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Energy Demand-Aware Open Services for Smart Grid Intelligent Automation

SmartHG

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Target Outcome	**d**) Home energy controlling hubs that will collect real-time or near real-time data on energy consumption data from smart household appliances and enable intelligent automation.

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To make this deliverable suitable for public dissemination, test-bed data have been anonymized.

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List of Acronyms

ADR Autonomous Demand Response

DaaS District as a service

DAPP Demand Aware Price Policies

DB&A Database and Analytics

DLC Direct Load Control

DSO Distribution System Operator

EBR Energy Bill Reduction

EDN Electric Distribution Network

EUMF Energy Usage Modelling and Forecasting

EUR Energy Usage Reduction

EVT EDN Virtual Tomography

GIAS Grid Intelligent Automation Service

HECH Home Energy Controlling Hub

HIAS Home Intelligent Automation Service

IAS Intelligent Automation Service

KPI Key Performance Indicator

PEV Plug-in Electric Vehicle

PPSV Price Policy Safety Verification

PV PhotoVoltaic

SEIL Smart Energy Integration Lab

ToU Time of Usage

Executive Summary

Objectives The purpose of this document is to describe second year achievements of SmartHG WP6. This WP started on M12 and its role within SmartHG is that of building test-beds to gather field data in order to enable evaluation of the services developed inside SmartHG.

Achievements We completed deployment of sensing and communication devices in 20 homes in Svebølle (Kalundborg, Denmark) out of the 25 planned in the project. We had problems with Belarus customs in shipping hardware devices there. Accordingly, so far we were only able to plan sensor deployment in Minsk and send there smart meters. In order to meet our goal of having two different test-beds ready by the end of second year as a recovery plan we deployed a test-bed in Central District (Israel). So far in Israel we completed deployment of sensing and communication devices in 9 homes out of the 13 foreseen in our present recovery plan. Finally, we are also experimenting with actuation of energy storage devices (modelling Plug-in Electric Vehicle (PEV) or home batteries). This cannot be done at the home premises. Accordingly we have also deployed one more test-bed at IMDEA Smart Energy Integration Lab (SEIL) where we drive Micro grid loads and generators using data from SmartHG home test-beds and we drive Micro grid batteries using data from PEV usage (recorded from the Danish project *Test-an-EV*) and SmartHG services. This allows us to carry out experiments with actuation much as if we were in one of the homes in our test-bed equipped with a PEV and a battery.

Limitations and Future Work Installation in Svebølle and Central District areas is almost complete. We are working to complete it within summer 2015. Minsk test-bed has not been deployed so far due to problems with Belarus customs. If such problems are solved by the summer 2015 we may go ahead with deployment in Minsk test-bed, else we will just use historical data from such test-bed and increase recruiting in Svebølle and Central District. In both cases we will be able to reach project objectives since data from Israel test-bed more than compensate for those missed from Minsk test-bed.

Chapter 1

Retrospect

The Work Package WP6, to which this deliverable refers, had no activities in the first year.

Chapter 2

Introduction

This deliverable reports about the work carried out in tasks T6.1, T6.2, T6.3 and T6.4 of WP6 of the SmartHG project.

2.1 Motivations and Objectives

SmartHG has the goal of devising economically viable open services for Intelligent Home Automation. WP6 role within SmartHG is that of building test-beds to gather field data in order to enable evaluation of the services developed inside SmartHG.

Accordingly, WP6 main objective is to plan and carry out deployment of the hardware devices in SmartHG test-beds.

2.2 Achievements

We outline SmartHG WP6 second year achievements.

2.2.1 Svebølle (Denmark) test-bed

We completed deployment of sensing devices for appliances and main in 20 homes in Svebølle (Kalundborg, Denmark) out of the 25 planned in the project. Communication devices have also been installed so that measurements are visible in real time on the Web.

2.2.2 Minsk (Belarus) test-bed

We had problems with Belarus customs in shipping hardware devices there. Accordingly, so far we were only able to plan sensor deployment in Minsk and send there smart meters and gateways (but not sensors and bridges). The current plan is to install sensors in 25 flats in Minsk monitoring only main consumption since electrical energy consumption is quite low in each flat.

2.2.3 Central District (Israel) test-bed

In order to meet our goal of having two different test-beds ready by the end of second year as a recovery plan we deployed a test-bed in Central District (Israel). So far in Israel we completed deployment of sensing devices for appliances and mains in 9 homes out of the

13 foreseen in our present recovery plan. Note that in Israel we are monitoring appliances and mains whereas in Minsk we were (planning) only for main monitoring.

2.2.4 IMDEA Smart Energy Integration Lab (SEIL)

We are also experimenting with actuation of energy storage devices (modelling Plug-in Electric Vehicle (PEV) or home batteries). This cannot be done at the home premises. Accordingly we have also deployed one more test-bed at IMDEA SEIL where we drive Micro grid loads using data from SmartHG home test-beds and we drive Micro grid batteries using data from PEV usage (recorded from the Danish project *Test-an-EV*) and SmartHG services. This allows us to carry out experiments with actuation much as if we were in one of the homes in our test-bed equipped with a PEV and a battery.

2.3 Outline

The rest of this document is organised as follows:

- Chapter 3 describes the rationale of our test-bed design;
- Chapter 4 describes the Hardware Devices deployed in SmartHG test-beds;
- Chapter 5 describes SmartHG Sensor Interface;
- Chapter 6 describes the Svebølle (Denmark) test-bed;
- Chapter 7 describes the Minsk (Belarus) test-bed;
- Chapter 8 describes the Central District (Israel) test-bed;
- Chapter 9 describes the Smart Energy Integration Lab at IMDEA;
- Chapter 10 describes the Data Showcase on the PANPOW dashboard.

Table 2.1 maps tasks of WP6 to chapters of this document.

Task id	Task Name	Chapters
T6.1	Hardware Deployment in Kalundborg Test-Bed	3, 4, 5, 6, 9, 10
T6.2	Interfacing Kalundborg DSO with the project services	3, 4, 5, 6
T6.3	Hardware Deployment in Minsk Test-Bed	3, 4, 5, 7, 8, 9, 10
T6.4	Interfacing Minsk DSO with the project services	3, 4, 5, 7, 8

Table 2.1: Mapping between tasks of WP6 and chapters of this deliverable.

Chapter 3

Demo Approach

In this section we outline the rationale behind SmartHG test-bed design and the approach we followed.

3.1 Energy Saving for a Residential Home Small wrt Technology Cost

Technology for monitoring and controlling energy consumption (e.g., smart sensors) has been widely investigated and is already commercially available.

However, the cost of such a technology makes its deployment economically viable only when we consider commercial buildings. In fact, commercial buildings have a high energy consumption. Thus, even saving a small percentage of their total energy cost is sufficient to pay for the deployment of the technology needed to attain such savings.

For residential homes the situation is quite different since energy consumption, and thus overall energy cost, of a residential home is much smaller than that of a commercial building. As a result, while from a technological point of view would be feasible to deploy in residential homes the very same technology used for commercial buildings, this approach is not economically viable since the savings obtained would not be enough to pay for the technology itself.

Accordingly, one of the main goals of SmartHG is to address exactly this issue by developing a technology that can support a business model that overcomes the obstacle outlined above. Accordingly, SmartHG demonstration should allow us to evaluate to what extent SmartHG technology indeed attains such a goal.

3.2 Incentive Based Demand Shifting Limited wrt Expected Needs

The main obstacle we need to overcome is that incentive based demand shifting is limited with respect to expected needs.

In fact, as discussed in [1], effectiveness of incentive based Autonomous Demand Response (ADR) can vary widely depending on tariffs and information about pricing provided to users.

The report in [1] reviews evidences from 30 International ADR trials in the domestic electricity sector. One of the key findings of such a study is that consumers do shift electricity demand in response to economic incentives. However, the size of such a shift is between 0% and 22%, depending on tariff type and trial (see Figure 3.1).

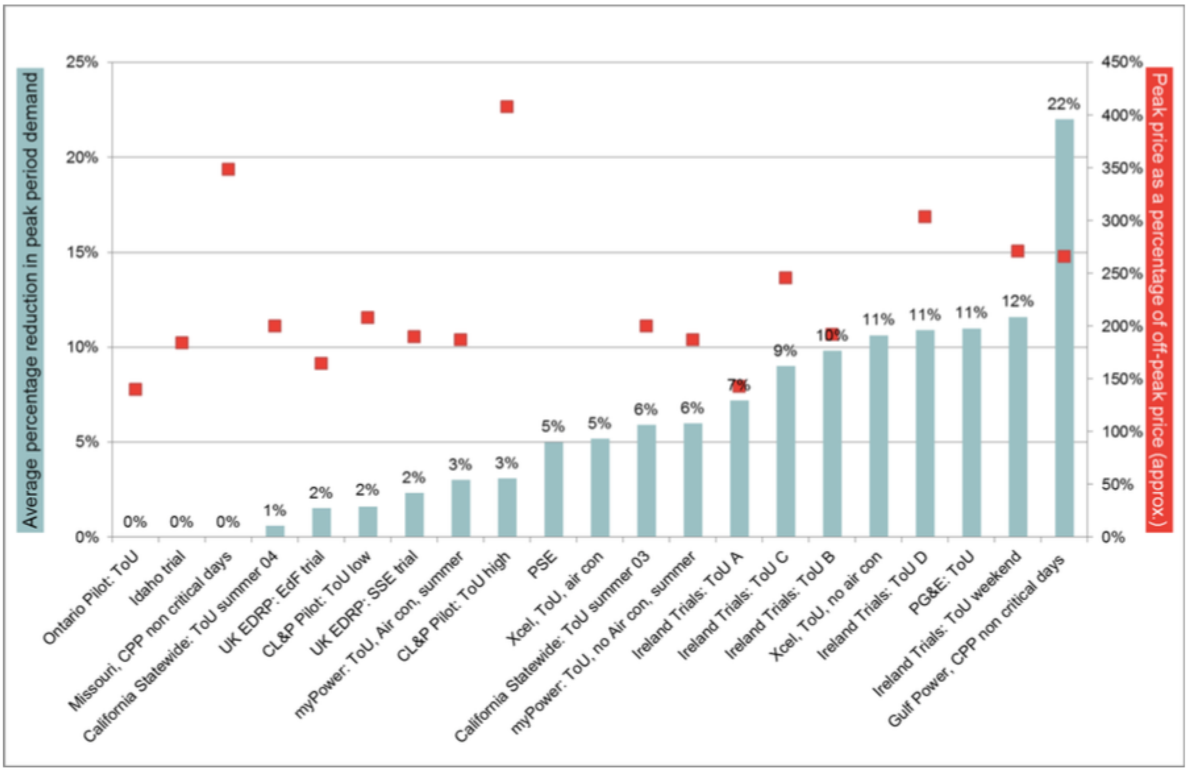


Figure 3.1: Peak period demand reductions and peak to off-peak price differentials under Time of Usage tariffs

Along the same line, are findings from the SEAS-NVE pilot study *Vind med nye elvaner* (Win with new electrical habits). About 300 customers without electrical heating are participating to such a pilot which runs from October 2013 to October 2014. Such a pilot project proposes to participating users the following Time of Usage (ToU) tariff:

- Day (6am - 5pm) = 0.20 Eur/KWh.
- Peak (5pm - 8pm) = 1.07 Eur/KWh.
- Night (8pm - 6am) = 0.0 Eur/KWh (i.e., electricity is *free* at night!).

It is very interesting to note that, notwithstanding the fact that electricity at night is *free* only 25% of electricity consumption has moved from peak hours to night accordingly to the data gathered in the pilot. This is basically in agreement with the findings of the report [1].

The point is that only certain tasks (such as, dish washing, laundry, etc) can be time shifted without creating discomfort to users. Others, energy eager, tasks such as cooking, heating, air conditioning cannot be significantly shifted and this limits the impact of incentive based ADR schemas.

Furthermore, we should also take into account that when a substantial number of users moves to off peak hours by following a given price policy we may have a *rebound* effect where demand peaks do not disappear but just move towards off-peak areas (e.g., see [2, 3]). The point is that users do not move their demand to a randomly selected off peak time, instead they tend to synchronise because of habits (e.g., dining time) or external events (TV shows, etc).

Last, but not least, we should consider that we plan also to address the effect of charging Plug-in Electric Vehicle (PEV) through the grid. This may further worsen the above scenario since availability of vehicles at home for charging may synchronise with non-working times (e.g., say after 6pm) resulting in the fact that many users will try to charge their vehicles more or less simultaneously. Incentives may move them at off-peak hours, but, this may just move the electricity demand peak to (previously) off peak hours (see, for example, [3]).

Steering the domestic electricity demand so as to optimise Electric Distribution Network (EDN) operations is one of SmartHG pillars since SmartHG sees the Distribution System Operator (DSO) as the final customer for the technology to be deployed being the DSO the one that may harvest significant economical advantages from peak shaving of the aggregated demand.

Accordingly, SmartHG demonstration should deploy an ADR approach that can attain a significant shifting of the electricity demand also in presence of heavy (possibly hard to shift) loads such as electrical heating, air conditioning, electrical cooking, charging of PEV.

Furthermore, the ADVANCED project [4] has conducted an intensive and very interesting study on user acceptance of ADR schemes and findings of such project show that:

- Domestic users are very "reluctant" to change habits, this limits the effectiveness of ADR resting on user active participation.
- Privacy is an important issue for domestic users so they are not happy to have DSO to monitor or even worst control their appliances (see Figure 3.2). This limits the use of a Direct Load Control (DLC) strategy.

3.3 SmartHG Test-Bed Design

Resting on the above considerations SmartHG follows a hierarchical approach where the DSO, using SmartHG Grid Intelligent Automation Service (GIAS) computes a price policy for each home which in turn follows the proposed price policy by managing devices in a fully automated way using SmartHG Home Intelligent Automation Service (HIAS).

This approach has the benefit that actuation of home devices to achieve energy/money saving is completely transparent to the user (thereby overcoming one of the main limitations of ADR) and, at the same time, the DSO does not have to monitor or control directly home appliances (thereby overcoming one of the main obstacles to DLC wide acceptance).

Accordingly, we focus our experiments on automatically managed home devices. More specifically, we plan to investigate how energy storage devices can be effectively used to move electricity demand.

We will consider two kinds of energy storage:

- Thermal (e.g., heat pumps, boilers).

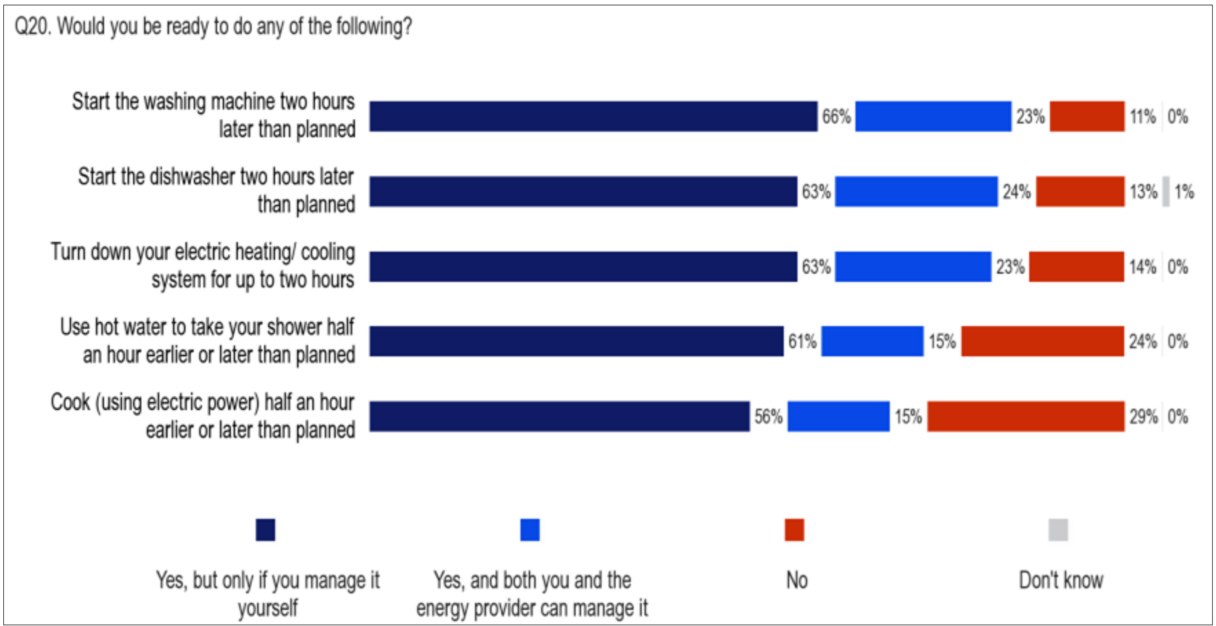


Figure 3.2: Results of interview with residential customers conducted by ADVANCED project

- Electric (e.g., batteries, PEV).

To meet the above goals we plan to equip homes in the test-beds with the following devices.

- Sensors measuring voltage and current at the level of the main home meter as well as at the level of single appliances (heat pump, refrigerator, boiler, dish washer, etc) when this is interesting. When a heat pump is present we will also have temperature sensors.
- Sensors measuring electrical energy produced from local generation (namely, PhotoVoltaic (PV)).
- Communication and management devices, gathering readings from home sensors and sending them on the Internet or using them to manage actuators (e.g., smart switches) in the home.

Of course, we cannot install batteries in each home of our pilots. However we can achieve the same result as follows.

First, we will *record* energy demand and production from each home in our pilot using the equipment installed in each home.

Second, we exploit IMDEA Smart Energy Integration Lab (SEIL) to reproduce energy demand and generation for any home in the pilot. More specifically, we use electronic loads to reproduce the (recorded) energy demand, generators to reproduce the (recorded) local generation and batteries to investigate the effect of energy storage (e.g., from batteries or PEV) on the overall home electricity demand.

3.4 How SmartHG Intelligent Automation Service will be used in the Pilot

We will use the SmartHG EDN Virtual Tomography (EVT) GIAS to identify constraints on the EDN (the low voltage substations in our pilots). Home energy demand will have to be steered so as to satisfy such constraints as much as possible.

We will use SmartHG Demand Aware Price Policies (DAPP) and Price Policy Safety Verification (PPSV) GIAS to design and verify the pricing schema that will drive home energy demand so that the above EDN constraints are satisfied.

We will use SmartHG Energy Bill Reduction (EBR) HIAS to actuate home enery storage devices (e.g., PEV) so as to minimise home energy costs. This means, for example, that the user will not have to worry about following a particular tariff profile or shift loads (e.g., by delaying usage of some appliances). The EBR service will manage the PEV battery on behalf of the user in order to shift home energy demand towards low tariff time slots.

We will use (inside EBR) SmartHG Energy Usage Modelling and Forecasting (EUMF) HIAS to forecast energy demand for each users.

We will use SmartHG Energy Usage Reduction (EUR) HIAS to identify exploitation opportunities for home thermal storage.

Communication between home devices and Database and Analytics (DB&A) Intelligent Automation Service (IAS) takes place through SmartHG communication infrastructure. Communication between SmartHG IASs and the DB&A takes place via Internet.

Chapter 4

Hardware Devices

In this chapter we describe the devices that will be deployed in our test-beds by the end of the SmartHG project.

4.1 Develco Products Smart Meters

Develco Products will provide (see Figure 4.1):

- Smart Plugs that can both act as meters and as relays. This means that the consumer is capable of diagnosing the exact energy consumption from every connected appliance in his home. He will be aware of how much energy is used on different times of the day/week/month/year, and he will be able to switch appliances on/off remotely. The smart plugs can easily be installed by an untrained user and do not require any installation costs.
- Gateways that will handle the wireless ZigBee [5] network, control devices, collect data, and transmit data to the Database and Analytics (DB&A).
- User interface for turning on/off all appliances at the same time. This unit is a battery driven device that has two LEDs that are controlled from the server or the local controller. The LEDs can be used for indicating anything to the end user (defined by the backend software).
- Temperature sensors. These units are battery driven and equipped with a ZigBee module which makes them capable of reporting temperature to the gateway and thereby to the DB&A.

4.2 Panoramic Power Sensors

Panoramic Power will provide (see Figuer 4.2):

- PAN10 sensors to monitor loads up to 63 Amperes, max cable diameter 7mm.
- PAN12 sensors to monitor loads up to 225 Amperes, max cable diameter 17mm.
- Bridges that deliver energy information from the sensors every 10 seconds.

Figure 4.1: Develco Products smart meters

Figure 4.2: Panoramic Power sensors

4.3 Home Energy Controlling Hub (HECH) kit

AU will provide Home Energy Controlling Hub (HECH) kits (see Figure 4.3), composed by:

- Raspberry Pi board
- Develco Products Smart Meters (ZigBee devices and gateway, see Section 4.1)
- USB stick
- Internet cable
- Power supply

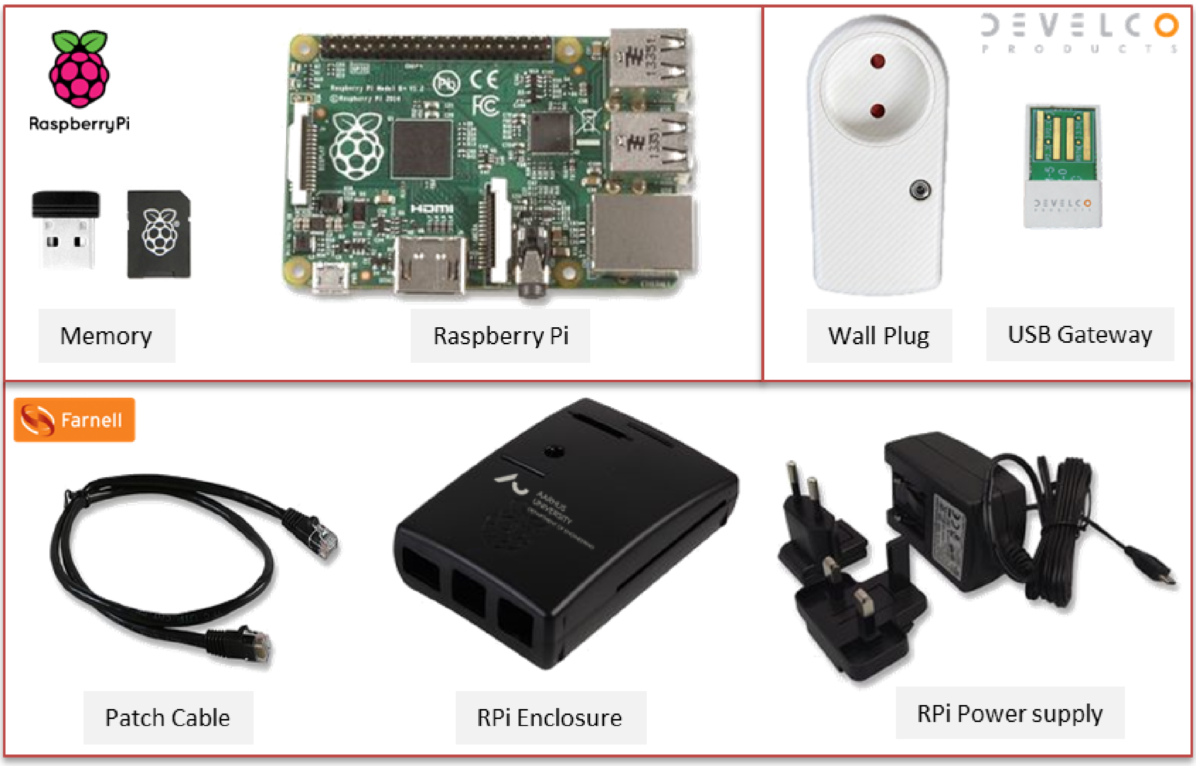


Figure 4.3: Home Energy Controlling Hub (HECH) kit

Chapter 5

Sensors Interface

This chapter describes communication interface between SmartHG hardware devices collecting measurements in houses and the Database and Analytics (DB&A) service gathering collected data.

5.1 Develco Products Smart Meters Interface

Figure 5.1 shows the design of communication between Develco Products smart meters (see Section 4.1) deployed in Svebølle test-bed and SmartHG DB&A.

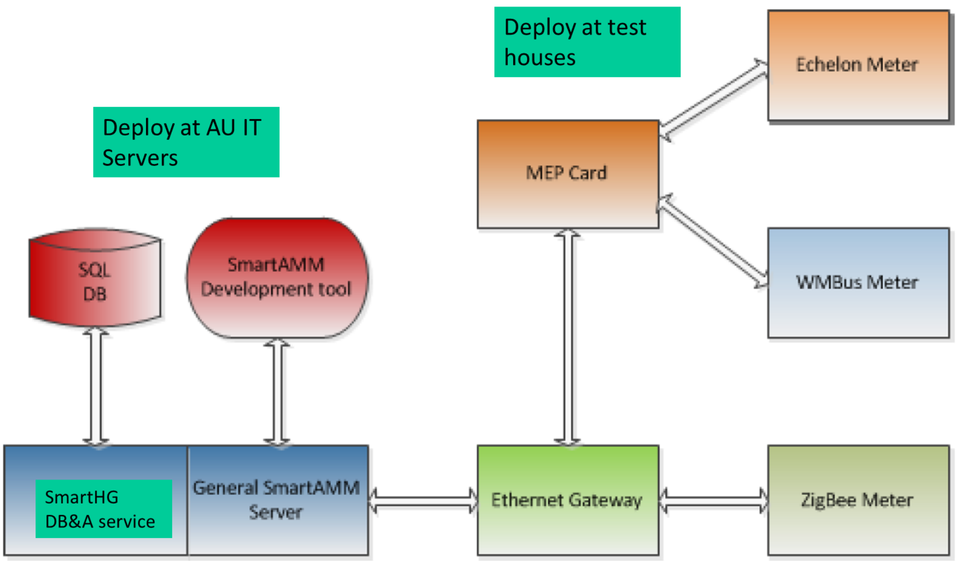


Figure 5.1: Database and Analytics (DB&A) and smart meters communication design

The smart meter interface provides the Echelon meters with ZigBee and Wireless M-Bus communication. Wireless M-Bus is intended for the readouts of meter data from water meters via the electricity meter. The ZigBee communication will be used for Home Intelligent Automation Service (HIAS) and load control. The meter interface, so-called MEP card, is designed as a drawer that can be inserted in the meter by the consumer himself without involving any electricians or installation contractors. Echelon meters (see Figure 5.2) are already installed in all homes in the Svebølle test area.

The heart of the system is a gateway that will handle the wireless ZigBee network, control devices, collect data, and transmit such data to the DB&A from where the data

Figure 5.2: Echelon main meter

will be available to the users. The gateway is connected to an existing Internet router and provides thereby full access to all ZigBee devices in the household. Different applications can access the system via different interfaces on the server side.

5.2 Panoramic Power Sensors Interface

Panoramic Power sensors (see Section 4.2) deployed in all SmartHG test-beds will send the data gathered from monitored appliances in the houses to Panoramic Power servers, via Panoramic Power bridge. All data are then sent to SmartHG DB&A and shown on the Panoramic Power dashboard (see Chapter 10), where only registered users can access them.

5.3 Home Energy Controlling Hub (HECH) Interface

The Home Energy Controlling Hub (HECH) (see Section 4.3) acts as a gateway between ZigBee and the RESTful interface of the SmartHG DB&A. In the houses in which HECH kit is installed, data will flow to DB&A through the HECH.

Chapter 6

Svebølle (Denmark) Test-Bed

The main motivation for deployment of home devices in private homes in Svebølle (Kalundborg Municipality) is to support the SmartHG project with real data from real homes. Kalundborg Municipality participates in a wide range of sustainability projects, supporting the utility infrastructure and industries. The SmartHG project gives to Kalundborg Municipality the possibility to involve citizens in these activities, which support the municipality brand as the Green Industrial Municipality [6].

6.1 Deployment and Maintenance Plan

In Svebølle test-bed we plan to have about 25 homes equipped with smart meters, sensors and communication devices. All houses in the test-bed will have sensors measuring instantaneous values for voltage and current at the main meter as well as sensors measuring inside temperatures and energy consumption for relevant appliances such as heat pump, electric oven, laundry machine, dishwasher, etc. Furthermore, we plan to equip 5 homes with the Home Energy Controlling Hub (HECH). This will allow us to further assess the effectiveness of SmartHG Energy Bill Reduction (EBR) service, which third year version is expected to use inside temperature information to control heat pumps.

See Figure 6.1 for an example of deployment in Svebølle.

The sensors available in *all* houses participating in the test-bed will allow us to measure all uncontrollable inputs (e.g., energy consumption as well as energy production from PhotoVoltaic (PV) panels, if any) for all houses in the test-bed. This will allow us to faithfully reproduce in IMDEA Smart Energy Integration Lab (SEIL) energy usage/production of each home and to experiment with different energy storage strategies for homes.

6.2 Deployment Preliminary

The work about finding relevant test homes in Kalundborg Municipality has been carried out in several steps. Before defining the test site, several areas in Kalundborg have been investigated. First we have looked at an area within the city of Kalundborg, but the houses in the district were primarily built in the 1960s and the families who live there represent a narrow part of a typical Danish population. The age of the houses could give challenges in installing test devices, and the high age of the families could give trouble in recruiting.

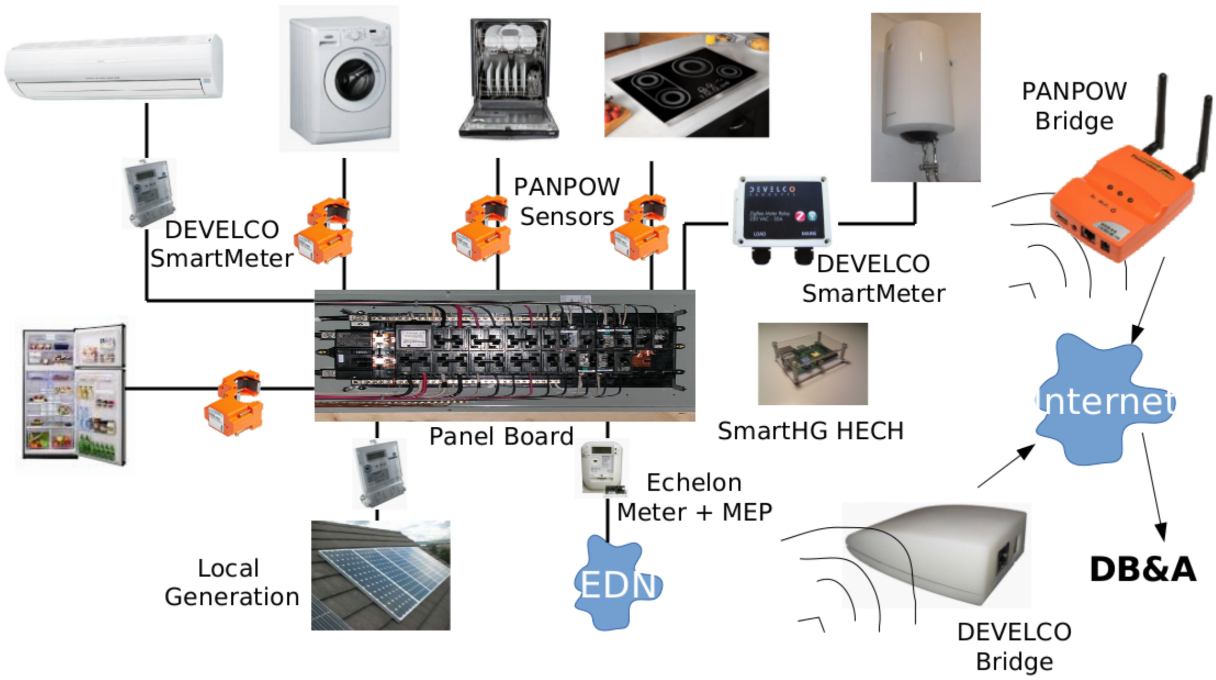


Figure 6.1: Svebølle deployment example

Then, we have decided to concentrate our effort in finding homes for tests and demonstration to Svebølle (see Figure 6.2), a village with approximately 850 homes situated 14 km east of Kalundborg city.

Figure 6.2: Svebølle

We selected test families mainly from a southern neighborhood in Svebølle without district heating, with citizens in all ages, newer houses (less than 15 years old, which makes installation easier, see an example of fuse box in Figure 6.3), a high range of electric heating, mainly based on heat pumps and a high concentration of PV panels (see Figure 6.4).

Two streets in Svebølle are identified as the main test area, because of its combination of houses with district heating, PV panels, heat pumps, and oil burners. Furthermore, the age of the houses span from the late 1980s to now, which gives a range of buildings with

Figure 6.3: Fuse box in a Svebølle test-bed home

Figure 6.4: A typical house in Svebølle, equipped with both PV panels and heat pump

different compliances to energy savings. The area is generally composed of two groups of people: a group of elder and retired persons and a group of young families.

6.2.1 Synergies with URB-Grade project

Svebølle is also test site in another FP7 project, the URB-Grade projects [7]. There are several positive synergies in running both project in the same area. In URB-Grade, the village is profiled, both from an anthropological and grid perspective. Experiences that give benefit in SmartHG activities. URB-Grade project consortium (which includes Kalundborg Municipality SmartHG partner) is in contact with about 100 citizens in Svebølle, profiling the village as an urban district in developing a digital platform as a decision support tool. The tool gathers different information about energy consumption, building standards, socio-economic Key Performance Indicators (KPIs) etc. It was decided to ask to the citizens involved in the URB-Grade project in Svebølle, whether they would like to participate in the SmartHG project. In that way, coordination with the URB-Grade project gave to our consortium knowledge about the citizens in Svebølle who can be interested in the SmartHG project, and helps SmartHG to get in contact with homeowners who want to participate. We also secure that demonstration or activities in the two projects are coordinated, and prevent any inappropriate coincidences. Also in the maintenance work the activities in the projects are coordinated. Studying the profiles of the citizens provided by the URB-Grade project, relevant homeowners in Svebølle have been contacted, mainly in newer houses and houses without district heating. To secure a good and smooth communication to the citizens in Svebølle, the project uses Facebook [8], and has created a group called “Smart Village Svebølle” [9]. Also the local council Facebook group is used to reach and inform the Svebølle citizens.

Also tests with smart streetlight, WiFi and intelligent lighting on sport arenas, are planned to be carried out in Svebølle.

6.2.1.1 URB-Grade Demo: Water Saving Campaign

The SmartHG project is coordinated with the tests and demonstrations in the URB-Grade project. The benefits are clear in the work of engaging the citizens in Svebølle, but also in the sensors deployment and maintenance. As an example of the consequence of this strategy, we also supply the households with water saving nozzles (see Figure 6.5) when we visit homes and install home devices for SmartHG. The water saving nozzles are distributed as a part of a water saving campaign, to demonstrate the URB-Grade District as a service (DaaS) Platform.

Figure 6.5: Water saving nozzles

6.2.2 Smart Grid in Kalundborg Municipality

Citizens in Kalundborg and Svebølle are used to smart technologies. It is standard for all homes to have installed smart meters for district heating, drinking water and electricity (see Figures 6.6 and 6.7). The smart meter for electricity, the Echelon meter (see Figure 6.8) can be supplemented with a MEP card, that makes it possible to gather and transmit data from several smart devices, supporting smart tech, both in energy and health care.

Figure 6.6: Diehl Hydrus smart meter for measuring drinking water/water flow

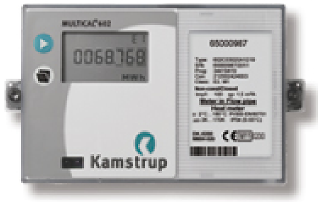


Figure 6.7: Kamstrup Multical 602 smart meter, for measuring district heating/water flow

Figure 6.8: Echelon Smart Meter with MEP card, for measuring electricity consumption, collect and send data from other smart meters/devices (e.g., from the smart meters for water and district heating)

6.3 Deployment and Maintenance Status

Sensors and smart meters have been deployed in the first twenty houses in Svebølle (see Figure 6.9 for an example of installed sensors), by SEAS qualified electricians, who will take also in charge the maintenance of installed devices.

All test families are informed about tests carried out in their homes. Each family receives information about technical issues, confidentiality, and how to react in case the system does not work. The benefit for the family participating is described in a welcome letter. The welcome letter also describes what will be installed, and who the family shall contact in case any problem arises with the installed devices. The letter is presented on the meeting that takes place, when we install the devices. A legal agreement for the citizens and for the electricians has been formulated including the involved SmartHG partners (SEAS, Kalundborg Municipality and Panoramic Power) and it will be signed by test families before installation takes place.

Figure 6.10 shows an example of installation overview from a test house, from which it is possible to see what has been installed. Minor differences will appear, e.g. in houses with heat pumps extra coils will be installed.

Data from monitored houses are already available in SmartHG Database and Analytics (DB&A) and showcased in the Panoramic Power Dashboard (see Chapter 10). We plan to complete the deployment in all Svebølle homes involved in SmartHG project by summer 2015.

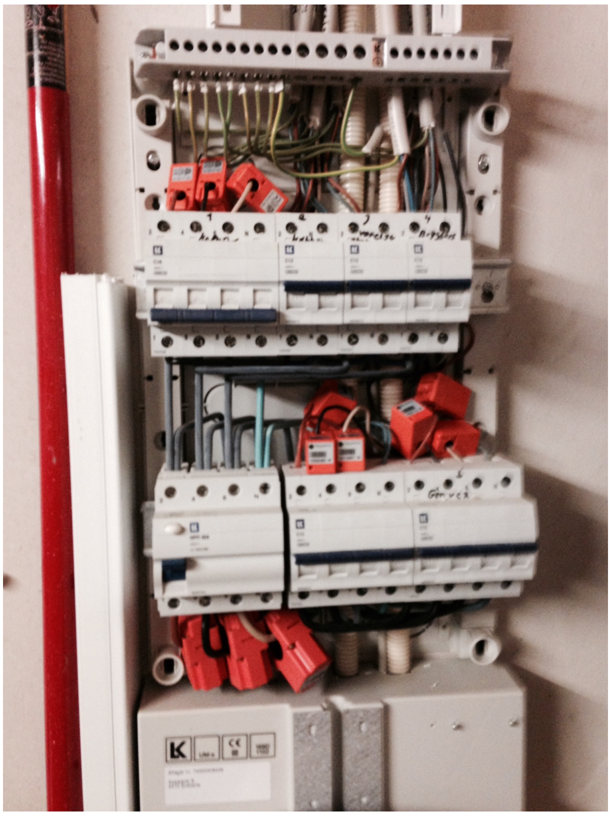


Figure 6.9: Sensors deployed in Sveb∅lle

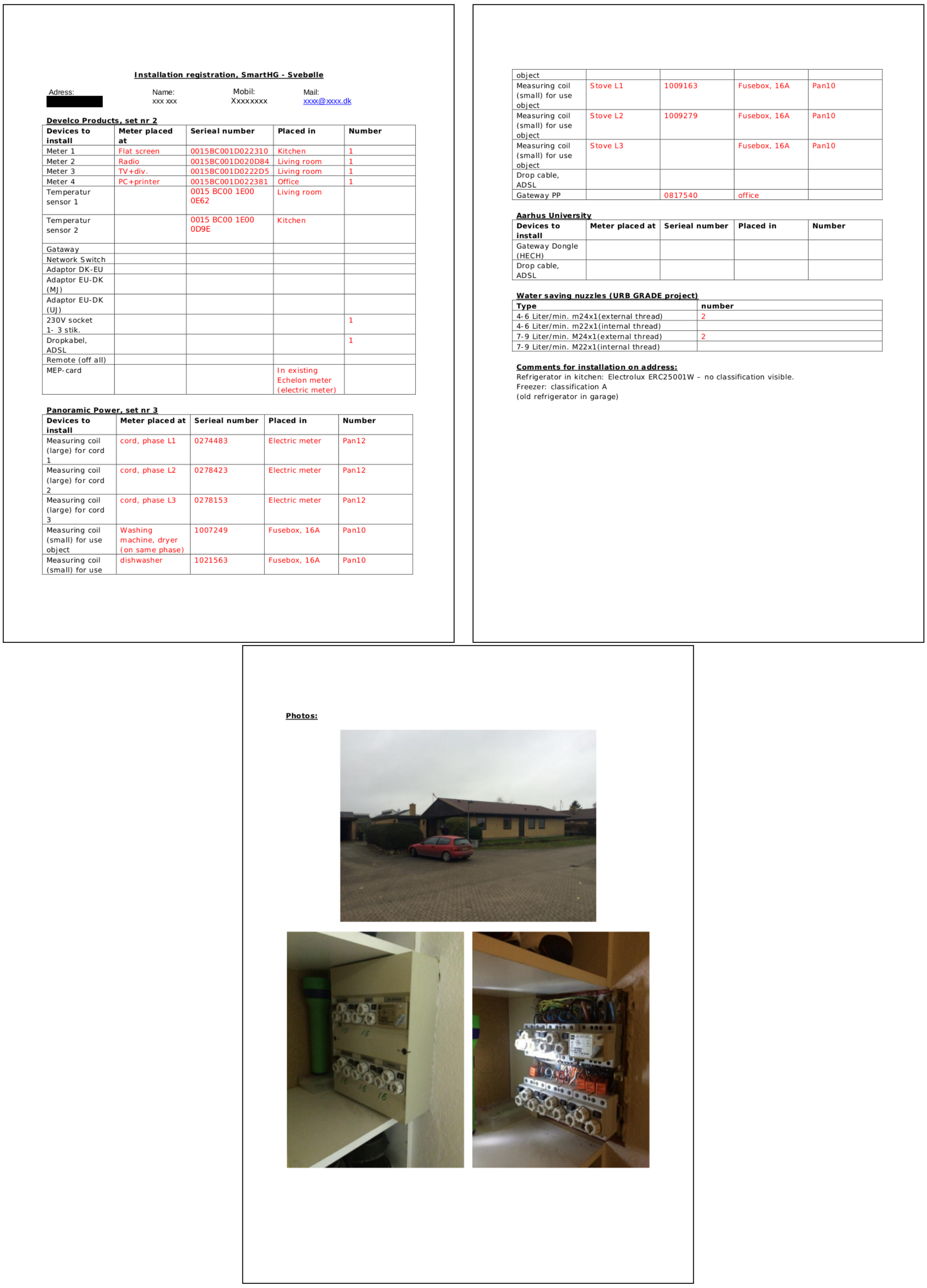
6.4 Distribution System Operator Interface

Deployment of IT solutions to interface test houses with the SmartHG project and with the local Distribution System Operator (DSO) is a vital part of demonstrating and testing the project services in interaction with the residential test houses. The deployment is a basis to get near "online" interaction data from the test houses interfacing the SmartHG project services and the DSO. The objectives of software deployment interfacing the local DSO with project services is to secure a model where the DSO can monitor, operate and control the grid by designing the right services.

6.4.1 Pre-pilot software deployment

In order to test the DSO software deployment in advance, an IT solution as shown in Figure 6.11 was designed. With deployment of this IT solution, the local DSO could test integration of smart meter infrastructure with SmartHG software and test how a rapid collecting of grid quality data from the smart meters would interfere with DSO vital collection of customer billing data.

The intention with the design was that all data communication interchange between the SmartHG project and the DSO should be through the DSO data Service bus. The data Service functionality bus was tested in another DSO project and therefore excluded in this pre-pilot test.



Installation registration, SmartHG - Svebølle

Adress: [redacted]
Name: xxx xxx
Mobil: Xxxxxxxx
Mail: xxxx@xxxx.dk

Develco Products, set nr 2

Devices to install	Meter placed at	Serieal number	Placed in	Number
Meter 1	Flat screen	0015BC001D022310	Kitchen	1
Meter 2	Radio	0015BC001D020D84	Living room	1
Meter 3	TV+div.	0015BC001D0222D5	Living room	1
Meter 4	PC+printer	0015BC001D022381	Office	1
Temperatur sensor 1		0015 BC00 1E00 0E62	Living room	
Temperatur sensor 2		0015 BC00 1E00 0D9E	Kitchen	
Gataway				
Network Switch				
Adaptor DK-EU				
Adaptor EU-DK (MJ)				
Adaptor EU-DK (UJ)				
230V socket 1- 3 stik.				1
Dropkabel, ADSL				1
Remote (off all)				
MEP-card			In existing Echelon meter (electric meter)	

Panoramic Power, set nr 3

Devices to install	Meter placed at	Serieal number	Placed in	Number
Measuring coil (large) for cord 1	cord, phase L1	0274483	Electric meter	Pan12
Measuring coil (large) for cord 2	cord, phase L2	0278423	Electric meter	Pan12
Measuring coil (large) for cord 3	cord, phase L3	0278153	Electric meter	Pan12
Measuring coil (small) for use object	Washing machine, dryer (on same phase)	1007249	Fusebox, 16A	Pan10
Measuring coil (small) for use object	dishwasher	1021563	Fusebox, 16A	Pan10
Measuring coil (small) for use object	Stove L1	1009163	Fusebox, 16A	Pan10
Measuring coil (small) for use object	Stove L2	1009279	Fusebox, 16A	Pan10
Measuring coil (small) for use object	Stove L3		Fusebox, 16A	Pan10
Drop cable, ADSL				
Gateway PP		0817540	office	

Aarhus University

Devices to install	Meter placed at	Serieal number	Placed in	Number
Gateway Dongle (HECH)				
Drop cable, ADSL				

Water saving nuzzles (URB GRADE project)

Type	number
4-6 Liter/min. m24x1(external thread)	2
4-6 Liter/min. m22x1(internal thread)	
7-9 Liter/min. M24x1(external thread)	2
7-9 Liter/min. M22x1(internal thread)	

Comments for installation on address:
Refrigerator in kitchen: Electrolux ERC25001W – no classification visible.
Freezer: classification A
(old refrigerator in garage)

Photos:

Figure 6.10: An example of installation overview document

6.4.2 Pre-pilot test results

The pre-pilot test of DSO software deployment gave some useful knowledge about the grid quality data provided by smart meters and about the DSO software solution. Smart meters are able to provide a lot of grid quality data measured at the customer site, but the test showed that the firmware version in the smart meters would have influence of the grid quality data logged in the meters. The pre-pilot test of DSO software solution

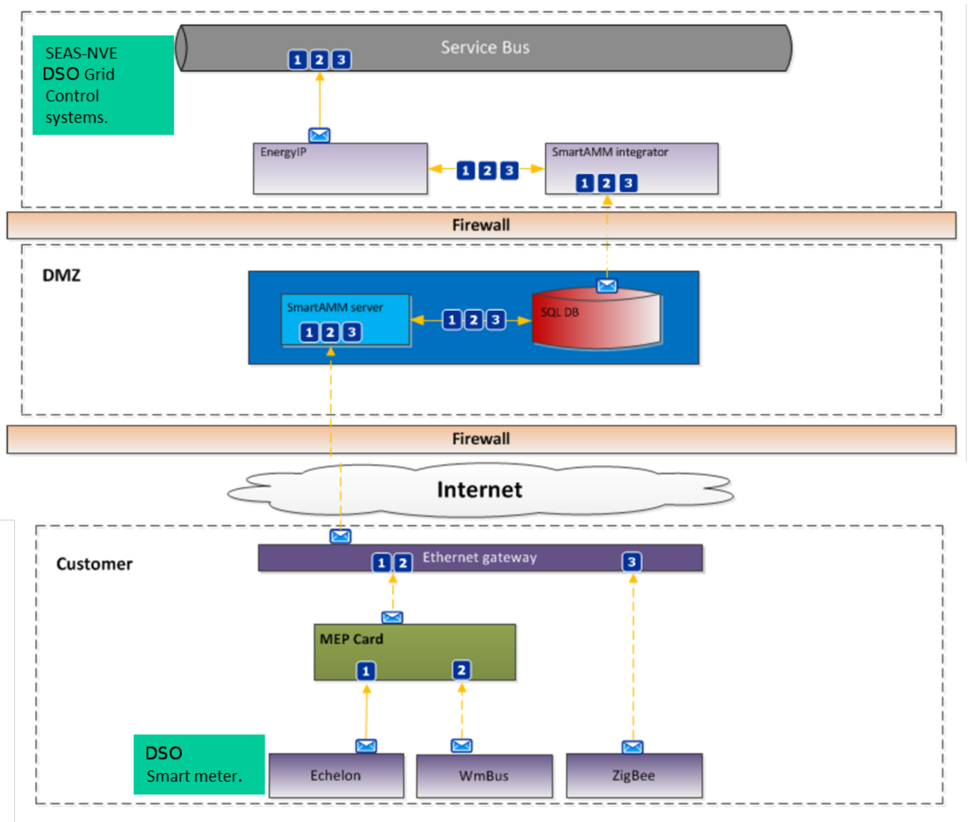


Figure 6.11: Distribution System Operator, smart meters communication design

showed that operation and maintenance of the MEP card infrastructure together with smart meter infrastructure need some functionality to cooperate with daily operation. Most important, seen from the DSO side, the pre-pilot test showed that rapid collecting of grid quality data through MEP card from smart meters did not interfere with the business vital collection of customer billing data. The smart meter stress test showed that customer billing data was collected as normal with hourly interval and transferred to DSO billing system every night in a right way.

6.4.3 Distribution System Operator (DSO) software deployment at Svebølle test site

With the change of SmartHG project partner from GridManager to Develco Products, the project software solution design was reconsidered regarding where to deploy and host the various parts of the software solution. A redesign of deployment plans was based upon the fact that the DB&A service, the core element in data transfer in SmartHG, moved from GridManager servers to AU servers. It was obvious that the best solution was to deploy the SmartAMM software (Develco Products home automation middleware, see Deliverable D3.2.1 - Second Year Design of Home Intelligent Automation Services) at AU where SmartHG DB&A service is deployed as well. In this way, the technical setup regarding the Svebølle test site was simplified and easy to operate and maintain.

The software deployment at the DSO demonstrates that Smart meter data can be rapidly collected through the MEP card into the SmartHG DB&A service for further use in the SmartHG project (see Figure 5.1). The software deployment demonstrated the ability to send and receive demand control signals between residential houses, DSO and

SmartHG services. These results are vital for demonstrating and achieving the SmartHG goals towards the test site in Svebølle. The current version of the DSO software deployment confirmed that the daily operation and maintenance of the MEP card infrastructure together with smart meter infrastructure needs some extra functionality to cooperate with daily operation in test mode. The most needed operation and maintenance functionality has to be developed before a more extensive DSO test is ready to be deployed.

The DSO pre-pilot test of demand control equipment shows that further work has to be done on the interface between future smart appliances, customer and user interfaces and the DSO safety grid operating policy.

Chapter 7

Minsk (Belarus) Test-Bed

Two multi-floor apartment buildings in the Fruzenski district of Minsk (Belarus) are selected as testbed for the SmartHG project.

Frunzenski district of Minsk was founded on April 17, 1951 due to the rapid post-war development of the city. It is the largest district in the north-west area of the capital, having a surface of 4,300 ha with 133 streets, alleys and driveways. In Frunzenski district live more than 373,000 people.

The two multi-floor apartment buildings are showed in Figure 7.1.

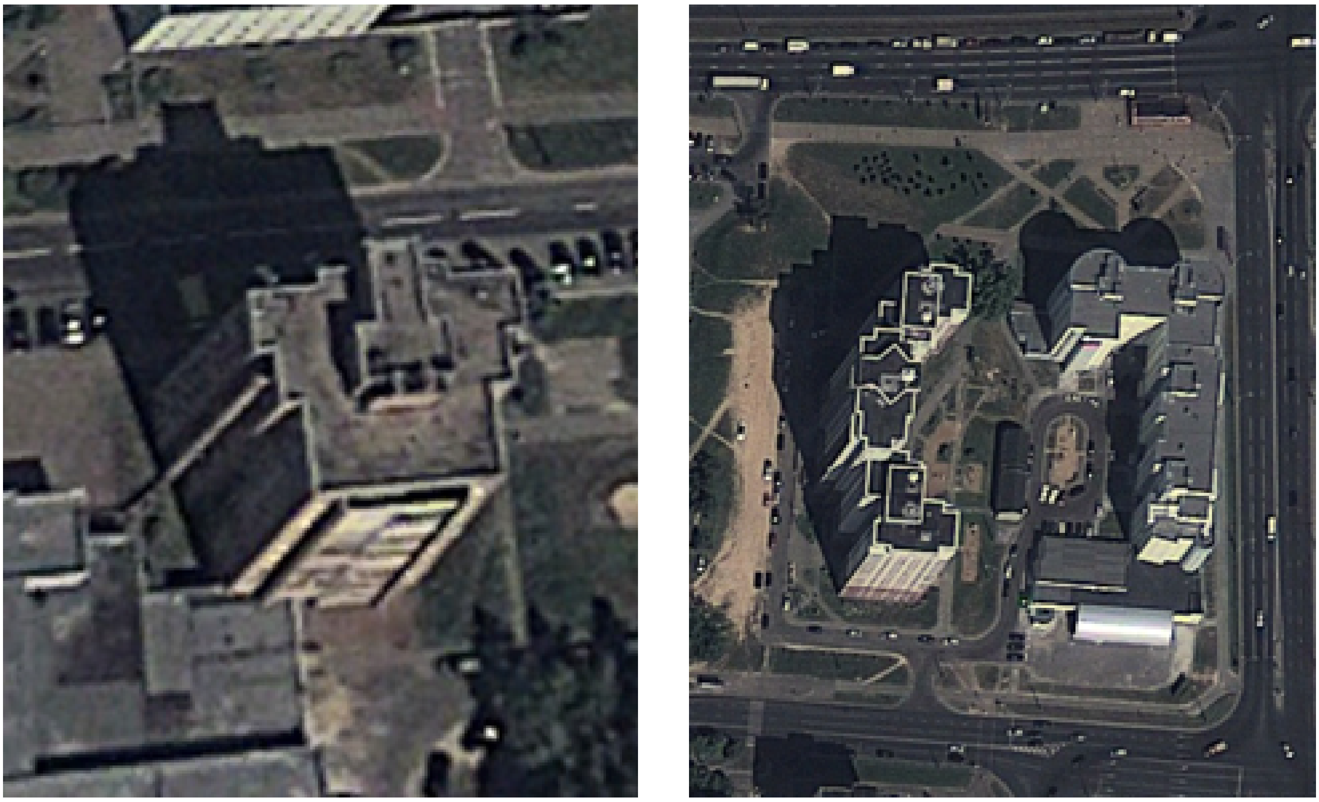


Figure 7.1: Buildings involved in Minsk test-bed

The building #1 includes 153 flats and the building #2 includes 116 flats. Furthermore, each building is served by two transformers. Each transformer has primary voltage of 10kV, secondary voltage of 400V and nominal power of 1000kVA.

Currently, in the Minsk test-bed there are no energy generators based on renewable sources, although the Minsk administration has plans to equip the city with a district heat pump and a wind farm.

7.1 Deployment and Maintenance Plan

In Minsk test-bed we plan to involve about 25 flats. The flats in Minsk test-bed have a rather modest energy consumption. In such a scenario the main interest in deploying smart devices is in counteracting the social impact of the foreseen increase of energy price at peak hours. Minsk flat in the test-bed are all in the same building which also contains the substation feeding the flats. Accordingly, in such a scenario it appears more interesting to deploy in each flat sensors measuring instantaneous values for voltage and current at the main meter and to use the data gathered to experiment in the IMDEA Smart Energy Integration Lab (SEIL) energy storage strategies at the level of the building substation (see Figure 7.2 for an example of deployment in Minsk).

In this way we will investigate energy storage at the home level in Svebølle and at the substation level in Minsk.

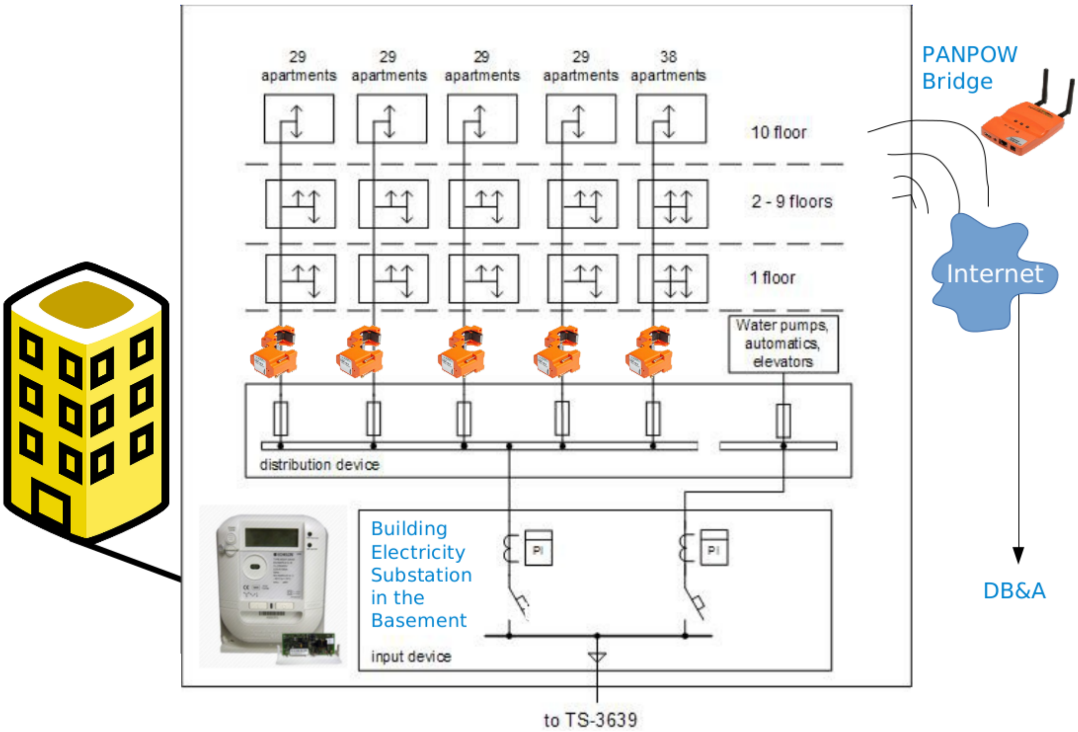


Figure 7.2: Minsk deployment example

7.2 Deployment and Maintenance Status

A first recognition in the buildings involved in SmartHG test-bed in Minsk showed that the sites are ready for the deployment (see Figures 7.3, 7.4, 7.5, 7.6, 7.7, 7.8 and 7.9 for substation level, Figures 7.11 and 7.10 for flats level).

Figure 7.3: Incoming panel of the building

Figure 7.4: Three phase power meter

Figure 7.5: Terminal box

Figure 7.6: Input circuit breakers

Figure 7.7: Panel with devices that gather and process information from meters and then transmits it via GSM modem

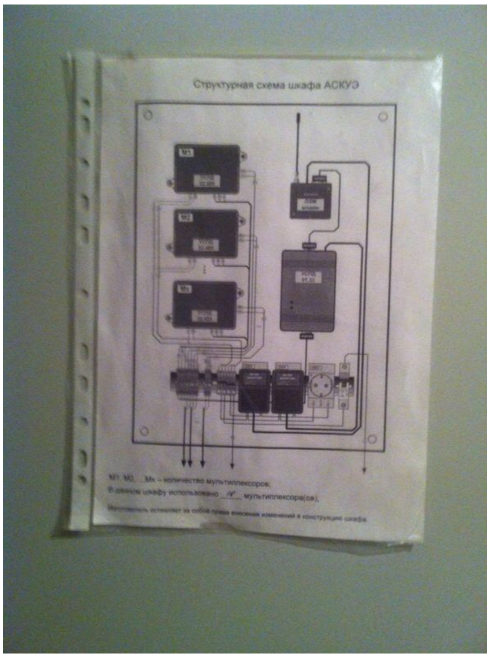


Figure 7.8: Scheme of the panel from Fig. 7.7

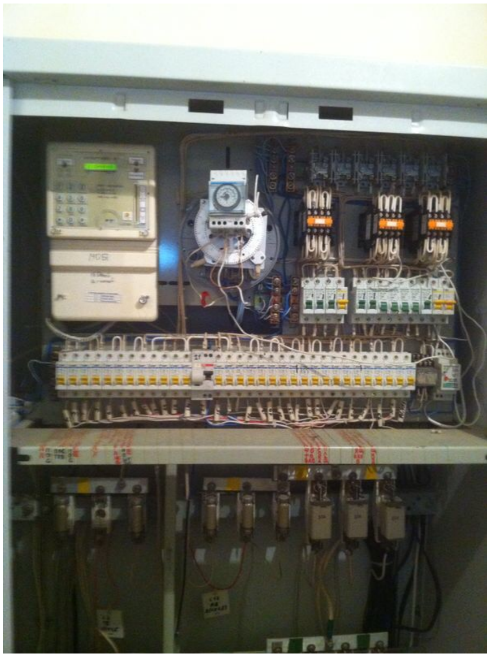


Figure 7.9: Panel for energy accounting of the common areas (elevators, water pump, etc)

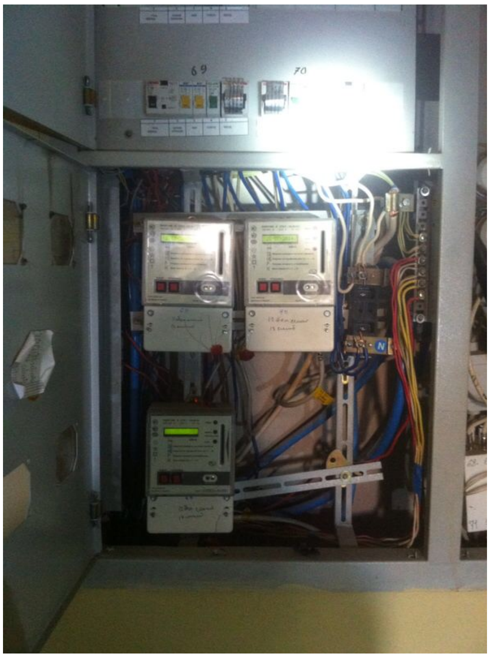


Figure 7.10: Floor level panel with a meter for each of three apartments

Figure 7.11: Apartment meter (single phase)

At the time of writing, we are waiting for the Belarus customs authorization about the shipment of sensors from Israel (Panoramic Power sensors).

Sensors and smart meters will be deployed in Minsk test-bed by qualified electrician who will take also in charge the maintenance of installed devices.

7.3 Distribution System Operator Interface

Minsk Distribution System Operator (DSO) infrastructure cannot manage the data flowing from SmartHG sensors and smart meters. Data and functionalities will be made available to the DSO through the SmartHG Web services. To see and download the data gathered from test-beds, the DSO will access SmartHG Database and Analytics (DB&A). Then Minsk DSO can submit these data to the Demand Aware Price Policies (DAPP) service in order to compute a price policy and to the Price Policy Safety Verification (PPSV) service to evaluate its robustness. The DSO can use the EDN Virtual Tomography (EVT) service by uploading to the EVT website the electrical network topology.

Chapter 8

Central District (Israel) Test-Bed

As a recovery plan for the delay in the deployment of Minsk test-bed due to customs problems with Belarus, we decided to have a test-bed in Central District (Israel). This allows us to gather data from two test-bed by the end of the project second year.

The Central District of Israel is one of six administrative districts, including most of the Sharon region. Panoramic Power plans to monitor consumption of houses in the Central District (mainly large private houses) by summer 2015. Those houses will be used as a (new and unplanned) SmartHG test-bed, allowing SmartHG to use a wider set of residential scenarios. Figures 8.1 and 8.2 show two of the houses involved in the Central District test-bed.

Figure 8.1: Central District involved home #1

Figure 8.2: Central District involved home #2

8.1 Deployment and Maintenance Plan

Panoramic Power plans to monitor about 13 houses using about 10 sensors per house, monitoring the main circuits to the house, the air conditioning (used for heating as well), the boiler (domestic water heating), and where present, the pool pump. These are the main electric consumers in the Central District home, given Israeli warm climate. Two of the homes will also show electric car charging spots.

8.2 Deployment and Maintenance Status

One fully monitored house was already available in Central District test-bed as the sensors were installed in it as pilot. We used data gathered from this house for the evaluation of Energy Bill Reduction (EBR) service (workpackage WP5). At the time of writing, other 8 houses are monitored. Data from monitored houses are already available in SmartHG Database and Analytics (DB&A) and showcased in the Panoramic Power dashboard (see Chapter 10). We plan to complete the deployment in all Central District homes involved in SmartHG project within the summer 2015.

Sensors are deployed in Central District test-bed by qualified electrician who will take also in charge the maintenance of installed devices.

8.3 Distribution System Operator Interface

A Distribution System Operator (DSO) is not directly involved in the Central District test-bed. However, as for the Minsk test-bed, data and functionalities are made available to a DSO through the SmartHG webservices. To see and download the data gathered from test-beds, a DSO will access SmartHG DB&A. Then a DSO can submit these data to the Demand Aware Price Policies (DAPP) service in order to compute a price policy and to the Price Policy Safety Verification (PPSV) service to evaluate its robustness. A DSO can also use the EDN Virtual Tomography (EVT) service by uploading to the EVT website the electrical network topology.

Chapter 9

IMDEA Smart Energy Integration Lab

In this section we describe the IMDEA Smart Energy Integration Lab (SEIL), where we carried out some demonstration experiments.

Electrical Systems Unit at IMDEA has created a test environment specifically designed for research, development and testing of control algorithms in energy systems. This environment (see Figure 9.1) is named "Smart Energy Integration Lab (SEIL)" for accelerating the process of control design development necessary for connecting energy resources to electricity networks.

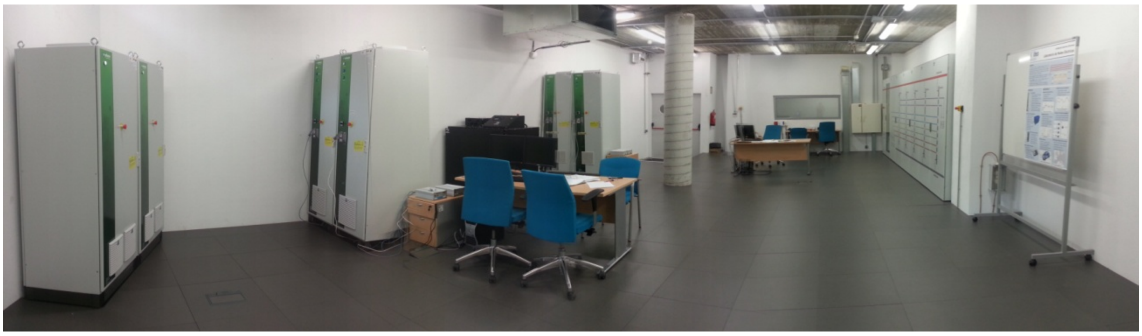


Figure 9.1: Smart Energy Integration Lab at IMDEA

The approximate lab capacity for power processing is 210kVA and it is formed by a set of power electronics converters, resistive loadbanks, 47kWh battery system, distribution panels and monitoring and control systems. This platform allows analysis, development and testing of realistic scenarios for energy integration in both AC and DC networks and also operation of distribution power networks, islanded networks and microgrids. The results obtained from this test environment are more reliable and accurate than any model based computer simulation. What distinguishes this laboratory is its flexibility in implementation of control algorithms and simple access to all test and management data from any part of the network. The lab microgrid is capable of recreating a large number of different events that occur in real power networks and, therefore, represents a useful tool when it comes to research, development and implementation of energy management algorithms. For example, the lab network is capable of emulating at the same time a generation and load mix consisting of various wind, photovoltaic and conventional generators and passive and active loads all together connected to a wide area network whose dynamic is emulated in real-time. The role for the power converters acting as energy resources in such network is simply defined by assigning a different control block to each one of them.

In addition to this, the battery system installation offers all the flexibility needed for the development of management algorithms for future power network.

The SEIL consists of (see Figure 9.2):

- 4 x 15kVA three-phase power inverters
- 2 x 75kVA three-phase power inverters
- 4 industrial PCs with RT operating systems
- 2 x 30kW balanced and unbalanced, programmable resistive loadbanks
- 47.5kWh Li-Ion battery system with BMS
- 90KW Bidirectional, wide bandwidth, programmable battery charger
- Distribution panels with 5 independent busbars and contactor control
- Independent monitoring and control system

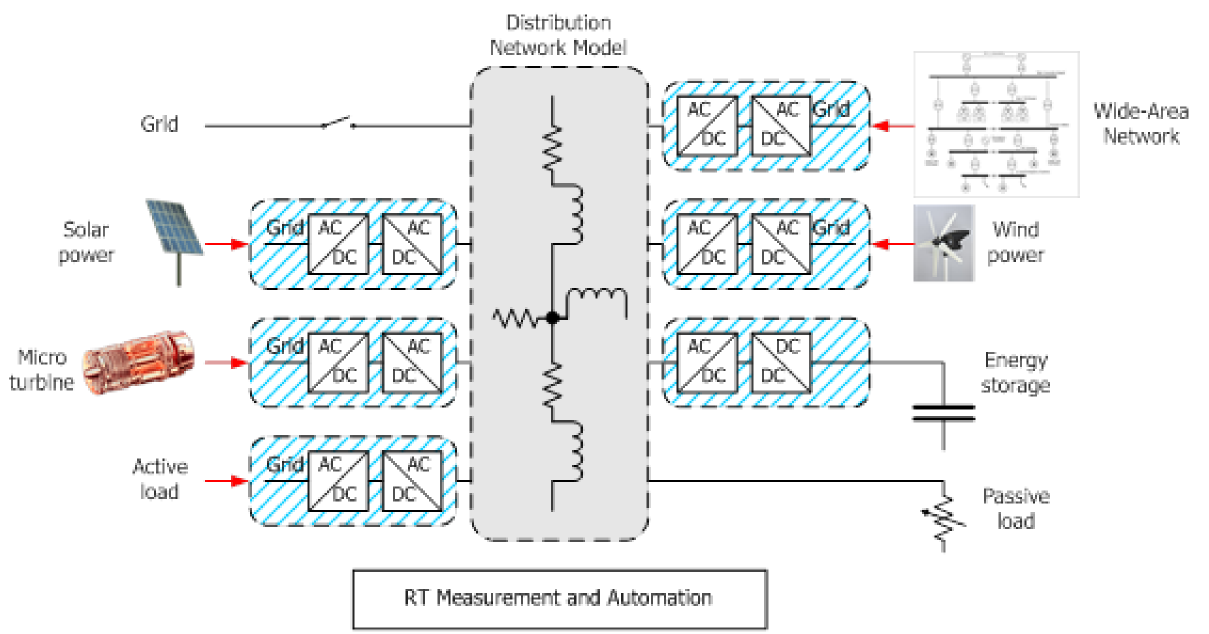


Figure 9.2: Description of Smart Energy Integration Lab at IMDEA

Control algorithms for power inverters are programmed via Matlab Simulink and code generation tools and are then executed in real-time on industrial PCs. Real-time data exchange provides access to all control variables and parameters during the test. In this way the desired flexibility in reproducing real dynamic characteristics of any energy source, generator or load is achieved. The monitoring and control system allows an independent, remote, real-time access to laboratory resources including the network reconfiguration, control of contactors and connection to the external power grid. Moreover, by harnessing the potential of the communication network installations any centralised or decentralised management control algorithm can be implemented.

Figure 9.3 outlines how we plan to use IMDEA SEIL, Figure 9.4 outlines the actual configuration on the lab equipment and finally Figure 9.5 outlines the interaction with the control algorithms from SmartHG Home Intelligent Automation Service (HIAS).

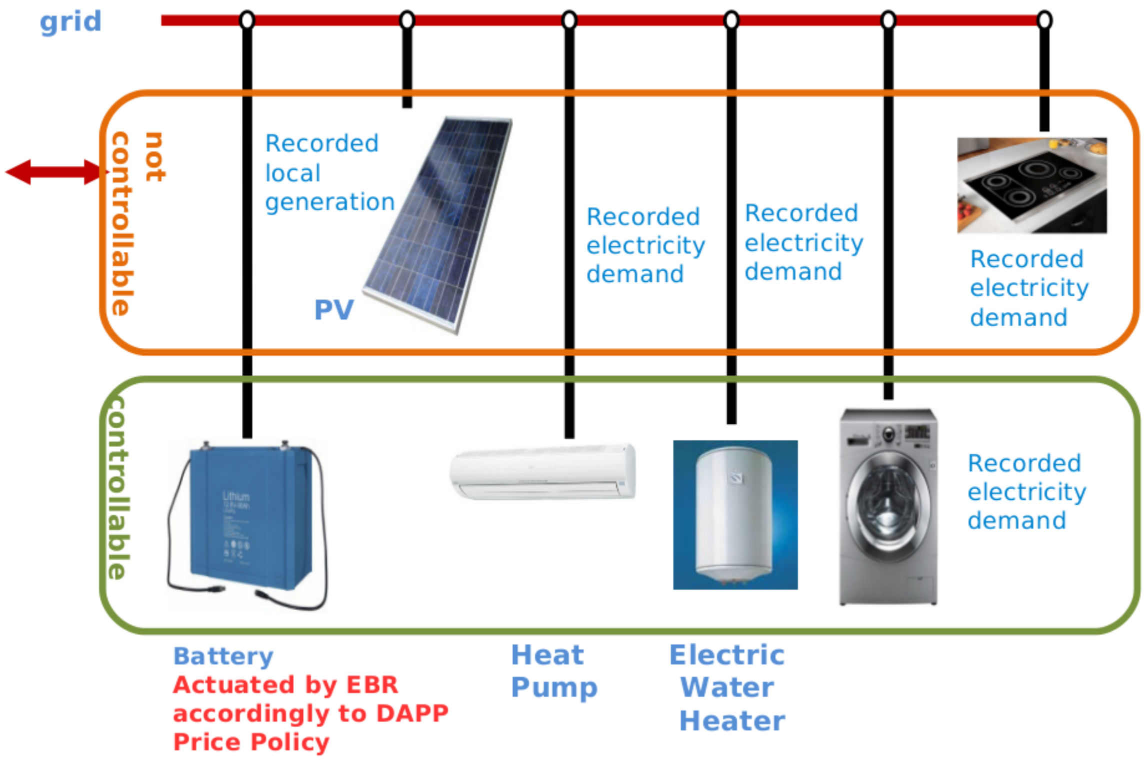


Figure 9.3: Smart Energy Integration Lab setting

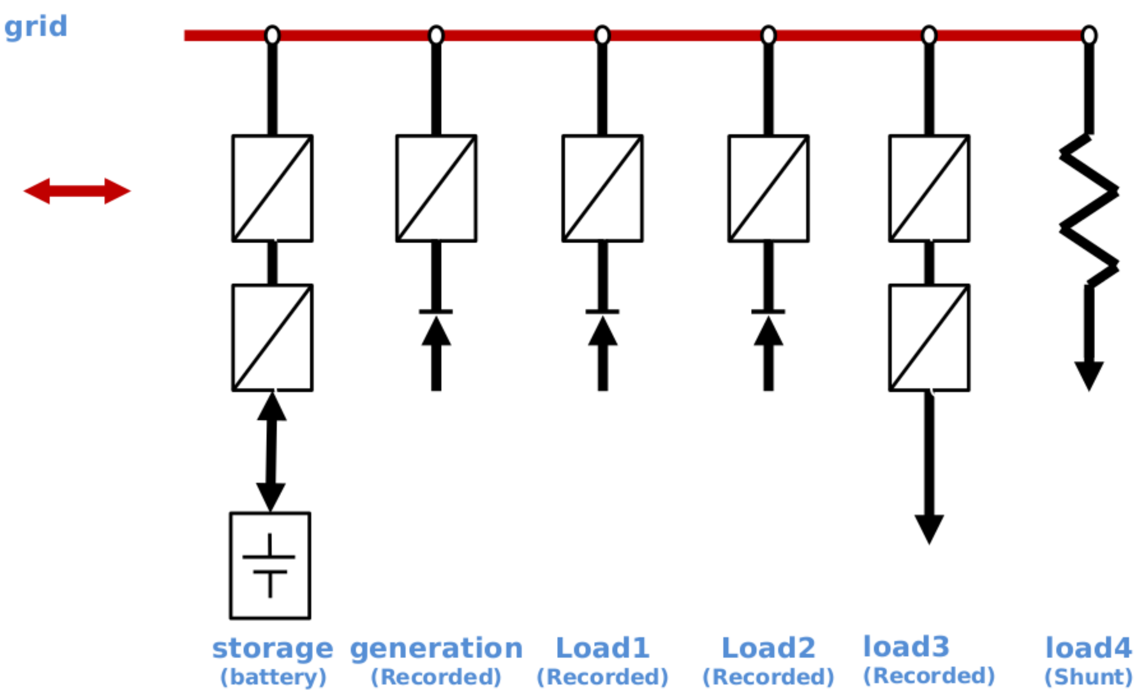


Figure 9.4: Smart Energy Integration Lab configuration

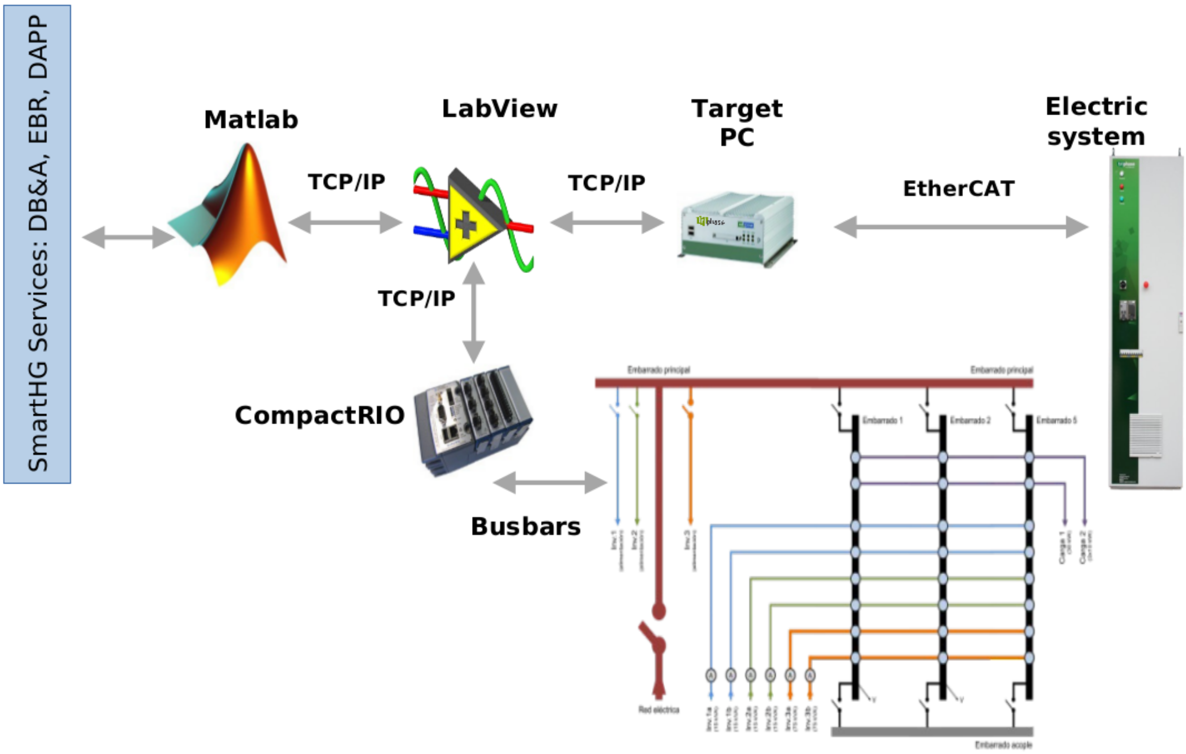


Figure 9.5: Controlling Smart Energy Integration Lab

Chapter 10

Data Showcase

All data gathered by sensors and smart meters deployed in the SmartHG test-beds are stored in the SmartHG Database and Analytics (DB&A). The Panoramic Power dashboard will be used by both the homeowners involved in SmartHG and the project partners to view the energy use of the individual homes monitored in the project's pilot sites. Only users with private and secure username and password can log in to the Panoramic Power dashboard (see Deliverable D7.2.2 - Sections of Project Web-Site for a description of the dashboard frontend).

Some snapshots of the Panoramic Power dashboard based on the data gathered from the houses monitored in the Svebølle and Central District test-beds are shown in Figures 10.1-10.14:

- Svebølle test-bed:
  - Figure 10.1 shows the energy consumption of one house.
  - Figure 10.2 shows the energy consumption of one house, with 1 minute data resolution.
  - Figure 10.3 shows the daily energy consumption, comparing site by site.
  - Figure 10.4 shows the weekly energy consumption, comparing site by site.
  - Figure 10.5 shows the weekly power consumption, comparing site by site.
  - Figure 10.6 shows the power consumption, with 1 minute data resolution, comparing site by site.
  - Figure 10.7 shows the daily electrical consumption Heat map.
- Central District test-bed:
  - Figure 10.8 shows the energy consumption of one house.
  - Figure 10.9 shows the energy consumption of one house, with 1 minute data resolution.
  - Figure 10.10 shows the daily energy consumption, comparing site by site.
  - Figure 10.11 shows the weekly energy consumption, comparing site by site.
  - Figure 10.12 shows the weekly power consumption, comparing site by site.
  - Figure 10.13 shows the power consumption, with 1 minute data resolution, comparing site by site.
  - Figure 10.14 shows the daily electrical consumption Heat map.

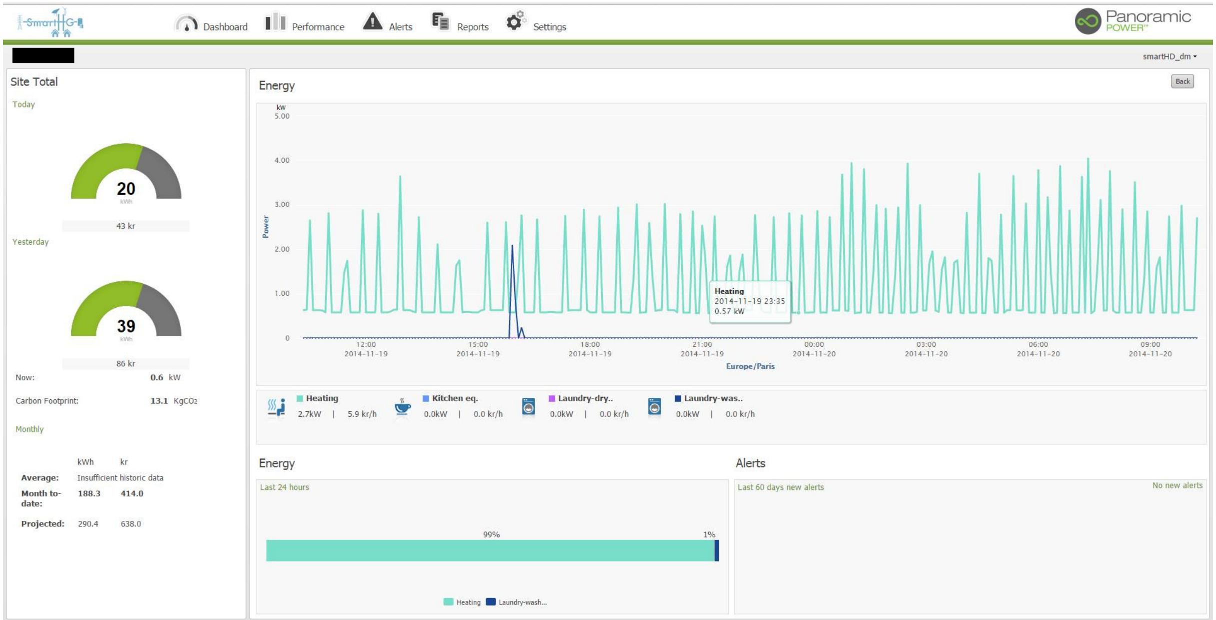


Figure 10.1: Single site dashboard for Svebølle test-bed

Figure 10.2: Device level - 1 minute data resolution (last 6 hours) for Svebølle test-bed

Figure 10.3: Daily energy consumption – comparing site by site for Svebølle test-bed

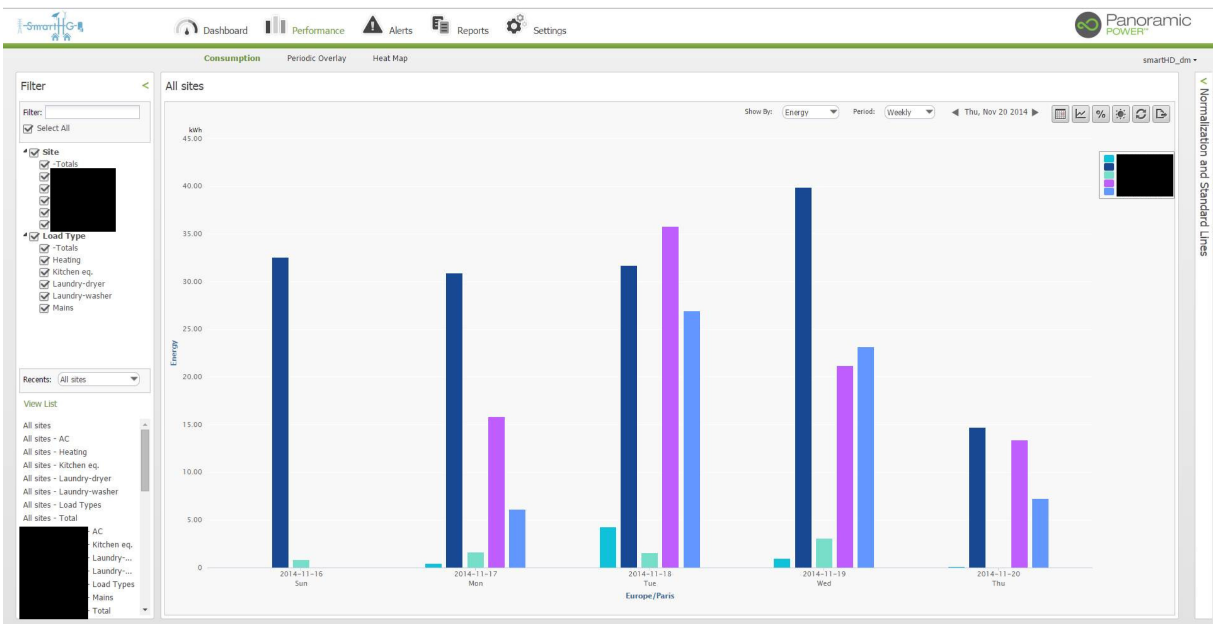


Figure 10.4: Weekly energy consumption – comparing site by site for Svebølle test-bed

Figure 10.5: Weekly power consumption – comparing site by site for Svebølle test-bed

Figure 10.6: Power consumption - 1 minute resolution view (last 6 hours) for Svebølle test-bed

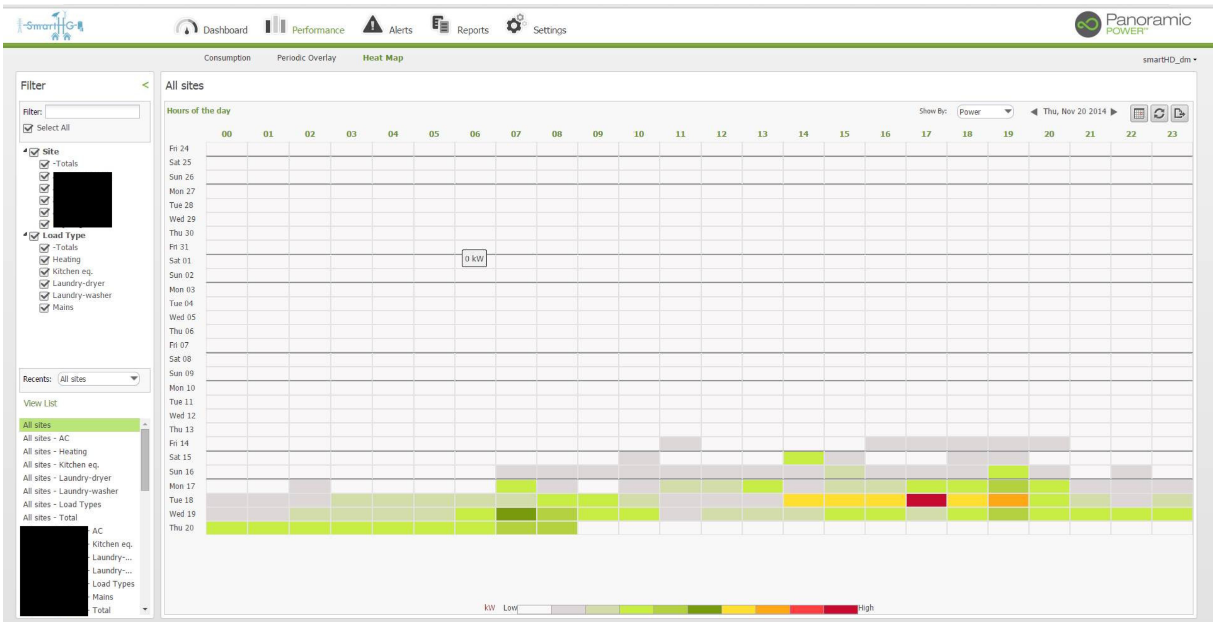


Figure 10.7: Daily electrical consumption heat map for Svebølle test-bed

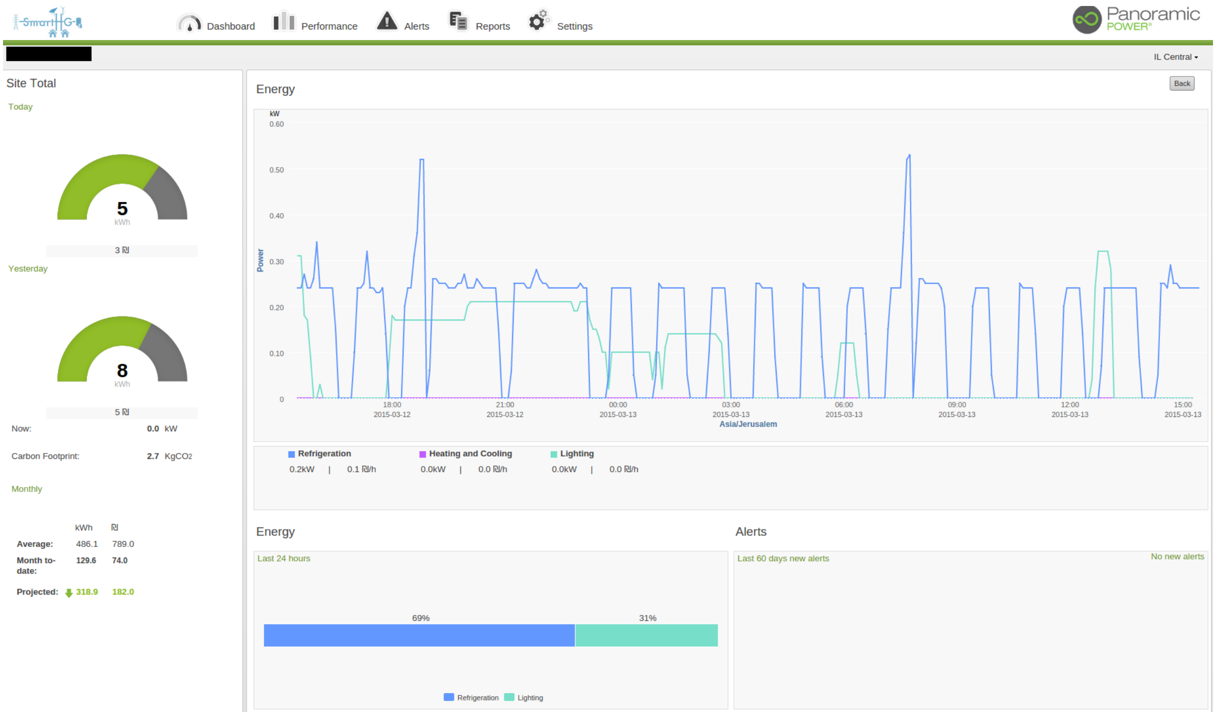


Figure 10.8: Single site dashboard for Central District test-bed

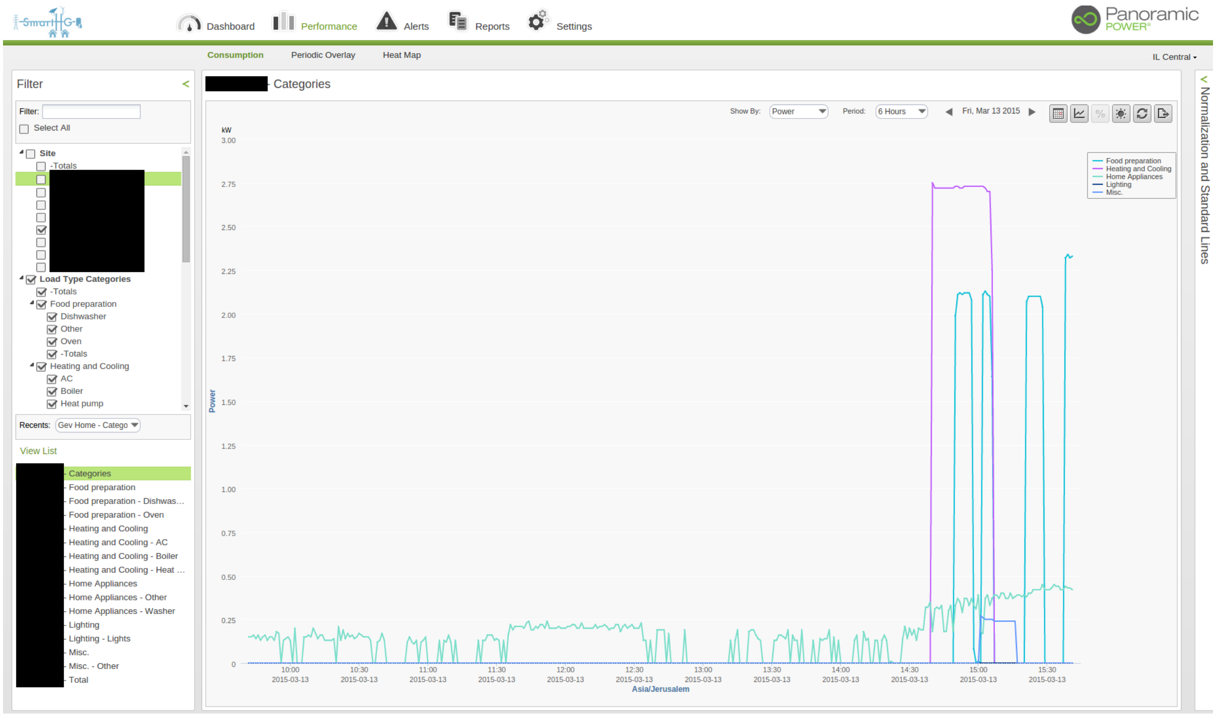


Figure 10.9: Device level, 1 minute data resolution (last 6 hours) for Central District test-bed

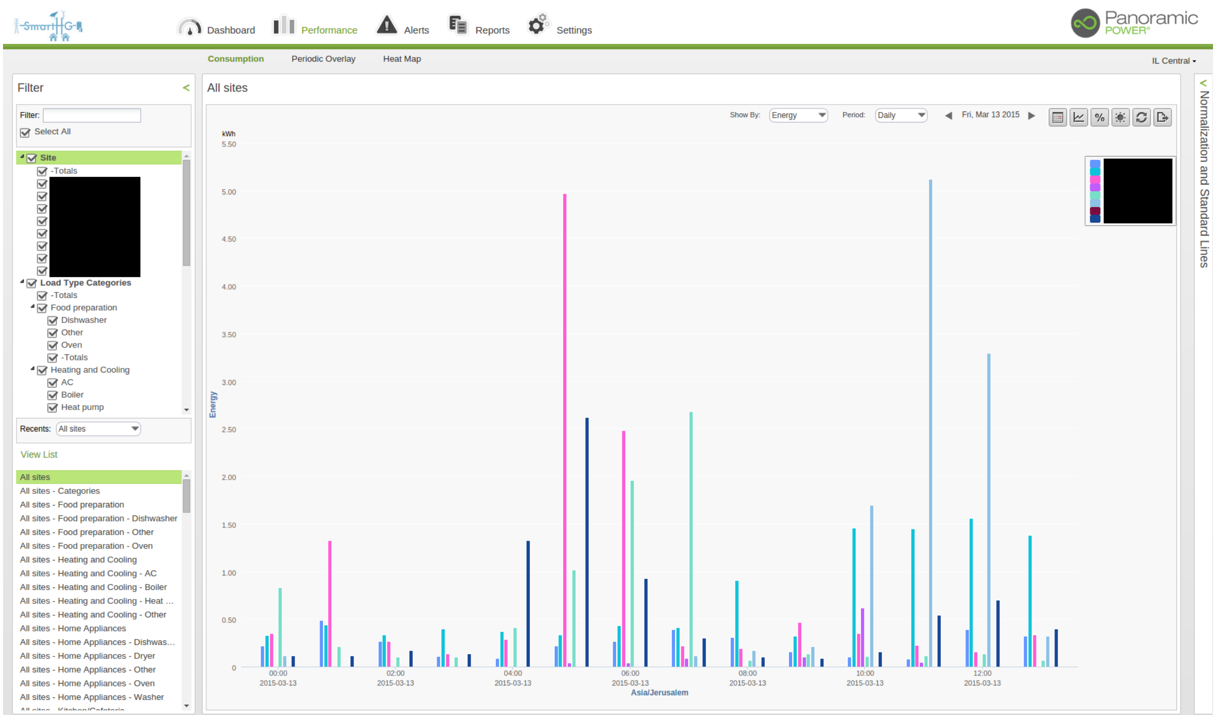


Figure 10.10: Daily energy consumption, comparing site by site for Central District test-bed

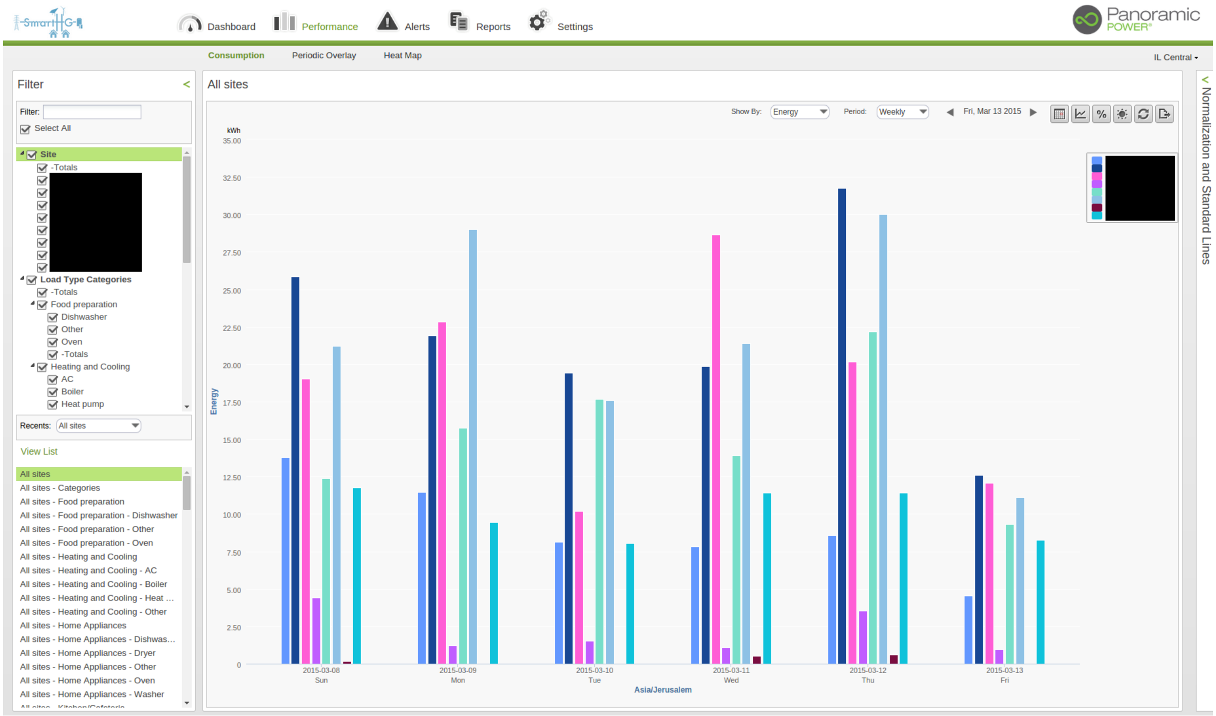


Figure 10.11: Weekly energy consumption, comparing site by site for Central District test-bed

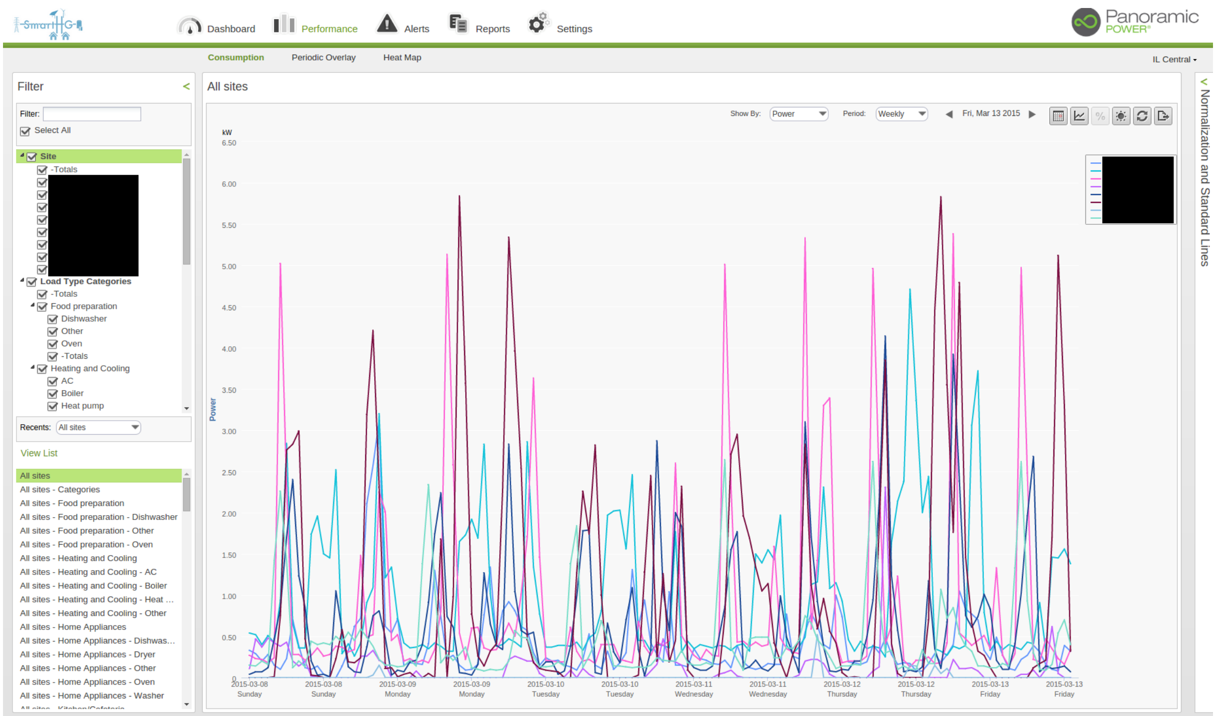


Figure 10.12: Weekly power consumption, comparing site by site for Central District test-bed

Figure 10.13: Power consumption, 1 minute resolution view (last 6 hours) for Central District test-bed

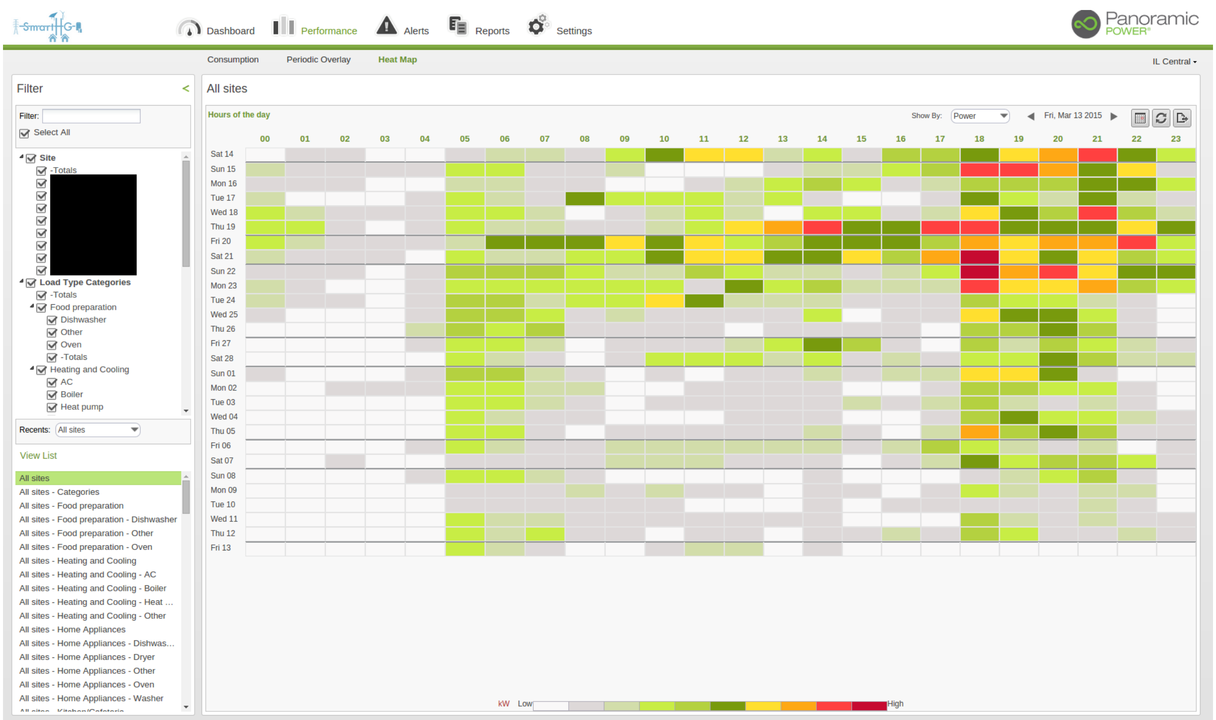


Figure 10.14: Daily electrical consumption heat map for Central District test-bed

Chapter 11

Conclusions

In this section we summarise achievements, limitations and future work for WP6 activities.

11.1 Achievements

Twenty houses are monitored in the Svebølle test-bed out of the 25 planned. About nine houses in the Central District area are monitored, out of the 13 planned. Table 11.1 summarises the planned and current hardware deployment on SmartHG test-beds.

Data gathered from those sites are available for homeowners and project partners on the Panoramic Power dashboard (private and secure username and password are needed to log in).

The software deployment at Distribution System Operator (DSO) demonstrates that it is possible to get access to near "online" data (every 2 minutes) from the meters in the test houses and to communicate with demand control equipment in the houses to shape the demand curve.

11.2 Limitations and Future Work

Since there were no activities in the first year for WP6, in this section we only account for the limitations for this second year iteration of WP6 activities and on future work planned for the third year.

The software deployed at the DSO has a structure to interface a limited numbers of residential homes connected to the project services. In the future, part of the software deployed at the DSO has to be redesigned to work in setups with many customers interfacing SmartHG services.

Installations at Svebølle and Central District areas are almost complete. We are working to complete them within the summer. In the third project year, five Home Energy Controlling Hub (HECH) kits will be deployed in the Svebølle test-bed. This will allow us to further assess the effectiveness of SmartHG Energy Bill Reduction (EBR) service on the user premises.

Minsk test-bed has not been deployed so far due to problems with Belarus customs. If such problems are solved by the summer we may go ahead with deployment in Minsk test-bed, else we will just use historical data from Minsk test-bed and increase recruiting in Svebølle and Central District. In both cases we will be able to reach project objectives since data from Israel test-bed more than compensate for those missed from Minsk test-bed.

Test-bed	Planned			Current		
	Monitored houses: appliances and main	Monitored flats: only main	Hardware deployment	Monitored houses: appliances and main	Monitored flats: only main	Hardware deployment
Svebølle (Denmark)	25		250 sensors 25 bridges 65 smartmeters 25 gateways 5 HECH 50 temperature sensors	20		202 sensors 20 bridges 49 smartmeters 20 gateways 36 temperature sensors
Minsk (Belarus)		25	78 sensors 6 bridges 1 smartmeter 1 gateway			
Central District (Israel) *Recovery Plan*	13		140 sensors 13 bridges	9		95 sensors 9 bridges

Table 11.1: Test-bed planned and current deployment status

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[4] ADVANCED project Web Page: `http://www.advancedfp7.eu/`.

[5] ZigBee Web Page: `http://zigbee.org/`.

[6] Green Industrial Municipality website: `http://www.kalundborg.dk/Erhverv/The_Green_Industrial_Municipality.aspx`.

[7] URB-Grade project website: `www.urb-grade.eu`.

[8] Facebook Web Page: `https://www.facebook.com/`.

[9] Facebook Smart Village Svebølle Web Page: `https://www.facebook.com/groups/smartsveboller/`.