Pilot test and large scale pilot simulation and impact assessment report

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Executive Summary

As the delivery date of this deliverable wrongly preceded the beginning of the pilot phase of the SEMIAH pilot, this document was submitted twice. The first time it included the results of the pre-pilot in both Norway and Switzerland, performed on 12 and respectively 10 households.

For this second submission, the pre-pilot part was nearly kept as it was, and installation and results of the full pilot involving close to 200 households were added to this document that encompasses both phases i.e. pre-pilot and full pilot.

This D7.2 report presents the whole installation of the pilot in both Norway and Switzerland. It also presents the hardware used and how it was installed inside the households. It presents finally the results achieved during the pre-pilot and pilot phases. The pilot phase showed that it is possible to install hardware to control and measure heating appliances. Also, it showed the potential of theses appliances and the offered flexibility due to their thermal inertia, as well as the simpler interaction involved by the solution with the end-user. It shows also the potential of the ICT solution deployed and the possibility of using the internet connection of the end-user. Indeed, the Front-end server has been online since the beginning of the pre-pilot and is still fully operational and collecting data more than a year and a half later. SEMIAH pilot phase paved thus the way to a DSM solution that would be reliable, flexible, and feasible. Finally, even if SEMIAH pilot was not a complete success, it showed the possibilities of the foreseen solution and demonstrated the good operation of most of the SEMIAH components.

Abbreviations

D	Deliverable
DR	Demand Response
DSM	Demand Side Management
DSO	Distributed System Operator
EC	European Commission
EDM	Exploitation and Dissemination Manager
GPRS	General Packet Radio Service
HAN	Home Area Network
ICT	Information and Communication Technology
OGEMA	Open Gateway Energy Management Alliance
PM	Person Month
T	Task
VPN	Virtual Private Network
WP	Work Package

Contents

List of Figures

List of Tables

1 Introduction

This report describes the activity carried out by the pilot partners (Develco, Adger Energi, EnAlpin, SEIC Teledis, Netplus, and HES-SO) as a work for the WP7 of the SEMIAH project. This work describes the installation and the running of the pilot phase that is done from winter 2016 to spring 2017. However, to already cope with the field problems that can arise when performing real installation with real households and real inhabitants, tests were already started one year in advance to already solve most of the problems and to insure a smooth running of the pilot phase of 200 households. This preliminary work was not planned in the DOW, but showed to be hugely interesting for understanding how real households can be connected.

The vision of the pilot changed a lot since the writing of the proposal and the final version of the DOW. At that time, the aim was to control white appliances with a local interface offered to inhabitants to put their smart-appliances in DSM mode. However, experience of the DSO concerning their clients and the low financial and personal interest for the end-user change our mind to focus on the problem to controlling heating appliances for both room heating and water boiling. They seemed to offer a greater flexibility and would make the shifting of their consumption unnoticeable for the households' inhabitants due to their thermal inertia. As a result, the front-end interface to control the white appliances was proven as useless, and planning in material and installations was greatly changed.

During this preliminary phase, a lot of tests were performed to see how demand side management could be implemented in the field, both in Norway and Switzerland. The Norwegian households are using a lot of electricity for both heating and water boiling. However, the way the electrical wiring is done (no separation between wiring for heating and wiring for other application such as light) making the control of the heating difficult to handle. Buildings have often direct electrical floor heating systems that are hard wired in the walls and floors and make the interfacing of a smart relay to control the heating extremely costly. On the other hand, boilers are easy to interface as they use only one phase and smart plugs can be used to control them. In Switzerland, a ripple control system is installed in all households using electrical appliance for heating, water boiling, or washing (washing machines and tumble driers). As a result, interfacing heating appliances appears to be easier to perform, even if the variety of existing controllers makes the control of these appliances difficult to handle.

This report presents the pre-pilot of 10 households in Switzerland and 12 households in Norway as well as the installation and the results of the large-scale deployment of almost 200 households in two countries.

1.1 Purpose / Objectives

The deliverable D7.2 presents the pilot installation, impact assessments and results. The installation aims to monitor several types of data and send them into a distant database. A pre-pilot was initiated, with a reduced number of household to ensure that all DR material satisfactory work before rolling out the main SEMIAH pilot. Furthermore, data is needed to be stored in a database to ensure that the controller can access these data to then influence the devices in the households. Therefore, during the pre-pilot, the bi-directional communication was tested.

1.2 Description of the pilot

The pilot installed in Valais/Wallis, Switzerland was planned for 100 households. The distribution of the households covers the two Swiss electricity providers, which are the members of consortium. The Figure 1 represents the geographical distribution of the households (EnAlpin in green, SEIC-Teledis in red). Most of the installations use a heat-pump for heating and the others use electrical heating systems. The temperature is measured both inside and outside the buildings, when space heating is involved. The householders of the Swiss pilot are all clients of EnAlpin or SEIC-Teledis. These clients are volunteers and were found through communication around the SEMIAH project.

HES-SO developed multiple software components for running the pilot and to retrieve monitoring data, including ZigBee library, network communication and database management. This software allows security and reliability of the data sent through Internet to a Netplus server where they are stored in a database.

To ensure the deployment of the pilot, a pre-pilot was implemented with 10 households with only employees of SEMIAH partners (from HES-SO, EnAlpin or SEIC-Teledis) during the cold season 2015-2016. This authorises tests and quick feedback when drawbacks arise.

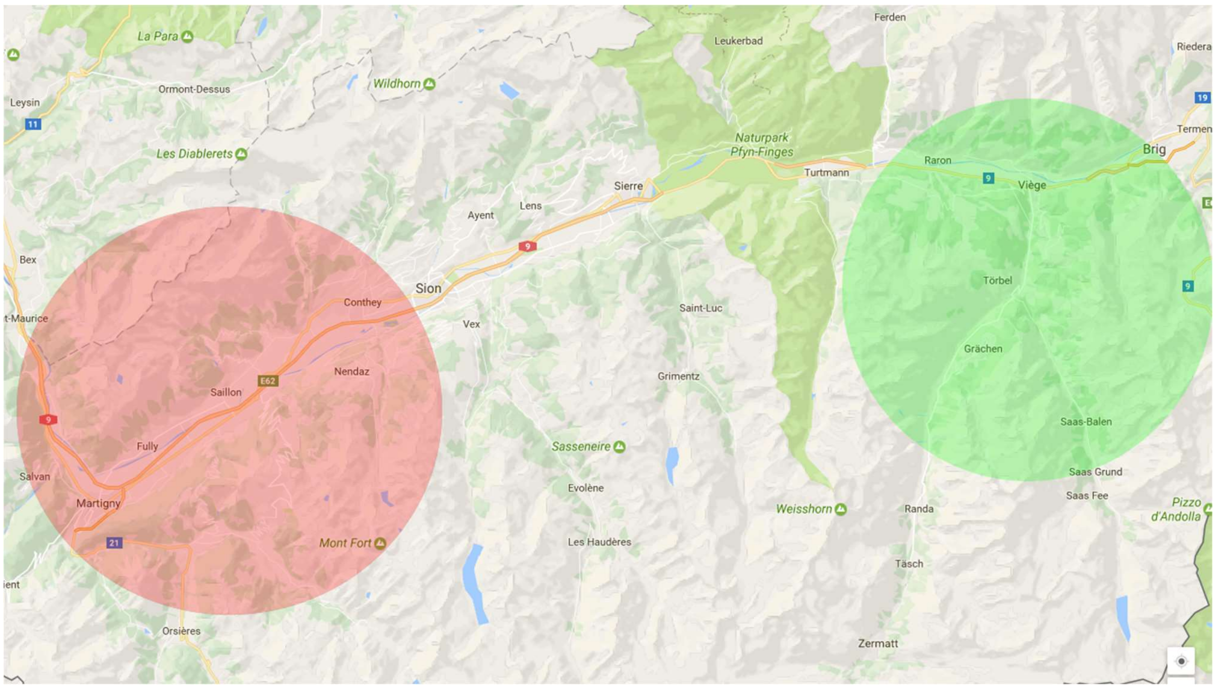


Figure 1: Distribution of the Swiss pilot households

The pilot in Aust-Agder and Vest-Agder County, Norway consisted of 100 households, which were distributed around the region as show in Figure 2.

All the householders in the Norwegian pilot are clients of Agder Energi Nett and uses electricity for both water heating and room heating. Two recruitment processes were done to ensure 100 pilot customers, where 50 customers were recruited in late June 2016 and additional 50 were recruited in late August 2016. The software used in Norway is the same as in Switzerland, the only difference is that the Norwegian pilot used mainly GPRS-communication.

Furthermore, a pre-pilot was also done in Norway, where 12 households with only employees from Agder Energi Nett were used. Feedback from the pre-pilot gave valuable data to regarding challenges with the customer solution.

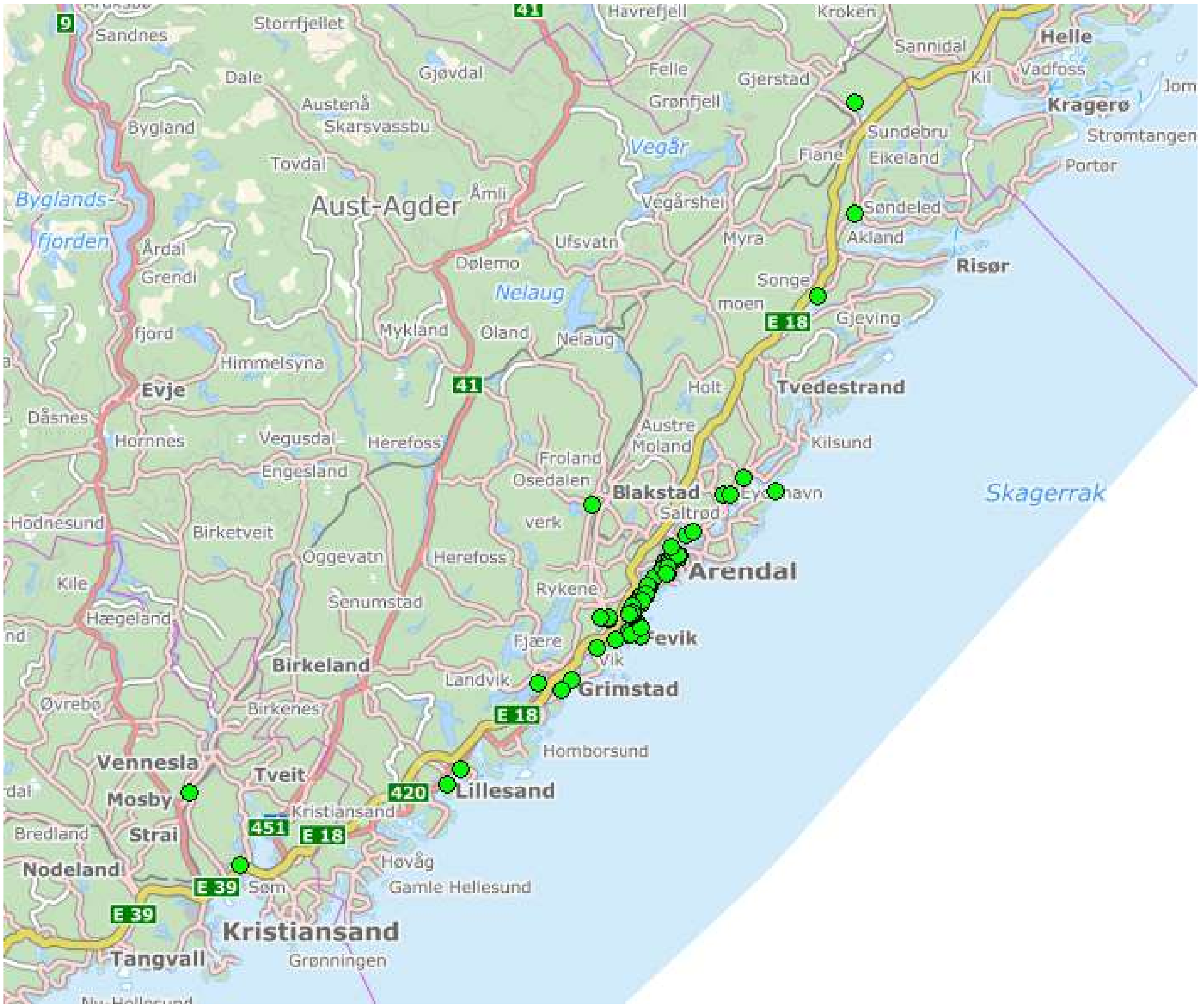


Figure 2 - Distribution of Norwegian pilot households

2 Detail of Develco hardware

For the pre-pilot and for the full pilot, Develco Products provides devices to create a Home Area Network. This network allows monitoring and communication of the data throughout the household.

These devices were installed in all households at different points depending on their functionality:

- The distribution board for power measurements, photovoltaic panels' production, and the control of some appliances,
- The heat-pump or electrical heating to control the system,
- The boiler to monitor the hot water temperature.

2.1 Squid.link Gateway

The multiprotocol gateway is a modular platform for flexible Home Area Networks (HAN). With this hardware, customers will be no longer dependent on specific vendor for their connected devices.

The Squid.link Gateway is an extremely flexible solution for connecting networks based on different technologies and can be modularly extended with new developed software.

Figure 3: The squid.link gateway

2.2 Motion sensor

The motion sensor is battery powered and can detect occupancy, light & temperature. With the wireless motion sensor, customers can be able to set lights to turn on and off as you come and go. Moreover, the temperature detector can be used to trigger smart thermostats or heaters to adjust the heat as desired.

The occupancy sensor is PIR based and can sense movement up to 6 meters from where the sensor is placed. The sensor includes two logical outputs - one for occupancy with high sensitivity and one for alarm with a lower sensitivity.

The wireless protocol is ZigBee, meaning that the motion sensor can be integrated with other ZigBee based systems for smart home, energy control, healthcare, or home security. The ZigBee Home Automation motion sensor is configured as an end-device.

In the SEMIAH project, the motion sensor is mainly used to monitor temperatures.

2.3 Smart relay DIN 16A

The relay consists of a DIN rail unit with built-in relay and it communicates with a ZigBee gateway. With this relay, user capable of configuring his home appliances in clusters and hence control a whole group of units instead of controlling each device separately.

DIN relay also includes built-in power meter functionality, which enables the user to monitor the power consumption of each group of appliances in the house, resulting in sharpened awareness of power waste and energy optimization. All data loggings are transmitted to a data concentrator

Figure 4: Smart relay DIN 16A

A modified version of the smart relay DIN 16A was realised by Develco especially for the SEMIAH project. This new smart relay allows control of heat-pump regardless of the voltage needed, as many heat-pump controls are not based on 230V.

2.4 External meter interface

This external meter interface serves as a ZigBee interface for electronic meter in households. The meter interface will collect readings and information from existing meters, and send data via the ZigBee communication to appliances in the building. To be as flexible as possible, the external meter interface works with various kinds of meters, such as power, water, gas or heating.

Figure 5: The external meter interface plugged in an installed meter

2.5 Prosumer meter

The Prosumer Meter from the Develco Products simply allows to monitor energy production combined with consumption in a real-time manner.

The Prosumer Meter is a triple three phase meter. It measures production and consumption of power on all three levels: the solar cell module itself, the total household, and the collected grid. This allows the user to get a live feed of how much electricity is produced by the solar module and compare it to the total consumption of the household as well as to the grid activity in general.

Logging the power consumption in all directions in 5-minute intervals enables to monitor the long-term patterns and deliverance of power consumption in all three different dimensions.

The meter also offers the flexibility of using it as two three phase meters for separate groups in a building. The Prosumer Meter can set up notifications regarding energy, power, voltage, and current per phase or in total. All data are sent via ZigBee to a gateway.

The Prosumer Meter is mounted directly on a DIN rail, with the size of 4 standard DIN modules.

Figure 6: The prosumer meter

2.6 **Smart plug**

The wireless smart plug with power metering feature is an intelligent remotely controlled adapter. This smart plug can be applied wherever a plug is already present and then monitor the plug-in device. The wall plug is based on ZigBee and can easily be integrated with other ZigBee products or smart control solutions.

In the case of SEMIAH, the smart plugs are mainly used as a repeater to transmit the data from a device to the gateway and to control Norwegian boilers.

Figure 7: The smart plug

3 Pre-pilot installations

This chapter presents the results of the pre-pilot phase that was implemented during the cold season of 2015-2016. The following chapter will then present the results achieved during the full pilot phase. This chapter was written in 2016, when D7.2 was first delivered. It was not completely rewritten, and thus time inconsistencies can exist.

3.1 Swiss installations

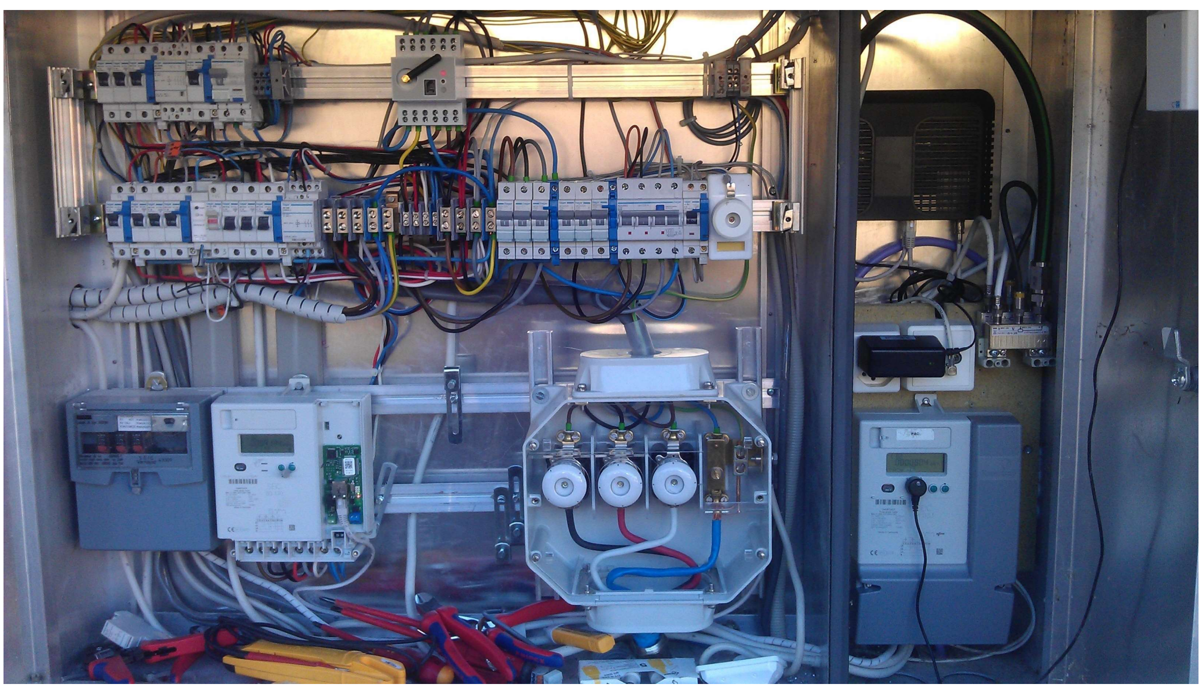
The deployment of hardware presented in the section 2 is different, depending on the installation in the households. This section presents the different installation made in the Swiss pre-pilot and details the monitored data and the possible control.

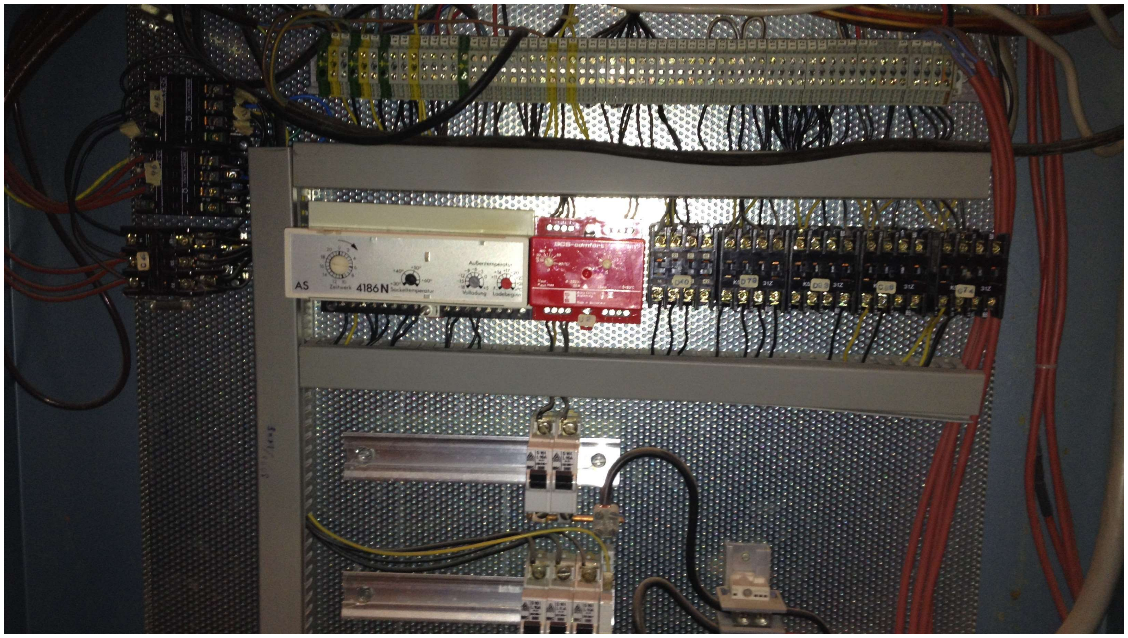
The Table 1 summarizes the type and the number of installation of the SEMIAH pre-pilot. Each of these installations has a monitoring and most of them have a control of their heating systems. The heating systems are separated into two types:

- The hot water system, which provides hot water for the households.
- The housing heating system, which can be provided by a heat-pump or an electrical heating system.

The most complicated issue to solve during the installation is the difference between each installation even with the same architecture. Each switchboard is different, depending on the installer, the year of the building, etc.

The following pictures present the variety of installations:

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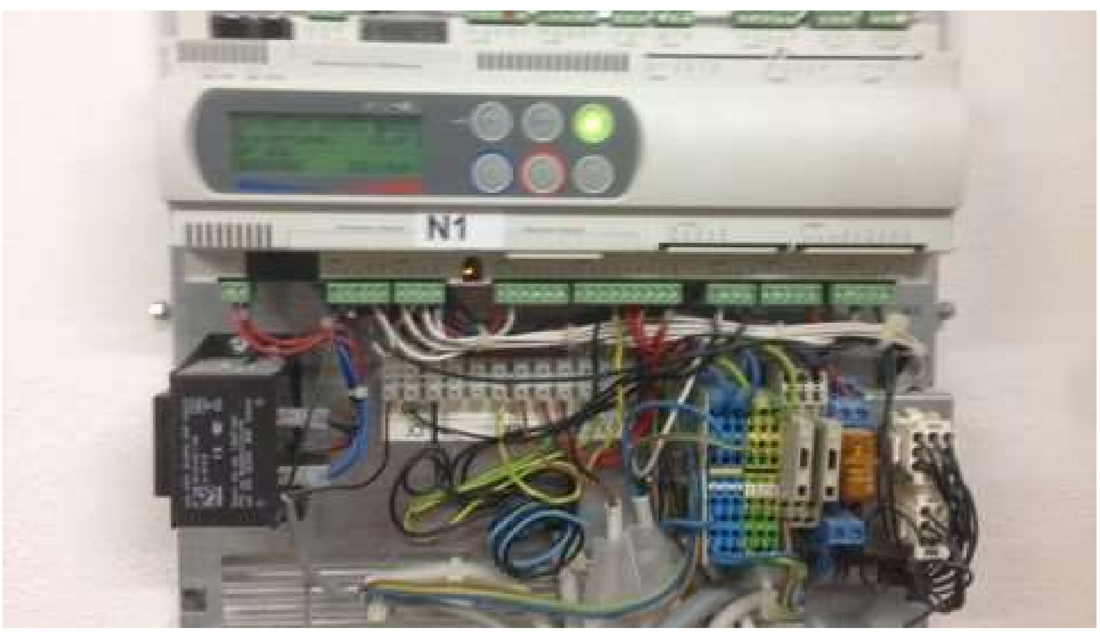
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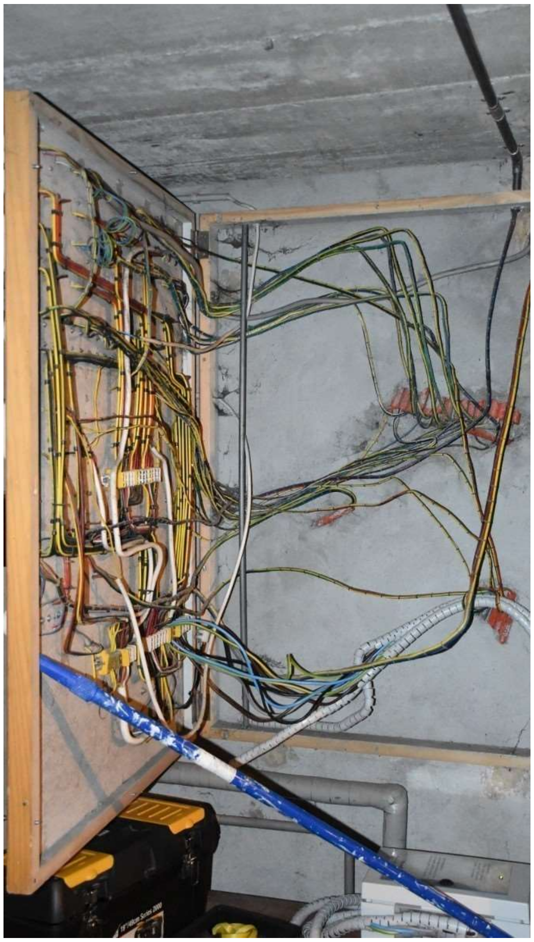
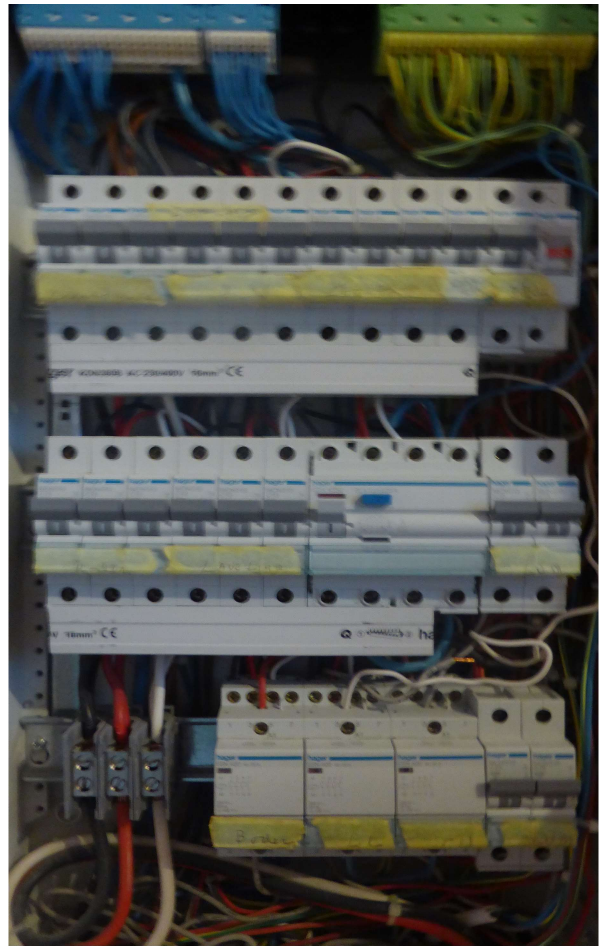
 

Table 1: List of the types of installation

Type of installations	Number of installation
PV metering and heating systems control – version 1	1
PV metering and heating systems control – version 2	1
PV and pulse metering, heating systems control	2
Pulse metering, heating systems control	3
Electrical heating and boiler control and metering	2
Heating systems monitoring	1

3.1.1 PV metering and heating systems control – version 1

In this installation, two heat pumps are present, one for the hot water and another one for the heating system. The household also owns photovoltaic panels for local production.

The modifications bring to the installation concerns the control of the homing heating systems and hot water system. The system is plugged above the ripple control, 4 smart relays (ZHDR201) are used (1 for the boiler, 3 for the central heating). The modifications also concern the monitoring of the consumption and the production of the photovoltaic panels. A prosumer meter (SMMZB-310) is added for this purpose.

Finally, two temperature meters (ZHOT101) are used, one to monitor the outside temperature and one to monitor the inside temperature.

The Figure 8 presents a simplified schema of the modifications.

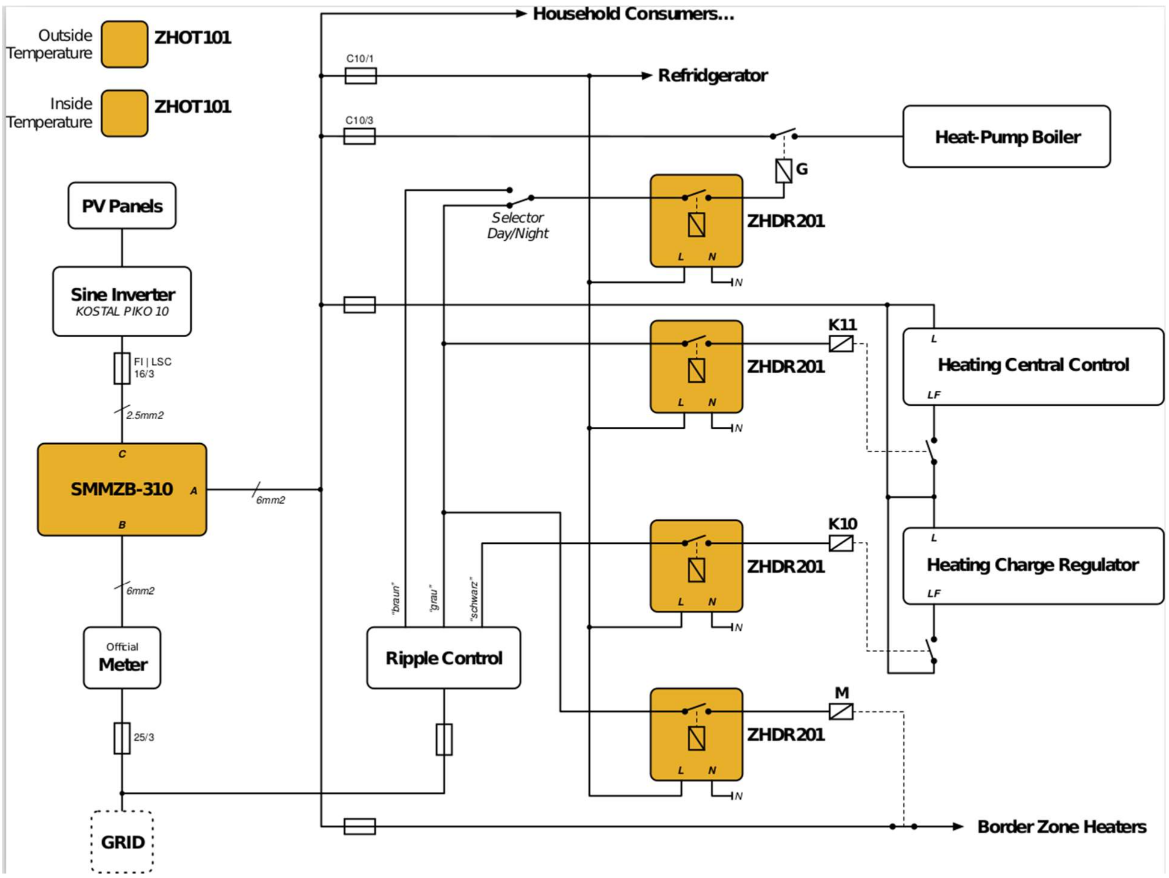


Figure 8: PV metering and heating systems control – version 1

3.1.2 PV metering and heating systems control – version 2

In this second version, the modification concerns the central heating systems.

Instead of heat-pump, the central system is an electrical system that heats water which will heat the household. Therefore, the system is also plugged above the ripple control, but 3 smart relays (ZHDR201) are needed (1 for the boiler, 2 for the central heating). The modifications to monitor the consumption and the production of the photovoltaic panels are also performed with a prosumer meter (SMMZB-310).

Finally, two temperature meters (ZHOT101) are used, one to monitor the outside temperature and one to monitor the inside temperature.

The Figure 9 presents a simplified schema of the modifications.

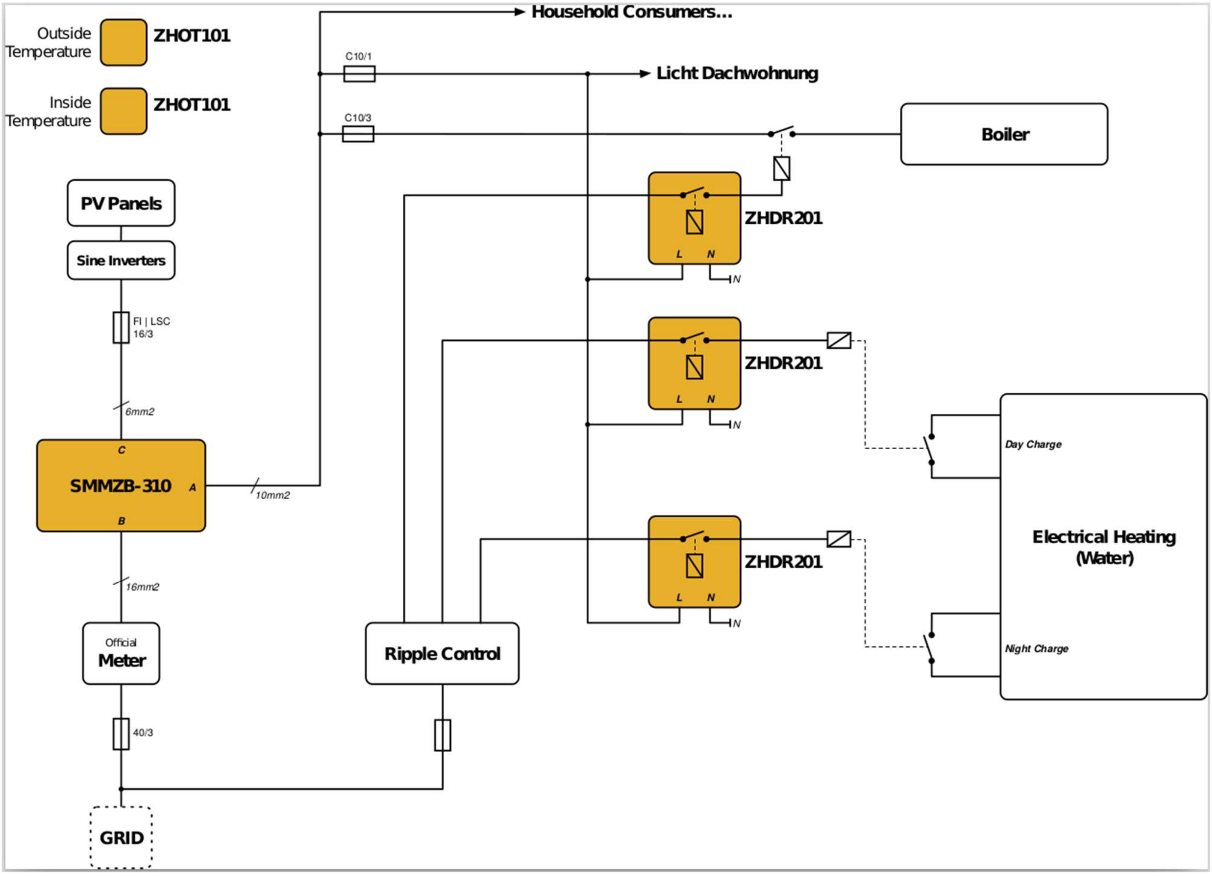


Figure 9: PV metering and heating systems control – version 2

3.1.3 PV and prosumer heating systems control

In this installation, the heat pump managed the hot water and the central heating system. This implies that the cut of the controller should take care of the two temperatures, the inside temperature and the temperature of the hot water. The system uses a modified smart relay (ZHDR201) to control the heating systems. The modifications also concern the monitoring of the consumption and the production of the photovoltaic panels. A prosumer meter (SMMZB-310) is added for this purpose.

Finally, two temperature meters (ZHOT101) are used, one to monitor the outside temperature and one to monitor the inside temperature.

The Figure 10 presents a simplified schema of the modifications.

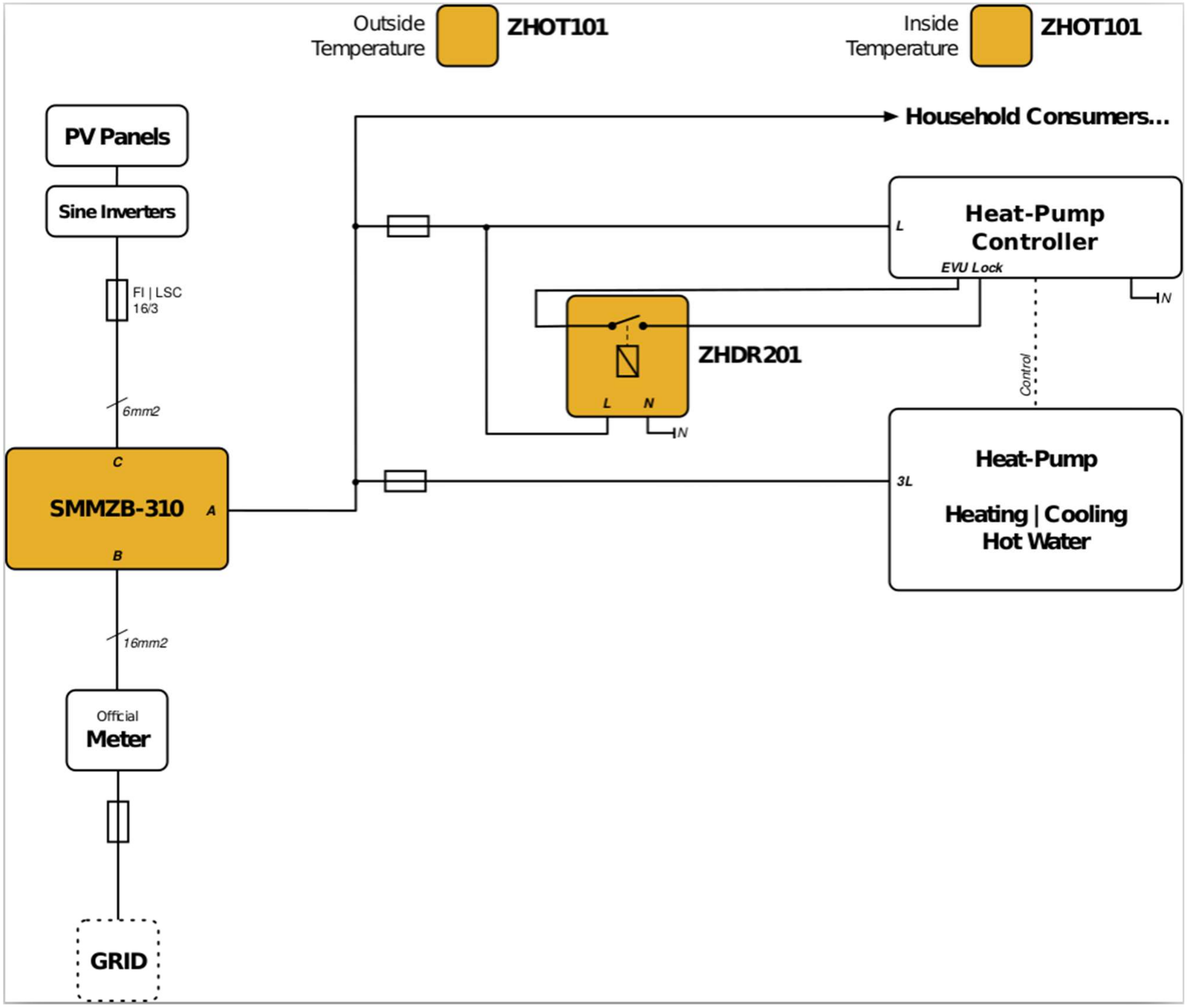


Figure 10: PV and pulse metering, heating systems control

3.1.4 Pulse metering, heating systems control

In this installation, the heat-pump managed the hot water and the central heating system. This implies that the cut of the controller should take care of the two temperatures, the inside temperature and the temperature of the hot water. The system uses a modified smart relay (ZHDR201) to control the heating systems.

Finally, two temperature meters (ZHOT101) are used, one to monitor the outside temperature and one to monitor the inside temperature.

The Figure 11 presents a simplified schema of the modifications.

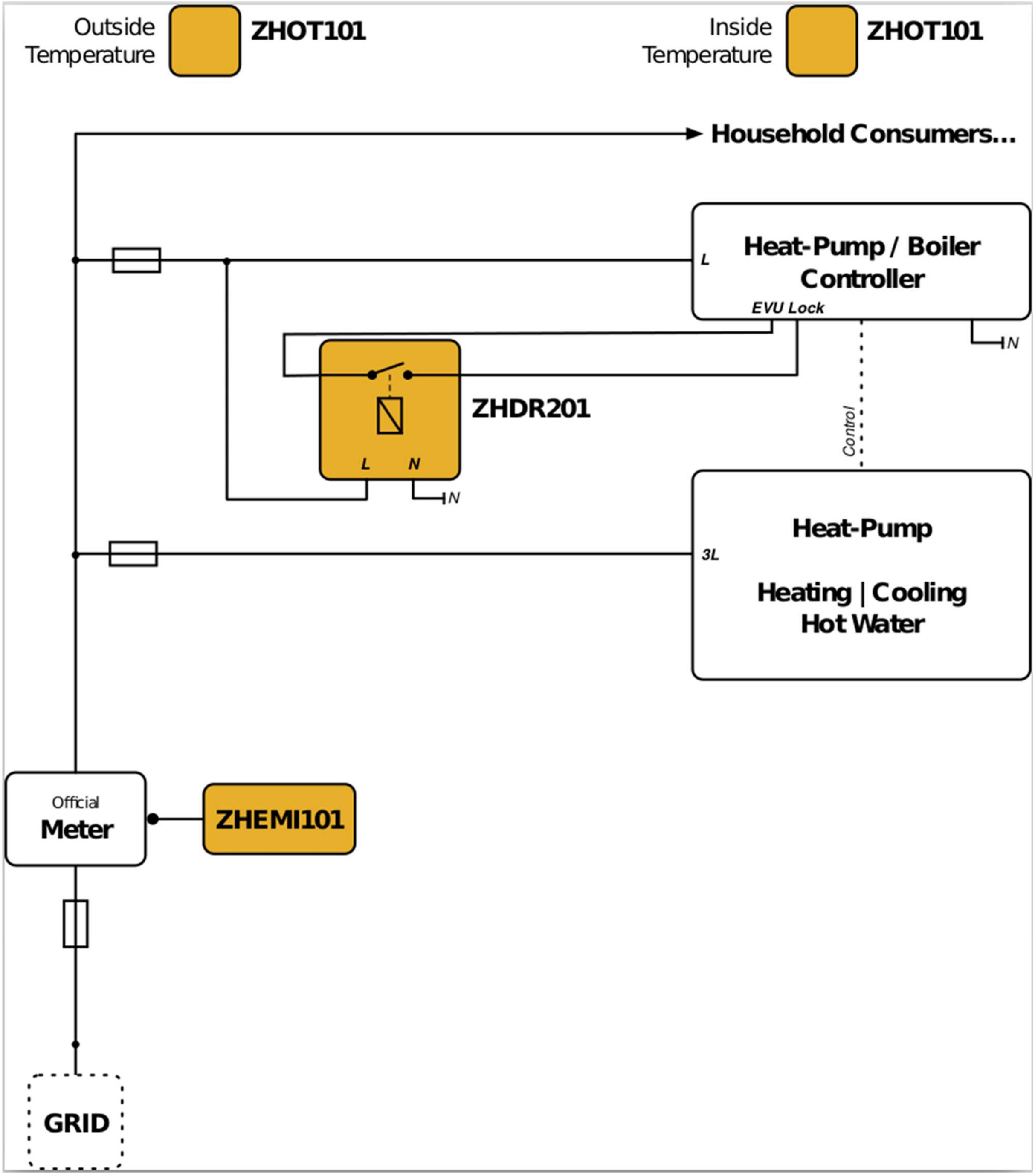


Figure 11: Pulse metering, heating systems control

3.1.5 Electrical heating and boiler control and metering

In this installation, the electrical heating system and the electrical boiler are managed by 3 smart relays (ZHDR201) each, one per phase. This allows us to monitor the consumption of heating system and boiler independently and also allows us to control of these devices.

Finally, three temperature meters (2xZHOT101 and 1xPT100) are used, one to monitor the outside temperature, one to monitor the inside temperature and one to monitor the water temperature in the boiler.

The Figure 12 presents a simplified schema of the modifications (the water temperature sensor is not represented in the schema).

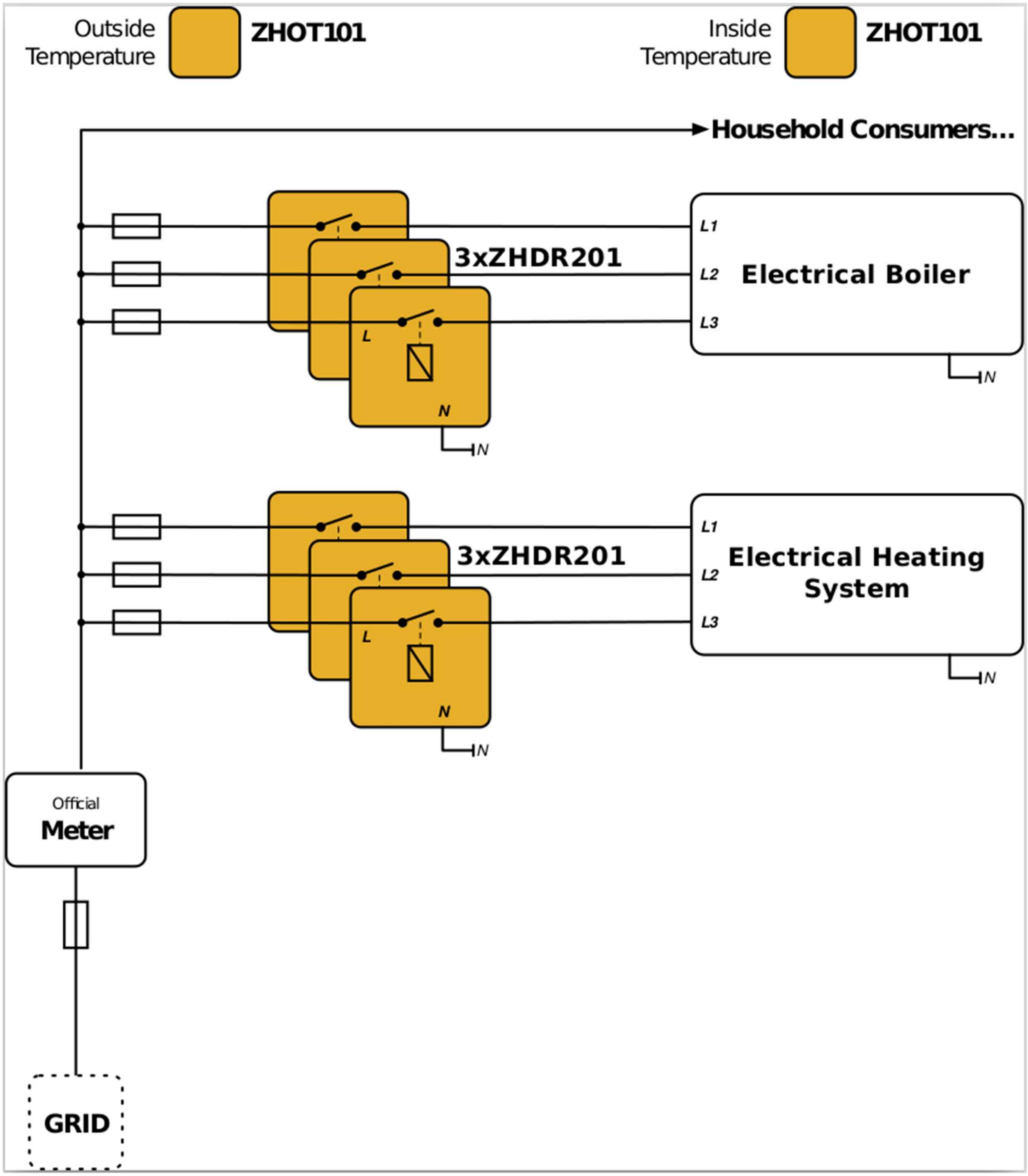


Figure 12: Electrical heating and boiler control and metering

3.1.6 Heating systems monitoring

In this installation, a prosumer meter (SMMZB-310) is present to monitor the consumption of the heat-pump which heats the boiler and the heating system.

Two temperature meters (ZHOT101) are also used, one to monitor the outside temperature and one to monitor the inside temperature.

The Figure 13 presents a simplified schema of the modifications.

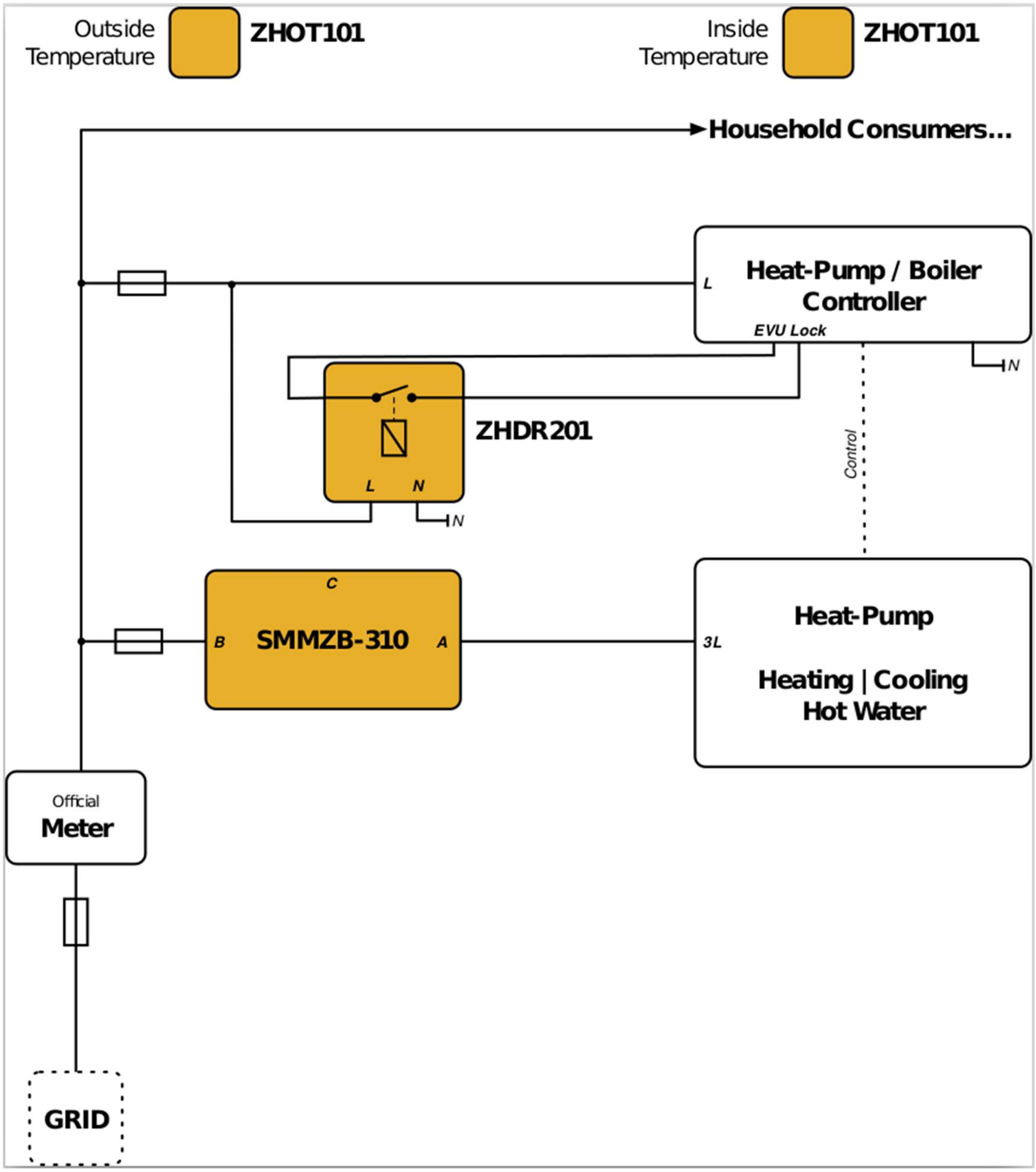


Figure 13: Heating systems monitoring

3.2 Norwegian installations

3.2.1 Pre-Pilot Location & Customer Segments

Agder Energi Nett (AEN) owns and operates the distribution system and the regional transmission system (a total of 20 900 km of lines and cables) in Aust-Agder and Vest-Agder, two counties in the southern part of Norway. The pre-pilot consists of 12 private households spread out in both counties. Nine out of ten customers are employees in Agder Energi Nett (AEN or AEnergi), one customer is employed in Devoteam. The Devoteam customer is referred to as the *Super-User*, as he has allowed a far more extensive installation than what is planned installed for the remaining pilot customers. It facilitated more testing options, and give valuable information and experience that potentially can be scaled up and used in simulations.

Figure 14 Aust-Agder and Vest-Agder county in the southern part of Norway[1].

From a risk perspective, it was considered reasonable to run the pre-pilot with internal participants. These customers are easy to communicate with, and they were assumed to have a greater understanding for "bumps along the way". Establishing a pilot of this type necessarily entails several unforeseen events, and it has been of high priority to eliminate as many of these as possible before roll-out to regular customers.

3.2.2 Architecture

3.2.2.1 Chosen hardware

One of the first challenges discovered in the early planning of the pre-pilot was *how to access the flexibility.* In Norway, it has been quite common to group the household installations per room,

1 https://www.ssb.no/befolkning/artikler-og-publikasjoner/sorlandet-fortsatt-paa-etterskudd

making it hard to control floor heating, boilers etc. from a DIN relay in the cabinet (which would have been the preferred solution). If a DIN relay is used to control the floor heating in the living room, and the group in the fuse cabinet compromise the entire room, cutting the power would cut the light and TV as well. This is naturally unacceptable. In an early phase of the project it was therefore decided that both the pre-pilot and the full-scale pilot mainly would cover boilers and electric panel heaters. These installations can in most cases be controlled by the use of smart plugs (boilers with plugs are permitted as long as the heating element is kept bellow 2kW. This is a common installation in existing households in Norway).

At a later stage in the pre-pilot, when the *super-user* was in place, additional hardware was introduced. This includes a smart thermostat for control of the bathroom floor heating, a DIN relay for monitoring of the entire bathroom group, motion sensors to detect movement and a led pulse reader for monitoring of the overall household consumption.

3.2.3 Early testing (phase 1)

AEN considered it was necessary to start the testing of the hardware as early as possible, and recruited 12 participants internally in AEN, who agreed to have the chosen hardware installed and tested in their private homes. As the SEMIAH infrastructure was not ready at that time, the hardware was installed with a software solution developed in cooperation with Develco and Develco Products. This solution comprised a simple data acquisition system. Data, in terms of power, energy and outdoor and indoor temperature, were sent from gateways to a database in Denmark every five minutes. AEN accessed the data by means of periodic backups of the database which was imported to a local database-server running on a local PC.

Phase 1 lasted from April 2014 until January/February 2016, with a longer downtime during the summer/fall 2015. The downtime was due to communication challenges (between gateway and server) and several cases of cold showers. The latter was caused by a defect in one of the smart-plugs. Develco Products assured that this was a very rare issue, and it is not considered a great risk for the remaining of the project. However, it was an event that gave a lot of learning, and showed the importance of the hardware.

As the system architecture used in the early testing is not the SEMIAH architecture, one could question the usefulness of the early testing. For AEN however, it has proved to be useful and instructive. It has brought out the challenge on how to access the flexibility, shown how the hardware "behaves" physically in Norwegian installations, and not least has it given experience on how to deal with unforeseen events related to DR. This makes it easier to prepare a good customer management system, to give the customer a good experience during the entire project period.

3.3 First results

The pre-pilot installation is already installed and running, for several households, since more than two months. Therefore, first analysis was already realised and highlight the variety of the installation.

The Figure 15 and Figure 16 show respectively the inside temperature of the households (Swiss pre-pilot) and the consumption of a heating system. In this example, the temperature increase is correlated with the power consumption. We can also see that cut of power for the heating for long duration (10+ hours) has a small influence on the temperature of the household (~1°C).

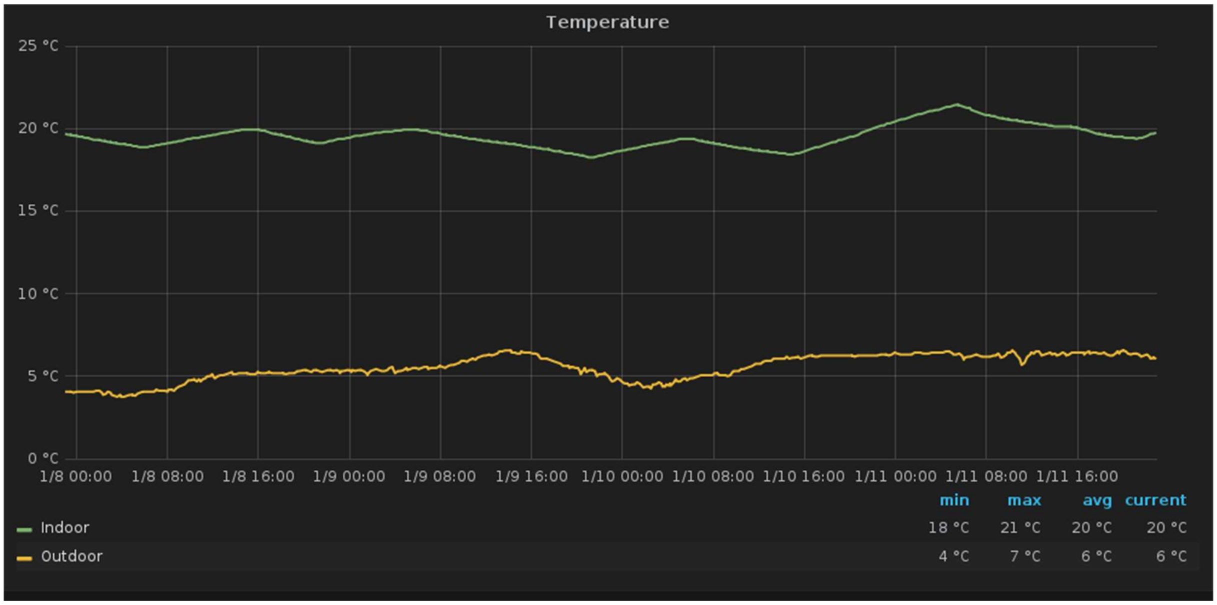


Figure 15: Temperature of the "household 01" from 08/01 to 11/01. We can observe that the outer temperature (Outdoor, yellow curve) is quite constant. Moreover, the inner temperature (Indoor temperature, green curve) is directly linked to the heating system power consumption (Figure 16). We can directly observe that when the power is on the inner temperature is increasing, and inversely.

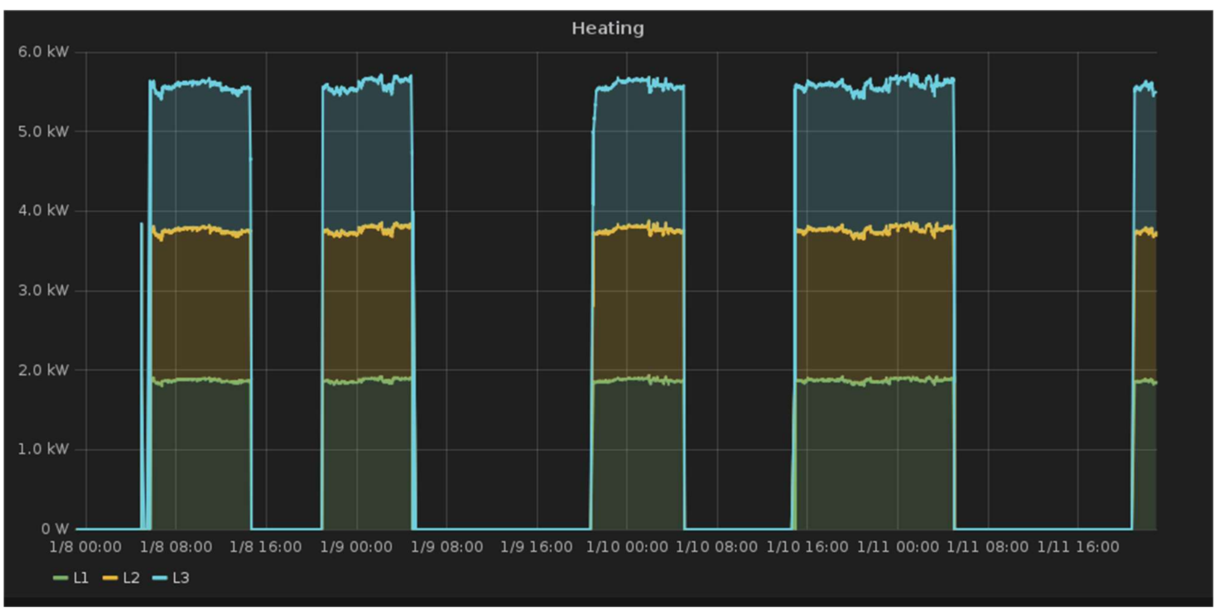


Figure 16: Heating consumption of the "household 01" from 08/01 and 11/01. This power consumption is linked to the inner temperature provided in Figure 15. The consumption of the three phases (L1 to L3) are clearly synchronized.

The Figure 17 and Figure 18 show the same information but the consumption is desynchronised from the temperature increase. This is due to the accumulation of the heat in a water tank before redistribution when needed. With such a local installation, shifting of energy consumption is easy to perform, as it is not linked anymore to the heat requirement.

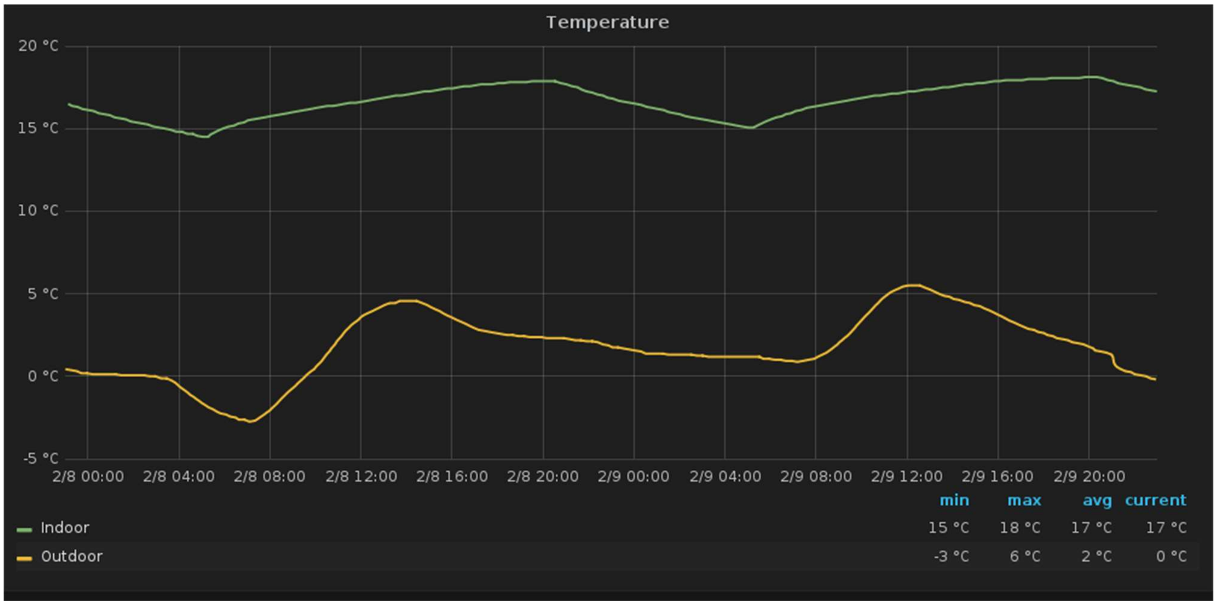


Figure 17: Temperature of the "household 08" from 08/02 to 09/02. We can observe that the inner temperature (Indoor, green curve) is not synchronized with the power consumption in Figure 18. This is due to a water tank used as heat storage.

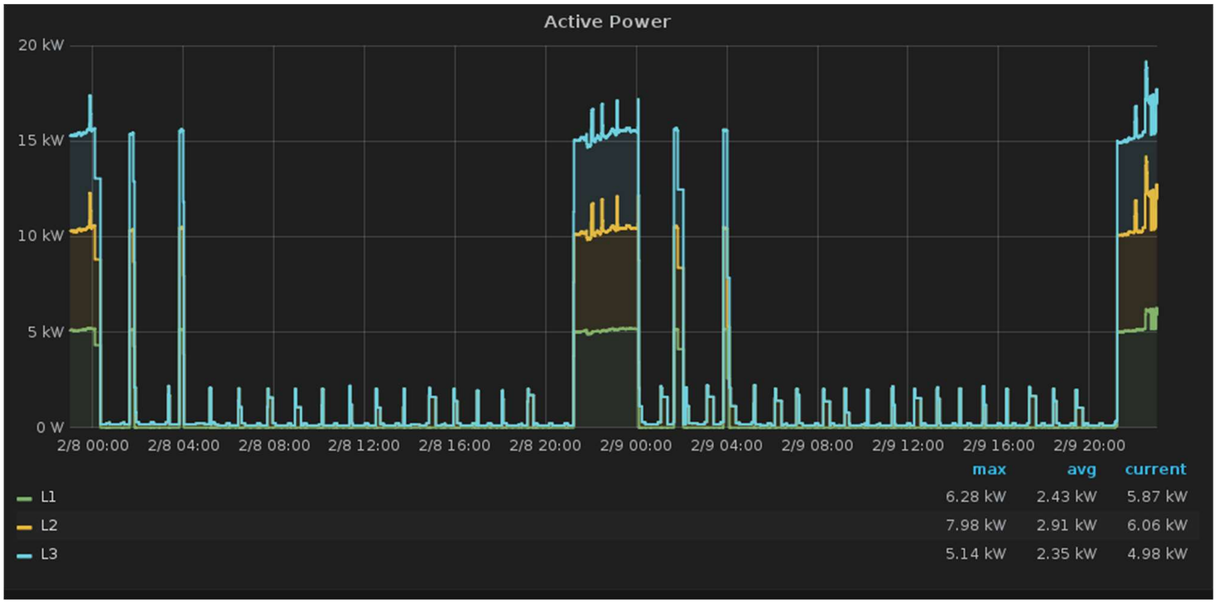


Figure 18: Heating consumption of the "household 08" from 08/02 and 09/02. The load curve represents the consumption of the whole building. However, the high-power peaks (> 10kW) correspond to the heating system. This power consumption is linked to the inner temperature presented in Figure 17.

Another point revealed during this pre-pilot phase is the variety of the boiler, especially in the variation of the water temperature. The Figure 19 and Figure 20 show two boilers' temperature. The first one present small variation – the temperature varies between 45°C and 49°C – the second present high variation between 12°C and 49°C. This is really linked to the boiler size and the inhabitants' number and behaviour. However, most of the boilers (4 on 5 monitored), seem really flexible.

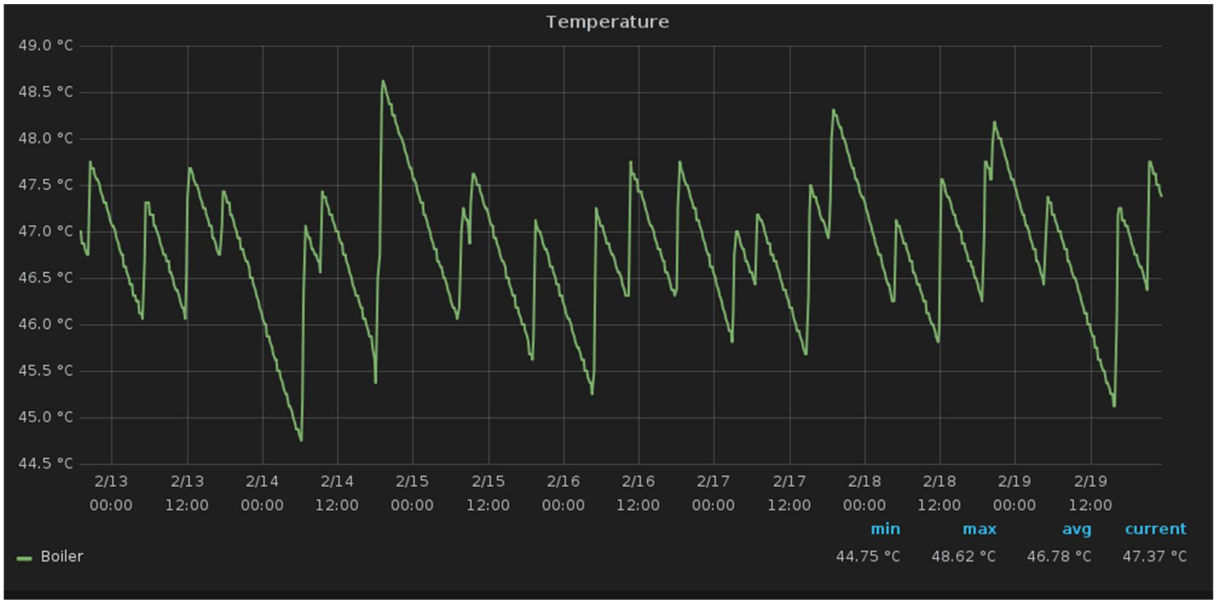


Figure 19: Temperature of the boiler in the "household 09". We can see that the temperature stays between 44.5° and 49° Celsius. It corresponds to a boiler with a big capacity in comparison to usage.

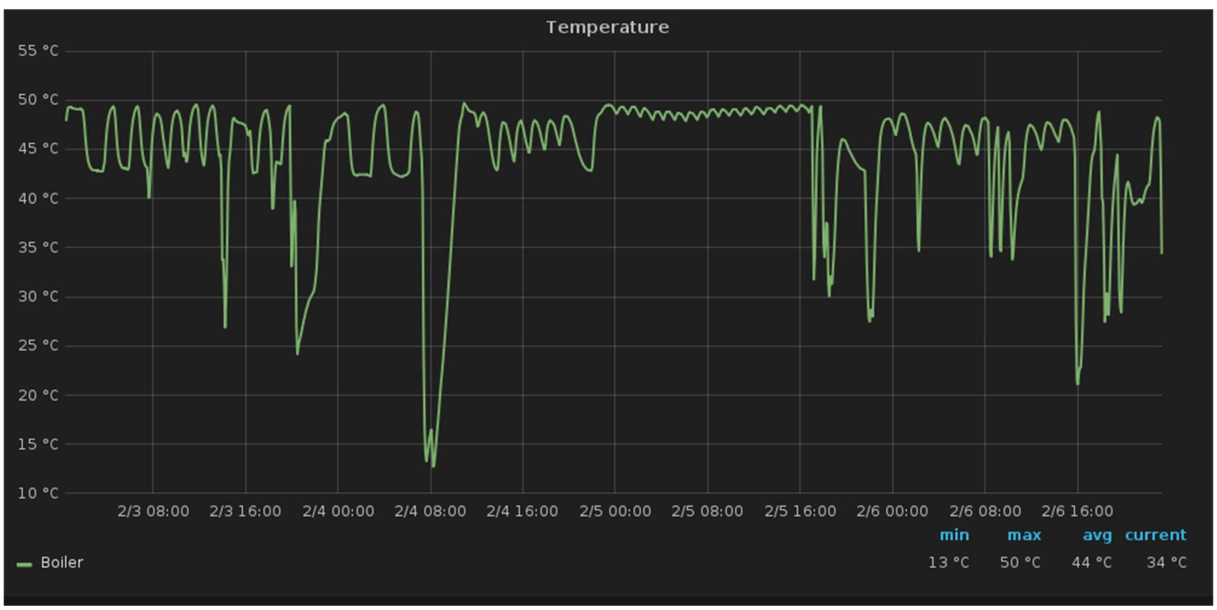


Figure 20: Temperature of the boiler in the "household 08". The temperature of the boiler is extremely variable, with some cold water happening (15° Celsius). It corresponds to a boiler too small on occasion in comparison to the corresponding hot water usage.

Finally, long cuts-off were made to assess the control from a distant controller using the installed smart relays and the influence of a long cut-off of the heating-system on the inside temperature. The Figure 21 and Figure 22 present respectively the temperature drop and the power consumption of the heating system. About 1°C was lost in close to 24 hours, with a sharp decrease at the end when the outer door close to the sensor was opened.

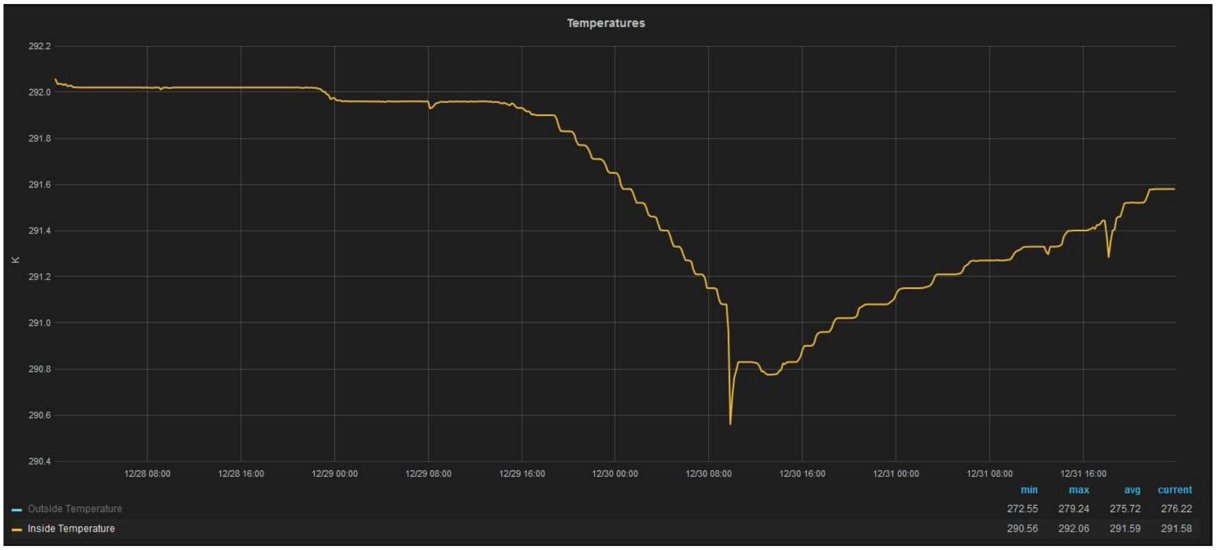


Figure 21: Temperature of "household 06" during a 24 hours cut-off.
Warning: the temperature is expressed in Kelvin in this pre-pilot graph. It spans between 17.5° and 19° Celsius.

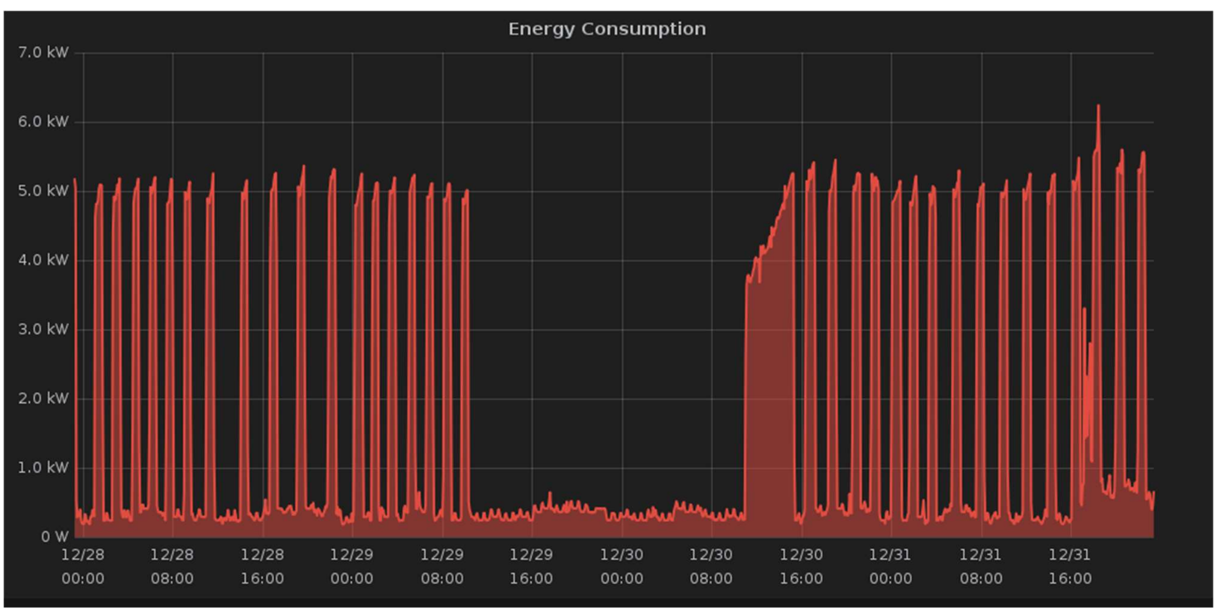


Figure 22: Power consumption of the "household 06" during a 24 hours cut-off

A 17 hours cut-off of a boiler was also performed. Measurements are shown in Figure 23. Figure 23 and Figure 24. As the boiler temperature measurement is located at 2/3 of the boiler's height, no cold water was really noticed, as there was still a small reserve before the heating was restarted. However, the decrease of the hot water temperature was clearly noticed during the third shower taken around 9 AM.

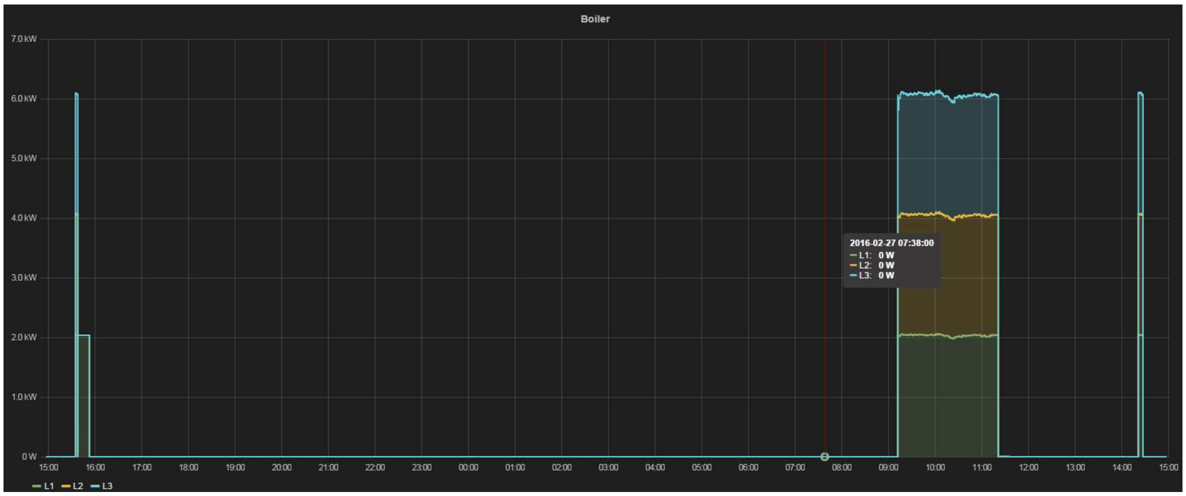


Figure 23 – power consumption of the boiler of household 1 during a cut-off of 17 hours.

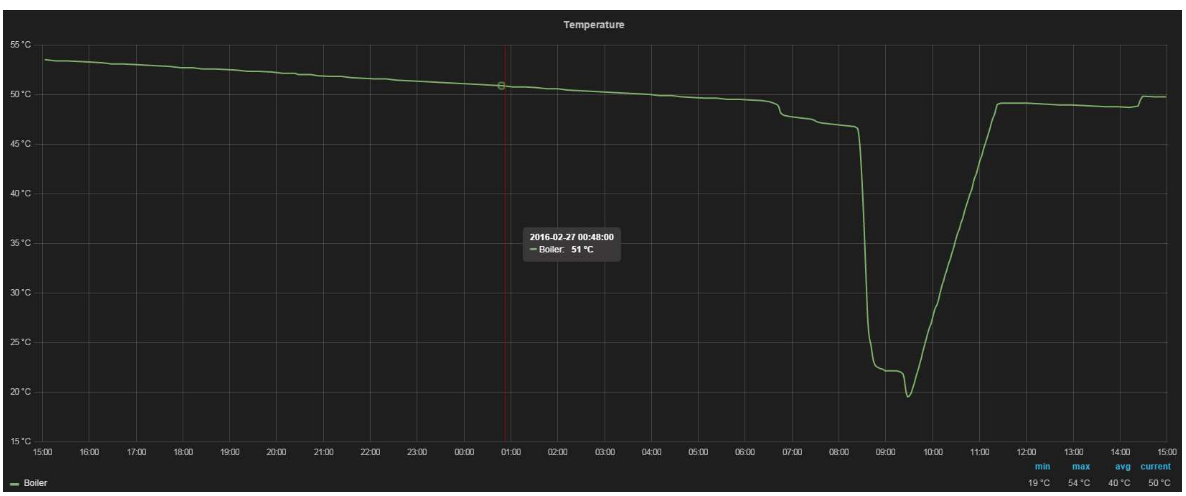


Figure 24 – boiler temperature of household 1 during a cut-off of 17 hours.

4 Pilot Installation

This chapter presents the result of the full pilot phase implemented between summer 2016 and May 2017.

4.1 The Norwegian Full Scale Pilot

4.1.1 Implementing the SEMIAH architecture (Phase 2)

After ending of pre-pilot in late April 2016, a recruitment process was initialized to recruit the last 90 customers to SEMIAH. However, due to lack of response, only 40 customers were recruited in May 2016. Hardware was installed in all the 40 households, and by the end of August 2016, the Norwegian pilot had 50 households up and running with the front-end server.

A second recruitment process was initialized in mid-September, and the feedback was overwhelming. The recruitment process, installation of hardware and connection to the front-end server for the last 50 households was completed by the end of October.

Implementation of SEMIAH Back-end was initialized in November, and by early December, Back-end was installed in 80 of 100 households. The testing of SEMIAH algorithms (forecasting etc.) was incomplete due to a major setback as described in the section 4.1.8.

The progress is illustrated in Figure 25 and Figure 26, Figure 27 shows the first Norwegian household connected to the Front-End Server.

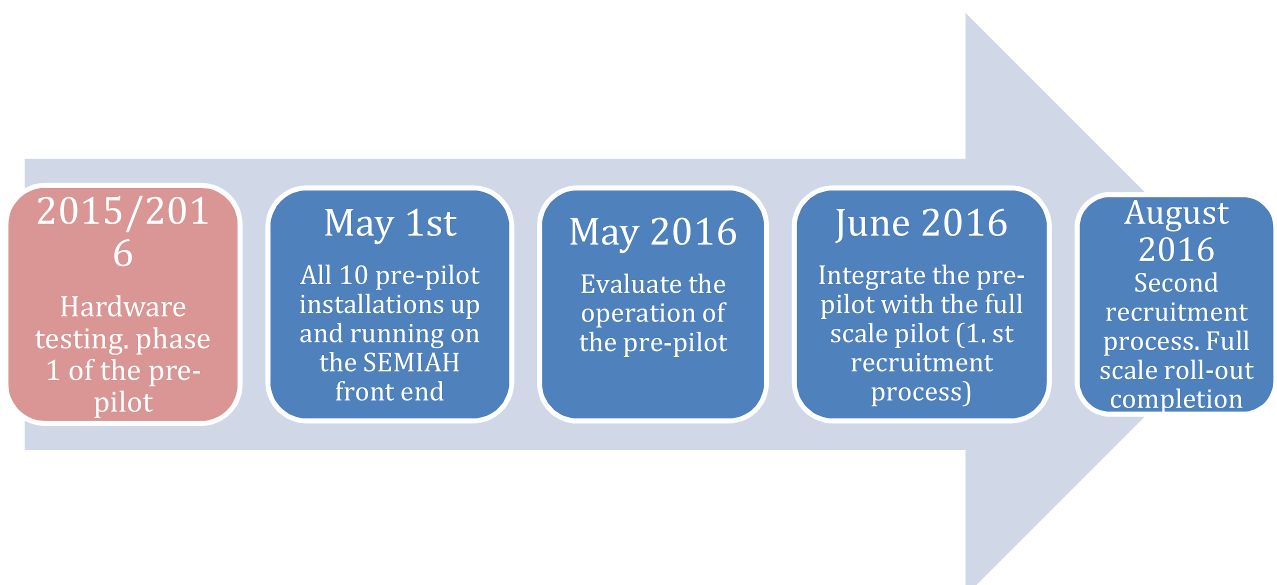


Figure 25 - Progress pilot integration

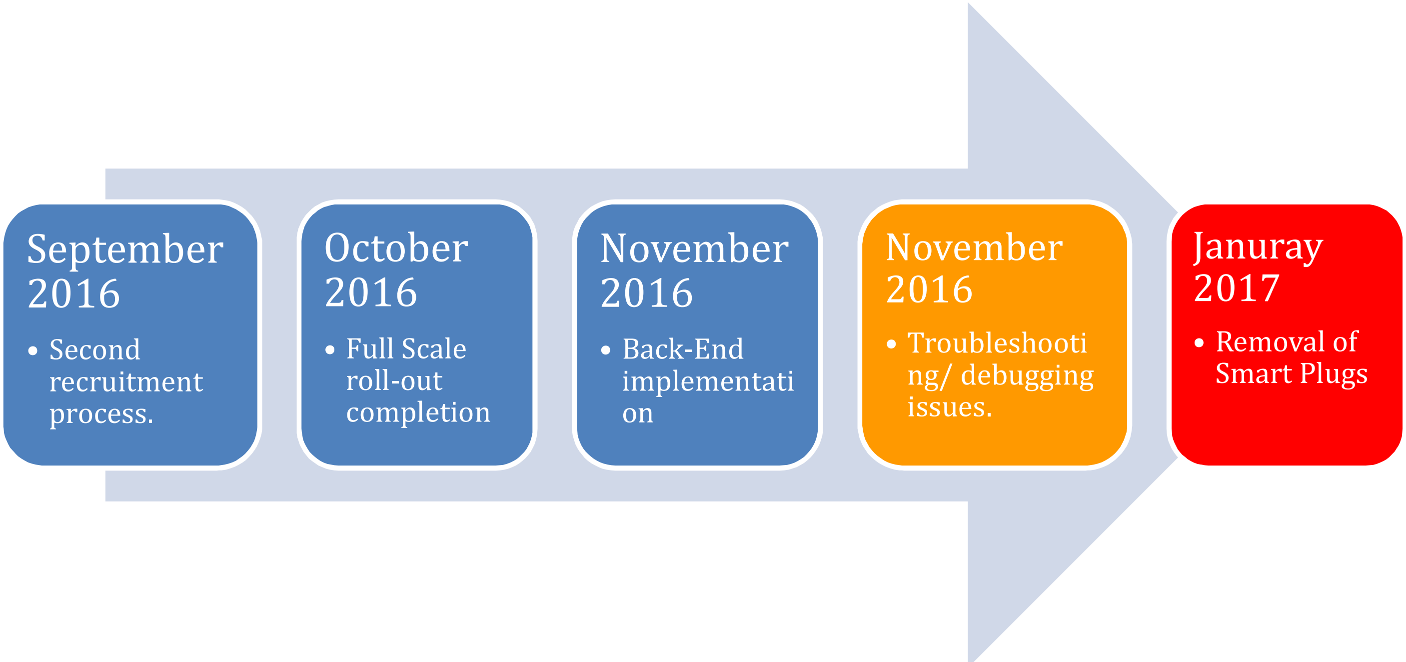


Figure 26 - Progress pilot integration

Figure 27 - Household 11, first Norwegian household connected to the Front-End Server

4.1.2 Pilot location

The location of the Norwegian Pilot was initially Sirdal, a winter holiday resort with several well-equipped and power demanding holiday houses. Sirdal was chosen as a pilot area due to lack of transformer capacity on very cold days, and because the power consumption is very high a couple of hours a year (these peaks make the area suited for DR). However, in 2016 a new transformer was installed in the area, meaning that the capacity is no longer an issue. Experiences from the pre-pilot also indicate that it is quite useful for Agder Energi Nett to be located close to the pilot during its operation. This makes the customer relationship management easier. Therefore, the main pilot area was moved from Sirdal to Nedenes and Hisøy, which are small residential areas between Arendal and Grimstad. The areas have a high share of private households, and the transformer has been shown to occasionally be overloaded during the cold winter season. Both these factors make the area suitable for testing DR.

Figure 28 - Private households at Nedenes

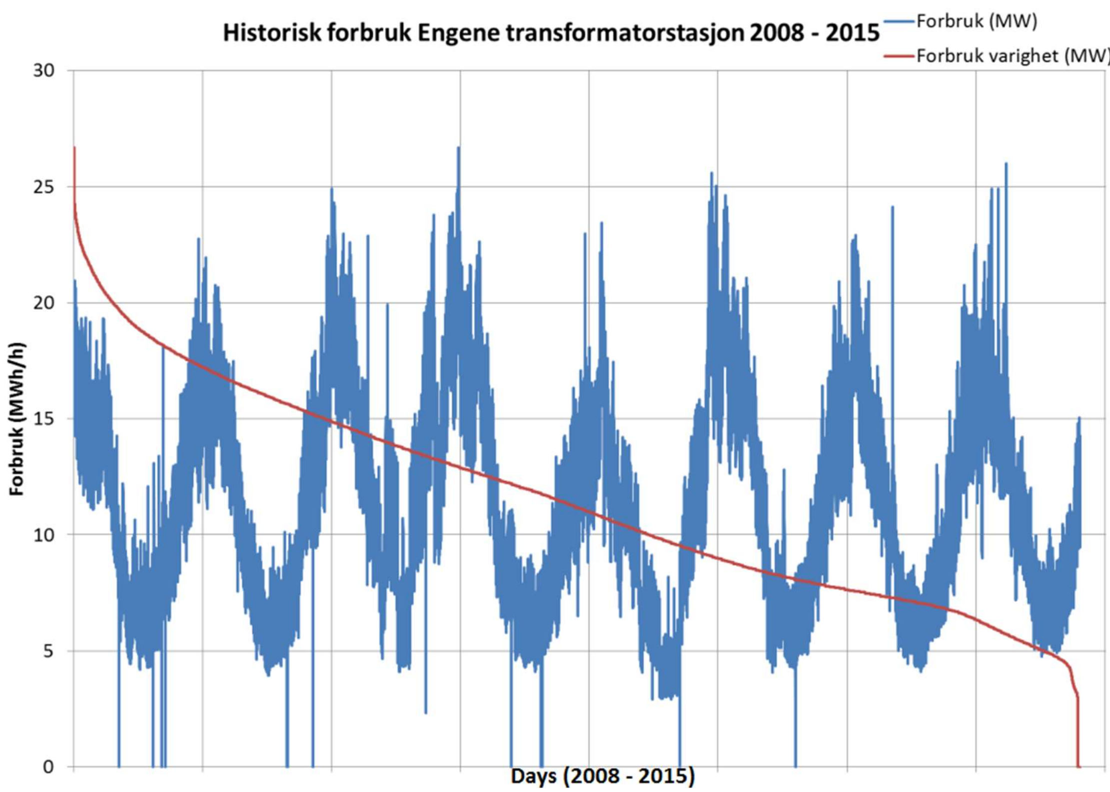


Figure 29 - Historical consumption at Engene transformer station. The installed capacity is 25 MW; the blue curve shows that the consumption occasionally exceeds this.

4.1.3 Architecture

4.1.3.1 Types of installation

There were two types of installations in the Norwegian Pilot. The main installation was Boiler Only. Here, the electrical boiler was controlled using a smart plug and a boiler TT sensor. The schematic of the installation can be seen in Figure 30.

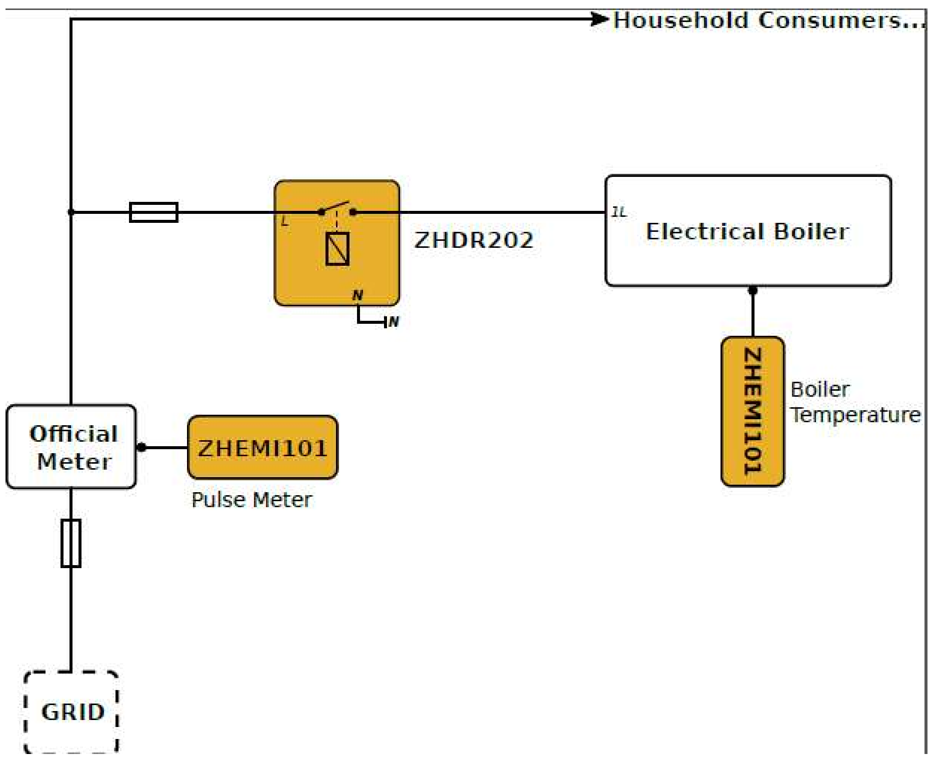


Figure 30 - The *Boiler Only* installation is the main installation to be deployed in Norway

The second installation was Heating Panels Only. Direct electrical heating in the form of heating panels was controlled using smart plugs and temperature sensors. The schematic for this type of installation can be seen in Figure 31.

In addition to the two main types of installations, extra hardware and features were tested at the household of the super-user. Mainly this includes controlling the bathroom floor heating through a Wireless ZigBee thermostat (ZED-TTR-HA), that was connected in series with the existing thermostat for control of the floor heating. The existing thermostat was needed as a "safety backup". The smart thermostat is designed to break one phase only, which is suitable for TN-systems. In Norway, IT- and TT-systems are still common, and the relay in the thermostat must by law be able to break two phases.

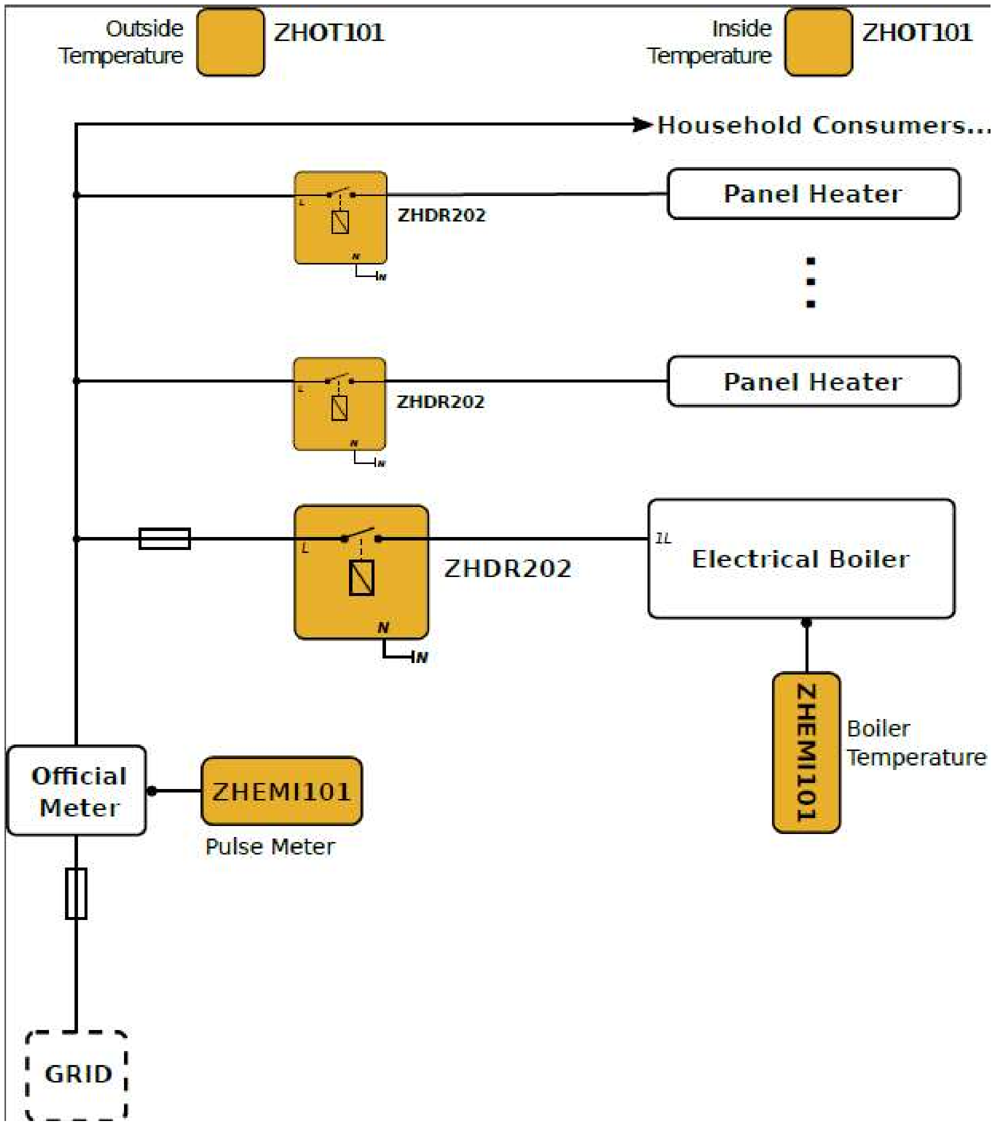


Figure 31 - The installation type *Boiler and Heating Panels*

4.1.4 Hardware

Table 2 shows the installed hardware for the Norwegian pilot. The pilot materials were delivered by Develco Products.

Table 2 - Hardware deployed in the Norwegian pilot

Installation Type	Households	Smart Plug	Led Pulse readers	Boiler TT sensor	Room TT sensor	Gateway (256 MB)	Smart Thermostat
Boiler only	95	95	95	95	0	95	0
Boiler and heating panels	4	8	8	0	16	8	0
Boiler and Smart Thermostats	1	3	1	1	2	1	1
Spare parts		44	6	14	4	1	0
TOTAL	**100**	**150**	**110**	**110**	**22**	**105**	**1**

4.1.5 Features

The list bellow shows, in order of priority, what features that was planned to be implemented and tested in the Norwegian pilot:

1. Install the front-end server
2. Connection to OGEMA
3. Connect the back-end (IWES.VPP)
4. Testing of the "special" algorithms from AU or UiA

It should be noted that step one was considered mandatory, and was implemented when the full-scale pilot was rolled out in October 2016. The remaining steps depended on the development of SEMIAH project where step 4 unfortunately was not feasible.

4.1.6 Rollout plans

Table 3 shows the list of tasks related to the rollout of the Norwegian pilot. The progress plan is illustrated in Figure 32.

Table 3 - The Norwegian Pilot - List of tasks

Task	Starting date	Days		
		Duration	Completed	Remaining
Finalize the pre-pilot	01.05.2016	31	31	0
First recruitment period	14.05.2016	62	62	0
First installation period	15.08.2016	31	31	0
Second recruitment period	15.09.2016	31	31	0
Second installation period	01.10.2016	31	31	0
Installation of front-end	15.08.2016	79	79	0
Installation of back-end	01.10.2016	31	31	0
Operation (Troubleshooting/debugging, customer relationship management)	15.08.2016	270	250	20

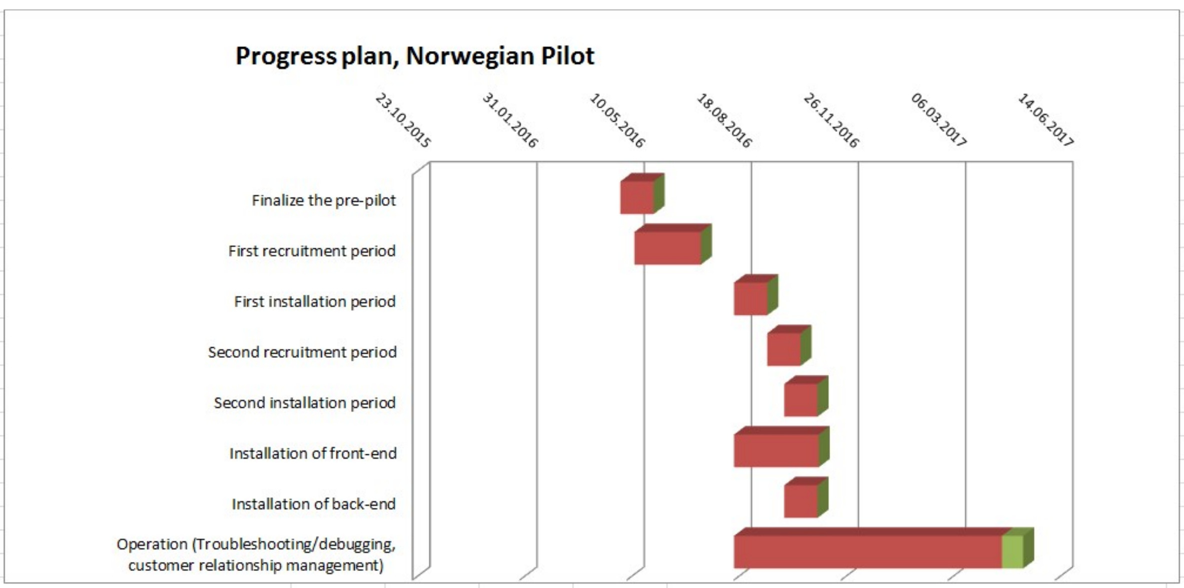


Figure 32 - The Norwegian Pilot - Progress plan

4.1.6.1 Customer segments

The pre-pilot customers joined the entire project, and followed into the full-scale pilot. The remaining 90 pilot customers were private households at Nedenes and Hisøy.

4.1.7 Installation process

The installation process was done in two stages, and started in mid-August and ended in late October.

4.1.7.1 First stage (Households ID 201 to 250)

The first stage covered 40 households mainly located at within the same street at Engene, Nedenes. In the range HH200-250 there were also 10 pre-pilot costumers. The Installation itself started in mid-August and ended in mid-September and proved challenging due to several unforeseen aspects.

Firstly, as the electrical meters in the pilot area were scheduled to be changed to new AMS meters, one had based the Develco meter reader on measuring light emitted from the meter blinking diode. However, as the change of electrical meters was postponed in the area, no such blinking diode was to be found on the old meters. Therefore, several of the meter-readers were not installable.

Secondly, reception from ZigBee-devices proved difficult because in households, where boilers are located in basements floors and fuse cabinets in second floor, there will be a considerable amount of damping of ZigBee-signals in the walls and floors themselves.

Thirdly, getting the Squid gateway up and running and connected to the GPRS also proved challenging. Cellular services in the area are not suitable or stable, hence the Squid gateways needed extensive placement "investigation" in each household.

Fourthly, not all costumers had read the documentation for participation in the project. As a consequence, some had boilers that were fixed to the electrical installation of the household, hence no Smart Plug implementation was possible.

4.1.7.2 Second stage (Households ID 201 to 299)

The second stage covered 50 households scattered around the county of Aust-Agder and started in early October and ended in early November. As with the first stage, also the second stage experienced the same issues with electrical meters, ZigBee-communication, Squid gateway communication and boilers being fixed.

4.1.8 Troubleshooting

In early November one started to troubleshoot on issues that had arisen in the pilot, some of these were:

- Unstable communication on GPRS
- Unstable ZigBee communication
- Squid Link power loss
- Super-user, DIN Relay failure

GPRS communication proved to be highly challenging, as the cellular reception in Norway is dependent on the cellular provider. Hence, because of selecting Telia AS as a preferred provider, the cellular receptions in some areas were as good as absent.

Furthermore, communication between ZigBee devices showed a tendency to come and go. Most likely because of devices being moved, doors slammed shut, obstacles in the signals pathway etc.

The Norwegian pilot also experienced Squid Link power loss because the output power of the power supply to the Squid link was too low.

The DIN-Relay at the Norwegian super-user had a failure in mid-October, reasons for the failure is unknown. However, the relay was removed and the super-user feedback was reduced.

In late December /early January further serious issues were discovered:

- AAA batteries powering temperature meters exploded.
- Smart Plug overloaded and melted (shown in Figure 33).

Figure 33 - Overloaded and melted smart plug

The cause of the exploded AAA batteries was not discovered. However, due to the severity of the issue every AAA battery was changed.

The Smart Plug overload was discovered by one of the householders, and caused Agder Energi Nett to perform an internal review. The review discovered that the Smart Plugs was not certified for loads above 10 A for long periods of time. Hence, as a boiler can be on for several hours, overheating can occur when one have boilers in the range 2-3 kW. The reason for the failure of the Smart Plug was a 3-kW boiler with long periods of ON-time. Furthermore, the review discovered regulations (NEK400 823.55.01) regarding limitation in connecting boilers with schuko plugs and sockets. This in turn lead to the conclusion that schuko plug and socket cannot be used for boiler controlling purposes when the power output of the boiler exceeds 1500W. As the boilers in the Norwegian pilot have a power output in the range 2kW-3kW, all Smart Plugs were removed as of mid-January.

4.1.9 Resources adaptation for Norwegian Pilot

Prior to start-up of the Norwegian pilot there were concerns regarding the lack of resources. Consequently, measures were taken to reduce the workload and minimize the risk for the pilot-customers. However, these measures showed to be insufficient. It resulted in overspending by Adger Energi Nett of several MMs. Some of these measures were detailed in the following subsections.

4.1.9.1 Use of GPRS dongle instead of WiFi communication

This was meant to provide cost predictability as it was supposed to eliminate the need for communication personnel on site during hardware installations. The idea was that no obstacles in forms of lack of ports on the router, or unpredicted firewalls, would cause trouble and demand for extra PMs. However, the GPRS dongle is dependent on cellular coverage, and as the coverage is dependent on location, free line of sight to transmitter etc. signal strength varies tremendously with geographical location. As the households are located in a non-ideal area for cellular reception, satisfactory reception proved difficult.

4.1.9.2 "Plug and play" installation

The Boiler Only installation (90% of the Norwegian installations) was meant to be a plug and play solution, meaning that the customers themselves were supposed to install it (as far as possible, personal preferences would be considered). However, the installation of SEMIAH had a more demanding user interface than expected. Therefore, all installations were done by Agder Energi Nett with additional technical support from Egde Consulting. Furthermore, experience shows that the solution did not offer a "Plug and play" installation, rater a "Plug and debug" installation.

4.1.9.3 Reducing installation costs

By using a "plug and play" solution, the idea was that parts of the installation budget could be released and used for maintenance, supervision and support. However, as the "plug and play" solution showed not to be "plug and play", and personnel from Agder Energi Nett and Egde Consulting had to install the hardware, installation cost were high.

In total, the workload for the Norwegian pilot exceeded the projects expectations which resulted in a more man-months than budgeted. Figure 34 shows the various partners' roles to the Norwegian pilot (as planned before the pilot's start).

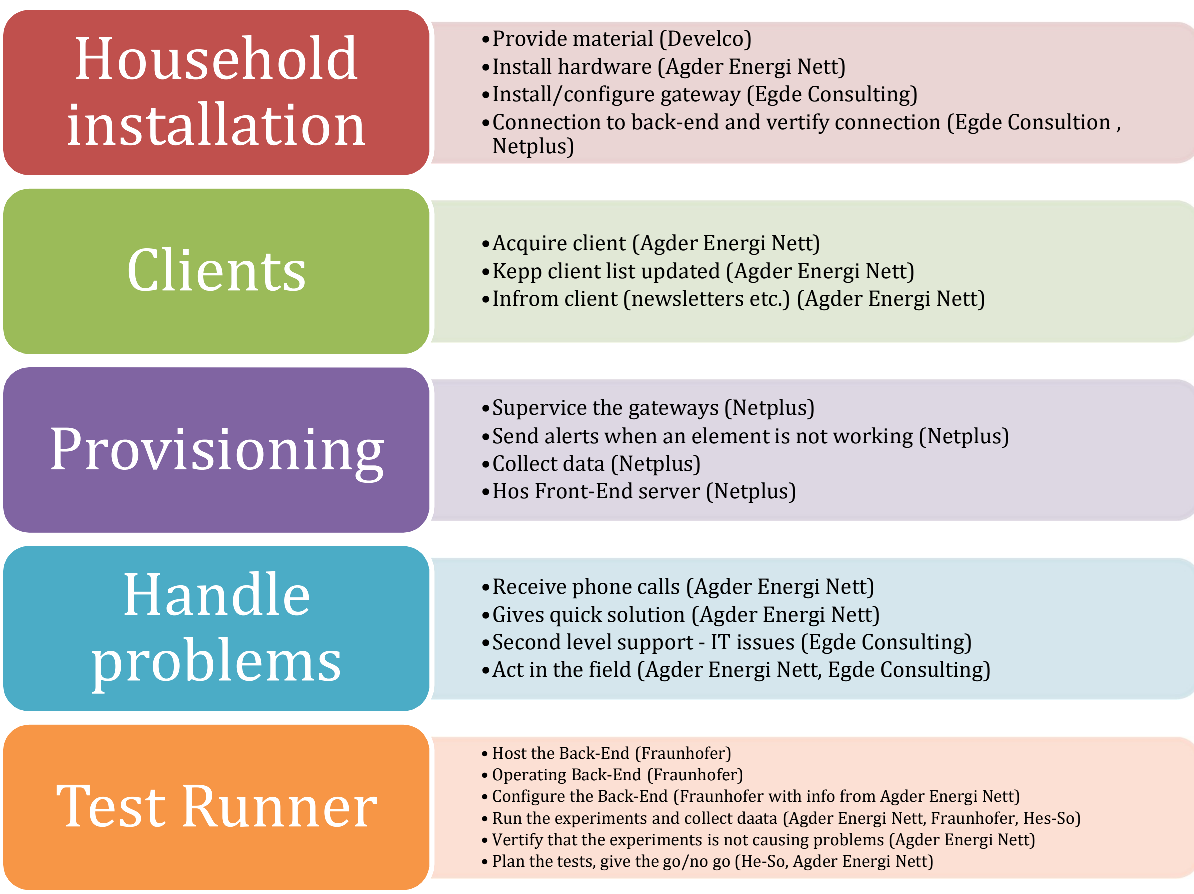


Figure 34 - The various partners' contribution to the Norwegian pilot

4.2 The Swiss Full scale pilot

The Swiss pilot is located between the area of SEIC-Teledis and EnAlpin. Initially, it was planned to have 50 households in each region for a total of 100 households. Figure 35 shows the intended timeline. Finally, due to a lack of participants a total of 89 households were installed, 50 installed by SEIC-Teledis and 39 installed by EnAlpin.

4.2.1 Implementing the Swiss Pilot

Most of the plan (Figure 35) was followed until end of June but the installation was mainly made during September and October for two reasons:

1. The lack of participants, as the DSO did not reach the number of participant, before installing the material, a second phase of research was done before the deployment
2. The pilot participants being on summer holidays

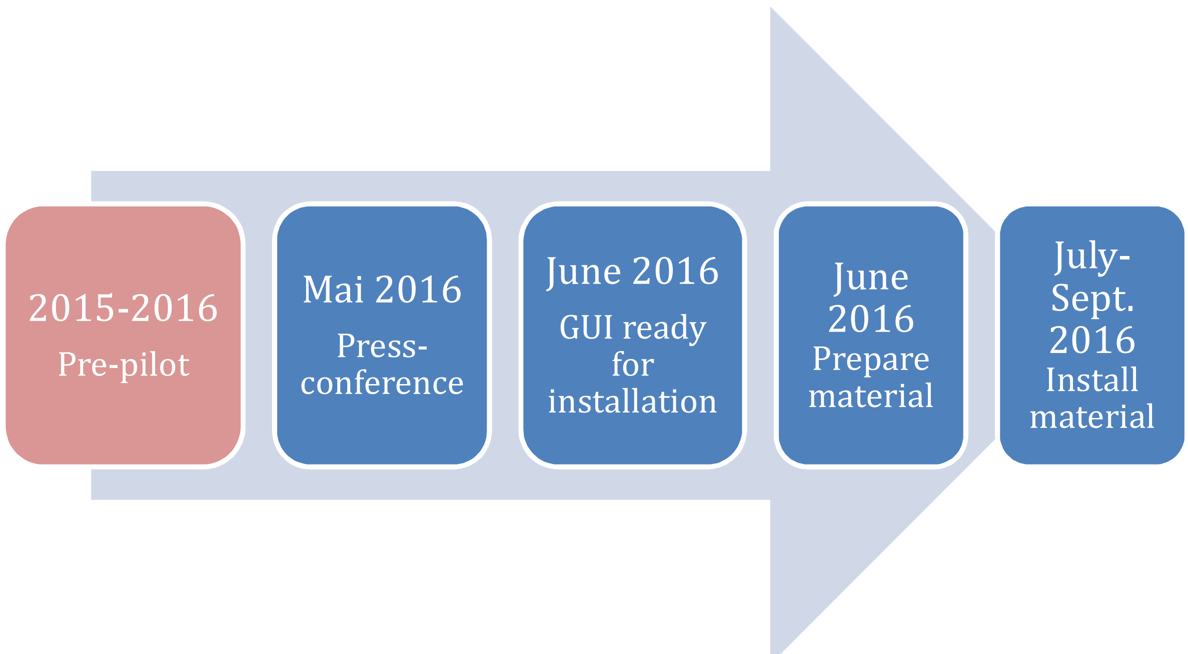


Figure 35 - Timeline of the Swiss pilot

4.2.2 Architectures

Unlike the pre-pilot installation and to simplify the deployment over one hundred households, standard architectures have been defined. The pilot is composed of two main architectures:

- controlling only the boiler (Figure 36), called Type A (called before type 3) in the rest of the document,
- controlling the whole heating by hacking the ripple control, called Type B (called before types 1, 2, and 4).

The second architecture is divided in 3 sub-architectures:

- controlling the heating and the global consumption via a pulse meter (Figure 37), called Type B1,
- controlling the heating, the global consumption and the PV production via a meter reader (Figure 38), called Type B2,
- only controlling the heating (Figure 39), called Type B3.

All these installations also include necessary temperature sensors. Each installation has a boiler temperature sensor and each installation of Type B also includes outside temperature sensor and inside temperature sensor.

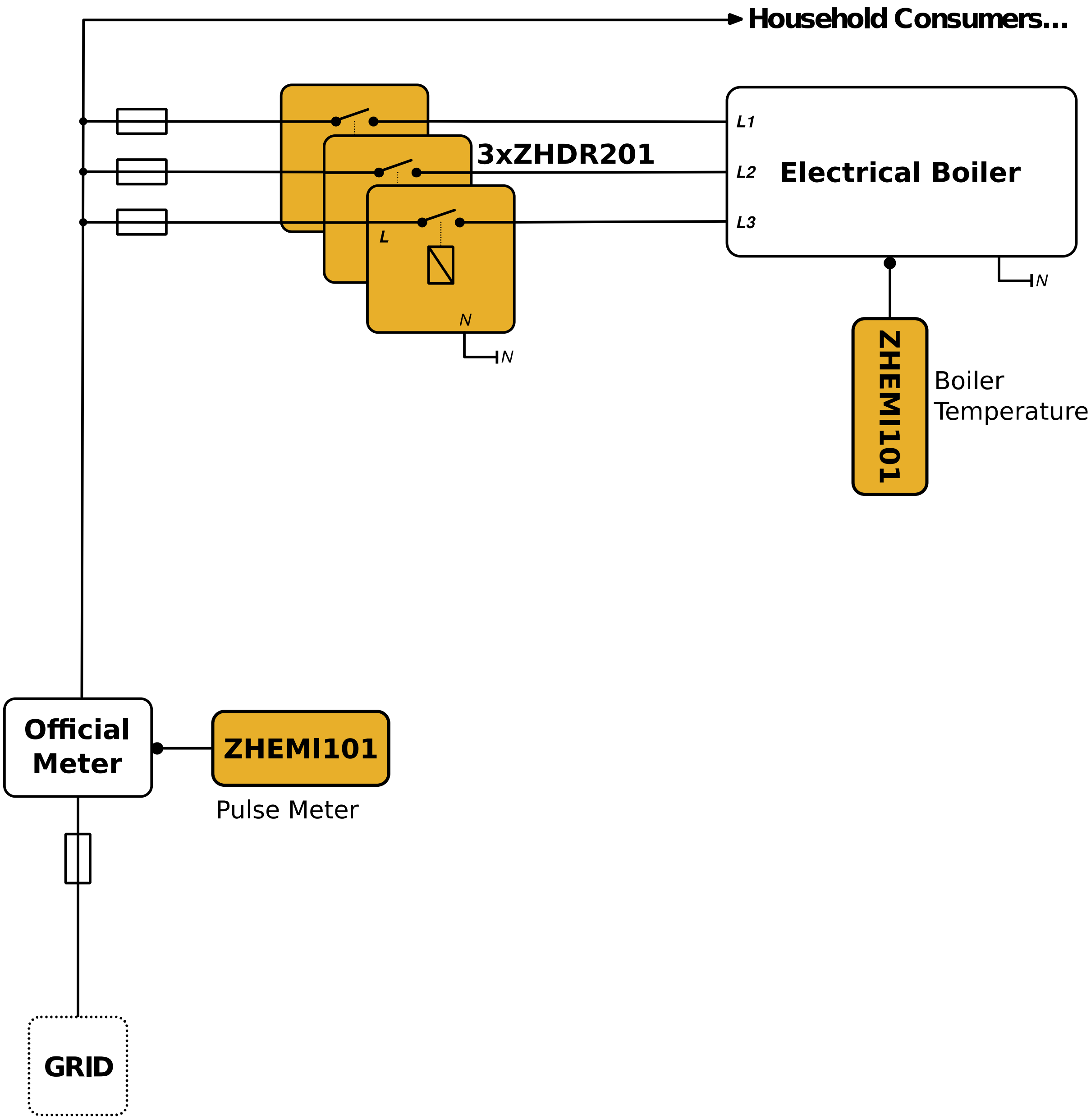


Figure 36 - Boiler only architecture

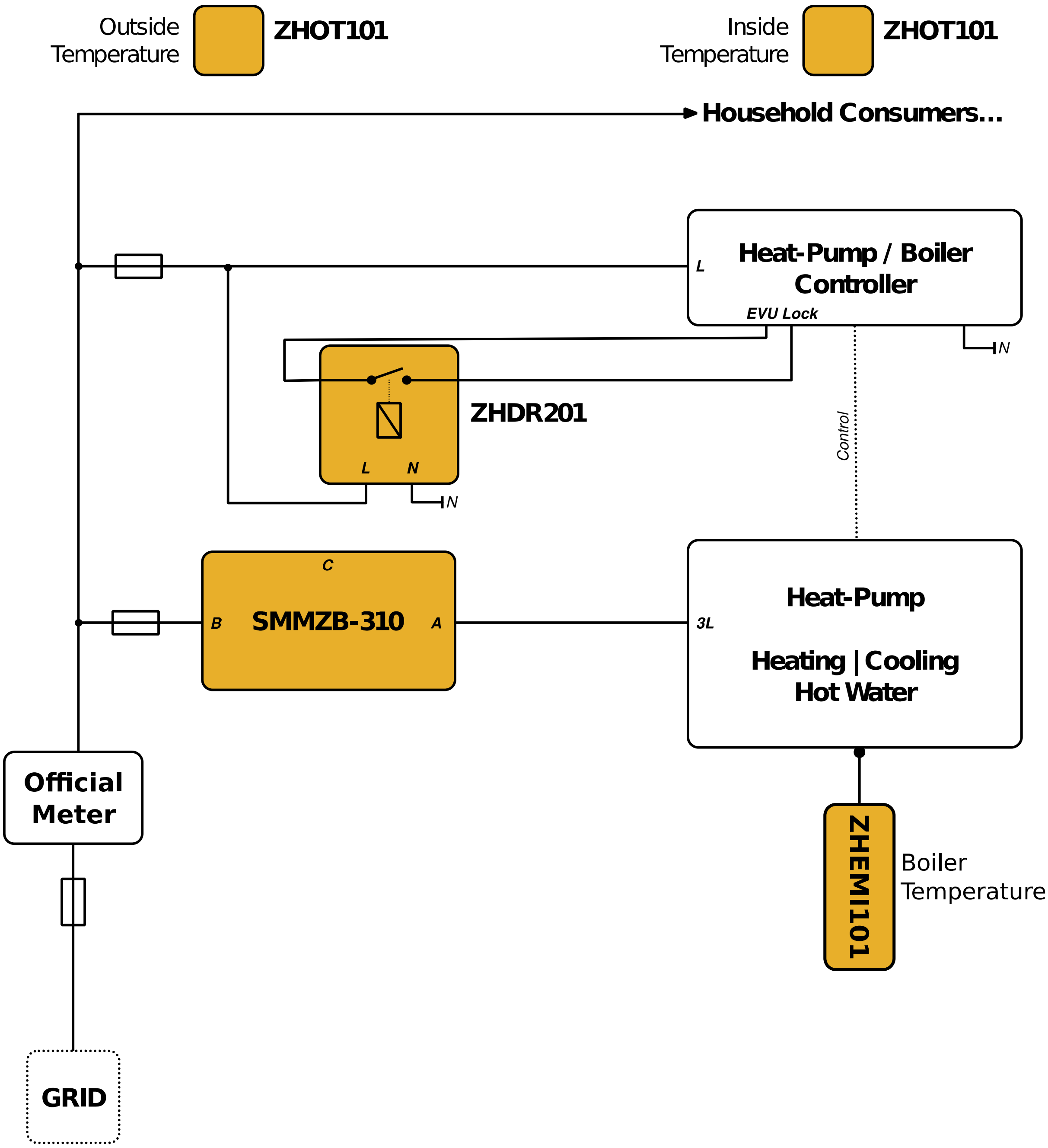


Figure 37 - Heating system through ripple control

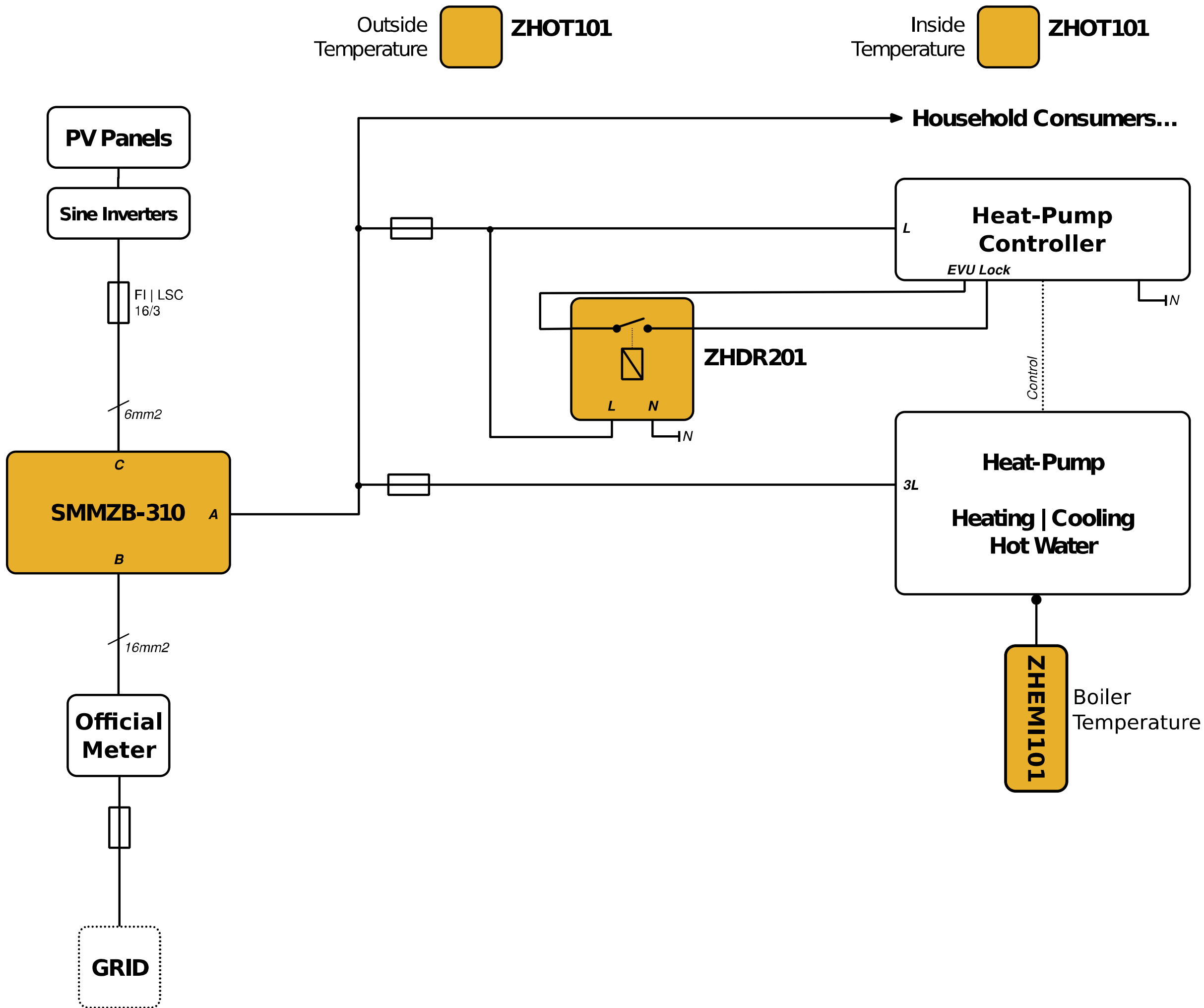


Figure 38 - Heating system through ripple control with PV panels

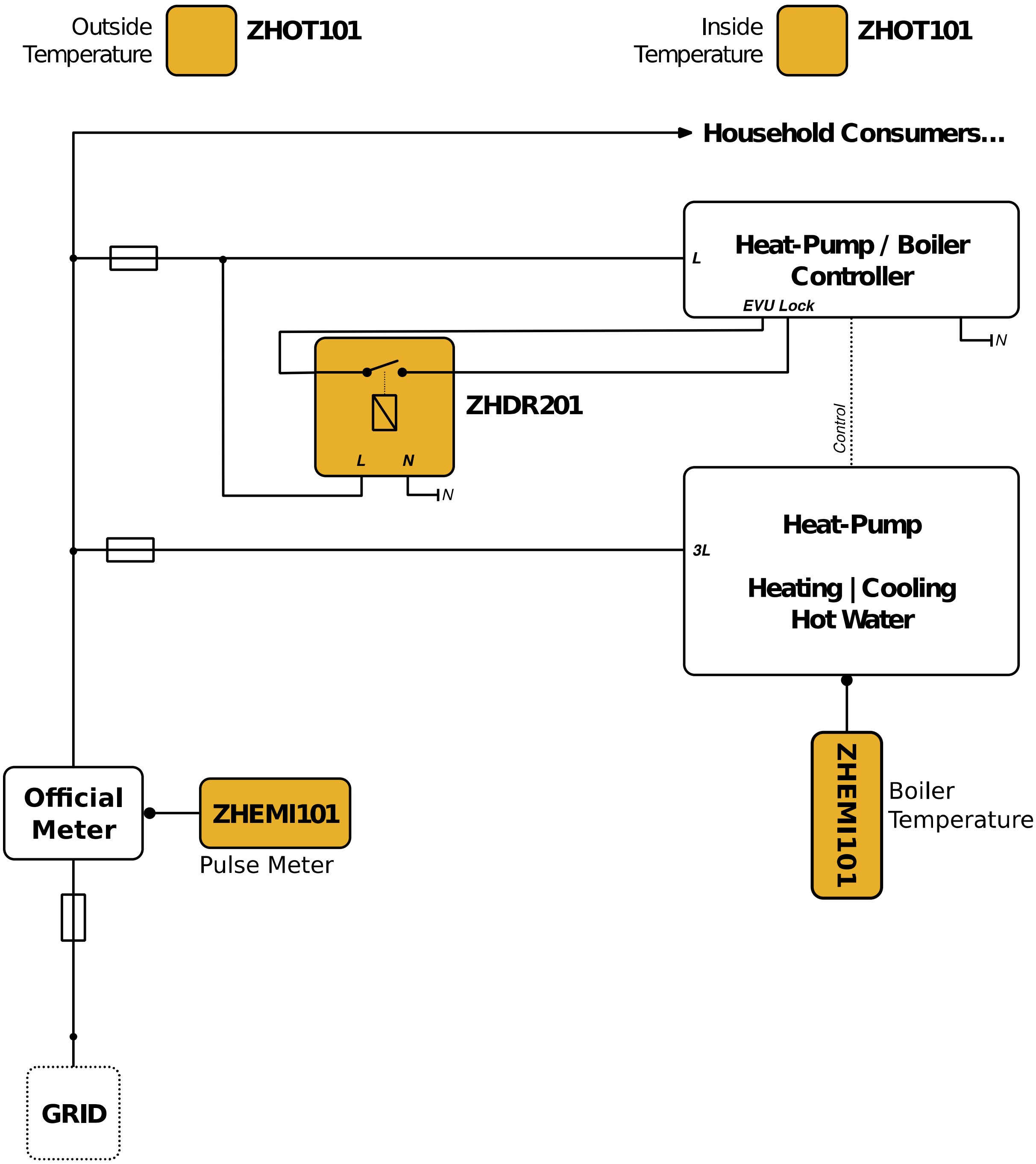


Figure 39 - Heating system through ripple control (only HP measure)

4.2.3 Hardware

The material used for the Swiss pilot can be found in Table 4. We can observe the two main categories of architectures for the Swiss pilot.

Table 4 - Material estimated for the Swiss Pilot

	Number of household	Modified DIN 16A relays	Smart plug (CH)	Unmodified DIN 16A relays	Prosumer Meter	LED Pulse reader	Boiler TT sensor	Room TT sensor	Gateway (256MB)
Pre-pilot 15-16	10	13	1	7	4	4	10	20	10
Household with boiler	50		5	150		50	50		50
Ripple control command	40	80	4		20	20	40	80	40
Spare parts & reserve		7	5	13	2	6	10	10	5
TOTAL	**100**	**100**	**15**	**170**	**26**	**80**	**110**	**110**	**105**

Figure 40 - Contribution of the different partner to the to the Swiss Pilot

4.2.4 System deployment costs

To install the system in one household, two technicians were necessary during 2 hours (including travel to the house). One electrical technician for the installation of the relays and one IT technician to validate that the installation is connected to the database.

Considering the cost of the installed devices (around 400€) and the cost of the personal (2x2h, around 400€), we can estimate the total cost for one installation to be 800€.

Additional costs must be added to ensure the follow-up of the pilot. Due to the instability of the system (the explanation of the instability will be detail thereafter) the additional cost finally was more important than the installation employees cost (400€).

4.2.5 Front-end installation

The Swiss part of the front-end installation involves 4 partners with specific tasks to ensure a good collaboration. Based on the experience gain through the pre-pilot installation, an installation plan was imagined defining the specific tasks, the Figure 41 presents this established plan:

- HES-SO prepared installations and managed the necessary actions appeared during the pilot (gateway stopped, broken sensors, etc.), based on the information given by the other partners.
- EnAlpin or SEIC-Teledis managed the hardware installation in the households.
- Netplus Server provided the data server and ensured the data are well received and stored.

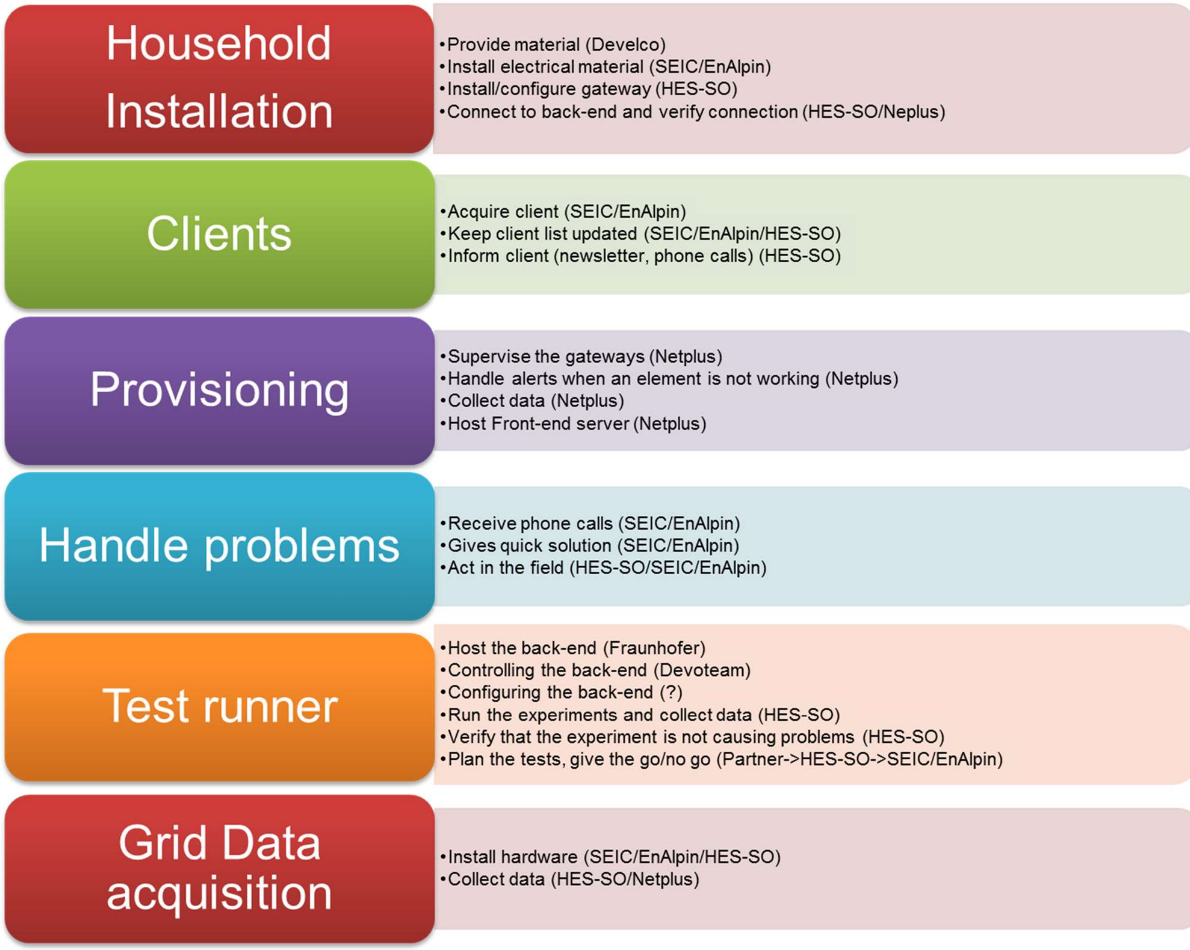


Figure 41 - Division of work between the partners

4.2.6 Feedback on installation

The installation of the 89 households and the harvest of the data revealed some problems during the implementation of the planning.

The instructions given to the installers turned up to be not accurate enough, resulting in some cases in sensors' misplacement. The reduced measurement accuracy resulted to be problematic for the back-end system, which could not ensure an optimal control of these households. This reduced the number of household that can be controlled by the back-end. More information on this issue is given in the section 5 of this document.

The delay in the implementation of the control algorithm (Salsa and OGEMA) provides additional work to the partner involved in the pilot. For example, the gateways finally needed a remote access to install software after the installation on site. This was not detailed during the planning thus additional work was necessary just before the installation and this work was not validated during the pre-pilot phase, thus it was more prone to errors.

Finally, the delay on the implementation of the provisioning implied a huge difficulty on the supervision of the households. Most of the problem detailed in the section 4.2.7, 4.2.8 and 4.2.9 were tardily discovered mainly due to a lack of a good monitoring tool.

4.2.7 Installation problems

Several problems arise during the installation and most of them were detected quickly and have been resolved quickly. Some of them were only detected with an analysis of the data stored in the database:

- 14 households (16% of the installed households) have problems with the Meter Readers which always sent a null value to the database. Two causes were imagined explaining this problem but no solution was made to resolve it:
    - A bad electrical connection between the optical sensor and the transmission box,
    - Or the optical sensor is defective
- 211 devices (around half of the installed devices) have a RSSI sent to the database lower than -80dBm. The value of -80dBm is the limit for a stable connection, a lower value means a poor connection thus the lifetime of batteries is drastically reduced. This problem is due to the position of the gateway and sensor in the household but it was obviously not always possible to change the position of the sensors. It is also due to Swiss building built with strong walls. This huge damping also had a great impact on battery life, some of the batteries had to be replaced after only six months.
- The RSSI issue also implies a lack of data during several periods. As it can be seen in Figure 42, several households have missing data, probably due to temporary connection loss, while 14 out of the 40 households are completely missing boiler consumption data on at least one of the three phases.
- An example of incomplete data is shown in Figure 43.

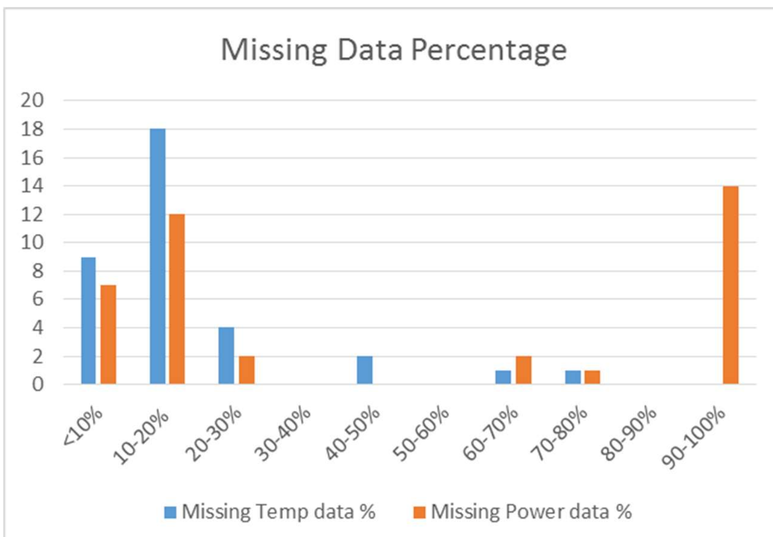


Figure 42 - Percentage of missing data over the period 01.01.2017-18.04.2017 for households of type A.

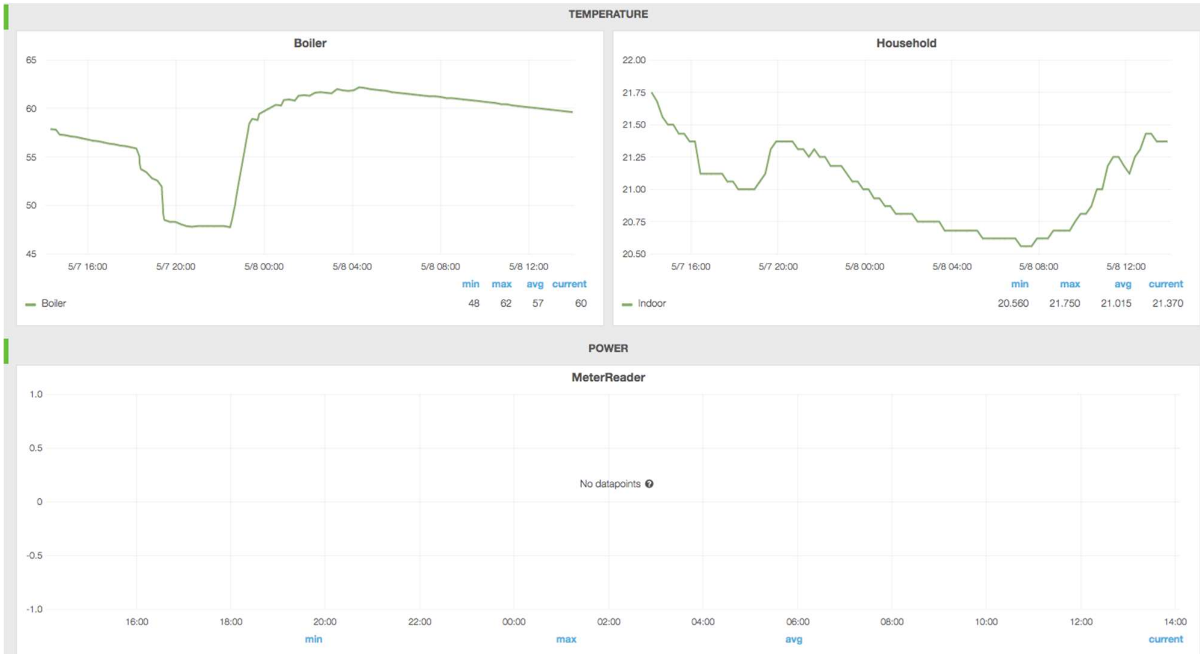


Figure 43 - Example of incomplete data (Household 144, May 8th 2017).

4.2.8 Device problems

Few of the Develco devices have shown problems months after the installations. However:

- In two ambient temperature sensors, the battery exploded. The explosions did not cause any damage to people or in household. The Figure 44 presents one of those batteries after the explosion.

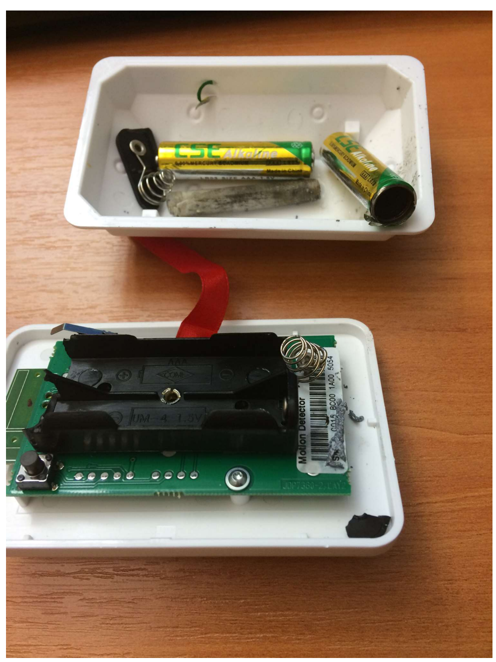


Figure 44 - An exploded sensor battery

- 5 of the installation boiler-only (9% of the installed Type A) are mainly heated by a heat pump whereas the sensors of the electrical consumption are installed on the auxiliary electrical heating system. The given values, stored in the database cannot be used to determine the behaviour of the boiler consumption.
- 2 prosumers (9% of the 22 installed) sent null value to the database probably due to a bad version of the firmware. Develco were contacted to update the firmware version.
- To have remote access to the gateway, and installed the control algorithm, a VPN was installed. The version installed on the gateway was an unstable version of Open VPN due to new needed features but this version crash sometimes and the gateway needs to be restarted. A simple call to the participants to disconnect and reconnect the gateway resolve the problem. It remains however a tedious job if it must be done regularly.

4.2.9 User behaviour

The installation of an innovative technology in households had shown unpredictable behaviours of the householders:

- Some of the participant turn off the gateway when they had an Internet problem because they thought that this technology was the cause.
- We received calls of participant to demand us to stop the pilot because the temperature inside their household was lower than usual. As at that time no control was done, this reaction was similar to a placebo effect, and after verification, we were able to ensure that it was never the case.
- 1 household has a surprising problem. From 6AM to 6PM every day no data were sent to the database. After some tests, we cannot find plausible explanation. The Figure 45 presents the problem.

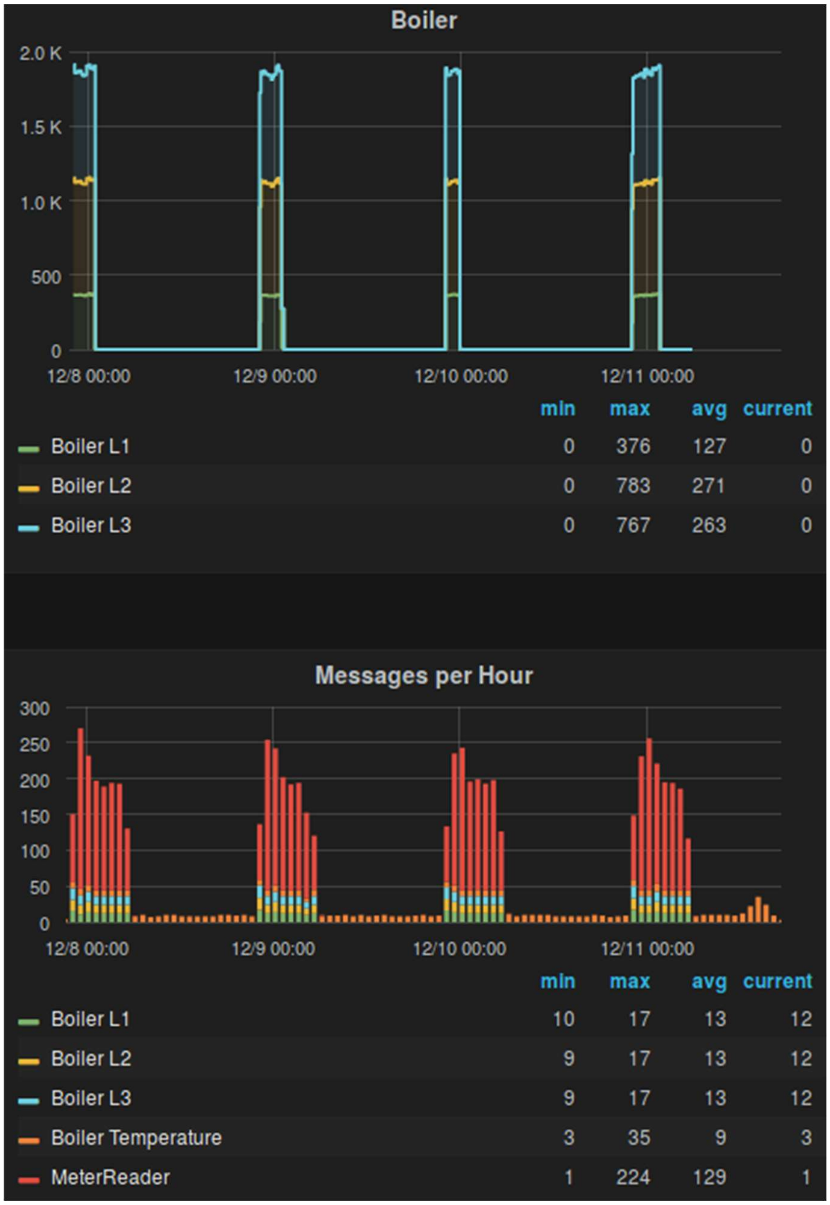


Figure 45 - Few messages between 6AM to 6PM

4.3 Connection to the back-end

As already described, only the front-end server was tested enough on the pre-pilot. However, in parallel to the pilot hardware installation, the connection to the back-end was finished, tested, and deployed.

A workshop between Fraunhofer, Devoteam, AdgerEnergi, and HES-SO was organized at the end of May to smoothen the transfer of information between the back-end developer and the partners running the pilot. The solution was tested and validate through the deployment on the gateways in winter 2016-2017.

More results from the back-end usage is given in the section 5.

4.4 Installation summary

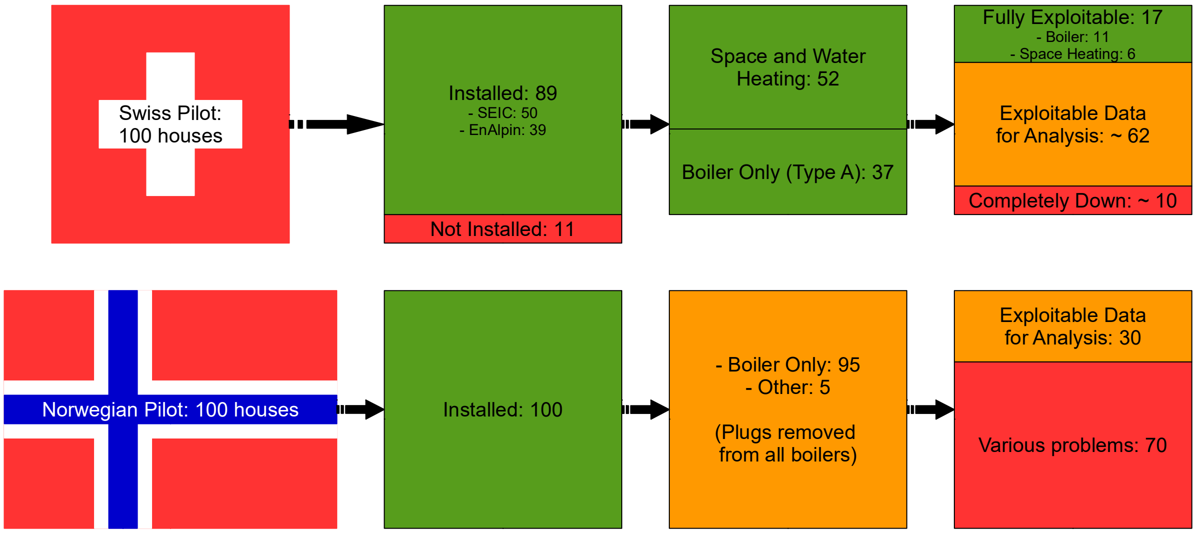


Figure 46 - From the installation to the exploitation in pilot

Figure 46 presents the summary of the resulting installation done in Switzerland and Norway. In addition, Section 5.1 describes also some problems that arise during the analysis of the data and led to such a small number of fully exploitable households.

5 Back-end analysis and results

5.1 Back-end consideration

As decided by the consortium, only IWES.VPP (developed by the Fraunhofer) was used with the pilot households. The option to test the SALSA algorithm was finally not implemented on pilot households.

As the use of IWES.VPP was not first designed for the SEMIAH pilot, several constraints, especially those given by the DSO, were not considered even if the specifications were written. For example, the control of IWES.VPP was only designed with German energy price market optimization using boiler consumption.

Therefore, the IWES.VPP algorithm were run on households with boilers with specific data corresponding with the requirements of IWES.VPP, which finally meant 11 households. Starting with 200 households, only 189 were installed. On these 189 households around 130 have boilers (households of Type A and Norwegian equivalent). Given the troubles with plugs in the Norwegian pilot, all these installations could not be used for control. Of the about 40 Swiss households running boilers, only 11 had sensors providing the right data for IWES.VPP and could be thus be controlled:

- 11 boilers (12% of the Swiss installed boilers) have not useable values for control. The sensors were placed on the pipe, at the exit of the boiler, as it was not possible to fix it on the boiler tank. This place was sufficient for security reason (detection of an empty boiler), but it was found to be not suitable for control. For example, the Figure 47 gives the temperature returned by a boiler temperature sensor. From this curve, we can assume that the sensor is placed on the pipe instead of on the boiler thus the temperature represents more the consumption of hot water (when the hot water goes through the pipe) than the temperature inside the boiler.

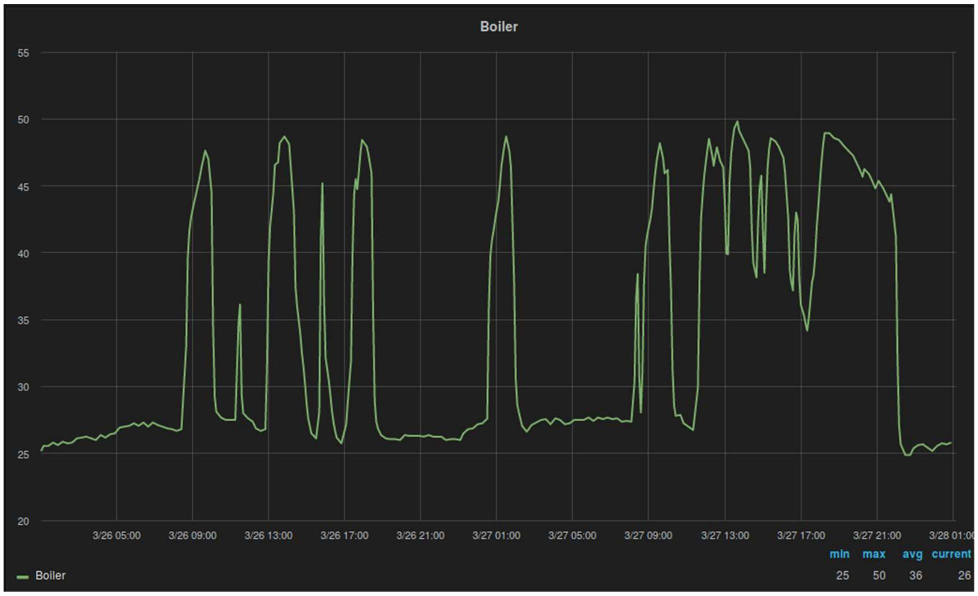


Figure 47 - Boiler temperature given by a misplaced sensor

- 15 boilers (17% of the Swiss installed boilers) have consistent temperature but with an offset on the values. The Figure 48 presents such a temperature stored in the database. This problem is probably due to a poor thermal conductivity between the sensor and the boiler. As the temperature sensor must be stick to the boiler, it seems the sensor has been partially detached during the pilot.

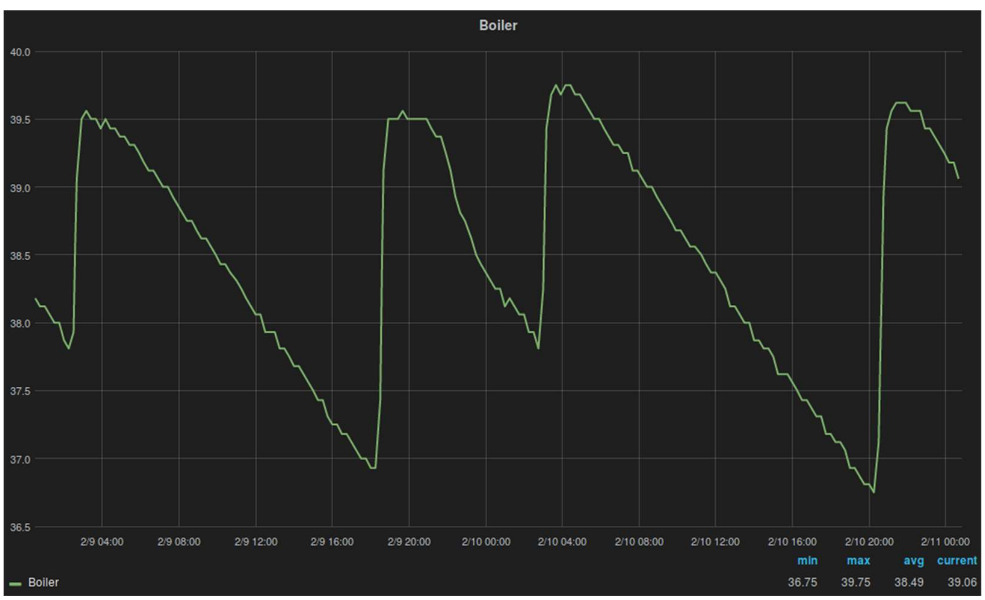


Figure 48 - Consistent but too low temperature of a boiler

The misplacement of the installation is due to the consideration used to do the installation. As no specification of the data needed by the control algorithm were delivered before the installation, it was not possible to anticipate the needs. Therefore, the sensors were installed mainly to ensure the welfare of the user with a consideration for the control algorithm, which sometimes turned out to be false. While the data given by the misplaced sensors are enough to monitor the temperature to ensure the welfare of the householders for all the households, these data were only usable for control algorithm in only 11 households.

Considering the installations, other analyses were still performed on more than 11 households. Statistical analyses were realized to validate that the switch from white appliances to heating systems were the right choice and to compensate the relatively small timeframe during which the remote control was active.

5.2 Heating power cut tests

This section presents the results of the heating power cuts performed on six households of type B1. Several problems encountered during data collection and retrieval explain this relatively low number of houses, as already reported in detail in Section 4.2.

These heating power cuts have four main goals:

- Test the relationship between the front-end server (Grafana) and the household realities
- Evaluate the impact of power cuts of various durations on both the temperature in the houses and the load curves
- Investigate to what extent these power cuts can be implemented for peak shaving, price optimization and other purposes, while guaranteeing the residents' comfort in terms of home temperature
- Characterize the thermal properties of the tested houses based on the internal and external temperatures and the electrical consumption

The power cuts duration (time during the heating relays were set to 0) were 1 hour, 2 hours and 4 hours and were performed during week 8 in 2017 (February 20 to 24). Five heating power cuts of 1 hour were performed between February 20 and 21, four heating power cuts of 2 hours were performed between February 21 and 22 and 2 heating power cuts of 4 hours were performed between February 23 and 24. Table 5 presents the details of the heating power cuts schedule.

Table 5 – Schedule of the heating power cuts

	Start Time	Stop Time	Duration	Houses
20.02.2017	09:00	10:00	1 hour	All
	14:00	15:00	1 hour	All
	19:00	20:00	1 hour	All
21.02.2107	00:00	01:00	1 hour	All
	05:00	06:00	1 hour	All
	10:00	12:00	2 hours	All
	18:00	20:00	2 hours	All
22.02.2017	02:00	04:00	2 hours	All
	11:00	13:00	2 hours	All
23.02.2017	08:00	12:00	4 hours	All
24.02.2107	00:00	04:00	4 hours	All

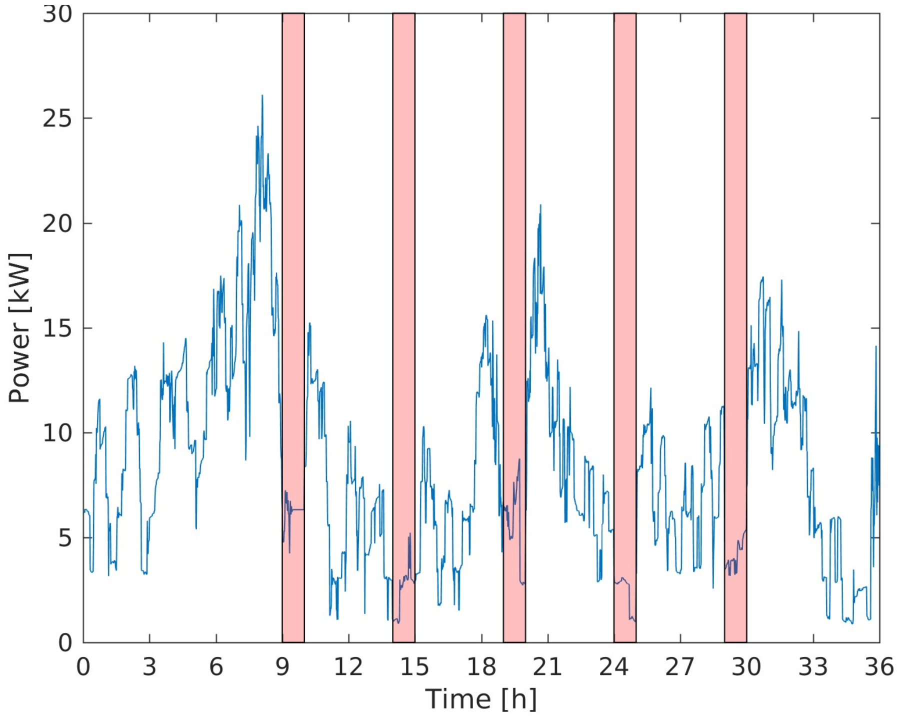


Figure 49 – Aggregated load curve of the six houses starting on February 20, 2017 at 00:00. The time slots in red correspond to the power cuts of 1 hour.

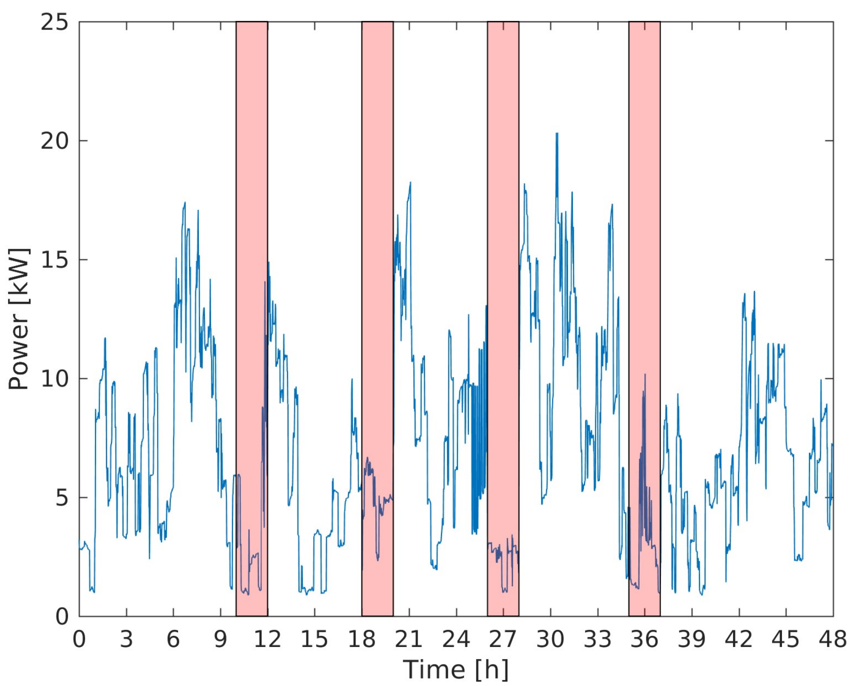


Figure 50 – Aggregated load curve of the six houses starting on February 21, 2017 at 00:00. The time slots in red correspond to the power cuts of 2 hours.

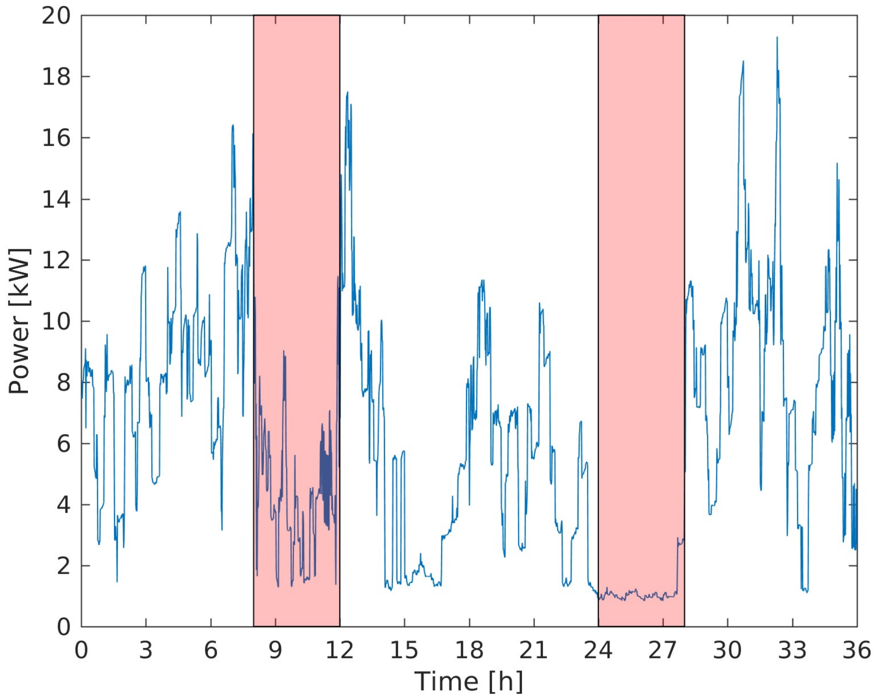


Figure 51 – Aggregated load curve of the six houses starting on February 23, 2017 at 00:00. The time slots in red correspond to the power cuts of 4 hours.

Figure 49, Figure 50 and Figure 51 show the aggregated load curve of the six houses for the heating power cuts of 1 hour, 2 hours and 4 hours, respectively. The time slots in red correspond to the power cuts. As expected, the power level during the cuts is lower but not equal to zero. Indeed, the houses consume electricity for other appliances during the cuts.

Similarly, Figure 52, Figure 53 and Figure 54 show the overlapped load curve a few hours before, during and a few hours after the cuts of 1 hour, 2 hours and 4 hours, respectively. Again, the time slots in red correspond to the power cuts.

Table 6 shows the average consumed power 1 hour before, during and 1 hour after the power cuts. The reference power levels (before the cuts) obviously depend on the number of cuts. The decrease in power during the cuts vary between 43 and 64 % whereas the increase in power after the cuts vary between 15 and 87 %. More cut tests involving more houses need to be performed in order to better characterize these changes in power. Furthermore, the timing of the power cuts is a key parameter since the heating is more likely to be on during the night than during the day. Finally, to accurately characterize these changes in power, the heating load curves should be extracted from the house load curve to remove the influence of the other appliances.

Table 6 – Average consumed power 1 hour before, during and 1 hour after the heating power cuts

	Power before (1 hour) [kW]	Power during [kW]	Decrease [%]	Power after (1 hour) [Kw]	Increase [%]
1 hour	48.5	20.7	57	55.6	15
2 hours	30.6	17.4	43	57.1	87
4 hours	38.6	13.9	64	53.7	39

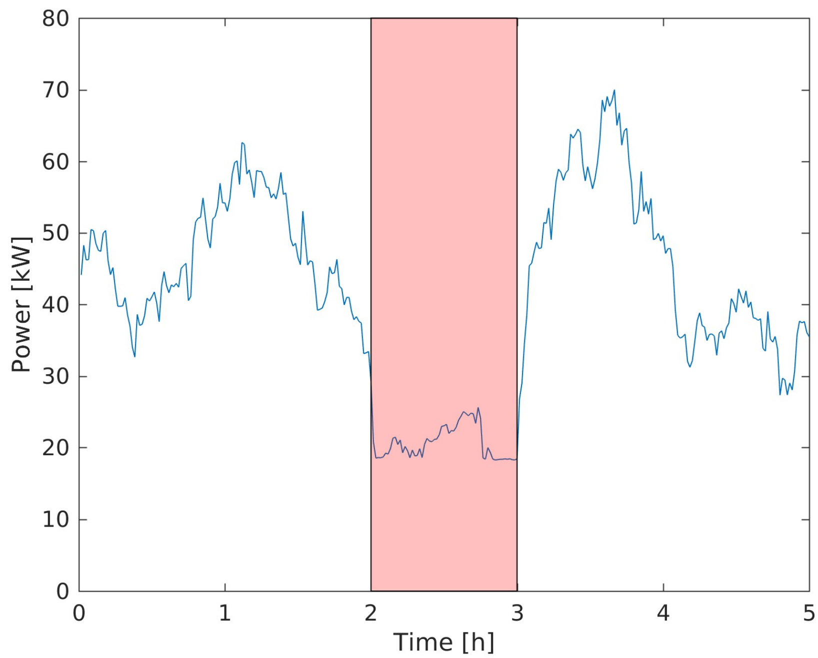


Figure 52 – Overlapped load curve of all 6 houses for all the power cuts of 1 hour. The time slot in red correspond to the power cuts of 1 hour.

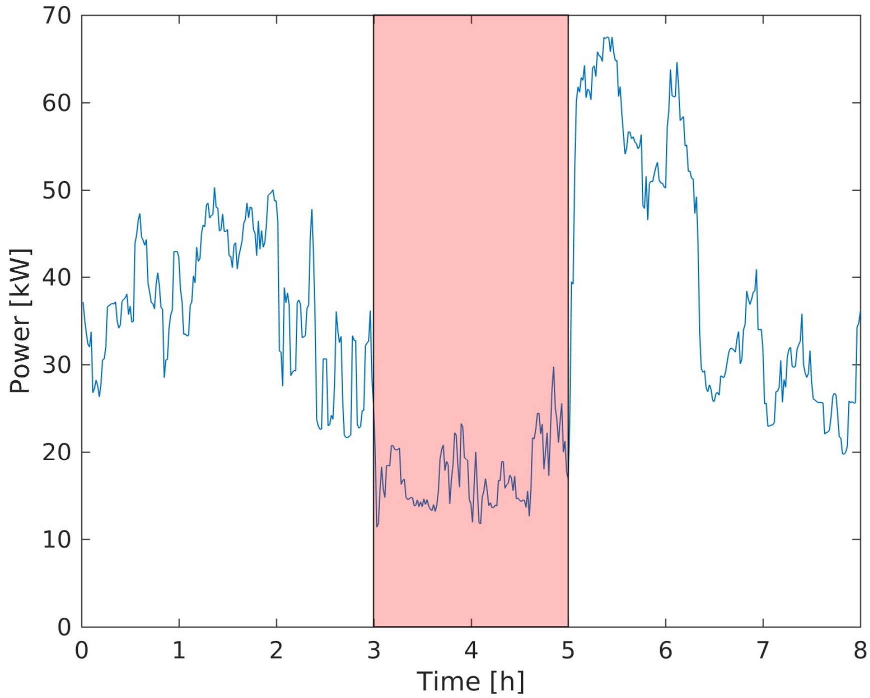


Figure 53 – Overlapped load curve of all 6 houses for all the power cuts of 2 hours. The time slot in red correspond to the power cuts of 2 hours.

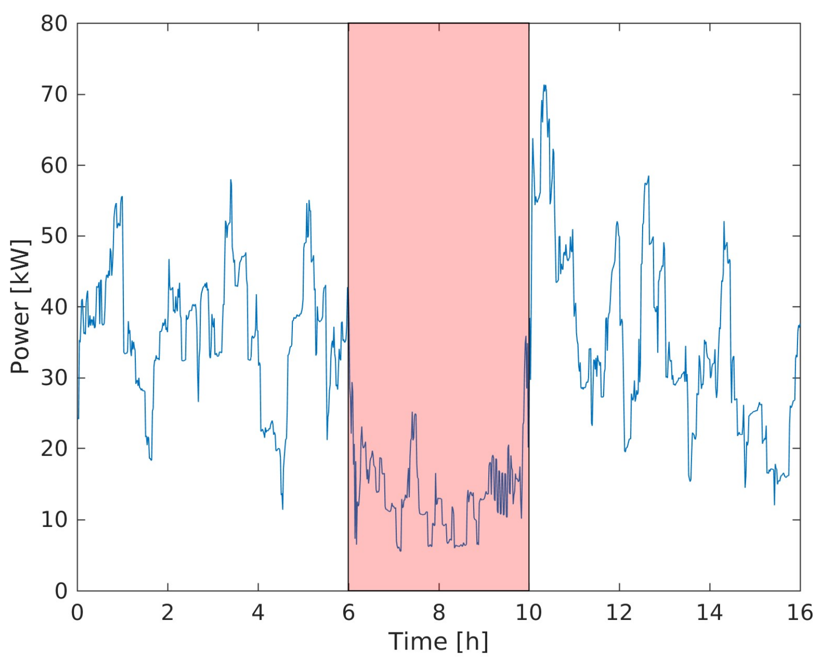


Figure 54 – Overlapped load curve of all 6 houses for all the power cuts of 4 hours. The time slot in red correspond to the power cuts of 4 hours.

Table 7 – Maximum decrease in temperature after the different heating power cuts for each house.

Household ID	ΔT (1 hour)	ΔT (2 hours)	ΔT (4 hours)
103	0.05	0.07	0.19
115	0.00	0.00	0.06
131	0.06	0.07	0.32
134	0.12	0.19	0.17
141	0.02	0.07	0.06
161	0.06	0.19	0.18

Finally, Table 7 shows for each of the six tested houses the maximum decrease in indoor temperature at the end of the different heating power cuts. The maximum decrease is 0.12 °C after a cut of 1 hour, 0.19 °C after a cut of 2 hours and 0.32 °C after a cut of 4 hours. This clearly shows that even relatively long power cuts (4 hours) have a very limited impact on the indoor temperature and definitely do not jeopardize the residents' comfort in terms of home temperature. As for the load curves, more cut tests involving more houses need to be performed in order to better characterize these changes in temperature. Finally, it is interesting to note that, for heating power cuts performed during the day, due to solar gains, the indoor temperature can actually increase during the cuts.

5.3 Heating statistical analysis

Based on the data harvested during the pilot, we try to characterize a building. This analysis was based on uncontrolled data to validate the possibility of characterization without influence on a household. The first analysis allows to define thermal properties of a building based on internal and external temperatures and electrical consumptions.

We define, as a first approximation, the building thermal behavior is modelled by the following differential equation:

$$C\frac{dT_i(t)}{dt} = P_h(t) + P_g(t) - K\big(T_i(t) - T_e(t)\big) \tag{5-1}$$

involving the following variables:

- $T_i(t)$, the indoor temperature, which should be thought as a global, over space averaged, temperature
- $T_e(t)$, the local outdoor temperature, also averaged over space around the building
- $P_h(t)$, the thermal power delivered by the heating system
- $P_g(t)$, the thermal power corresponding to passive gains like solar irradiation and presence of inhabitants

and the following parameters:

- C: the building thermal capacitance
- K: the thermal conductance of the building envelope

The integral form of equation (5-1) is:

$$C\big(T_i(t_2) - T_i(t_1)\big) = \int_{t_1}^{t_2} \Big(P_h(t) + P_g(t) - K\big(T_i(t) - T_e(t)\big)\Big)\, dt \tag{5-2}$$

or, equivalently,

$$\frac{C\big(T_i(t_2)-T_i(t_1)\big)}{t_2-t_1} = \frac{\int_{t_1}^{t_2}\Big(P_h(t)+P_g(t)-K\big(T_i(t)-T_e(t)\big)\Big)dt}{t_2-t_1} \tag{5-3}$$

Since the purpose of the heating system is to keep the indoor temperature almost constant (around 20 °C), $\big(T_i(t_2)-T_i(t_1)\big)$ is rather small. However, since C is relatively large, the product $C\big(T_i(t_2)-T_i(t_1)\big)$ may be not negligible. But the quotient $C\big(T_i(t_2)-T_i(t_1)\big)/(t_2-t_1)$ tends to zero when the time difference (t_2-t_1) becomes large:

$$\lim_{(t_2-t_1)\to+\infty} \frac{C\big(T_i(t_2)-T_i(t_1)\big)}{t_2-t_1} = 0 \tag{5-4}$$

Therefore

$$\frac{\int_{t_1}^{t_2} P_h(t)dt}{t_2-t_1} \cong K\frac{\int_{t_1}^{t_2}\big(T_i(t)-T_e(t)\big)dt}{t_2-t_1} - \frac{\int_{t_1}^{t_2} P_g(t)dt}{t_2-t_1} \tag{5-5}$$

shortly written:

$$\overline{P_h} \cong K\overline{\Delta T_{ie}} - \overline{P_g} \tag{5-6}$$

These equations define thermal dynamic in a building, as the monitored power is the electrical power, we need to convert these equations to electricity. Electricity may be used to produce heat in two main ways: either by Joule effect (resistive heater) or by vapor-compression-refrigeration cycle (heat pump).

In both cases, the thermal heating power$P_h(t)$ is related to the consumed electric power $P_{he}(t)$ by the efficiency factor η:

$$P_h(t) = \eta P_{he}(t) \tag{5-7}$$

In the case of a resistive heating system, η is equal to 1. In the case of a heat pump system,

$$\eta = \frac{1}{1-\frac{T_c}{T_h}} \tag{5-8}$$

where T_c is the temperature of the cold medium (heat source) and T_h is the temperature of the hot medium (heat sink), in most cases the circulating hot water transporting heat into the different rooms.

For every household, the three following time series are supposed to be available: the total consumed electrical power $P_c[k]$ (in some cases available for each phase), the temperature $\theta_i[k]$ given by a sensor placed in a representative room (e.g. living room), and the temperature $\theta_e[k]$ given by a sensor placed outside the building.

The total consumed electrical power is made of the power consumed by the heating system and the power used by other appliances:

$$P_c[k] = P_{he}[k] + P_{oe}[k] \tag{5-9}$$

The electric power consumed by the heating system is linked to the delivered thermal power by equation (5-6), hence

$$P_c[k] = \frac{1}{\eta}P_h[k] + P_{oe}[k] \tag{5-10}$$

then

$$\sum_{k_1}^{k_2} P_c[k]\Delta t[k] = \frac{1}{\eta}\sum_{k_1}^{k_2} P_h[k]\Delta t[k] + \sum_{k_1}^{k_2} P_{oe}[k]\Delta t[k] \tag{5-11}$$

and

$$\frac{\sum_{k_1}^{k_2} P_c[k]\Delta t[k]}{t[k_2]-t[k_1]} = \frac{1}{\eta}\frac{\sum_{k_1}^{k_2} P_h[k]\Delta t[k]}{t[k_2]-t[k_1]} + \frac{\sum_{k_1}^{k_2} P_{oe}[k]\Delta t[k]}{t[k_2]-t[k_1]} \tag{5-12}$$

where $\Delta t[k]$ is the, may-be variable, time interval between two consecutive measured values.

Making use of equation (5-5) and considering that $\theta_i[k]$ and $\theta_e[k]$ are good estimates of $T_i[k]$ and $T_e[k]$, respectively, we get

$$\frac{\sum_{k_1}^{k_2} P_c[k]\Delta t[k]}{t[k_2]-t[k_1]} \cong \frac{K}{\eta}\frac{\sum_{k_1}^{k_2}(\theta_i[k]-\theta_e[k])\Delta t[k]}{t[k_2]-t[k_1]} + \frac{\frac{-1}{\eta}\sum_{k_1}^{k_2} P_g[k]\Delta t[k]+\sum_{k_1}^{k_2} P_{oe}[k]\Delta t[k]}{t[k_2]-t[k_1]} \tag{5-13}$$

shortly written:

$$\overline{P_c} \cong \frac{K}{\eta}\overline{\Delta\theta_{ie}} + \left(\frac{-1}{\eta}\overline{P_g} + \overline{P_{oe}}\right) \tag{5-14}$$

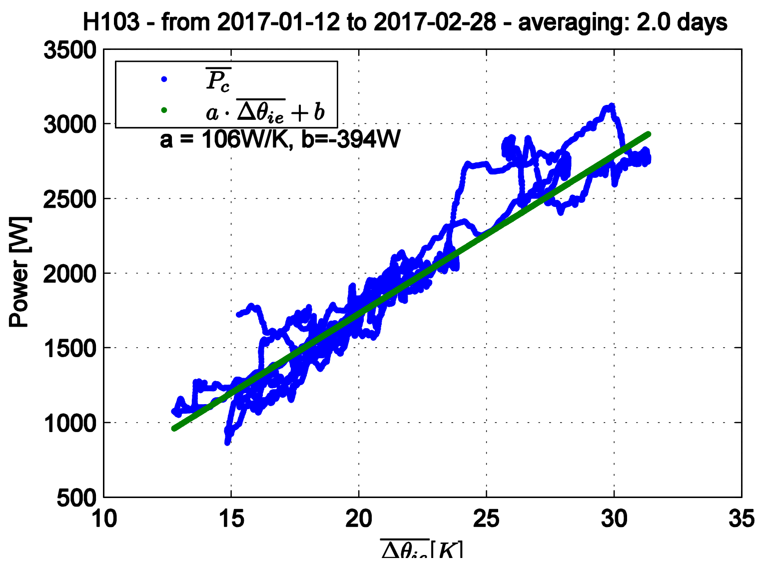
As a conclusion, if the electrical power consumption is mainly due to the heating system and if the efficiency η of the heating system may be considered as constant, the mean consumed power over a sufficiently long time interval varies linearly with the mean difference between of the indoor and outdoor temperatures. The proportionality constant is K/η.

We have applied moving averages on the consumed power $P_c[k]$ and on the temperature difference$\Delta\theta_{ie}[k]$. With this, equation (5-14) gives the overdetermined equations system:

$$\overline{\Delta\theta_{ie}}[k] \cdot a + b = \overline{P_c}[k] \tag{5-15}$$

where the unknowns a and b are determined as the solution which minimizes the mean square error.

Figure 55 compares for household 103 in the period from 2017-01-12 to 2017-02-28 the averaged consumed power $\overline{P_c}[k]$ with the power resulting from the temperature averages $\overline{\Delta\theta_{ie}}[k]$ using the parameters a and b. The averaging time is 2 days. The found parameter values are $a = 106\, W/K$ and$b = -394W$. Subjectively, the matching between the two curves in time domain.



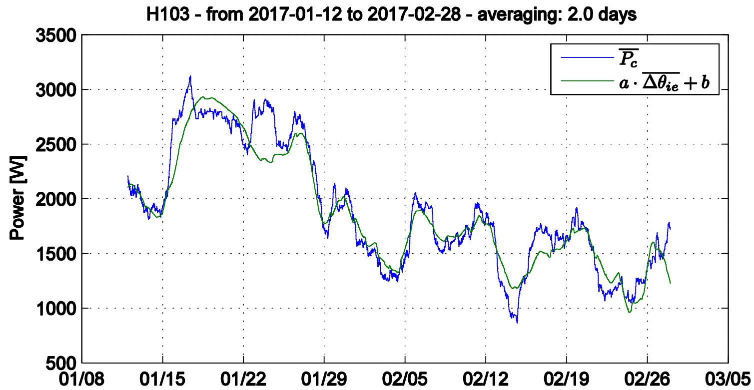
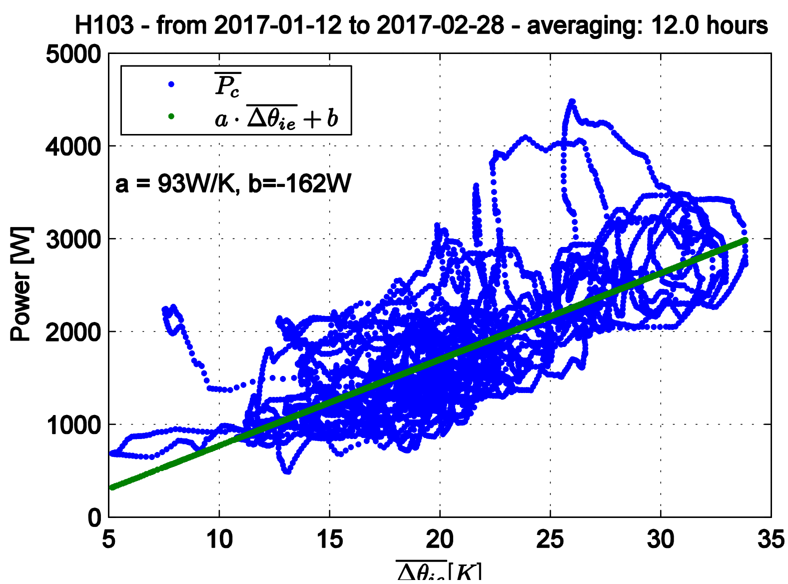


Figure 55 Consumed power compared with the estimated power needed to maintain the internal temperature (case household 103 and 2-days averaging). (i) comparison in the space of the equation system (5-15), (ii) comparison in the time-domain

If the averaging time is decreased to 12 hours, as shown in Figure 56, the matching is however poor. This tends to prove that the heating system controller does not compensate instantly for the changes in heating needs according to the changes in external temperature.



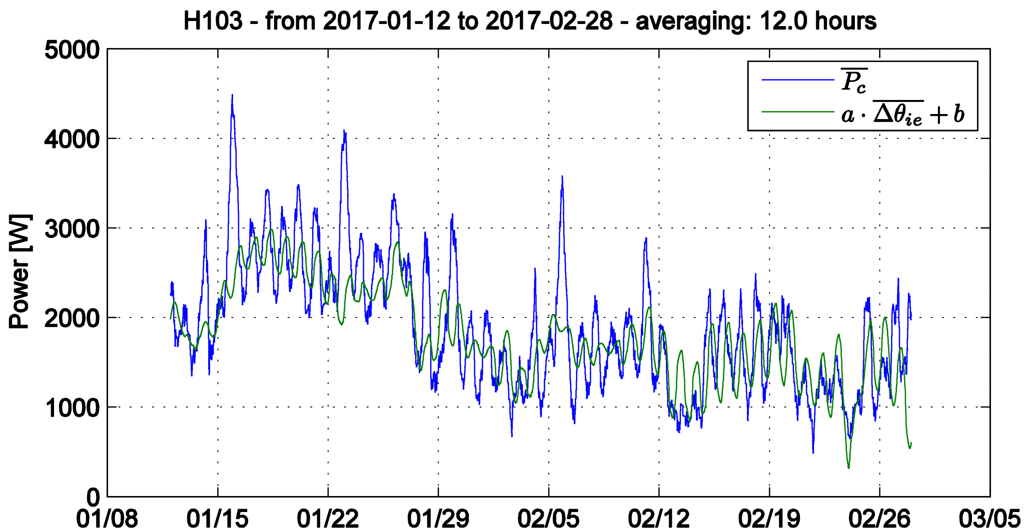
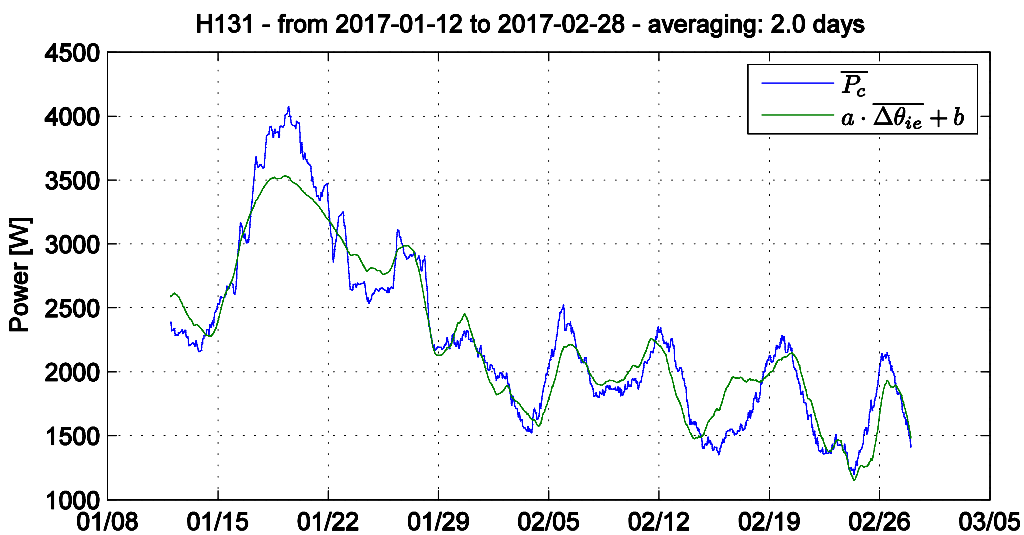


Figure 56 Consumed power compared with the estimated power needed to maintain the internal temperature (case household 103 and 12-hours averaging). (i) comparison in the space of the equation system (5-15), (ii) comparison in the time-domain



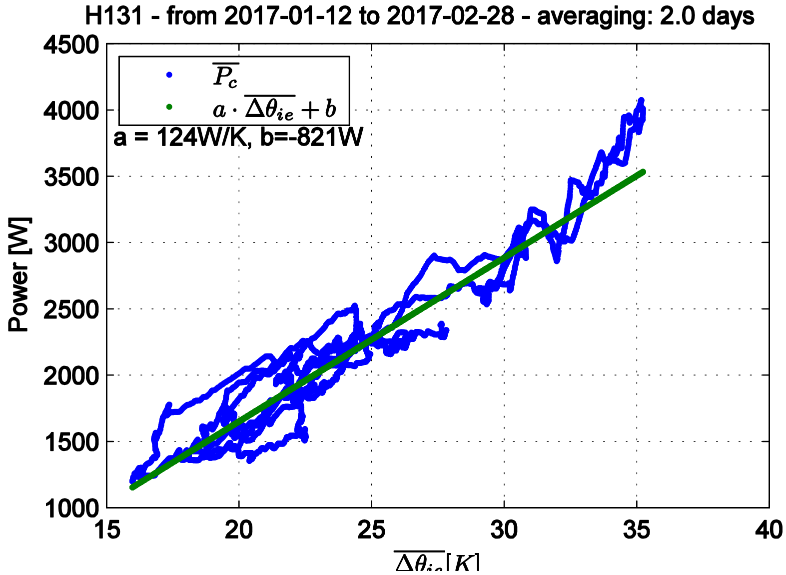
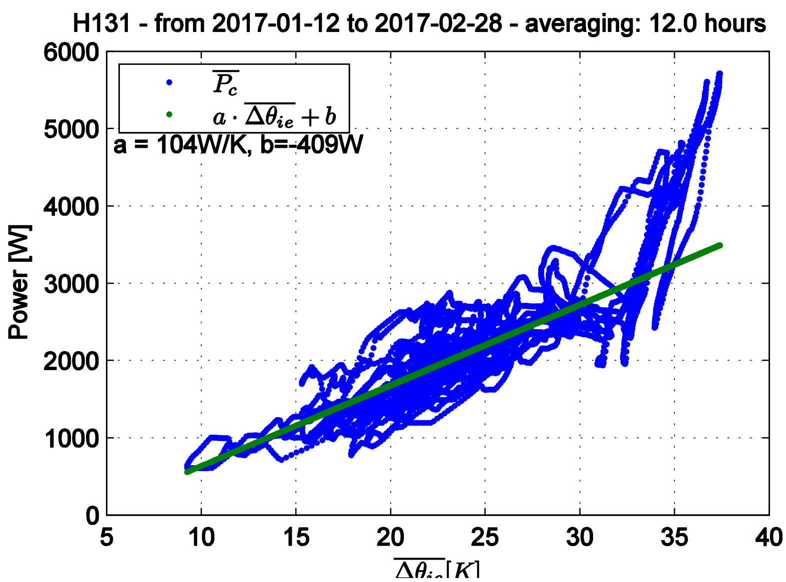


Figure 57 Consumed power compared with the estimated power needed to maintain the internal temperature (case household 131 and 2-days averaging). (i) comparison in the space of the equation system (5-15), (ii) comparison in the time-domain

In the case of household 131 however (Figure 57 and Figure 58), the matching between curves is subjectively good for 2-days averaging as well as for 12-hours averaging. This tends to prove that the heating system controller compensate immediately for changes in outdoor temperature.



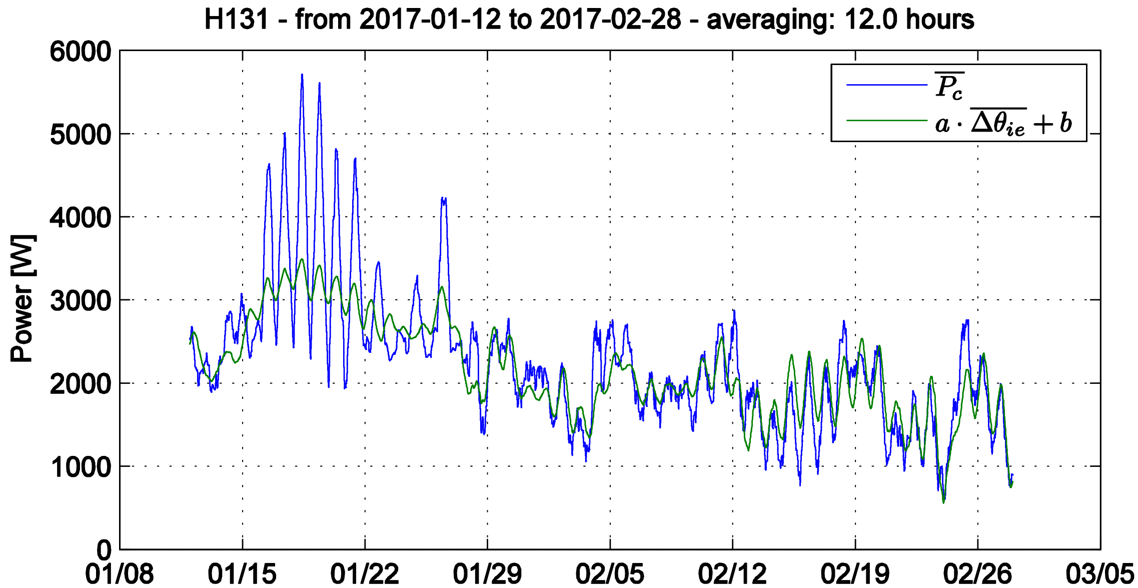


Figure 58 Consumed power compared with the estimated power needed to maintain the internal temperature (case household 131 and 12-hours averaging). (i) comparison in the space of the equation system (5-15), (ii) comparison in the time-domain

In the case of household 131, it can also be observed, especially when averaging over 12 hours (Figure 58), that there is a strong increase in electric power consumption when the difference between indoor and outdoor temperature is above about 32K. This tends to prove that the heating system of household 131 is bimodal.

These analysis on different buildings allows prediction of power consumption given the difference of internal and external temperatures. The error in the precision is based on the approximation of the equation (5-1) but especially on the approximation of the electrical power, as we consider the global consumption as the heating consumption.

5.4 Boiler analysis

In this section, we consider the Swiss pilot households with boiler's metering installation, i.e. houses of Type A. There are 37 households corresponding to this description.

We analyzed the data collected during the period 1st of January 2017 to 18th of April 2017. As reported in section 4.2, some problems have been encountered in the data collection and retrieval.

Figure 59 shows the distribution of temperature measurements for every household of Type A using a box plot. The plot shows the high variability between the households that can be encountered. Some boilers show a very narrow distribution, with temperatures varying in a limited range, as is the case for houses 120, 121, 188, and 189 for instance. On the other hand, houses like 160, 174, 193, and 194 show wider distributions. This difference can be associated with at least two possible phenomena:

- Control systems: boilers are usually controlled using a bang-bang (or on-off) method, meaning that the feedback controller abruptly switches between the on and off states. According to the analysis of measured data two main strategies seems to be uses:
    - Maintain the temperature constant around a given set-point. In this case, the boiler is switched on every time hot water is drew.

  - Switch on the boiler at given time and maintain the temperature above a given threshold.
- Sensors' positioning: some of the temperature sensors were not optimally placed or fell. They are measuring ambient temperature (i.e. house 188) or water temperature coming out of the boiler.

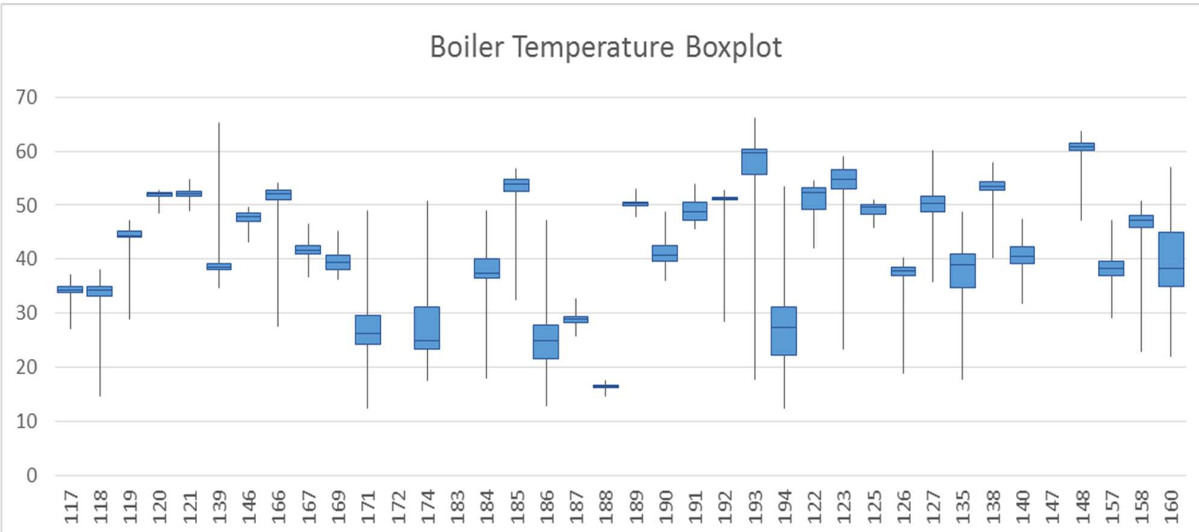


Figure 59 - Boxplot of boiler temperatures for houses of type A.

5.4.1 Preliminary analysis on pre-pilot data

A preliminary study on boiler data of the Swiss pre-pilot was conducted to detect patterns and modelling potential. We present in this paragraph the analysis performed on house 001 considering the following time frame: 1st of February 2016 to the 01 of May 2016.

We started by analysing the on and off time of the boiler (Figure 60). The histogram of the boilers on time shows that it is generally switched on during 7 minutes and then switched off. The off-period duration is quite variable, as it can be seen in Figure 61. The boiler temperature when the power is switched on has a mean value of 52.3 °C and a standard deviation of 1.9 °C, when the power is switched off the mean is of 52.8 °C and the standard deviation 1.6 °C. The Gaussian shapes of the temperature distribution during the mentioned times suggest that the boiler controller is not correlated with the measured boiler temperature. This is consistent with the fact that the boiler temperature that is recorded, is measured at 2/3 of the boiler's height, while the controller uses the temperature at the base of the boiler.

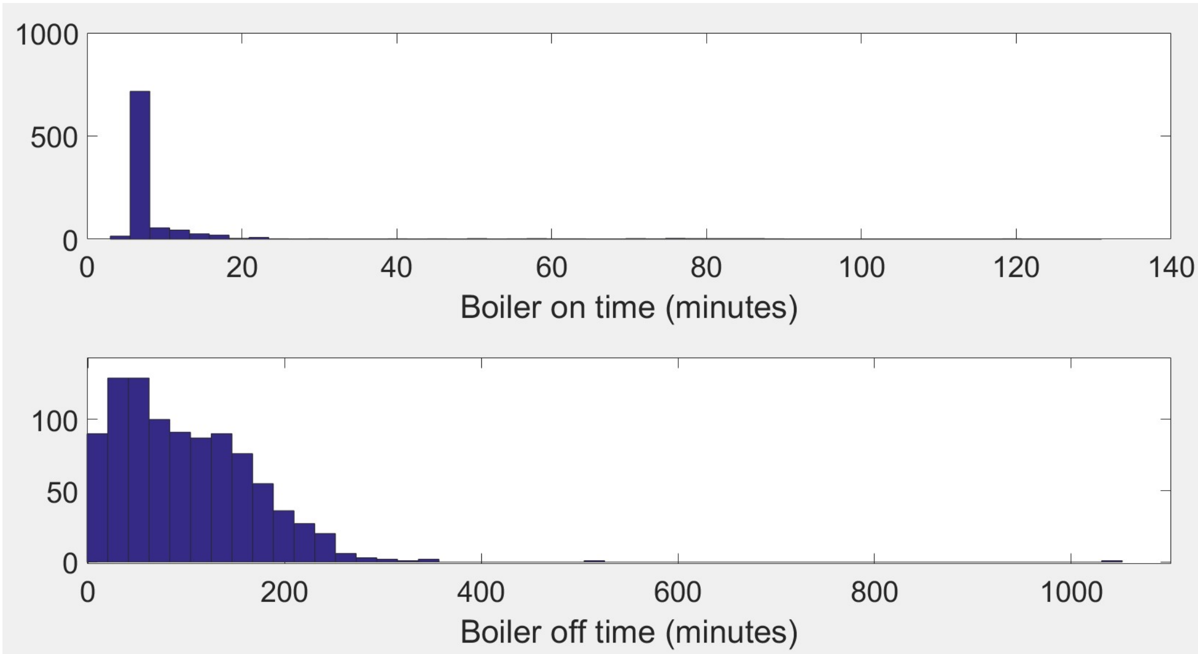


Figure 60 - Histogram of boiler on and off time duration

In Figure 61 and Figure 62 the average hourly consumption and boiler temperature are showed. No clear patterns can be detected from these plots. We could infer that higher consumption is measured in the morning, but the pattern is not regular enough to be used for modelling. A stochastic approach might be preferred in this case, given the stochastic nature of water consumption and the poor correlation between the temperatures measured at the boiler and its consumption.

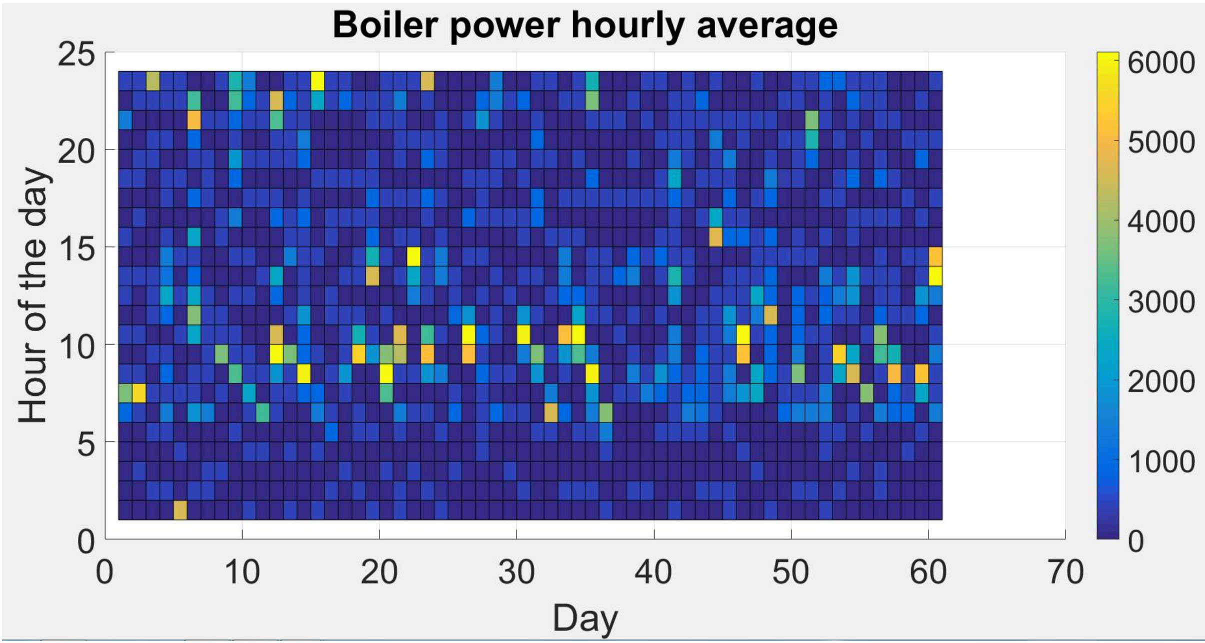


Figure 61 - Boiler power consumption hourly average

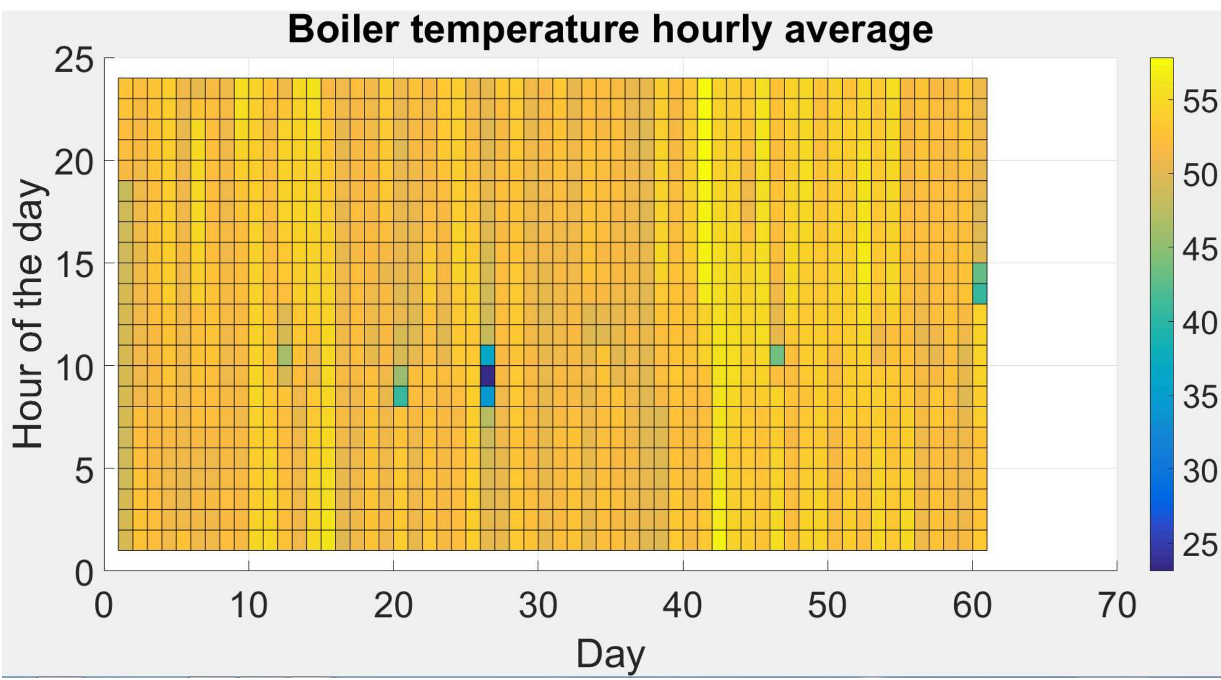


Figure 62 - Boiler temperature hourly average

5.4.2 Boiler model

Three parameters are computed to characterize the boiler behavior:

- *heatLossRate*: the average temperature decrease when the boiler is off. This represents the amount of heat lost in standard conditions, which is strictly linked to the insulation properties of the water tank. This is computed as the average of the negative temperature variations that are included in a specific range, defined statistically. This restriction is added to avoid accounting for the faster temperature decreases that occur when hot water is used in the house.
- *heatLossMax*: the maximum temperature decrease, which occurs when the hot water is used.
- *heatGain*: the average temperature increase, which is directly linked with the boiler energy consumption. A delay exists between the increase of the boiler consumption and the increase of temperature, since the temperature sensor is placed at 2/3 of the boiler's height.

These three parameters define a first simplified model of the boiler functioning, which could then be refined by adding a stochastic model of water consumption.

5.4.3 Power cut tests

Power cut tests were performed in order to:

- Test the relationship between the back-end and the front-end
- Characterize the boiler, namely the impact of power cuts of various durations on hot water temperatures, as well as on the load curves
- Investigate to what extent these power cuts can be implemented for peak shaving, price optimization and other purposes, while guaranteeing the residents' comfort in terms of both hot water and home temperatures.

A first batch of tests on households of type A consisted in setting the boiler power relays to 0 for a duration of 1 to 3 hours. The tests schedule is reported in Table 8.

Table 8 - Schedule of boiler power cuts

	Start Time	Stop Time	Duration	Households
23.01.2017	09:00:00	10:00:00	01:00:00	All
	12:00:00	13:00:00	01:00:00	All
	15:00:00	16:00:00	01:00:00	All
24.01.2017	08:00:00	10:00:00	02:00:00	All
	14:00:00	17:00:00	03:00:00	All
25.01.2017	07:00:00	09:00:00	02:00:00	All
	13:00:00	17:00:00	04:00:00	All
26.01.2017	06:00:00	09:00:00	03:00:00	All
	15:00:00	17:00:00	02:00:00	All

The graphs below show, for a single household, the measured boiler temperature and power consumption. Time is expressed in days starting from the 1st of January 2017 and the time slots highlighted in red corresponds to the scheduled power cuts.

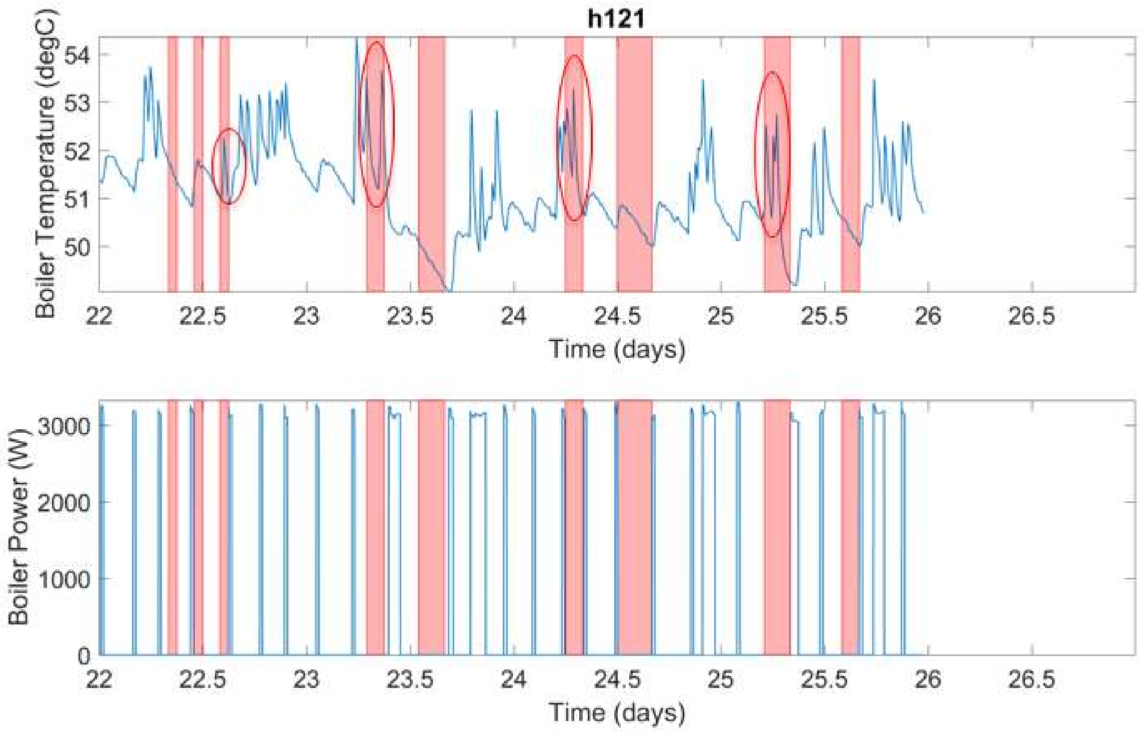


Figure 63 – House 121 measured boiler temperature and power. Power cuts are performed by opening the power relays. Power cuts are highlighted in red.

Figure 63 shows the measured data during the test periods for house 121. As highlighted by the red circles on the top graph, there are some problems with the temperature measurements, as the temperature increases also during the power cuts, when no thermal energy is added to the water. These temperature spikes might be explained by the sensors placement, as mentioned in paragraph in Section 4.2.7. In fact, if the temperature sensor is placed on the pipes, it would measure an increase when hot water is used and thus flowing into the pipes and not when water is heated.

Figure 64 shows the behavior of house 146, which is performing as expected. During power cuts, there is no power consumption and the temperature is decreasing.

The boiler's parameters computed for house 146 are:

- *heatLossRate* = -4.7 °C/day. This means that, on average, the boiler water temperature decreases by 4.7 °C every day due to heat losses
- *maxHeatLoss* = -13.8 °C/day. The maximum rate at which temperature decreases within the boiler is 13.8 °C per day, or 0.57 °C/hour.
- *heatGain* = 41.2 °C/day. On average, when the boiler is switched on the water temperature increases with a rate of 41.2 °C/day or 1.71 °C/hour.

The computed parameters show that the maximum temperature drop that we can expect in 1 hour can be compensated by switching on the boiler for 20 minutes. Furthermore, if we perform a power cut of 3 hours we can expect a decrease in temperature between 0.59 and 1.71 °C, which can then be compensated by switching on the boiler for 20 to 60 minutes. These parameters can be useful in computing the flexibility offered by the boiler for the scheduling algorithm.

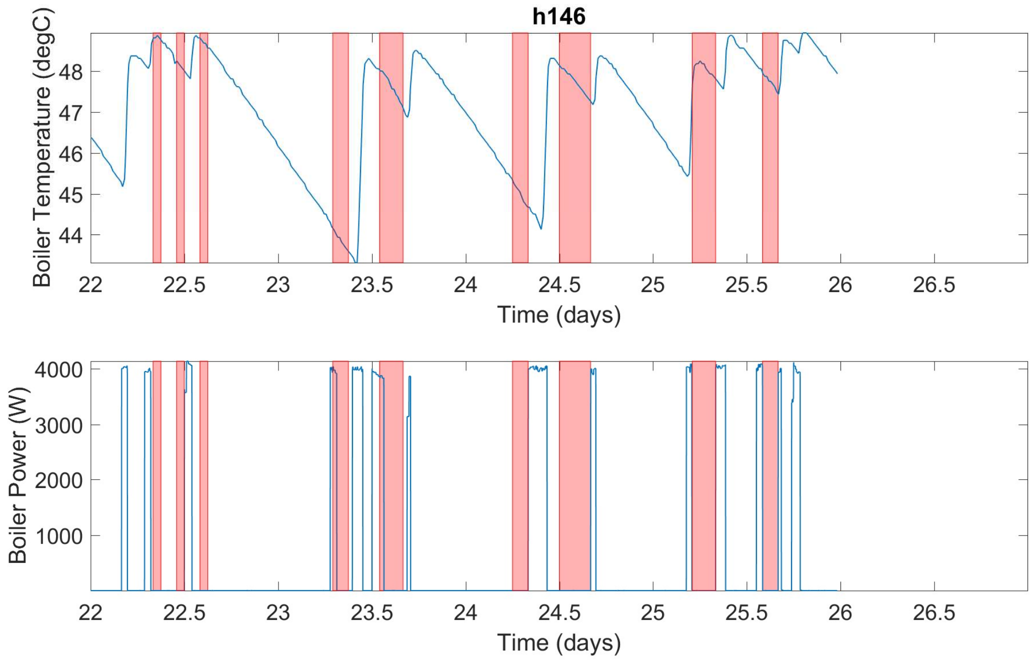


Figure 64 - House 146 measured boiler temperature and power. Power cuts are performed by opening the power relays. Power cuts are highlighted in red.

5.5 Stochastic Scheduler evaluation results

During the pilot, the test cases regarding the SEMIAH stochastic system described in D5.4 were conducted with real households and real inhabitants. For testing, the households used were those meeting the requirements of the flexibility forecast introduced in Neuchatel in September 2015 as the flexibility forecast is one of the basic input parameters for the SEMIAH stochastic system. 30 such households in Norway and 11 households in Switzerland were used for the stochastic scheduler evaluation.

5.5.1 Results for Norway

For the pilot and pre-pilot households in Norway measurement data were collected since September 2016 to generate the flexibility forecast. Figure 65 and Figure 66 show some examples of the flexibility forecast. Flexibility forecast is developed as probabilistic forecast in term of quantiles for the set of quantiles [0.01, 0.05, 0.1, 0.15, 0.2, …, 0.85, 0.90, 0.95, 0.99]. On the graphs below, quantiles are illustrated by the blue areas. The red line represents the expected value from these quantiles.

Based on the flexibility forecast, user constraints and grid constraints, the SEMIAH stochastic system generates the cost optimized schedules to manage the Demand Response of the households. Then, the system transmits the schedule to the households.

As the smart plugs were removed before the evaluation phase, the schedules of the SEMIAH stochastic optimization cannot be sent to the households. That is why there are no evaluation results for the households in Norway.

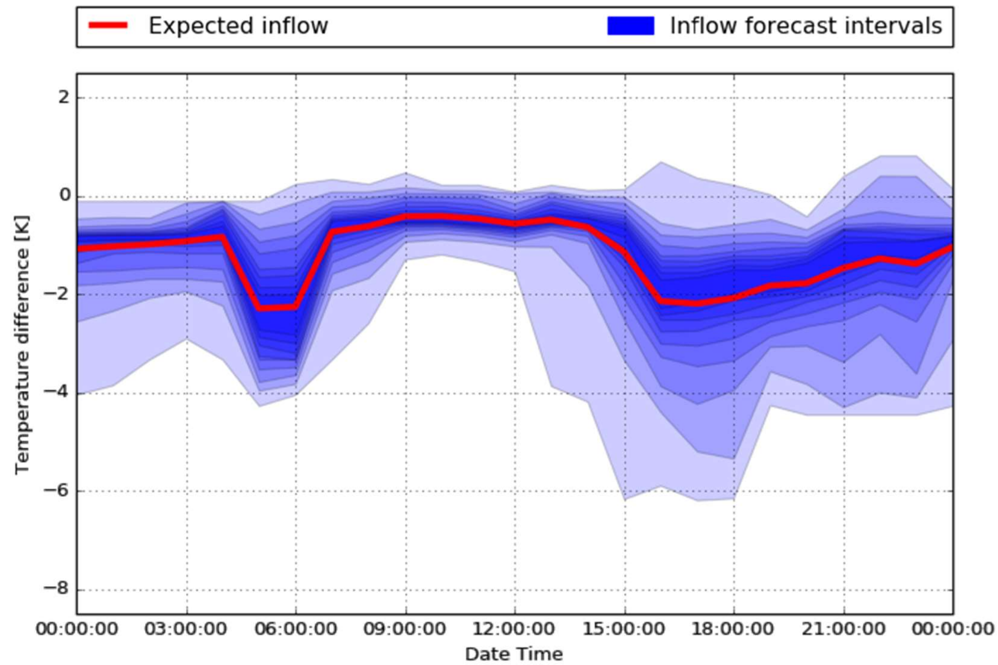


Figure 65 - Flexibility forecast for the household 281 for 20.12.2016

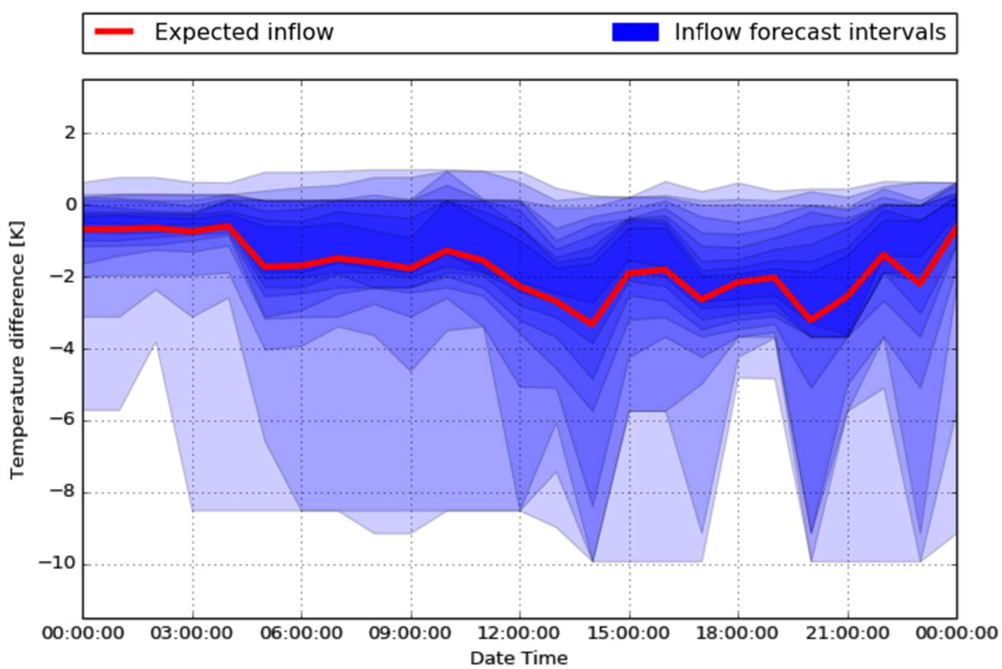


Figure 66 - Flexibility forecast for the household 273 for 15.04.2017

5.5.2 Results for Switzerland

During the pilot test the SEMIAH stochastic system can be evaluated with the households in Switzerland. There are 2 pre-pilot and 9 pilot households in total.

Table 9 - Pre-pilot and fully functional pilot households in Switzerland

Households	Installation Type	Capacity [kW]	Volume [l]
001	Boiler + heating	6	300
010	Boiler + heating	4	400
138	Boiler only	0.6	300
146	Boiler only	4.2	300
148	Boiler only	0,8 (1,7)	300
164	Boiler only	4,6	300
166	Boiler only	3,3	300
167	Boiler only	4,2	300
185	Boiler only	3,4	300
189	Boiler only	3,4	300
192	Boiler only	6	300

From these households, 6 households are used to form a first group. This first group will be managed by the SEMIAH stochastic system. A second group is also defined and consists of 6 "reduced functional" households. For these households, temperature measurements are not present, and flexibility forecast is not possible. But measurements of the global consumption are enough to determine costs, which is necessary to compare the costs of the two groups. The Table 10 and Figure 67 give information about the households in these groups and their location.

Table 10 - Groups of households for the evaluation

Group	Households	Total capacity
Gr1: managed households	001, 148, 164 167, 185, 192	26,5 kW
Gr2: unmanaged households	117, 139, 157 169, 174, 191	25,7 kW

Figure 67 - Managed (red) and unmanaged (green) households in the Swiss pilot

From the 11 households, the household 010 is excluded because of the frequent connection state errors with IWES.vpp. However, these frequent connection state errors did not occur with the Front-end server. Figure 68 shows the connection state for this household. The households 166 and 189 were connected after the test was started. The first forecasts for these households were computed on 09.04.2017 and 12.04.2017 respectively.

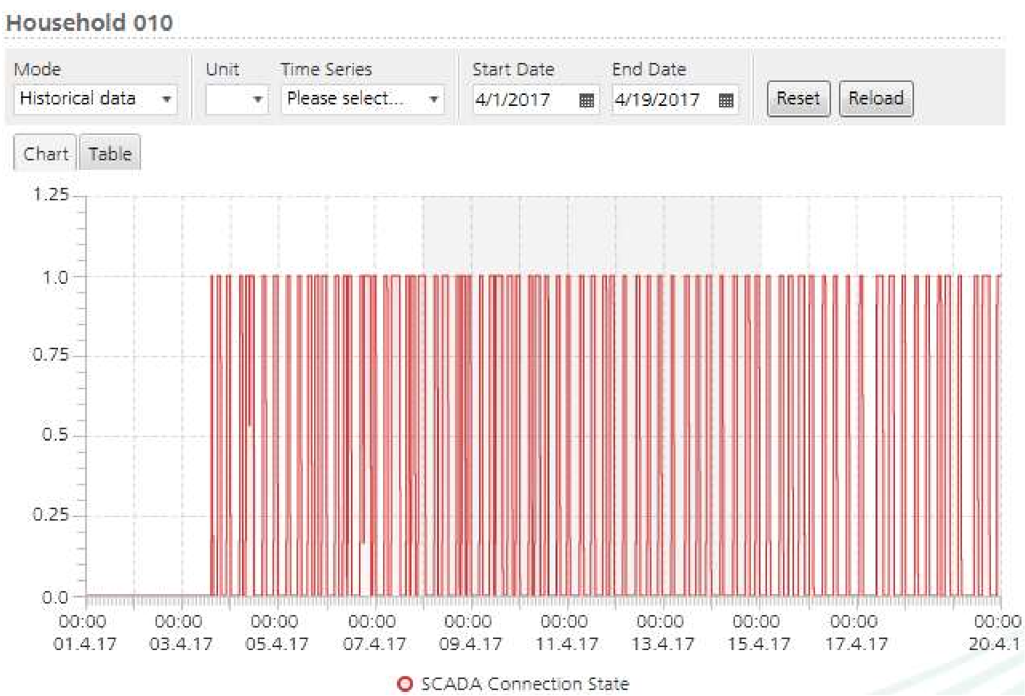
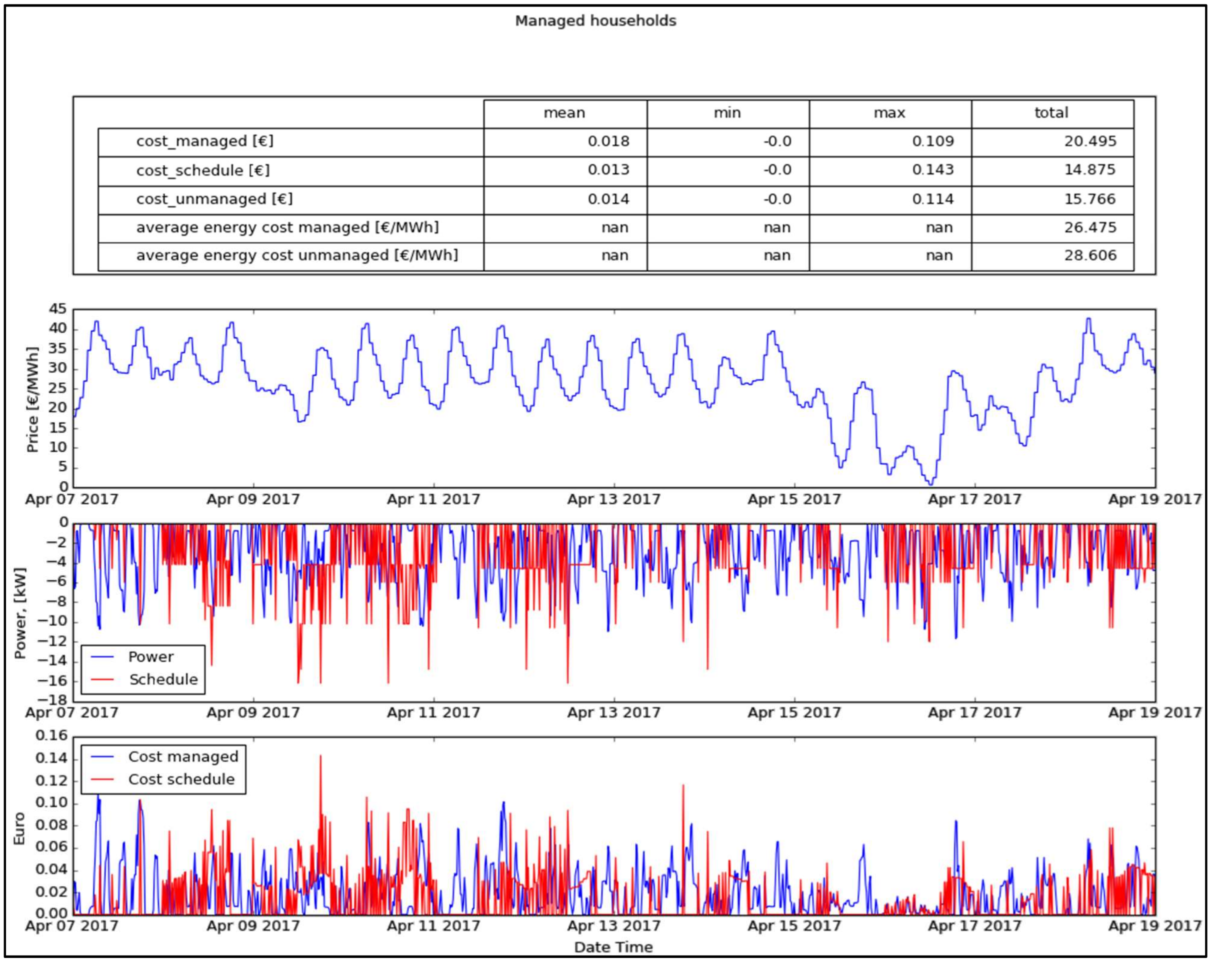


Figure 68 - Connection state of the household 010

The control of the households of Group 1 was started on 06.04.2017 and for the evaluation of the SEMIAH stochastic system, two weeks of data were collected, from 07.04.2017 till 19.04.2017. With these data, we analyzed the cost effectiveness of the managed households, if the schedules are held and if the temperature after the optimization satisfies to the user constraints.

In the Figure 69, the power and schedules for all managed households are illustrated. The table presents the cost results. The energy price is shown in the first plot, the power and schedules for all managed households are displayed in the second plot and the last plot is a graph of the cost as a time series for the managed households and for the schedules.



	mean	min	max	total
cost_managed [€]	0.018	-0.0	0.109	20.495
cost_schedule [€]	0.013	-0.0	0.143	14.875
cost_unmanaged [€]	0.014	-0.0	0.114	15.766
average energy cost managed [€/MWh]	nan	nan	nan	26.475
average energy cost unmanaged [€/MWh]	nan	nan	nan	28.606

Figure 69 - Power and schedules for all managed households

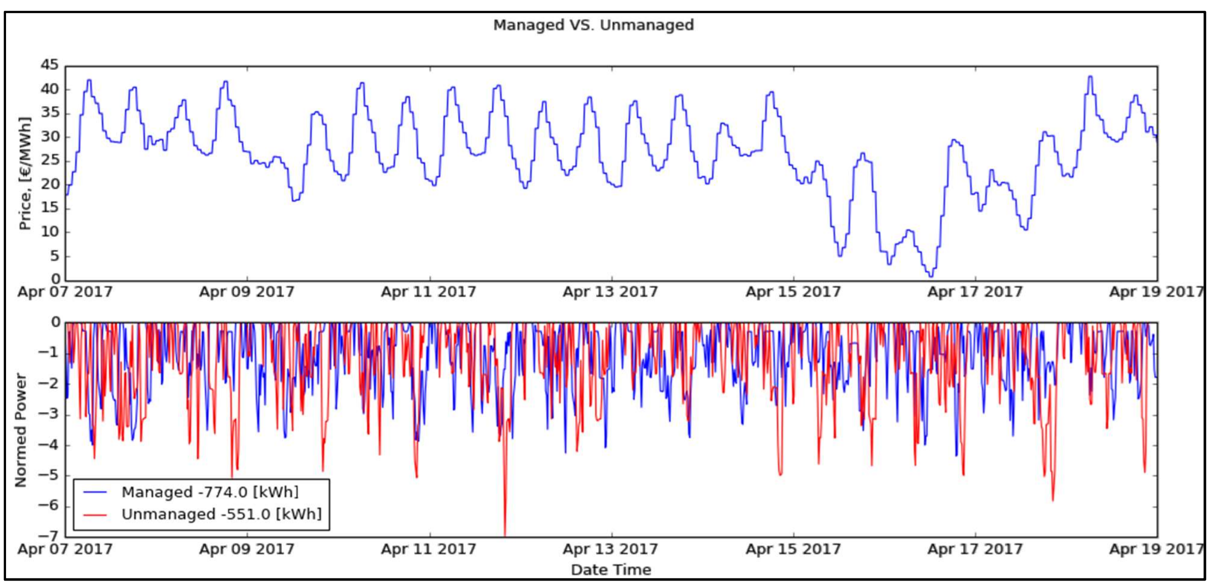


Figure 70 - Normed power and schedules of managed households

As shown in the table in the Figure 69, the total cost for the controlled households during the considered 2 weeks is 20.5 euros. For the same period, the total cost of the unmanaged households is 15.8 euros. It is because the absolute power values are not comparable – the total absolute energy for managed households is equal to 774 kWh, and for the unmanaged households is equal to 551 kWh. To group quite similar households was impossible because of the lack of households with correct measurement data. But the calculation of the average energy cost shows, that the demand of the controlled households is cheaper as the demand of the unmanaged households – the average energy cost for the managed households is equal to 26.5 €/MWh and the average energy cost for the unmanaged households is equal to 28.6 €/MWh.

In order to analyze the temperature profile and if the schedules are held, we consider individual households.

The Figure 71 shows the results of the energy management for the household 001 from 07.04.2017 00:00:00 till 19.04.2017 00:00:00 (all times are specified in UTC). In the first plot the energy price is presented, the power and schedules are in the second plot, the third plot shows the temperature profile with temperature limits (caption is wrongly stating it as kWh, when it is degrees), and the last subplot is the flexibility forecast.

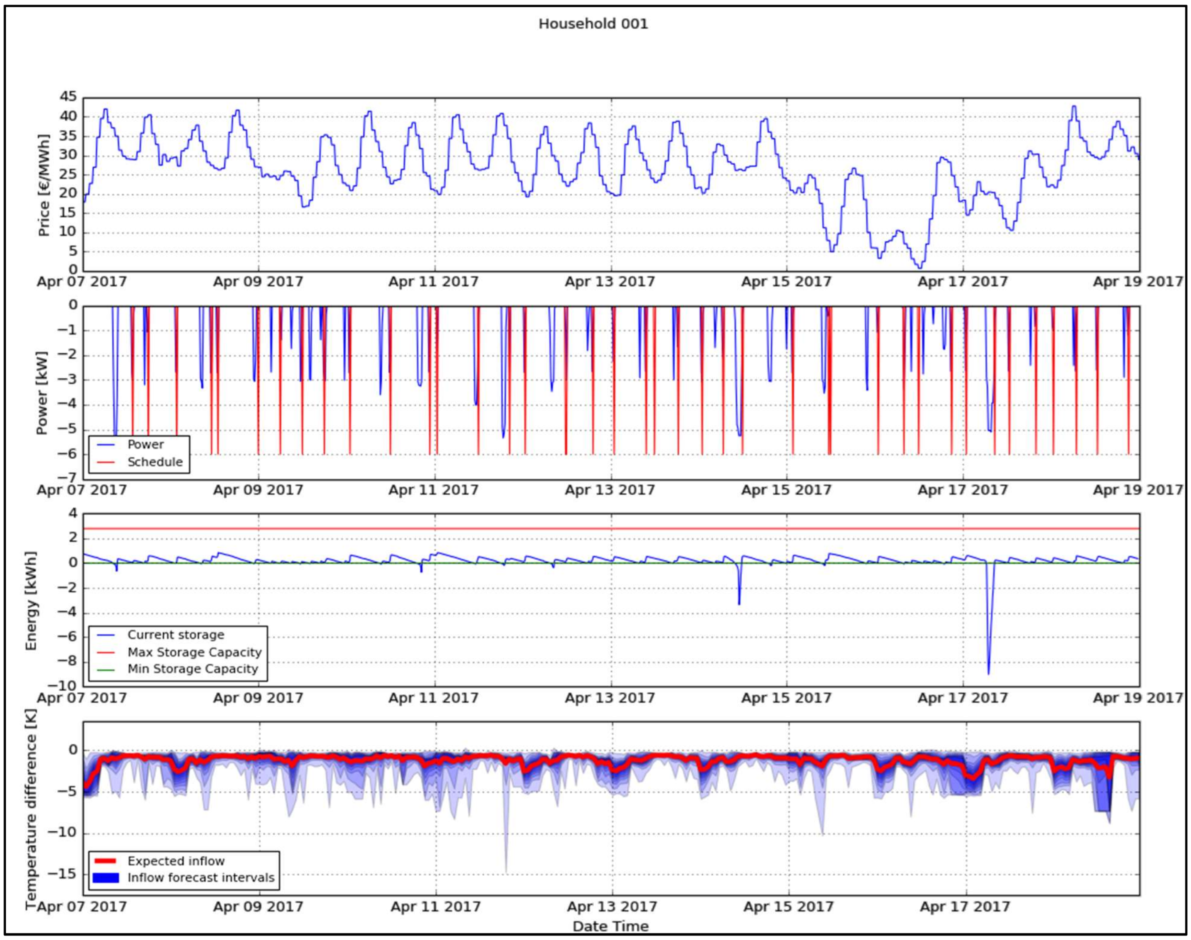


Figure 71 - Energy management for the household 001

To go further in the temperature profile and how the schedules are held, let us consider a small-time period. For example, the Figure 72 illustrates results for the same household 001 for one day, namely from 10.04.2017 00:00:00 till 11.04.2017 00:00:00. On the graph, we can see that boiler were started 5 times. Two starts were during a temperature limits violations. The system allows the boilers to be switched on immediately if there are limit violations where the temperature is lower than the specified lower limit, which we see in the picture at about 9 a.m. and about 8 p.m. Other three cases of the electricity consumption correspond to the schedules. The optimization generates schedules

considering the energy price, user constraints (temperature limits) and the flexibility forecast. It implies that if the current temperature in the boiler is between the limits, and there is demand according to the flexibility forecast and the energy price is low, then we can charge the hot water storage. And this can be observed in the Figure 72.
Also, we see in this figure that there is a bit time shift in the setting of the schedules. We suspect that it can be due to the technical communication.

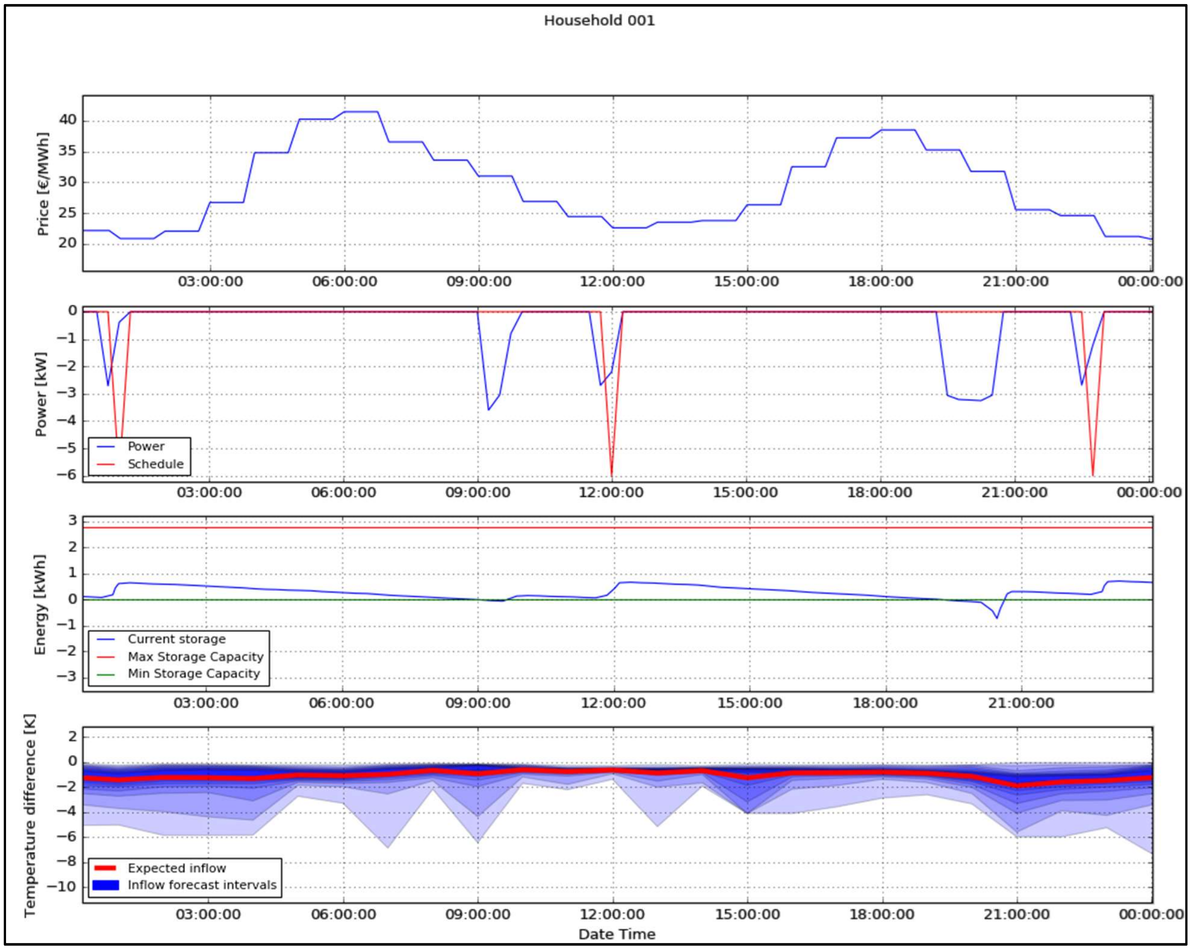


Figure 72 - Energy management for the household 001 from 10.04.2017 00:00 - 11.04.2017 00:00

The next example is the household 185. Its results are shown in the Figure 73 and Figure 74. As with the household 001, we see the temperature limits violations where the current temperature is below or close to the lower limit. In these cases, the boiler starts even if the measured temperature is not below the lower limit, but close to the lower limit. It can be explained with the setup of the field test applications. The temperature values shown in the Figure 74 are measured at upper 1/3 part of the heat storage, whereas the boiler has its own temperature sensor placed in the bottom of the storage. Due to the differences of these temperature measurements (thermal stratification), the boiler can start operating even if the temperature in upper third storage doesn't falls below the lower limit.

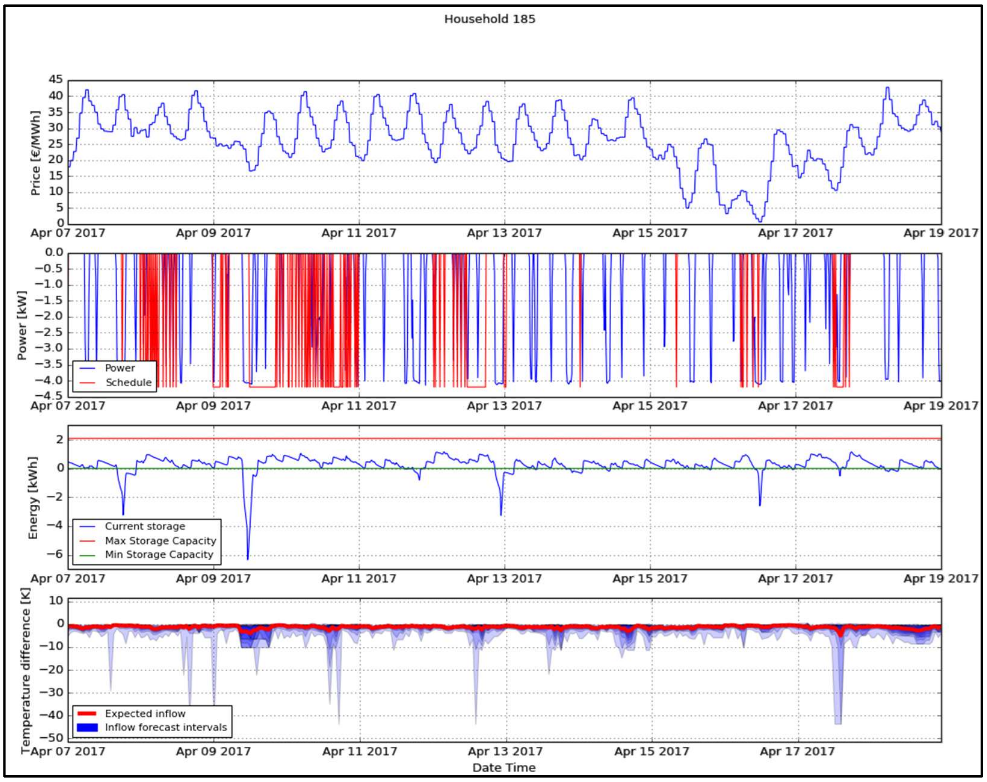


Figure 73 - Energy management for the household 185

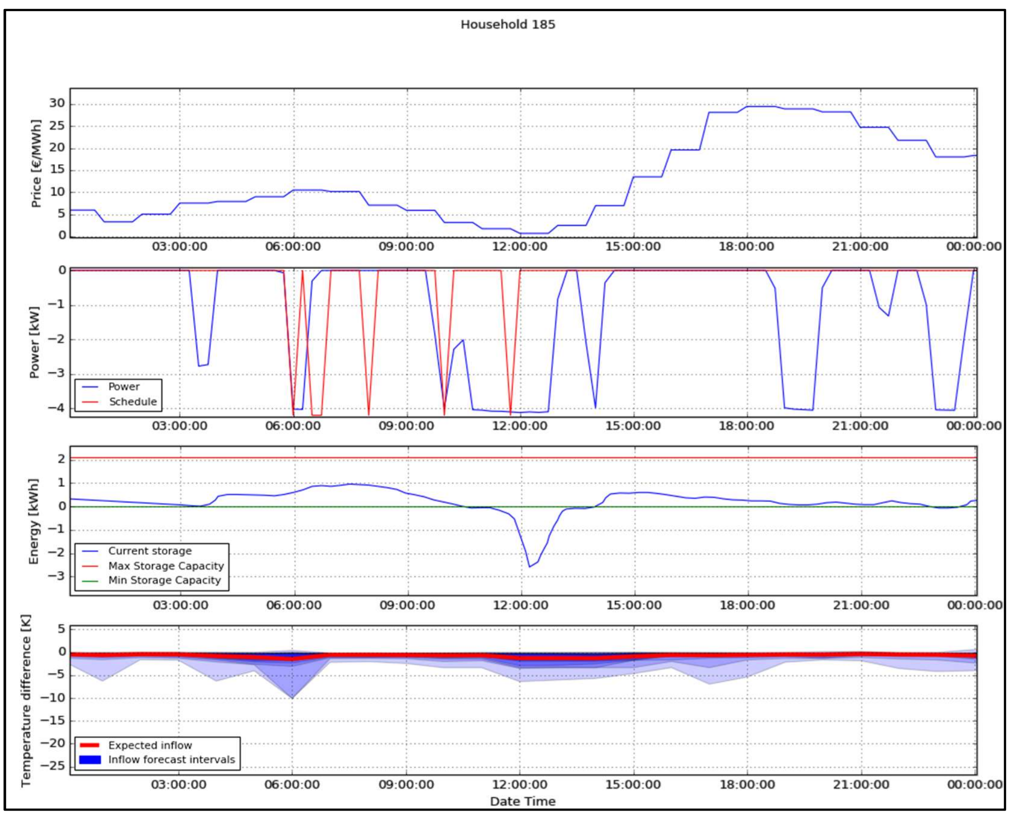


Figure 74 - Energy management for the household 185 from 16.04.2017 00:00 - 17.04.2017 00:00

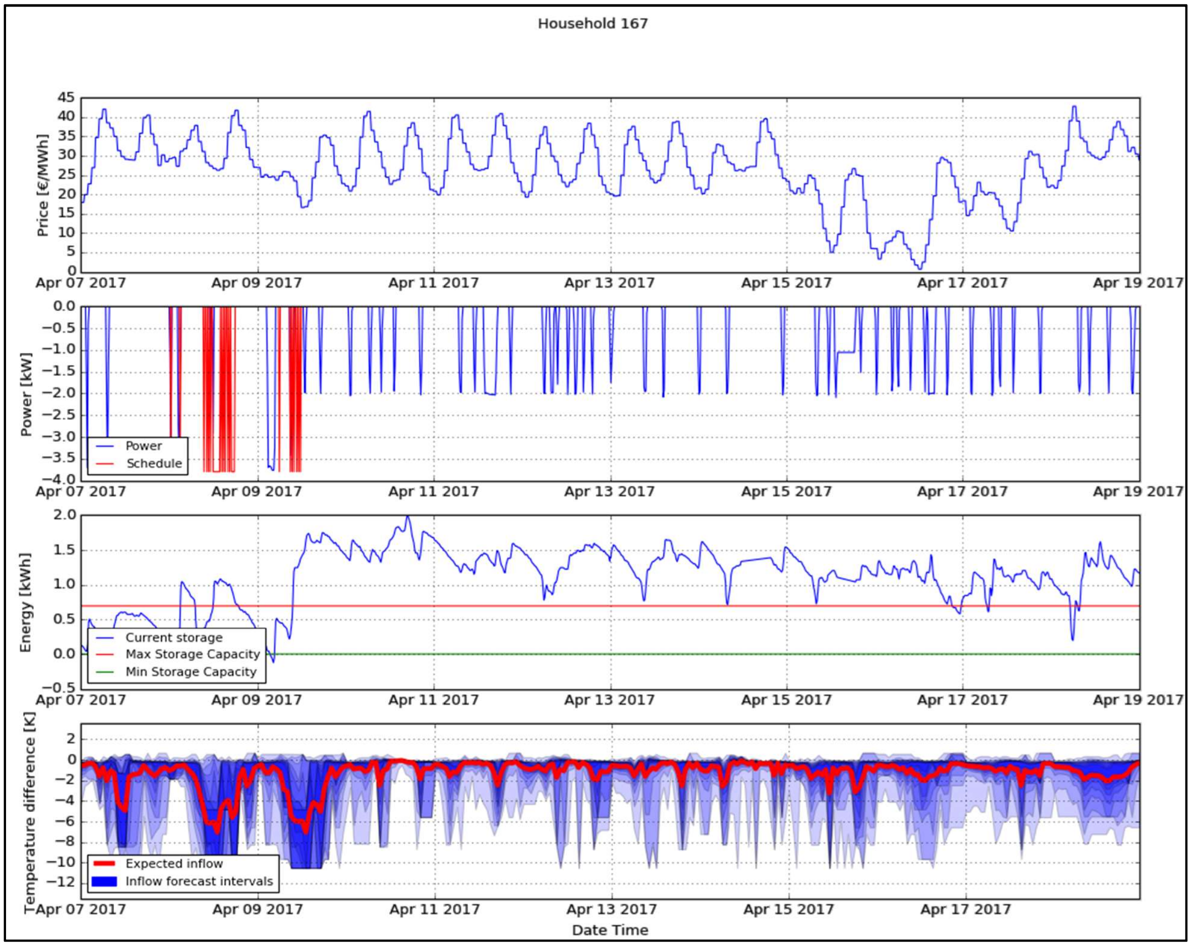


Figure 75 - Energy management for the household 167

The example with the household 167 (Figure 75) shows that the configuration of temperature limits was not correct or they were changed locally after the initial configuration. For the scheduler, this situation means that the current temperature is above the upper temperature limit, and that's why it is not needed to charge the hot water storage.

In summary, despite some incorrect configuration data and some technical communication problems we could show, that the SEMIAH stochastic system can save the cost. In our test with 6 households during two weeks the average savings are about 8%. If all deficiencies will be fixed there is potential to save even more.

6 User comfort

During the whole pilot phase, it was almost surprising how few reactions came from the participants about their comfort. There were some critical cold showers (hardware malfunctions, or installation errors provoking software malfunctions), but they remained really few and they could be easily explained. Moreover, they were not inherent to the usage of water or space heating installations. There were still sort of "placebo effect" people complained about the solution, even if it was not currently active. As a result, the use of space and water heating installation was demonstrated as a good idea to facilitate user involvement and guaranty his comfort.

7 Conclusion

This report presents the whole installation of the pilot in both Norway and Switzerland. It also presents the hardware used and how it was installed inside the households. It presents finally the results achieved during the pre-pilot and pilot phases.

From these results, the first element that can be extracted is that the pilot phase was not completely successful. Multiple reasons can be listed to explain the absence of a perfect result. The first one was the selection of a ZigBee communication between the different components installed to measure or control the appliances, and the central gateway. The topology of the buildings where the SEMIAH solution was installed (boilers in basement, electrical meters outside…), as well as the sources of damping (concrete walls, metallic cabinets…) and interference (WIFI interaction) were the cause of a lot of data transmission problems that impaired the stability of SEMIAH solution. The second problem was the inadequacy between the back-end (IWES.VPP) requirement for control and the possibilities offered by the existing electrical appliances and the useable hardware to control and measure those appliances. The third problem was a new Norwegian regulation that forbids the use of plugs on more than 1.5 kW boiler appliances. Other problems also impacted the pilot, but on a smaller scale, such as hardware or software malfunction, participant behavior, GPRS communication problems, etc. All these problems explained why only a small number of households were totally controlled by the full SEMIAH solution.

However, even if those problems were critical for running the pilot phase, they are not reducing the potential of a product based on SEMIAH achievements. The pilot phase showed that it is possible to install hardware to control and measure heating appliances. It showed also the potential of theses appliances and the flexibility offered, as well as the simpler interaction involved by the solution with the end-user, more than if the focus was on controlling washing machines. It shows also the potential of the ICT solution deployed and the possibility of using the internet connection of the end-user. Indeed, the Front-end server has been online since the beginning of the pre-pilot and is still fully operational and collecting data more than a year and a half later. SEMIAH pilot phase paved thus the way to a DSM solution that would be reliable, flexible, and feasible. The pilot phase showed also the excellent stability of the Develco Gateway, as well as the main software components installed (Front-end, OGEMA, IWES.VPP), that all run for a long duration.

To achieve a working product, there is still a long way to go, but no insurmountable obstacle seems to be on the way. A first task would be to reduce the communication problems both inside and outside the household. For in-house communication, going to lower frequencies (sub-gigahertz) should provide a solution, whereas GPRS communication could be optimized. A second task would be to improve the back-end to be more adequate with what existing installations and households can offer. Finally, the lack of a good tool showed also how much a full provisioning system is mandatory to handle a big number of households, to verify installations, monitor the pilot status, detect failures, and remotely update the gateways. It indicates also that the solution should be kept as simple as possible on the gateway to reduce the burden of keeping it running.

Finally, even if SEMIAH pilot was not a complete success, it showed the possibilities of the foreseen solution and demonstrated the good operation of most of the SEMIAH components.