of 5 indoor sensors and 1 master unit 2018, July: Installation of NODA control equipment in substation: 1 NODA controller, 1 modem, 5 pipe sensors. 2018, July: Installation of 1 energy meter. Details: It was possible to use the standard installation method, but more pipe sensors were used compared to what is used in a district heating substation.
Configuration	Outcome: 2018, July Configuration of indoor sensors in NODAs web interface EnergyView. 2018, July: Configuration of substation equipment in NODAs web interface EnergyView. 2018, July: Configuration of energy meter in NODAs web interface EnergyView. Details: The collected data was presented in NODAs web-based interface EnergyView. Access to EnergyView was granted to the project partners.

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Verification (toggle)	Outcome: 2018, August: Operational tests performed. Details: The communication to the installations was confirmed.
Validation (response tests)	Outcome: It was possible to get a response on the electricity load from control actions. However, it was hard to determine the magnitude of the response. Details: The heat pump used is frequency controlled. Even so, the behaviour of the electricity load is similar to that from an on/off heat pump. Data logging showed oscillating electricity use over 2 h time periods. This oscillating behaviour shadowed the response of the control signal and made the analysis more complex. See also details for premise 2.1.

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3.1.9 Site 3, Supermarket

After an extended audit in the autumn of 2017 by KEAB, NODA and RISE at the Supermarket the conclusion of leaving Premise 3 out from further testing was made. The heating and energy system were too complex for integration together with a high economical risk for dealing with freezers for food, the decision was just to keep Premise 3 for data collection. The supermarket also changed owner twice and it was not possible to get hold of the new owner in order to get permission to use the premise in the project.

3.1.10 Site 3, RISE Research House

This site was not included in the demonstration. The site was identified as a demonstrator candidate in the beginning of the project. However, it was not possible to get an approval to use the facility from the responsible managers.

3.1.11 Substation monitoring

Technical audit, grid data and analysis for the different considered substations was made early on in the project. Due to expensive equipment, scattered pilot sites and limited value for the project, the decision was only to install substation monitoring for one substation instead of 5-7 as mentioned in the GA.

Substation 1.1 supplies the industrial premises, P1.1-1.3, which are all located in the same grid area. KEAB with help from subcontractor installed monitoring equipment and performed commissioning tests 2018-10-23.

3.2 Generation and evaluation of thermal models

The generation and evaluation of thermal models can be split into 3 subtasks:

- Making the setup suitable for collecting data required by model training.
- Calculating the COP of the installed heat pumps.
- Finally, training the grey box model to best fit the data that is collected.

3.2.1 Data collection for Model training

For calibrating the data-driven models that characterize the dynamic thermal behaviour of the building, it is important to provide the right data – solar irradiation, outdoor temperature, indoor temperature and heat delivered to the building. One of the most challenging aspect here is to be able to estimate the amount of heat delivered to the building (purely meant for space heating). In the residential buildings, the heat pumps are being used for both space heating and domestic hot water (DHW) requirements. We thus needed to do some thorough analysis on the available data, to be able to deduce the amount of heat delivered for space heating. Following were the steps that were followed:

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- **Sensor installation**: We had to additional install sensors, on the piping of the hydronic system (done by KEAB, pointed out in the schematics below).
- **Data analysis**: In the schematics shown in Figure 1, the sensors placed for supply and return temperatures help in making the distinction between space heating and domestic hot water usage. For instance, as shown in Figure 2Figure 3, DHW starts being produced when the supply temperature is starting to decrease (blue bubble). When it bounces back up again DHW is stopped (orange bubble). The blue and yellow lines will cool down slowly when the flow is stopped, but the DHW is stopped when those temperatures are starting to decrease. Similarly, Figure 3 suggests that there are moments when the return temperature exceeds the supply temperature, which can be explained only by the mixing (on the return side) that happens when DHW starts being produced. Hence, in both cases, by analysing the measurements, one can identify when space heating is active and when DHW is being produced (Note that these are mutually exclusive in the premises that we have).

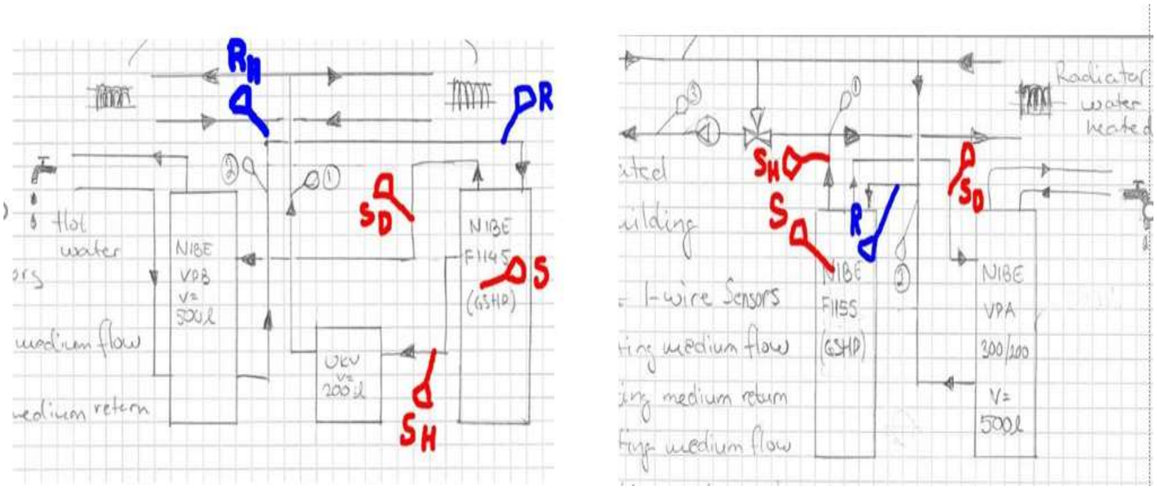

Figure 1 — Sensor placement in premise 2.1 and 2.3

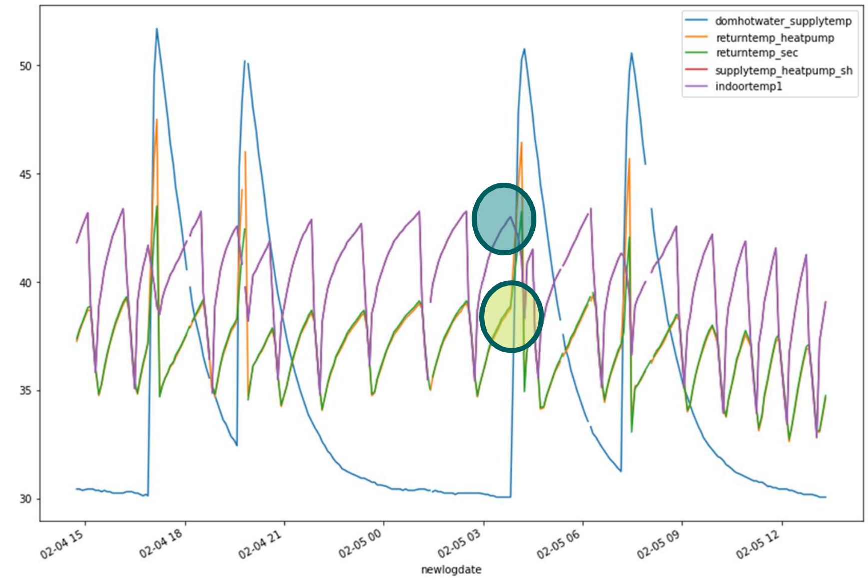

Figure 2 — Measurements of different temperatures for Premise 2.1

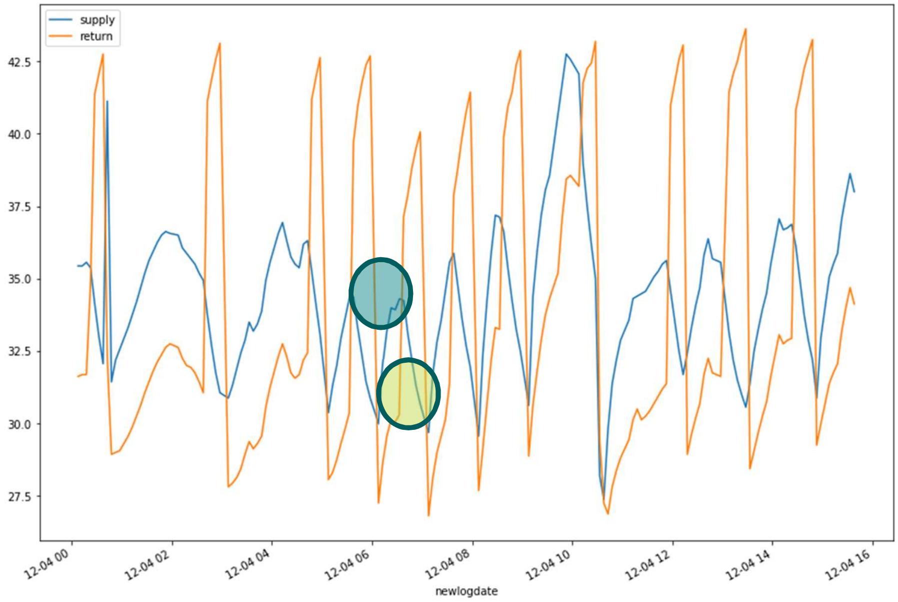

Figure 3 — Measurements of different temperatures for Premise 2.3

- **Final calculation for heat delivery**: The heat $\dot{Q}$ that is delivered for space heating in premises 2.1 and 2.3 is calculated this way:

$$\dot{Q} = mc_p \Delta T$$

$$\Delta T = T_{supply} - T_{return}$$

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Where T_{supply} and $T_{return}$are the supply and return temperatures respectively. The heat $\dot{Q}$ is then

Where $c_p$is the heat capacity of water (4.187 kJ/kgK), and m is the mass flow rate (calculated at 0.35 kg/s).

The electric and thermal power are the readings retained after filtering out instances where $\Delta T < 0$. The east and west wings of the premise use air heat pumps and are used purely for space heating. The heat delivered to those premises are calculated using the following equation:

$$\dot{Q} = v\rho c_p \Delta T$$

where is the v volume flow, ρ is the air density and c_p in this case is the heat capacity of air. The following values are used in each case

- 1.2 West: v is 9000 m3/h, in SI-units 9000/3600 = 2.5 m3/s, ρ is 1.20kg/m3, c_p is 1006 J/(kg·K)
- 1.2 East: v is 12000 m3/h, in SI-units 12000 /3600 = 3.33 m3/s, ρ is 1.20kg/m3, c_p is 1006 J/(kg·K)

3.2.2 COP calculation

The trained models are used in MPC optimization routines to determine optimal thermal energy consumption profiles to be followed. These need to be converted to corresponding electric power profiles for applying controls to the buildings (heat pumps). For this, we need to calculate the COP for each of the premises. This is done using simple regression for linear dependence on outdoor temperature (in degree Celsius) using the historical data of the electric power and heat delivered measurements. The following relationship was used where c_1 and c_2 for the various premises were calculated using linear regression.

$$COP = c_1 T_{outdoor} + c_2$$

3.2.3 Model training

For the characterization of the dynamic thermal behaviour of the buildings, the RC models developed in WP2, Task 2.1 were used. The method has access to 4 different model structures, briefly described below:

- **Zon_D**: is the most basic model structure encompassing a capacitance resembling the internal thermal mass of the zone, a resistance representing the heat transfer through the shell to the ambient. The final parameter is the initial condition (starting temperature) of the zone.
- **Zon_A**: builds upon Zon_D and adds solar gains to it, using the parameter gA.

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- **ZonWal_B**: extends Zon_A and adds thermal mass of the external walls to the model. This adds a capacitance to the parameter list along with an additional initial temperature.
- **ZonWalInt_B**: is the final extension and adds internal walls as well as infiltration losses to the model. The inclusion of internal walls leads to a third capacitance, along with an initial condition and resistance of the internal walls. The infiltration losses are modelled as a single resistance between the internal thermal mass and the ambient.

Model definitions are taken from the FastBuildings library included on the OpenIDEAS toolbox. The following procedure is applied to identify the model parameters:

- Preparation of data: The model parameters are estimated using data from the field demonstrators. In case of this particular Swedish pilot data from four buildings is available. In case multiple temperature sensors are available indoors, the average is used as input value. The data are provided with a sampling time of 15 minutes. In case of missing data points or mismatches, interpolation is applied. Concerning the time span of the training data, typically 10 to 15 days are sufficient.
- The user provides data to the method and has access to the following options to facilitate or customize the fitting procedure: Zone volume, Sampling frequency, number of trials (for Latin Hypercube sampling for initial guesses), total training period: the amount of days used for fitting and validation criteria (auto or cross).
- Upon executing the fitting routine, the data that is used is graphically presented to the user as a final check to verify the validity of the input data.
- The fitting routine takes roughly 20 to 30 minutes to complete, depending on the amount of data and user specified options. At the end of the procedure the parameter values are returned as well as RMSE values.

Results regarding the accuracy of the dynamic thermal model are presented in D4.5.

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4 Integration testing

4.1 Integration tests TECNALIA solution

The integration tests are focused on the verification of the use cases and data flows, described in D2.5. The functionalities to be tested during the integration phase can be summarized as:

- Verification of train model generation request / response
- Verification of flexibility constraints request / response
- Verification of incentive offer request / response

The integration test that will be described in the following paragraphs were carried out during the month of march, the shown data belong to the integration tests acceptance milestone (1st of April)

The verification of the model train functionality as it requires at least 3 months data was carried out with dummy data that was not covering the whole training window. As the goal for the integration testing is to validate the interfaces/usability of the implemented functionalities and the training of the model is something that may happen in batch mode, the use of dummy data is not a relevant constraint during the integration test phase.

The training phase is divided in two steps that are sequentially triggered by the same request. The first step takes as input features the outdoor conditions, the indoor current temperatures and the provided thermal energy and delivers as output the indoor temperature that will be achieved, as well as the label for the thermal energy profile required to satisfy it, i.e. the baseline.

The second step is model the flexibility to produce a consumption profile from those periods of the day in which the energy price is high without impact in the indoor comfort conditions.

The reference flow for the train functionality testing is taken from D2.5

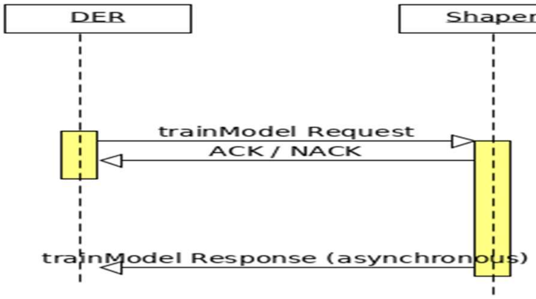

Figure 4 — Model train flow

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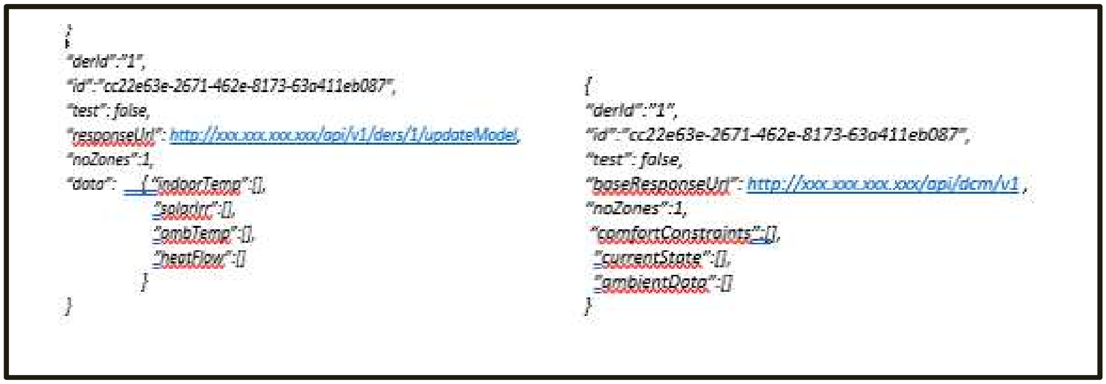
The format of the messages involved is shown below.



```
}
“derId”:”1”,
“id”:”cc22e63e-2671-462e-8173-63a411eb087”,
“test”: false,
“responseUrl”: http://xxx.xxx.xxx.xxx/api/v1/ders/1/updateModel,
“noZones”:1,
“data”:  { “indoorTemp”:[],
          “solarIrr”:[],
          “ambTemp”:[],
          “heatFlow”:[]
         }
}
```

```
{
“derId”:”1”,
“id”:”cc22e63e-2671-462e-8173-63a411eb087”,
“test”: false,
“baseResponseUrl”: http://xxx.xxx.xxx.xxx/api/dcm/v1 ,
“noZones”:1,
 “comfortConstraints”:[],
 “currentState”:[],
 “ambientData”:[]
}
```

Figure 5 — Conceptualized train model request (right) and response (left) messages structure

Even they could be considered out of the integration testing phase, in parallel the “offline” test of the model train functionalities were carried out. The table below shows some figures of the tests done offline.

Premise	Required Time (Average)
Premise 2.1	≈20 seconds
Premise 2.3	≈25 seconds

For illustrative purposes dump of the logs generated during the train model for the premise 2.1 and premise 2.3 have been included below.

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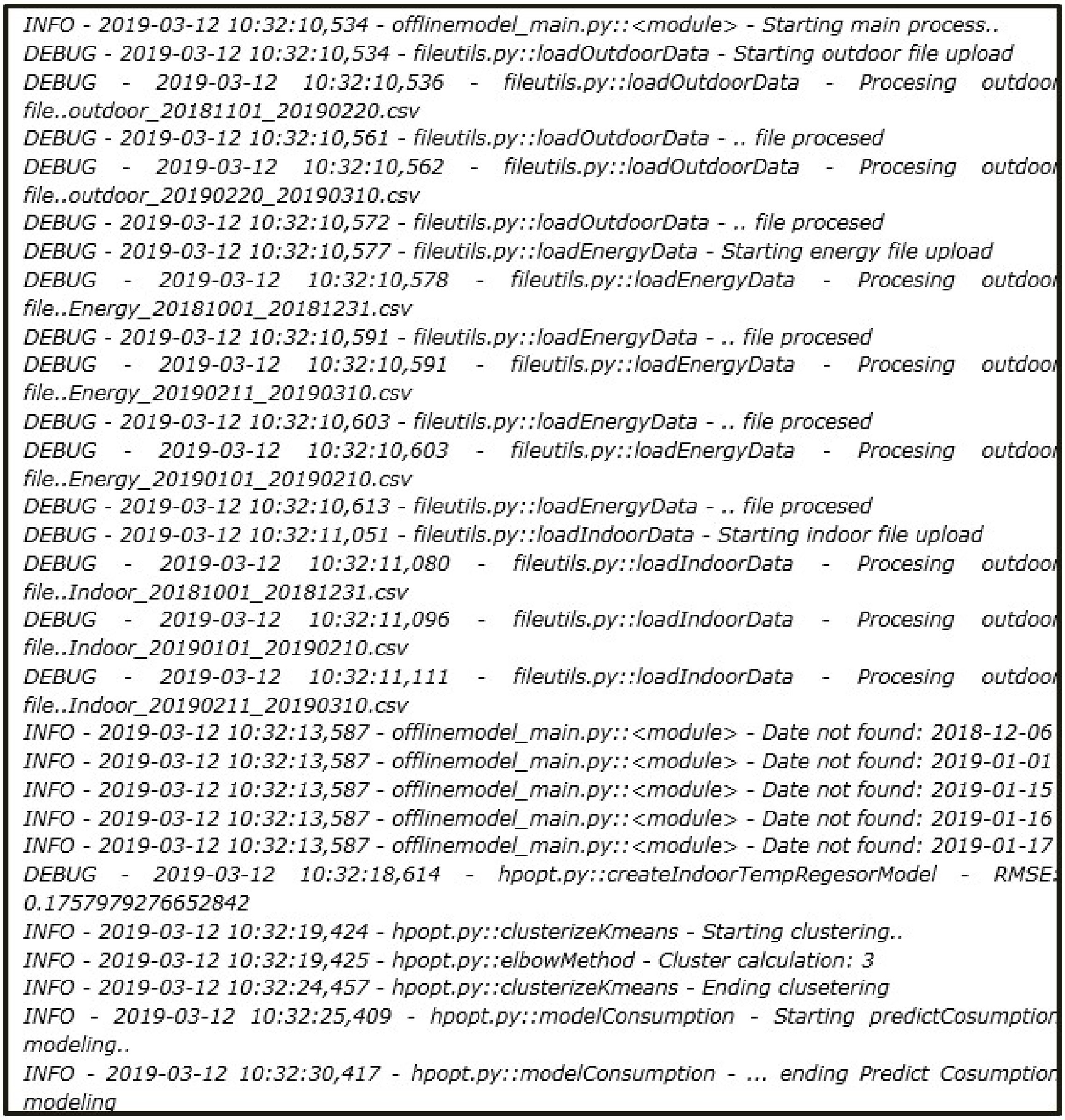

```
INFO - 2019-03-12 10:32:10,534 - offlinemodel_main.py::<module> - Starting main process..
DEBUG - 2019-03-12 10:32:10,534 - fileutils.py::loadOutdoorData - Starting outdoor file upload
DEBUG - 2019-03-12 10:32:10,536 - fileutils.py::loadOutdoorData - Procesing outdoo
file..outdoor_20181101_20190220.csv
DEBUG - 2019-03-12 10:32:10,561 - fileutils.py::loadOutdoorData - .. file procesed
DEBUG - 2019-03-12 10:32:10,562 - fileutils.py::loadOutdoorData - Procesing outdoo
file..outdoor_20190220_20190310.csv
DEBUG - 2019-03-12 10:32:10,572 - fileutils.py::loadOutdoorData - .. file procesed
DEBUG - 2019-03-12 10:32:10,577 - fileutils.py::loadEnergyData - Starting energy file upload
DEBUG - 2019-03-12 10:32:10,578 - fileutils.py::loadEnergyData - Procesing outdoo
file..Energy_20181001_20181231.csv
DEBUG - 2019-03-12 10:32:10,591 - fileutils.py::loadEnergyData - .. file procesed
DEBUG - 2019-03-12 10:32:10,591 - fileutils.py::loadEnergyData - Procesing outdoo
file..Energy_20190211_20190310.csv
DEBUG - 2019-03-12 10:32:10,603 - fileutils.py::loadEnergyData - .. file procesed
DEBUG - 2019-03-12 10:32:10,603 - fileutils.py::loadEnergyData - Procesing outdoo
file..Energy_20190101_20190210.csv
DEBUG - 2019-03-12 10:32:10,613 - fileutils.py::loadEnergyData - .. file procesed
DEBUG - 2019-03-12 10:32:11,051 - fileutils.py::loadIndoorData - Starting indoor file upload
DEBUG - 2019-03-12 10:32:11,080 - fileutils.py::loadIndoorData - Procesing outdoo
file..Indoor_20181001_20181231.csv
DEBUG - 2019-03-12 10:32:11,096 - fileutils.py::loadIndoorData - Procesing outdoo
file..Indoor_20190101_20190210.csv
DEBUG - 2019-03-12 10:32:11,111 - fileutils.py::loadIndoorData - Procesing outdoo
file..Indoor_20190211_20190310.csv
INFO - 2019-03-12 10:32:13,587 - offlinemodel_main.py::<module> - Date not found: 2018-12-06
INFO - 2019-03-12 10:32:13,587 - offlinemodel_main.py::<module> - Date not found: 2019-01-01
INFO - 2019-03-12 10:32:13,587 - offlinemodel_main.py::<module> - Date not found: 2019-01-15
INFO - 2019-03-12 10:32:13,587 - offlinemodel_main.py::<module> - Date not found: 2019-01-16
INFO - 2019-03-12 10:32:13,587 - offlinemodel_main.py::<module> - Date not found: 2019-01-17
DEBUG - 2019-03-12 10:32:18,614 - hpopt.py::createIndoorTempRegesorModel - RMSE
0.1757979276652842
INFO - 2019-03-12 10:32:19,424 - hpopt.py::clusterizeKmeans - Starting clustering..
INFO - 2019-03-12 10:32:19,425 - hpopt.py::elbowMethod - Cluster calculation: 3
INFO - 2019-03-12 10:32:24,457 - hpopt.py::clusterizeKmeans - Ending clusetering
INFO - 2019-03-12 10:32:25,409 - hpopt.py::modelConsumption - Starting predictCosumptio
modeling..
INFO - 2019-03-12 10:32:30,417 - hpopt.py::modelConsumption - ... ending Predict Cosumptio
modeling
```

Figure 6 — Train model logs dump (premise 2.1)

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```
INFO - 2019-03-12 10:33:35,490 - offlinemodel_main.py::<module> - Starting main process..
DEBUG - 2019-03-12 10:33:35,490 - fileutils.py::loadOutdoorData - Starting outdoor file upload
DEBUG - 2019-03-12 10:33:35,492 - fileutils.py::loadOutdoorData - Procesing outdoor
file..outdoor_20181101_20190220.csv
DEBUG - 2019-03-12 10:33:35,517 - fileutils.py::loadOutdoorData - .. file procesed
DEBUG - 2019-03-12 10:33:35,522 - fileutils.py::loadEnergyData - Starting energy file upload
DEBUG - 2019-03-12 10:33:35,523 - fileutils.py::loadEnergyData - Procesing outdoor
file..Energy_20181101_20190119.csv
DEBUG - 2019-03-12 10:33:35,538 - fileutils.py::loadEnergyData - .. file procesed
DEBUG - 2019-03-12 10:33:35,538 - fileutils.py::loadEnergyData - Procesing outdoor
file..Energy_20190120_20190211.csv
DEBUG - 2019-03-12 10:33:35,549 - fileutils.py::loadEnergyData - .. file procesed
DEBUG - 2019-03-12 10:33:35,823 - fileutils.py::loadIndoorData - Starting indoor file upload
DEBUG - 2019-03-12 10:33:35,823 - fileutils.py::loadIndoorData - Procesing outdoor
file..Indoor_20190120_20190210.csv
DEBUG - 2019-03-12 10:33:35,849 - fileutils.py::loadIndoorData - Procesing outdoor
file..Indoor_20181101_20190119.csv
INFO - 2019-03-12 10:33:39,010 - offlinemodel_main.py::<module> - Date not found: 2019-01-14
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-01-15
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-01-16
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-01-17
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-02-03
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-02-04
INFO - 2019-03-12 10:33:39,011 - offlinemodel_main.py::<module> - Date not found: 2019-02-05
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-06
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-07
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-11
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-12
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-13
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-14
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-15
INFO - 2019-03-12 10:33:39,012 - offlinemodel_main.py::<module> - Date not found: 2019-02-16
INFO - 2019-03-12 10:33:39,013 - offlinemodel_main.py::<module> - Date not found: 2019-02-17
INFO - 2019-03-12 10:33:39,013 - offlinemodel_main.py::<module> - Date not found: 2019-02-18
INFO - 2019-03-12 10:33:39,013 - offlinemodel_main.py::<module> - Date not found: 2019-02-19
INFO - 2019-03-12 10:33:39,013 - offlinemodel_main.py::<module> - Date not found: 2019-02-20
DEBUG - 2019-03-12 10:33:44,070 - hpopt.py::createIndoorTempRegesorModel - RMSE:
0.1746191754730052
INFO - 2019-03-12 10:33:44,704 - hpopt.py::clusterizeKmeans - Starting clustering..
INFO - 2019-03-12 10:33:44,705 - hpopt.py::elbowMethod - Cluster calculation: 3
INFO - 2019-03-12 10:33:49,736 - hpopt.py::clusterizeKmeans - Ending clusetering
INFO - 2019-03-12 10:33:50,439 - hpopt.py::modelConsumption - Starting predictCosumption
modeling..
INFO - 2019-03-12 10:33:59,452 - hpopt.py::modelConsumption - ... ending Predict Cosumption
modeling
```

Figure 7 — Train model log dump (premise 2.3)

The verification of the flexibility constraints request / response and incentive offer request / response have been done taking as refence the scenario described below, the integration tests focused on the flow highlighted in red.

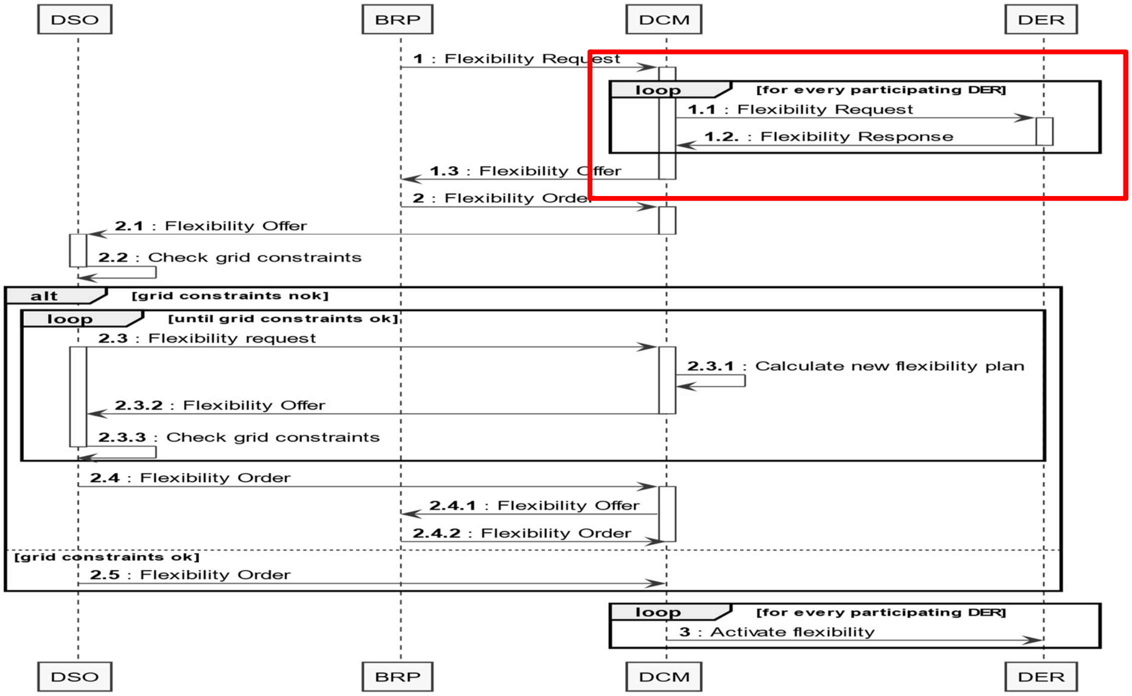
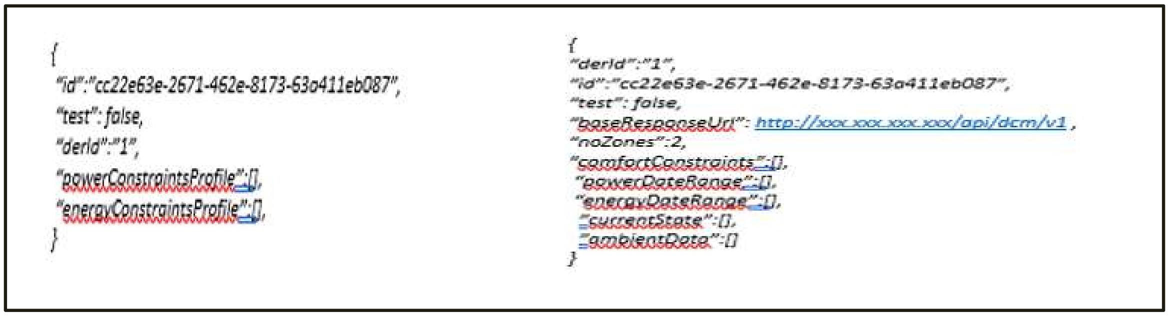


Figure 8 — Flexibility request use case

The overall use case in which the flexibility request and incentive offer are involved can be described by the figure above. The BRP requests the DCM to collect the optimal baseline of its cluster together with the available flexibility, which is given by both an upper bound and a lower bound (msg 1). This information is collected by the DCM by sending a flexibility request message to the individual DERs in its cluster (msg 1.1 and 1.2). When all information is received, the DCM calculates the aggregated optimal baseline and aggregated flexibility available in its cluster. This is sent to the BRP as a flexibility offer message (msg 1.3). Based on this offer, the BRP calculates the amount of flexibility needed in order to mitigate the forecasted RES curtailment. The BRP orders the necessary flexibility to the DCM by sending a flexibility order (msg 2). First, the DCM checks if this order is feasible within the boundaries of the flexibility offer that it has sent previously to the BRP. Secondly, the BRP checks the flexibility order with the DSO to check if the underlying grid constraints are respected (msg 2.1 and 2.2). If grid constraints are not violated, the DSO informs to the DCM by sending an equal flexibility order to the one received from the BRP (msg 2.6). If grid constraints are violated, the DSO sends a new flexibility request to the DCM (msg 2.3). Based on this new flexibility request the DCM calculates a new optimal flexibility plan (msg 2.3.1) and sends it back to the DSO (msg 2.3.2) which checks the grid constraints again (msg 2.3.3).

The flexibility request flow implemented as HTTP-Rest service involves an asynchronous mechanism with JSON formatted messages.



```
{
“id”:”cc22e63e-2671-462e-8173-63a411eb087”,
“test”: false,
“derId”:”1”,
“powerConstraintsProfile”:[],
“energyConstraintsProfile”:[],
}
```

```
{
“derId”:”1”,
“id”:”cc22e63e-2671-462e-8173-63a411eb087”,
“test”: false,
“baseResponseUrl”: http://xxx.xxx.xxx.xxx/api/dcm/v1 ,
“noZones”:2,
“comfortConstraints”:[],
 “powerDateRange”:[],
 “energyDateRange”:[],
 “currentState”:[],
 “ambientData”:[]
}
```

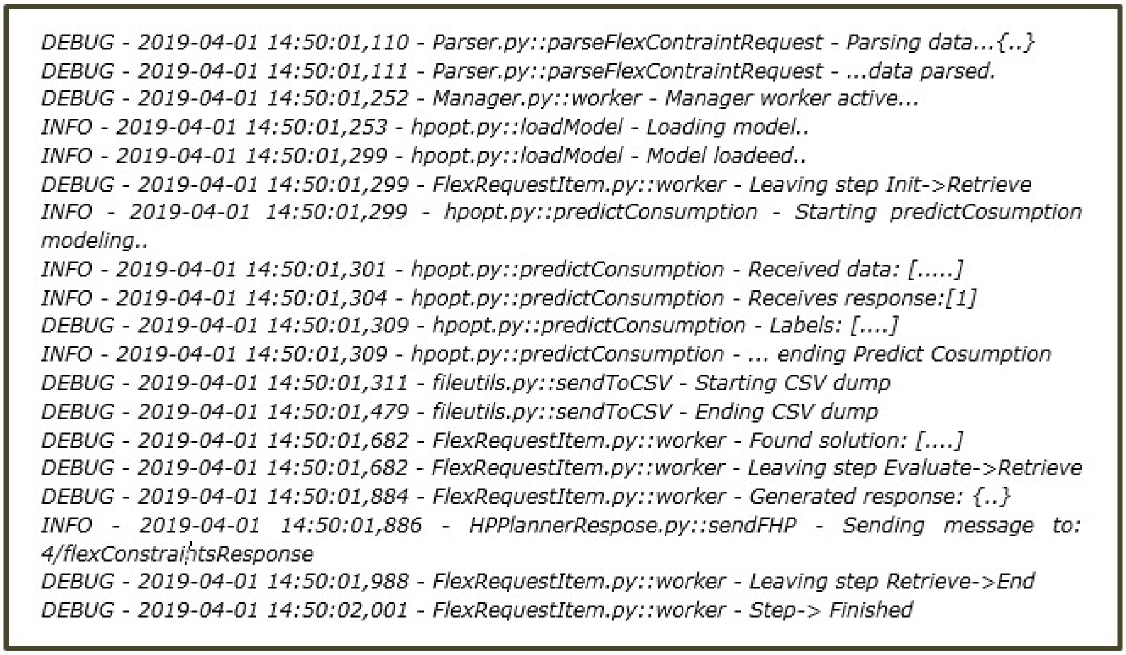
Figure 9 — Conceptualized flexibility request (right) and response (left) messages structure

The flexibility request verification involved not only the compliance with the data format designed for that purpose but also the performance in terms of time required from the request reception to the response (asynchronous) release. The outcomes are show in the following table.

Premise	Required time (average)
Premise 2.1	≈1 second
Premise 2.3	≈2 seconds

The difference in time between the tested pilot cases, the calculation for premise 2.3 requires slightly more time, is due to the complexity of the black – box model behind. The set of traces below describe the flow and times for a single flexibility request scenario (some values have been removed to enhance readbility).

For illustrative purposes dump of the logs generated during the flexibility request for the premise 2.1 have been included below.



```
DEBUG - 2019-04-01 14:50:01,110 - Parser.py::parseFlexContraintRequest - Parsing data...{..}
DEBUG - 2019-04-01 14:50:01,111 - Parser.py::parseFlexContraintRequest - ...data parsed.
DEBUG - 2019-04-01 14:50:01,252 - Manager.py::worker - Manager worker active...
INFO - 2019-04-01 14:50:01,253 - hpopt.py::loadModel - Loading model..
INFO - 2019-04-01 14:50:01,299 - hpopt.py::loadModel - Model loadeed..
DEBUG - 2019-04-01 14:50:01,299 - FlexRequestItem.py::worker - Leaving step Init->Retrieve
INFO  -  2019-04-01  14:50:01,299  -  hpopt.py::predictConsumption  -  Starting  predictCosumption
modeling..
INFO - 2019-04-01 14:50:01,301 - hpopt.py::predictConsumption - Received data: [.....]
INFO - 2019-04-01 14:50:01,304 - hpopt.py::predictConsumption - Receives response:[1]
DEBUG - 2019-04-01 14:50:01,309 - hpopt.py::predictConsumption - Labels: [....]
INFO - 2019-04-01 14:50:01,309 - hpopt.py::predictConsumption - ... ending Predict Cosumption
DEBUG - 2019-04-01 14:50:01,311 - fileutils.py::sendToCSV - Starting CSV dump
DEBUG - 2019-04-01 14:50:01,479 - fileutils.py::sendToCSV - Ending CSV dump
DEBUG - 2019-04-01 14:50:01,682 - FlexRequestItem.py::worker - Found solution: [....]
DEBUG - 2019-04-01 14:50:01,682 - FlexRequestItem.py::worker - Leaving step Evaluate->Retrieve
DEBUG - 2019-04-01 14:50:01,884 - FlexRequestItem.py::worker - Generated response: {..}
INFO  -  2019-04-01  14:50:01,886  -  HPPlannerRespose.py::sendFHP  -  Sending  message  to:
4/flexConstraintsResponse
DEBUG - 2019-04-01 14:50:01,988 - FlexRequestItem.py::worker - Leaving step Retrieve->End
DEBUG - 2019-04-01 14:50:02,001 - FlexRequestItem.py::worker - Step-> Finished
```

Figure 10 — Flexibility request log dump

The incentive offer request / response flow verification took as reference the conceptualization done in the D2.5 that can be summarized as the following flow.

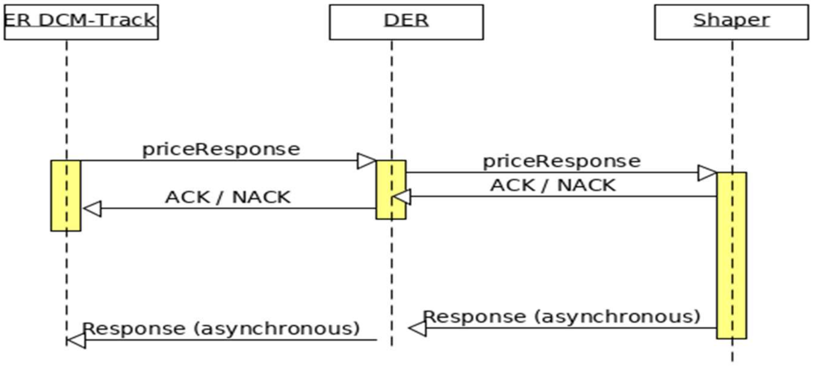


Figure 11 — Incentive Offer flow

The format of the messages involved is shown below.

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```
{
”derId”:”1”,
”id”:”cc22e63e-2671-462e-8173-63a411eb087”,
”test”: false,
”baseResponseUrl”: http://xxx.xxx.xxx.xxx/api/dcm/v1 ,
”noZones”:1,
 ”comfortConstraints”:[],
 ”currentState”:[],
 ”ambientData”:[]
}
```

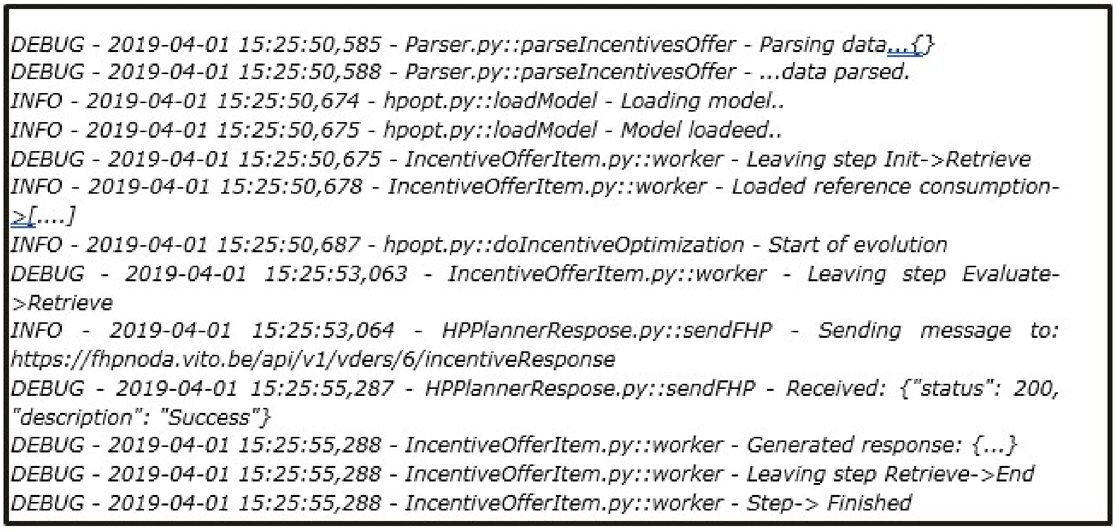
```
{
"test": false,
"derId": "0",
"consumptionPlanProfile": {
    "dataArray": [],
    "unitInfo": {},
    "dateRange": {}
},
"id": "59ef310f-d920-4e53-9947-4c88378bfc33"
}
```

Figure 12 — Conceptualized incentive offer request (left) response (right)

As well as for the flexibility request verification, the incentive verification involved not only the compliance with the data format designed for that purpose but also the performance in terms of time required from the request reception to the response (asynchronous) release. The outcomes are show in the following table. The incentive offer requires considerably more time due to the optimization processes that have to be implemented

Premise	Required time (average)
Premise 2.1	≈5 seconds
Premise 2.3	≈6 seconds

For illustrative purposes dump of the logs generated during the incentive offer request for the premise 2.3 have been included below.



```
DEBUG - 2019-04-01 15:25:50,585 - Parser.py::parseIncentivesOffer - Parsing data...{}
DEBUG - 2019-04-01 15:25:50,588 - Parser.py::parseIncentivesOffer - ...data parsed.
INFO - 2019-04-01 15:25:50,674 - hpopt.py::loadModel - Loading model..
INFO - 2019-04-01 15:25:50,675 - hpopt.py::loadModel - Model loadeed..
DEBUG - 2019-04-01 15:25:50,675 - IncentiveOfferItem.py::worker - Leaving step Init->Retrieve
INFO - 2019-04-01 15:25:50,678 - IncentiveOfferItem.py::worker - Loaded reference consumption-
>[....]
INFO - 2019-04-01 15:25:50,687 - hpopt.py::doIncentiveOptimization - Start of evolution
DEBUG - 2019-04-01 15:25:53,063 - IncentiveOfferItem.py::worker - Leaving step Evaluate-
>Retrieve
INFO - 2019-04-01 15:25:53,064 - HPPlannerRespose.py::sendFHP - Sending message to:
https://fhpnoda.vito.be/api/v1/vders/6/incentiveResponse
DEBUG - 2019-04-01 15:25:55,287 - HPPlannerRespose.py::sendFHP - Received: {"status": 200,
"description": "Success"}
DEBUG - 2019-04-01 15:25:55,288 - IncentiveOfferItem.py::worker - Generated response: {...}
DEBUG - 2019-04-01 15:25:55,288 - IncentiveOfferItem.py::worker - Leaving step Retrieve->End
DEBUG - 2019-04-01 15:25:55,288 - IncentiveOfferItem.py::worker - Step-> Finished
```

Figure 13 — Incentive offer log dump

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4.2 Integration tests VITO solution

The integration tests focusses on treating the buildings as a cluster of flexibility that is aggregated by the DCM and offered to the DSO and BRP[3].. We will first discuss the test setup, the IT infrastructure setup, and then the test cases.

4.2.1 Test setup

The buildings of the pilots were considered to form one cluster of buildings, which together participated with a single DCM to achieve the goals of UC1. In particular, the flexibility in the buildings was used to remedy local problems faced by the DSO. This was achieved in an interactive and iterative way in the following manner.

- After having created the building's dynamic thermal model, it determines and sends the baseline and flexibility to the DCM.
- DCM aggregates this information and sends the same to the DSO.
- The DSO does the calculation for power flows and then sends the flex request to the DCM.
- This request is disaggregated between the various building participants.

Four buildings were considered for the test :

- Premise 1.2-East
- Premise 1.2-West
- Premise 2.1
- Premise 2.3

The NODA API allows for the following interactions with the buildings' hardware:

- Querying the current/historical states and information from the buildings
- Making the appropriate settings such that the building follows the required power profile.

---

[3] The main focus has been on integration with the DSO.

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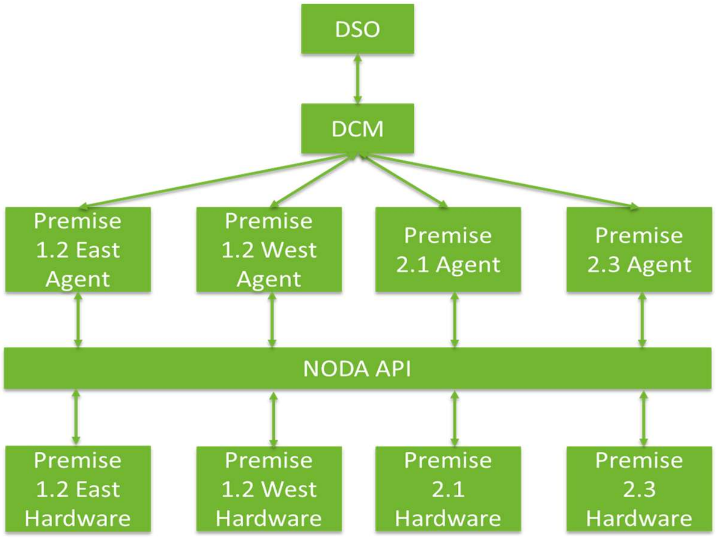

Figure 14 — Schematic of integrated setup.

The baseline determination (optimal planning) and flex characterization of each building happens in day-ahead mode with time horizons of 24 or 36 hours (in steps of 15 minutes). This per-building information is then aggregated by the DCM and communicated to the DSO to enable a grid check and if needed Optimal Flex Dispatch request (within the available flexibility that was communicated).

If there is a flex request, the DCM interacts with the buildings through the ADMM mechanism to disaggregate the request over all buildings. The main outcome of the disaggregation process is a power profile that needs to be followed by each of the buildings. Once the power profiles are decided, these are sent to the NODA EnergyView platform that generates from this the appropriate control signals for the buildings.

The entire process described above is then repeated in a rolling horizon fashion. That is, after a 90-minute interval (6 quarters), the internal states of all the buildings are queried again, and a fresh planning is done, reflective of the new states. Therefore, the resulting power profiles that are sent to NODA are for the next period of 90 minutes, until the next planning is done. [4]

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[4] For compatibility with the NODA EnergyView platform, this 90 minutes profile is not sent at once by the DCM – which conceptually is the preferred solution, but instead is chopped the DCM sends every minute the profile for the next minute.

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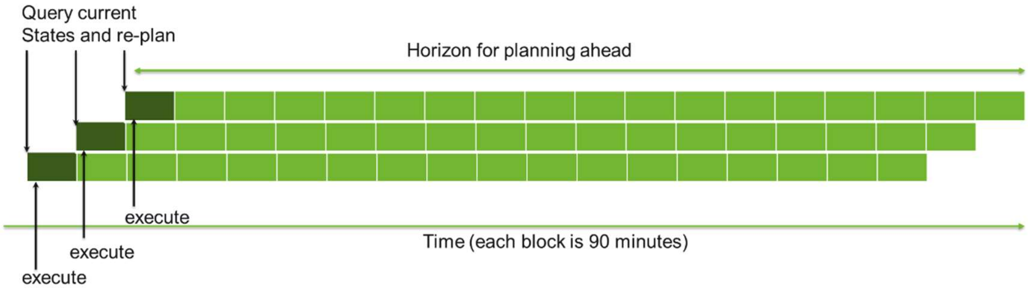

Figure 15 — Sequence of actions

4.2.2 IT infrastructure

The IT setup applied in the Karlshamn demonstrator is shown in Figure 18. Four virtual servers were used to deploy the solution in a development and production environment:

1. Windows Server 2016 (blue server Figure 18)
    - Deployed in the VITO internal network
    - Hosts a flask web service which exposes the Shaper functionalities to train the building models
2. Windows Server 2016 (red server Figure 18)
    - Deployed in the VITO dmz and accessible for external networks
    - Hosts a flask web service able to send and receive all messages related to the DCM
3. Linux server puppet/Capistrano Development (orange server Figure 18)
    - Deployed in the VITO network
    - Hosts the Django web services which expose the planner, tracker, forecaster and DSO functionalities to the DCM
4. Linux server puppet/Capistrano Production (green server Figure 18)
5. Deployed in the VITO network
6. Hosts the Django web services which expose the planner, tracker, forecaster and DSO functionalities to the DCM

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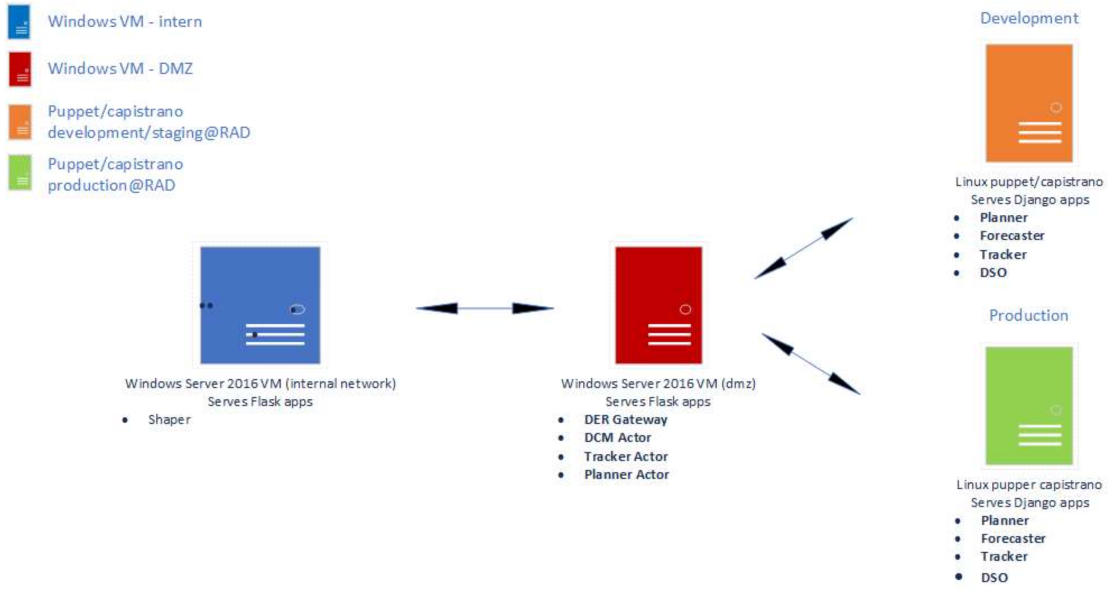

Figure 16 — IT setup for the Karlshamn pilot

4.2.3 Field tests

Following table summarises selected end-to-end tests that were conducted.

ID	Premise	Start	End
No_Flex	2.1,2.3,1.2 east,1.2 west	18-02-2019	23-02-2019
Flex_1	2.1,2.3,1.2 east	13-03-2019	15-03-2019
Flex_2	2.1,2.3,1.2 east	18-03-2019	19-03-2019
Flex_3	2.1,2.3,1.2 east	26-03-2019	30-03-2019

It is to be noted that before executing the tests with the cluster of buildings, end-to-end connection tests were first performed with individual buildings (as and when they became available for testing).

As the name suggests, in the first test No_Flex, DSO accepted the baseline consumption of the cluster as is, and no flexibility requests were made. In the tests there after, some flexibility requests were made. The detailed results from each of the tests are presented below.

In the first test, the DSO accepts the baseline as is. In the further tests, the DSO sent a flex request to the DCM. The quantities of interest are

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- the requested power consumption profile for the HP applied to each of the buildings
- the actual power consumption profile of the HP for each of the buildings
- and the corresponding totals (for the aggregated cluster performance): total requested HP power consumption profile, total actual HP power consumption profile

We calculate the following performance indicators for the different pairs of signals:

- the correlation coefficient (where 1 means perfect linear dependence, -1 is negative linear dependence, and 0 means no correlation),
- the p-value for a statistical test independence where the null hypothesis is that the quantities of interest are probabilistically independent of one another. With a low p-value (< 0.05), the null hypothesis can be rejected (with 95% significance), and otherwise not.
- the sMape calculated as $\frac{2(y-x)}{x+y}$

These quantitative results are summarized in D4.5.

4.3 Stress test

Class	Stress Test (D4.1 Section 4.2.3.1)
Date	2019-02-25 09:00-15:00 (UTC)
Premises	P2.1, P2.2, P2.3

The three premises 2.1, 2.2 and 2.3 were subjected to a square pulse of negative offset (charge) for two hours followed by a square pulse of positive offset (discharge) for two hours. There were some technical issues with the communication (09:00-10:00 UTC) delaying the onset of the first part of the test, as well as some technical issues with premise 2.3 (10:00-11:00 UTC) corrupting the first part of the test for premise 2.3. However, taking this into account when analysing the resulting measurements, the test confirms that although the buildings respond to control signals, the response mostly lacks determinism and limits the extent to which profile following services (like balancing) can be offered. The key reason for this is that had to do with the heatpumps that were available, and their limited flex capabilities. As was demonstrated in T2.4 (Grid Flex HP design) though, with a properly selected HP (brand/model) and a direct control strategy, very accurate profile following behaviour can be obtained.

The delays between control action and response falls within what can be expected from communication delays within the system, which in turn derives from the choice

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of communication hardware/software, and not the method of control by temperature offset.

The three buildings have different heating system,

1. premise 2.1 has an on/off heat pump.
2. Premise 2.2 has an air-to-water heat pump retrofitted on the previous heating system.
3. Premise 2.3 has a frequency-controlled heat pump supplying two secondary circuits, one with radiators and one with floor heating.

Moreover, the heating systems also supply heat to DHW. Taken together, this makes it difficult to come up with a definitive measure that captures the observed impact on the HP power consumption. However, partitioning the data according to the absence/presence of a temperature offset, and performing linear regression on the two parts with respect to the power (P) as a function of the outdoor temperature (T_0) and the temperature offset (T_1), $P = P_0 + P_1 \times (T_0 + T_1)$, we can compare P_1 ($T_1 = 0$) and P_1 ($T_1 \neq 0$). The quotients P_1 ($T_1 \neq 0$) / P_1 ($T_1 = 0$) then provide a measure on how well we are able to impact the power consumption.

As can be read from the table below, P2.1 and P2.2 responded well to the control signal with P_1 ($T_1 = 0$) = -0.227 and P_1 ($T_1 \neq 0$) = 0.002. The figures for P2.1 and P2.2 indicate that the buildings respond well to the control signals but for the need to exaggerate the control signal somewhat.

Premise	P_1 ($T_1 \neq 0$) / P_1 ($T_1 = 0$)	Comments
P2.1	0.556	OK
P2.2	0.685	OK
P2.3	-0.013	

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5 Learnings

5.1 Identification and commitment of pilot sites

Participants for the Karlshamn pilot are recruited among existing Karlshamn Energi AB, hereafter KEAB, customers. With these customers KEAB already has an existing agreement in place about being allowed to read out the metering data from the electrical meters. With regard to this, the participants have signed the *Flexible Heat and Power, Information Sheet and Consent Form*. This agreement is high level and basically states that the privacy and data protection laws need to be followed. It’s also stated that participation is voluntary, and that participants have the right to withdraw at any time without prejudice and without providing a reason.

The industrial premises 1.1-1.3 were included early on in the project, April 2017.

The identification and commitment of residential premises took longer time than expected, since the combination of a larger building with a heat pump system was hard to find in Karlshamn. A comprehensive sounding with the Geological Survey of Sweden’s Energy wells archive and a lot of effort with contacting all major building owners in March 2018 resulted in some suitable premises. One building owner lately withdraw from the project but was replaced by a reserve building (premise 2.1) with similar heating system, hence the later agreement for participation month.

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Table 5, Commitment of pilot sites

Site 1: Industrial premises	Agreed on participation and signed off (year-month)
Premise 1.1	2017-04
Premise 1.2	2017-04
Premise 1.3	2017-04
Site 2: Residential Premises	
Premise 2.1	2018-01
Premise 2.2	2018-10
Premise 2.3	2018-03
Site 3: Supermarket	
Premise 3	2017-03

After an extended audit in the autumn of 2017 by KEAB, NODA and RISE at the Supermarket the conclusion of leaving Premise 3 out from further testing was made. The heating and energy system were too complex for integration together with a high economical risk for dealing with freezers for food, the decision was just to keep Premise 3 for data collection.

5.2 Installations, verification and validation of installed equipment

The HP-systems used in the premises in the Karlshamn pilot show both similarities and differences to the district heating substations that NODA normally works with.

The similarities are e.g. that both systems use outdoor temperature readings to control space heating. Also, most of the HP-systems in the pilot are hydronic, i.e. they use water to transfer heat to radiator systems. These circumstances enabled NODA to use existing equipment and processes to perform audits and installations.

Differences (to district heating systems) encountered at the pilot premises and that required actions outside the normal installation process included:

- HP-systems did not have electricity meters that could be accessed. Therefore, NODA had to install electricity meters in order for the project to be able to collect data on electricity use.

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- Two premises had complex heating systems with several heat sources besides the heat pump, e.g. boilers and electric immersion heaters. In these cases, additional work and expertise were required to find out how the heating system actually operated. Even with the use of collected data and expertise (e.g. discussions with the property owner) this evaluation was complicated.
- One premise uses an air-to-air heat pump. This is not a hydronic system and NODA lack prior experience in controlling such equipment.
- Often HPs are used to produce both space heating and hot tap water. In district heating systems, this is often solved with two different heat exchangers – one for space heating and one for tap water. The current implementation of the FHP-system required data that enabled the system to estimate the amount of energy going to space heating specifically, i.e. extracting the energy used for tap water. To achieve this, a deeper analysis of the set-up and functionality of some of the heating systems were required, as well as installation of additional pipe sensors in some cases.
- Two different types of HP:s were encountered in the pilot premises:
    - On/off: The compressor in the HP is either on and operating at a constant speed, or off.
    - Frequency controlled: The compressor can operate with variable frequency, i.e. at different speeds.

  The on/off HP is more complicated to control using NODAs sensor override technology. This since the impact of the control signal is not determined by the amplitude of power use of the HP, but rather on the frequency of HP start and stops.

- In general, a large effort was put into the following activities throughout the installation and test phases of the project:
    - Understanding the set-up of the heating systems, including dialogues with building owners and external experts.
    - Understanding the dynamics of the heating systems once installations had been performed and data was being collected and monitored. This involved several discussions and investigations within the project.

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5.3 Integration tests of the FHP-solution

This section summarizes practical learnings related to the tests conducted in order to validate the FHP solution. The actual validation tests are described in sections 4.

5.3.1 Learnings from VITO integrations tests

One of the goals of the pilot testing was "Data-driven Building Thermal Characterization "with as no/limited intervention from experts (and applicable across buildings). With the exercise on pilots, we learn that existing infrastructures are far from ideal, to achieve expert free training of building models. But in the process, we have learnt what we need and are able to come up with a checklist, with the help of which we can further progress towards making the training expert free. As the name suggests, for data-driven modelling, we need the right data.

This can go as follows:

- How many indoor temperature sensors do we have?
- Do we have direct heat meters for space heating?
- if not, is the heat pump used for space and hot water heating?
- If yes, does it do simultaneous heating, or mutually exclusive (if simultaneous heating, is there a corresponding meter for hot water tapped, if mutually exclusive, is there a way to tell when the heat pump is active for space heating)?
- Do we have sensors for the supply, return and mass flow rates (placed in the right place, is the supply return from space heating exclusively, does it have mixing from DHW etc)?
- If not do we have the meter readings for electricity, being consumed only by the heat pump?
- Are there any extra heating installations (oil boilers, electric room heaters)?
- How long has the building been commissioned, how much historical data is available.
- How easy or difficult is it to install new sensors

One can then design a flow chart, to pick the right type of data processing/collection. For new buildings, this also means, we know what the preferred sensor specification would be.

With respect to the flexible control of heatpumps to offer higher value services that require – close to – profile following capabilities, i.e. with a deterministic behaviour with respect to the given control signal, the learning is mixed. From T2.4 (Grid Flex HP design) it was clear already that the extent to which deterministic behaviour can be achieved, depends very much on the HP brand and model. Even though they all obey the same laws of mechanics and thermodynamics, the internal HP controllers are very different, and a decisive factor for their 'fitness-for-flexibility'. And these controllers were not designed with the goal to offer flexibility, other than coarse granular control, where very deterministic behaviour is less of a concern. The

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capabilities provided through the SG Ready interface is an example of this. As in the pilots we had to live with the HP that were available, the obtainable accuracy with respect to profile tracking were limited by the characteristics and capabilities of the HP at hand. Moreover we had to restrict ourselves to a indirect control strategy, although we know from T2.4 that with a direct control strategy approach (i.e. Grid Flex HP concept), far better results can be achieved. For such an indirect control strategy, a HP signature model must be created (learned from measurements) that can be used to create a control signal profile (i.e. sensor override profile) for a given desired power consumption profile. This proved very challenging (given further evidence that the direct control strategy is by far the most promising approach), mostly because of the quality of the measurement (training) data. E.g. factors that impact the quality of this data, is the clear separation between ‘running for space heating’ versus ‘running for DHW’, and the ‘hidden’ internal controller that obfuscates relevant correlation between measurements.

With respect to the deployment of the Multi-agent system, connecting flex providers (e.g. buildings, via the NODA EnergyView platform) via the DCM to flex needers (e.g. DSO, BRP) was positive. The end-to-end integration went smoothly, though doing the actual integration revealed some minor issues related to interpretation/implementation of defined APIs, and assumed functionalities of the NODA EnergyView platform (e.g. capability to receive a profile i.e. plan versus a control). This required – all by all relatively minor – adaptations of some of the components during the pilot integration testing phase.

As part of the pilot testing, also the integration of other party functionalities through the defined webservices approach has been validated. Specifically, the VITO Shaper webservice was replaced by the TEC Shaper webservice, incl. re-moting it to a TEC server. Apart from some minor issues related to firewalls and access rights, this was evaluated positively, and shows that given the defined webservice APi spec, (Shaper) functionalities could be developed by 3rd parties.

5.3.2 Learnings from TECNALIA integration tests

The implantation and deployment of black-box model relies strongly in the quality of the available data. In this context prior to start modelling activity the deployment scenario, pilot, has to be understood so rational assumptions can be done. This preliminary step in the FHP project went smoothly, mainly due to the well knowledge of the pilot that have been show by the FHP member in charge of the pilot deployment activities. Misunderstanding or miscommunication would jeopardize the overall modelling task.

The integration of the Shaper with the rest of the FHP platform was designed by means of HTTP-Rest based JSON messages. In this context the adoption of

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asynchronous paradigm performed very well allowing to implement almost real time web services and time-consuming web-services seamlessly. The selection of the asynchronous paradigm prevents the timeout events in cases in which the training/forecasting/optimization process would take long. **The approach has shown that the inclusion of new shapers in the FHP platform can be easily and without painful customization and tweaking efforts.**

Last but not least the usage of UML diagrams to exchange implementation details among partners did the communication among development teams smooth and effective.

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