SmartCoDe

Evaluation Report

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Executive Summary

The objective of SmartCoDe is to enable the application of advanced techniques for energy management in private and small commercial buildings and neighbourhoods. To show the impact of the SmartCoDe project, a demonstrator was implemented at two sites (Almersberg and Buchberg, near Vienna, Austria), equipped with energy using products (household appliances and lighting systems) and local energy production (small scale wind and photovoltaic generators).

At **Almersberg** the effects of customary methods of the energy management (optimisation of the current systems, spare investments) and the influencing of the user's behaviour via the visualisation of the energy consumption was examined. These methods influence the energy consumption of single devices as well as the consumption of the whole facility in a relevant way. At **Buchberg** the focus was on decreasing the external use of power from the grid by optimise the usage of the energy produced by the wind turbine. These methods influence the load profile of single devices and of the whole facility and optimise the economical ratios.

The demonstrator has been used to **collect real world data** and to **calculate and evaluate energy savings** which are due to the use of the SmartCoDe concept. In order to full fill the main measuring target to get the baseline data, building features, user behaviour and the weather impacts we traced the readings form the main meters (public grid supply and delivery), sub meters (Windturbine and single EuP Meters), temperatures of different EuPs, temperatures outside and windspeed for Production and Forecasting and room temperature.

In order to **optimise the usage of local produced power** we developed **forecast methods** to predict the power curve, a PV- or Wind Turbine System will deliver over the following hours. Work completed during year one and the year two of the project culminated in a model which developes correction factors for published forecasts for specific site conditions and a means to publish the corrected forecast in a manner that could be read and used by the energy management software.

Load balancing is the most important sub-task in the SmartCoDe demand side management approach. One goal regarding demand side management is to increase the local EuPs combined power consumption at favourable times, e.g. when the wind turbine has an increased power output. However, we must also ensure that this increased consumption still

stays within certain bounds. For example if *all* of the local EuPs choose to switch on resp. increase their power consumption in a favourable time period, the overall power drawn might surpass the power provided by the turbine by far. Therefore the power drawn from the grid might even increase above average, with the corresponding unfavourable results regarding e.g. monetary cost or grid stability.

We calculated and evaluated energy savings which can be reached by **awareness** in combination with modern energy controlling and visualisation systems, the savings we get by **balancing the local energy load** and finally the savings from **shaping the local energy load** using the SmartCoDe Technology.

For the **example calculations** we assume 40.3 million households in Germany with an average electrical power consumption of 3.600 kWh and an electricity price of 0,25 €/kWh. The potential energy savings for traditional **awareness, monitoring and analysis** measures for an average household totals to 36%, 1.300 kWh with a cost reduction of 325 EUR per annum. The potential energy savings through **manual and automatic load balancing** for the average household therefore totals to 11% or 400 kWh per annum. Finally the potential **reduction of grid peak loads** resulting from SKDSVC and VSTSVC totals to 24% referred to their average power consumption.

A rollout of these systems to only 20% of the German households would lead to **energy savings of about 10,5 TWh** and a potential for **load balancing of about 3.3 TWh**.

On the **cost-side** we analysed **two scenarios**: The first one considers an **early, low volume roll out of SmartCoDe technology** (100.000 nodes). For this scenario it is assumed that all HW will be built by means of standard PCBs and discrete components. The second scenario considers **a mature market** which can be supplied by **high integration SmartCoDe technology** (10.000.000 nodes). White good appliances are assumed to provide digital communication interfaces and DC power supply, therefore the complexity of the wire-less controlling nodes can be significantly reduced, resulting in simple node architecture, similar to a node used for LED-lighting control.

In the **low volume scenario** the average cost/node over all SmartCoDe nodes not including the infrastructure is with more than 24€ much higher than achievable by mass deployment of a fully integrated solution, however one can see that the target price is already very attractive for at least a minor percentage of the households across Europe, i.e. those who are aware of energy saving possibilities and have not a big problem making 500€+ investment for an overall SmartCoDe enabled package. For the **high volume scenario** the situation is different. While the share of infrastructure costs is still a dominant cost factor, the total cost of a package including 15 wireless nodes has become affordable (214,60€). This is due to the cost-benefit of the integrated sensor nodes and the assumed reduced complexity of white good controlling wireless nodes, resulting in average costs of 6,85€ per node (in comparison: 24,45€ per node for the low volume scenario).

The system amortisation time **heavily depend on the tariff development** in the next years. In case of timeframe dependent tariff-models, where the user gets a **payback for load balancing** (e.g. 15 cent as a middle difference between high- and low tariff x 400 kWh = 60 €/year), the amortisation time in the high volume scenario shrink to a realistic duration **below 4 years**.

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1 Introduction to the Demonstrators

The objective of SmartCoDe is to research and demonstrate advanced techniques for energy management in private and small commercial buildings and neighbourhoods. This is essential for future large-scale integration of locally available renewables into local grids.

Initially it was planned to demonstrate SmartCoDe technology at the Almersberg site (details below). However, analysis of the wind conditions revealed that the average wind speed at the site was too low to operate the QR5 wind turbine efficiently. An alternative demonstration site was found nearby, at the Buchberg location, featuring an average wind speed of 6.6 m/sec. The predicted yearly energy output at the new site is 5000 kWh of electricity, taking into account the local regulation stipulating the shut-down of the turbine at wind speed above 14 m/sec.

The two demonstration sites (Almersberg, Buchberg) are fairly typical “real world” objects, both presenting different challenges for the project:

- Almersberg – a domestic single family house, below-average energy consumption even prior to the project
- Buchberg – a partly commercial partly domestic building, where SmartCoDe has to take special care of not interrupting day-to-day business

Both locations are located in the municipality of Neulengbach, Lower Austria, about 40 km west of Vienna. The locations are approximately two kilometres apart. The names Almersberg and Buchberg are local names and not widely recognized outside the county.

Both demonstrators supplement each other. The sites as well as the differences in usage, available local energy producers (“LEPs”) and energy using products (“EuPs”) are described in the following section.

1.1 The Almersberg Demonstrator

The Almersberg demonstrator is a single family house, inhabited by two adult people and also used as home-office. Almersberg is equipped with photovoltaic and solar-thermal LEP. It was originally envisioned to also erect the QR5 wind turbine on site, a plan later abandoned because of the lack of reliable wind resource.

Table 1 lists basic data of the site:

Location:	A- 3040 Almersberg, Austria
Altitude	48.20°
Longitude	15.92°
Sea level:	250 m
Year of construction, refurbishment:	1901 / 1928 / 1993
Net base area:	718 m²
Gross floor area:	379 m²
Reference area:	535 m²
Net base area (thermal):	249 m²
V (thermal gross volume):	1.266 m³
A (surface area):	2.840 m²
A/V:	2,24 m^{-1}
BRI (gross volume):	1.955 m³
Average outdoor temperature:	11 °C

Table 1: Basic Information on the Demonstrator in Almersberg

The main controllable EuPs are:

- Dish Washer
- Washing Machine
- Oven (AEG Competence and BSH)

- Deepfreezer
- Heating & pumps

Collection of baseline data was started at Almersberg in spring 2010.

The photovoltaics, installed in 2009, deliver local produced energy in form of direct current through 20 Sanyo Hit 210 elements (24 m²):

- Module Efficiency: 16.7%
- Cell Efficiency: 18.9%
- Power Output: 210 Watts

Figure 1 shows the system installed on the roof, photovoltaics to the left, solar thermal further right.

Figure 1: Building with photovoltaic & solar thermal

Heating is electric, supported by solar-thermal (vacuum solar panels). The electric boiler, as well as several pumps, bring the heating system into scope of the SmartCoDe project. A well pump (360 W) pumps the water from the well to the solar boiler (500 l). The electric boiler

(1500 W, 100 l) is connected in series to the solar boiler. It is only active in times with insufficient solar energy output.

Quite remarkably, water from the solar boiler is also used to feed the washing machine.

1.1.1 Past Consumption

Table 2 gives an overview of the consumption of energy and water during the 5 years before the start of SmartCoDe project. All data are extrapolated for a period of 365 days.

Medium period	*PE factor*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*
electricity pub supply [kWh]	2,97	10.609	10.776	10.030	5.755	4.863	5.211
electricity sold to pub grid [kWh]	-2,97	0	0	0	0	2.874	2.387
electricity production PV [kWh]		0	0	0	0	4.510	4.286
consumption electric [kWh]		10.609	10.776	10.030	5.755	6.499	7.110
solarthermal water heating [kWh]	0	No data	No data	No data	No data	No data	No data
warm water [m³]		No data	No data	No data	98	82	77
room heating gas [kWh]	1,12	2.306	823	321	339	494	0
room heating wood [kWh]	0,2	18.240	16.416	14.592	12.768	14.592	14.592
consumption room heating [kWh]		20.546	17.239	14.913	13.205	15.168	14.669
Heat Degree Days (average)	2.705	2.834	2.784	2.385	2.360	2.683	2.705
heat consumption HDD corrected [kWh]		19.611	16.750	16.914	15.135	15.292	14.669
consumption total [kWh]		32.135	28.519	23.179	17.191	21.462	21.702
Primary Energy Balance [kWh]		38.037	36.333	32.679	19.652	9.350	11.304
consumption electric [kWh/m²]		20	20	19	11	12	13
Primary Energy Balance [kWh/ m²]		71	68	61	37	17	21
CO2 emissions [kg]		7.420	7.129	6.495	3.782	4.320	4.588
CO2 emissions [kg/m²]		14	13	12	7	8	9

Table 2: Consumption data of demonstrator site Almersberg

Remarks w.r.t. past consumption and production:

2008

- Heating circulation pumps henceforth switched off during summer season
- Electric boiler was renewed, boiler temperature lowered
- 3 PCs are switched off when not in use
- Exchange of the inefficient deep freezer

2009

- Photovoltaics installed

2010

- Installation of IT equipment for measuring wind speeds

Costs are primarily due to electricity consumption. Electrical energy is procured from “Kelag”, grid provider and local utility is “EVN”. The observed reductions are due to the measures described above and also in part attributable to changed user behaviour. Achieved reductions prior to the start of the project, between 2005 and 2008, amount to 43%.

1.1.2 *Components of the demonstrator*

Table 3 lists the LEPs and EuPs at Almersberg in more detail:

Local Energy Production (LEP)	*kW*
Solar Heating Vacuum tubes	1,2
Photovoltaic	4,0
Supply from public grids	
public grid supply gas	35,0
public grid supply Electric Power	25,0
local water supply	2,0
Energy storage	
Battery 24V / e-car power supply	2,0
WW Watertank 2 400l	2,0
WW Watertank 3 100l	2,0

Energy using Products (EuP)	*kW*
Fridge	0,05
Deep Freezer	0,12
Water pump Gardening	0,22
Heating pump	0,05
Illumination	4,50
Indoor	
Car Parking	
Outdoor (Park, Terrace)	
Water heater electrical	1,50
Washing machine BSH	1,60
Dishwasher BSH	2,40
Water supply pump	2,00
Pumps (technical room)	0,25
Cooking	3,60
Oven BSH	3,70

Table 3: Components of the demonstrator in Almersberg

1.1.3 *Measurement concept*

In order to measure baseline data, building features, user behaviour and the weather impacts, the following quantities are recorded:

- **Electricity - main meters** (public grid supply and delivery)
- **Electricity - sub meters** for photovoltaics and selected EuPs
- **Ambient Temperature outside and inside**
- **Water temperatures** inside boilers
- **Wind speed and sun radiation** for production forecasting
- **CO_2, room temperature and humidity** to document user comfort

Table 4 lists the sensors installed at Almersberg in more detail; Figure 2 gives a schematic overview.

Name	*medium*	*technical entity*	*measuring cycle [min]*
Energy supply			
Gas counter	gas	m³	15
Electricity from pubic grid	el. Cur 3phase	kWh	2
Electricity to pubic grid	el. Cur 1phase	kWh	2
Photovoltaic LEP	electricity	kWh	2
Solarthermie LEP	water	kWh	2
Warm Water 100l (WW)	electricity	kWh	2
	heat	kWh	2
Biomass	heat	kWh	5
Warm Water counter	water	l	2
Solar counter	heat	l	2
Temperatures			
T Outdoor north	air	°C	15
T Solar RL	solarwater	°C	15
T Solar VL	solarwater	°C	15
T Warm Water	freshwater	°C	15
T Solar Thermie roof	solarwater	°C	15
T Cold Water	freshwater	°C	15
T Solarwatertank up 400l	freshwater	°C	15

Name	*medium*	*technical entity*	*measuring cycle [min]*
Other sensors			
Windspeed m/s	wind	m/s	10
Global radiation	sun	W/m²	2
Temperature PV Surface	temperature	°C	15
Temperature WW El.tank 100l	temperature	°C	15
Energy using Products (EuP)			
Washing machine	electricity	kWh	2
Dishwasher	electricity	kWh	2
Watersupply pump well	electricity	kWh	2
Oven Kittchen (coocking)	electricity	kWh	2
Technician room (pumps, IT)	electricity	kWh	2
Fridge	electricity	kWh	2
Deep Freezer	electricity	kWh	2

Table 4: Overview of the EMS channels at Almersberg

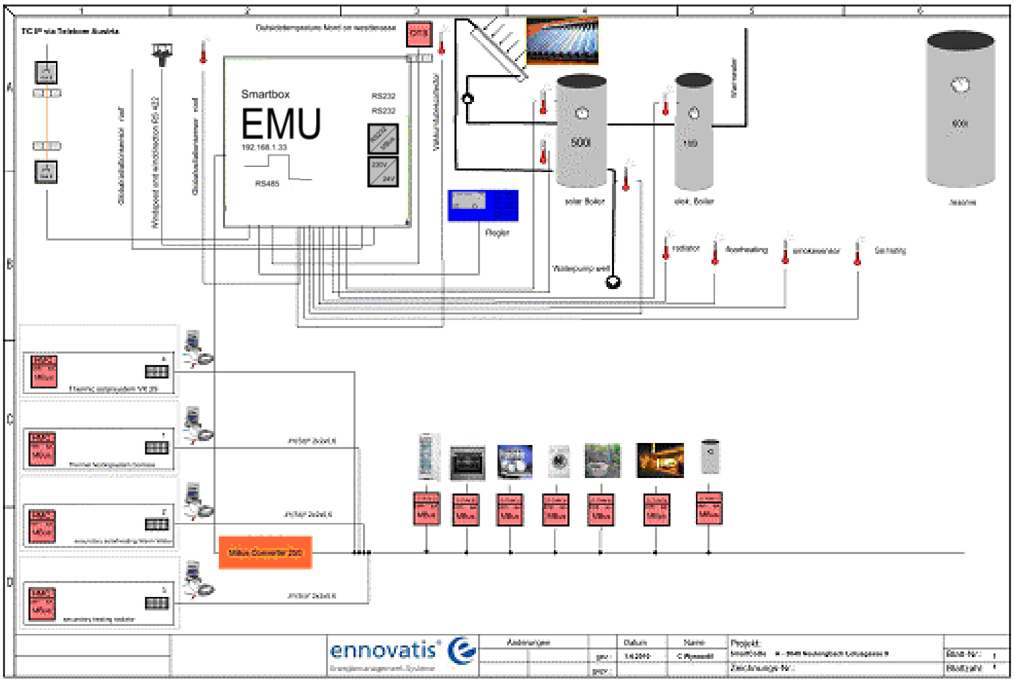

Figure 2: Schematic overview of the Almersberg demonstrator

1.1.4 Features demonstrated

In contrast to the demonstrator at Buchberg (described below), the Almersberg demonstrator focuses on the following issues:

- **Classical, individualized approach** to energy management (optimisation of the legacy system, only small investments)
- **Influencing of user behaviour** via the visualisation of energy consumption

The optimization goal is minimizing primary energy usage and thus saving CO_2.

1.2The Buchberg Demonstrator

The Buchberg demonstrator is a restaurant and home to the tenant’s family. It is located on a hill-top (“Buchberg”) surrounded by woods. It serves the local population as hiking destination, but is also reachable by car via public roads. Ownership is shared between three municipalities (Neulengbach 40%, Maria Anzbach 40%, Asperhofen 20%).

The tenants family (2 adults, 2 children aged under 10) live permanently on the premises, the cook only during the opening season of the restaurant. Opening hours of the restaurant are Thursday to Monday from 9 am to 22 pm.

The site was developed as demonstration site for the SmartCoDe project starting in autumn 2010. Meteorological measurements are available from prior to that time, since the nearby look-out tour is equipped with a metering station by ZAMG (the Austrian national weather service). In August 2011 a QR5 wind turbine was installed at the site.

Table 5 lists general information of the demonstration site:

Location	A- 3034, Austria
Adress	Buchbergstraße 12, Maria Anzbach
Altitude	47.43°
Longitude	13,23°
Sea level:	469 m
Year of construction, refurbishment:	1945 / 1990 / 2006
Net base area	311 m²
Reference area	683 m²
Net base area (thermal)	249 m²
V (thermal gross volume)	681 m³
A (surface area)	635 m²
A/V	0,93 m -1

BRI (gross volume)[1]	791 m³
Average outdoor temperature:	8 °C

Table 5 Basic Information on the Demonstrator (Schutzhaus Buchberg)

Figure 3 setting up the qr5 wind turbine

Commercial considerations can be both a motivation, as well as barrier to adoption of energy optimization. In the case of a restaurant, timely running of dish-washers are critical to the business and therefore not eligible to small scale optimization. The SmartCoDe project therefore focuses on the following EuPs:

- 4 Deepfreezers
- 2 Washing machines
- 2 Laundry-dryers

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[1] Remark: BRI is without cellar (heating room & storage)

1.2.1 *Past Consumption*

Table 6 gives an overview of the consumption of energy and water during the 4 years prior to the start of the project.

Medium period	*PE factor*	*2006*	*2007*	*2008*	*2009*
electricity pub supply [kWh]	2,96	45.873	51.159	54.802	59.260
electricity sold to pub grid [kWh]	-2,96	0	0	0	0
electricity production wind turbine [kWh]		0	0	0	0
consumption electric [kWh]		45.873	51.159	54.802	59.260
warm water [m³] (Oct - Sep)		no data	priv well	577	524
consumption room heating [kWh]		42.312	77.795	52.882	105.732
Heat Degree Days (average)	3343	3.252	2.997	3.033	3.090
heat consumption HDD corrected [kWh]		43.496	86.776	58.287	114.389
cooking gas [kWh]		19.524	28.263	23.423	31.768
consumption total [kWh]		108.893	166.198	136.512	205.417
Primary Energy Balance [kWh]		206.961	273.822	250.085	334.379
consumption electric [kWh/m²]		67	75	80	87
Primary Energy Balance [kWh/ m²]		303	401	366	490
CO2 emissions [kg]		46.951	63.311	56.522	77.194
CO2 emissions [kg/m²]		69	93	83	113

Table 6: Past consumption of Buchberg demonstrator

Remarks w.r.t. past consumption:

- Accounting period is Feb. to Jan. of the following year
- Room Heating: One circuit of radiators. Primary energy source: oil

The 87 kWh/m² from 2009 serve as starting point for SmartCoDe energy optimization at the Buchberg site.

1.2.2 *Components of the demonstrator*

Table 7 gives an overview of the LEPs and EuPs available at Buchberg. Included is an estimation of the relative relevance of the different EuPs and compound consumption.

Energy using Products (EuP)	*kW*	*Power Share*	*Usage [h]*	*Con-sumtion [kWh]*	*Con-sumtion Part*	Estimation
Heat:						
Pump	0,05	0,2%	5.856	293	0,5%	8 month/a 24 hours/d in use
Ventilation:						
Ventilator	0,25	0,9%	1.098	275	0,5%	12 month/a 3 hours/d in use
Others:						
Deepfreezer						12 month/a 24 hours/d in use
Whirlpool AFG 6512G	0,20	0,7%	2.281	456	0,8%	DF1 / 1,25 kWh p d / 503l est: 0,2kW
Austria Haustechnik GTX 47SS	0,22	0,8%	4.480	986	1,6%	DF2 / 2,70 kWh p d / 386l
AHT CC400 Type 807 Eskimo	0,30	1,1%	3.772	1132	1,9%	DF3 / 3,10 kWh p d / 364l
Elin GTL 0191	0,14	0,5%	4.171	584	1,0%	DF4 / 1,60 kWh p d / 180l (est: 1,6 kWh pd)
Washingmashine BSH WM16S750	2,30	8,1%	209	480	0,8%	estimation 300 washings a 1,6 kWh
Washingmashine Miele Meteor 1000	2,40	8,4%	213	510	0,9%	estimation 300 washings a 1,7 kWh
Dryer BSH WDT60	1,50	5,3%	160	240	0,4%	estimation 150 dryings a 1,6 kWh
Dryer Electrolux EDC 5310	4,37	15,3%	150	656	1,1%	estimation 150 dryings a 4,37 kWh
Oven BSH HTSHBP7	3,70	13,0%	81	300	0,5%	estimation 500 preparations a 0,6 kWh
Cold Storage Room	0,80	2,8%	8.760	4205	7,0%	est. 12 month/a 24 hours/d 60% on duty
Restaurant	5,00	17,5%	5.368	26840	44,7%	est. 11 month/a 16 hours/d in use
Sigthseeing tower	1,80	6,3%	8.760	15768	26,3%	12 month/a 24 hours/d est 1,8kW in use
Houshold	0,50	1,8%	8.760	4380	7,3%	12 month/a 24 hours/d est 0,5kW in use
Events, outdoor, others	5,00	17,5%	579	2897	4,8%	

Local Energy Production (LEP)	*kW*
Windpower generator	6,5

Supply from public grids	
public grid supply gas	35,0
public grid supply Electric Power	35,0

Energy storage	
WW Watertank 1 500l	not used

Table 7: Overview of connected EuPs at the Buchberg demonstrator

The EuPs with the biggest connection power are not necessarily those that consume the most energy. For example, the laundry dryer potentially consumes 15% of the power, but has only a 1% share of the energy consumption. On the other hand the cold storage room has a share of the power of 3%, but a consumption of 7%. It follows that high power low energy EuPs (laundry dryer) have relatively short duty-cycles and vice versa.

This point is useful for illustrating the SmartCoDe approach: Classical measures focus on lowering energy consumption. In addition to that, SmartCoDe aims to shift the duty-cycle to times when local energy is available, thereby also reducing volatility.

1.2.3 *Measurement concept*

In order to measure baseline data, building features, user behaviour and the weather impacts, the following quantities are recorded:

- **Electricity – main meters (**public grid supply and delivery)
- **Electricity – sub meters** (QR5 wind turbine, single EuP meters)
- **Temperatures** of different EuPs
- **Ambient temperature outside & wind speed** for production forecasting
- **Room temperature and humidity** to document the user comfort

Table 8 lists the sensors installed at Almersberg in more detail; Figure 4 gives a schematic overview.

Name	*medium*	*technical entity*	*measuring cycle [min]*
Energy supply			
Public Supply	electricity	kWh	15
Pub-Sup Buy	electricity	kWh	15
Pub-Sup P-Sell	electricity	kWh	15
Turbine_Supply	electricity	kWh	15
Temperatures			
Outside	air	°C	15
Bathroom	room	°C	15
Restaurant	room	°C	15
Grocery	room	°C	15
DF1 Whirlpool 503l	freezer	°C	15
DF2 AHT GTX 386l	freezer	°C	15
DF3 Eskimo 364l	freezer	°C	15
DF4 ELIN GTI 0191	freezer	°C	15
Other sensors			
Humidity Grocery	humidity	%	15

Name	*medium*	*technical entity*	*measuring cycle [min]*
Energy using Products (EuP)			
DF1 Whirlpool 503l	electricity	kWh	15
DF2 AHT GTX 386l	electricity	kWh	15
DF3 Eskimo 364l	electricity	kWh	15
DF4 ELIN GTI 0191	electricity	kWh	15
Washing machine 1 BSH	electricity	kWh	15
Washing machine 2	electricity	kWh	15
Dryer 1 Electrolux	electricity	kWh	15
Dryer 2 Main house	electricity	kWh	15
Kitchen	electricity	kWh	15
Tower	electricity	kWh	15
Main house	electricity	kWh	15
Freeze-house	electricity	kWh	15
Oven 1	electricity	kWh	15
Washing room	electricity	kWh	15
E-heating Washing room	electricity	kWh	15

Table 8: Overview of the EMS channels at Buchberg

The schematic also includes the SmartCoDe elements: SmartCoDe Coordinator (connected to the EMU), the SmartCoDe ZigBee routers and the SmartCoDe nodes which are connected to the EuPs.

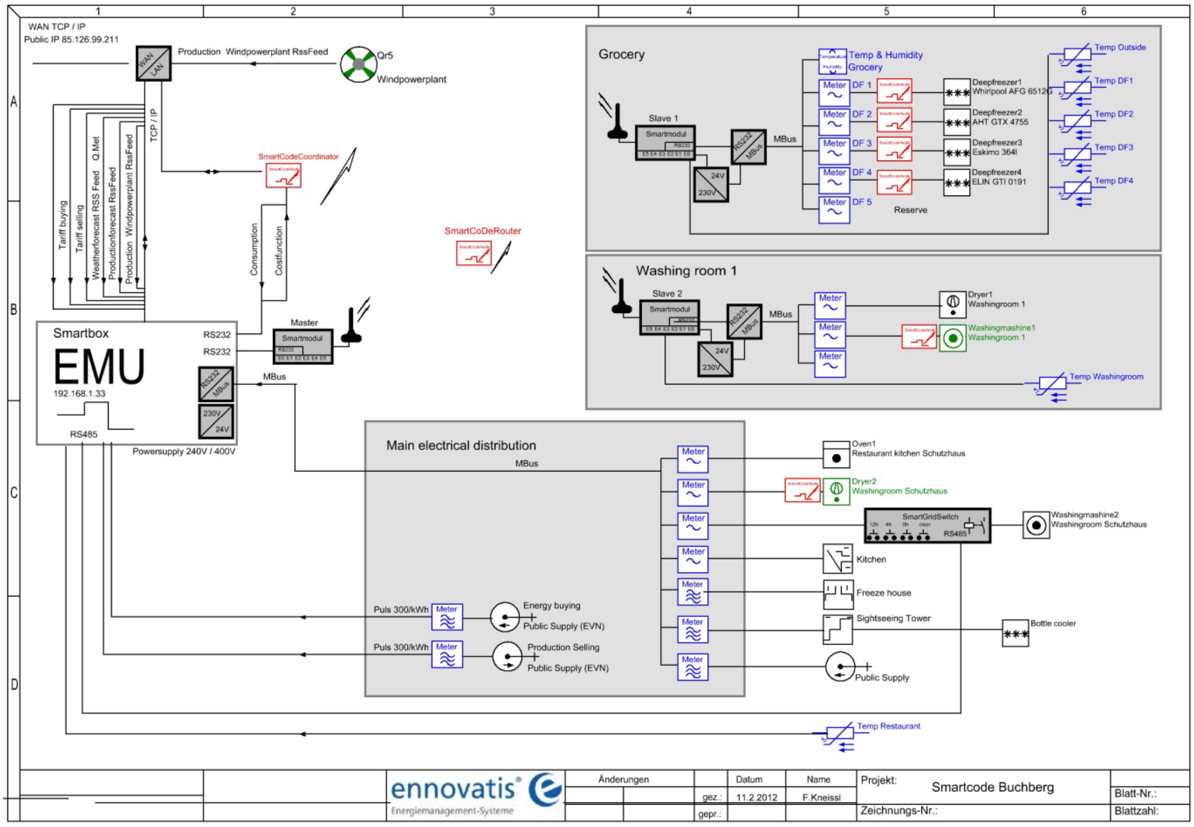


Figure 4: Schematic overview over the Buchberg demonstrator

1.2.4 Features demonstrated

The Buchberg demonstrator is primarily used to show SmartCoDe energy balancing with the aim to reduce volatility: Specifically the whole chain of local energy production, forecasting, scheduling future energy consumption and proper load plan execution.

Together with classical energy optimization as demonstrated at Almersberg, a process facilitated by SmartCoDe consumption monitoring, a model calculation for a typical house-hold is presented in chapter 5.

2 Baseline Development – the Base to proof results

This chapter describes the methodologies to determine and to document energy savings achieved in the SmartCoDe demonstrators by classical energy management as well as applying SmartCoDe nodes and SmartCoDe energy management. For this we modified the methodology for Energy Efficiency Measurement (EEM) developed in the 3-e HOUSES project [R. Silvero et.al., 2010], based on Energy Savings, avoided CO2 emissions and load curve shifting (demand response) measurements. This enables the SmartCoDe project to meet one of the objectives of the project, namely the replicability and standardisation of the results achieved in the demonstrator.

In order to know and evaluate the energy consumptions prior to the implementation of the Energy Conserving Measure (ECM) solution, it was necessary to develop energy audits and a measurement campaign. The necessary information was:

- equipment in the facility
- state and operation profile of the equipment
- operation detail to calculate the distribution of the energy consumption
- behaviour of the energy consumption in the facility.

In order to calculate the energy savings, it is necessary to know the baseline consumptions, the consumption after the ECM solution implementation and the necessary adjustments to do.

After an introduction to the methodology we describe its usage in the SmartCoDe project and the concrete application to the demonstrator sites.

2.1 Methodologies to determine and adjust the Baseline

Energy savings can’t be measured directly. It is always necessary to compare different situations: The situation before the implementation of the ECM (the *baseline period*), and the one after the implementation (the *reporting period*). More practical is a calculation of the energy savings with a standardised calculation methodology. This chapter gives an overview about the different types of methodology to calculate these savings.

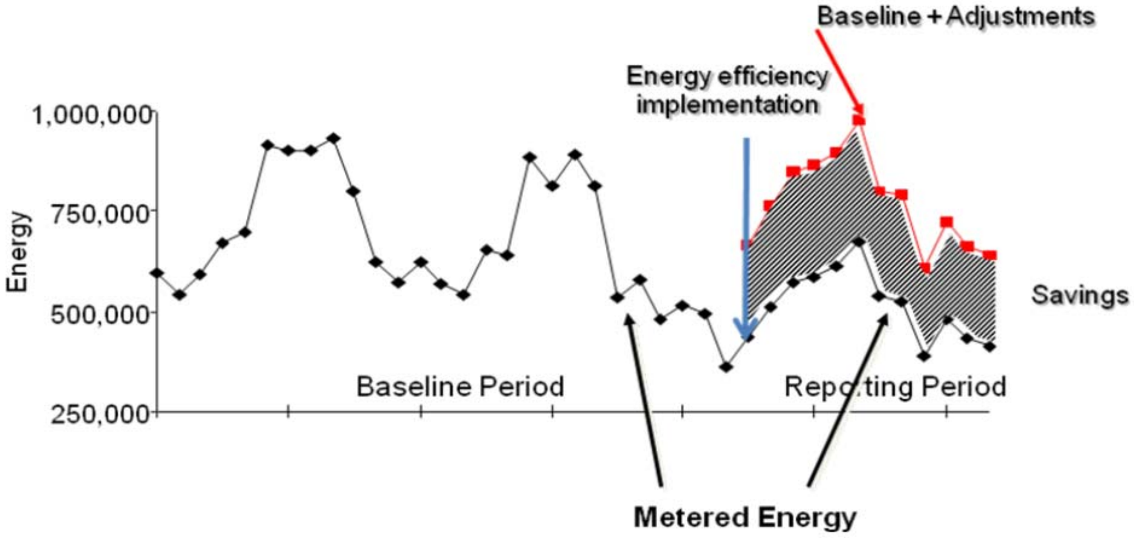


Figure 5: Definitions of Baseline, Reporting and Saving periods

In general, , the energy-saving is the difference of the consumption according to the energy efficiency measures (EEM) and the consumption prior to the EEM-implantation (see Figure 5). Power consumption, however, is influenced by different variables like weather, usage or occupancy, which makes a direct comparison difficult since it might not be obvious if an observed difference is caused by EEM or other effects. If the differences are small in absolute values, as it is the case in the SmartCoDe demonstrator, it is necessary to eliminate these influences as much as possible. Ideally, the two periods which are to be compared should have the same conditions (e.g. be in the same time of the year with the same weather conditions). Where this cannot be achieved, suitable adjustments have to be made. The calculation of baseline and reporting period energy can originate from short-term or continuous measurements of key operating parameter(s) (sub-metering ECM affected system), consumption measurements of the whole building and calibrated simulations.

The method which has to be chosen to describe the baseline and to make the necessary adjustments should be easy to implement, deliver accurate, useful and transparent results and – quite important – has to be adaptable for this type of project.

2.1.1 *Quantities to formulate ratios to the baseline – Key Performance Indicators*

Generally, there are different ratios which can be measured and monitored to calculate energy savings (technical, environmental, economical) but there are also ratios which can be only rated in a specific way (social) or only indicators to relate to this ratios can be measured. The following list shows existing ratios in relation to energy efficiency:

- **technical ratios** are important to calculate the energy savings and therefore measure the energy efficiency. With technical ratios it is possible to visualise the results in diagrams to analyse them and show inconsistency clearly. Examples are “heating consumptions per person (kWh/person)”, “lighting consumption per square meter (kWh/m²)” or “cooking consumption per person (kWh/person)”.
- environmental ratios: The level of this ratio is depending on the previous known technical ratios; the higher the energy savings are, the lower are the emissions caused by the energy generation. Examples are “HVAC, lighting: CO2 emissions per m2” or “cooking, pumping: CO2 emissions per person”.
- social ratios: An important ratio is the “comfort” which is directly influenced by the general condition of the building and the installed technical systems. A very important factor to regulate the comfort is the behaviour of the tenant. With the knowledge of the use of the technical systems the tenant can influence the comfort level directly. Ratios to measure the comfort are room temperatures and relative humidity in the dwellings.
- economical ratios: These ratios are directly related to the energy consumption and their costs. Economical ratios shall be provided e.g. in a web interface to have a direct overview of the costs and savings generated by the measured energy consump-

tions. Examples are "€/person or €/m2: total consumption / key factor" or "cent/saved kWh: costs per saved kWh of end energy on the level of a building or dwelling".

2.1.2 *Options to determine the baseline and the energy savings*

Baseline and energy savings can be determined either by measurements or calibrated simulations. The International Performance Measurement and Verification Protocol (IPMVP) gives different options to measure the achieved savings after the introduction of a energy management solution. Depending on the project, the energy efficiency savings potential and the measurement capabilities different options are available. In the case of SmartCoDe, measurements are primarily for monitoring and therefore performed with high time resolution. Thus we were able to identify the Key Parameters *energy consumption* and *operating hours* by simply analysing the consumption data.

In each method, adjustments have to be used. We make a distinction between routine and non-routine adjustments.

- **Routine adjustments** are used for changes in selected independent variables that can be expected to happen throughout the baseline period. These adjustments are often seasonal or cyclical (weather or occupancy variations). Therefore heating degree days (HDD) or cooling degree days (CDD) are used for these reasons as the climatic changes are the main reason of variability in the residential consumption profiles.
- **Non-Routine adjustments** are adjustments for changes in parameters which cannot be predicted and for which a significant impact on energy use/demand is expected. Non-routine adjustments should be based on known and agreed changes to the facility, for example changes in the amount of space being heated or air conditioned, respectively, or changes in the amount or use of equipment.

Depending on the adjustments, we evaluated four options: measurements of the consumptions of the whole system using utility meters (A), specific measurements of Key Parameters of ECM-affected systems (B), calibrated simulations based on the EPBD assessment of the building (C) and the Demand Response methodology (D).

In **Option A, the measurement of consumption of the whole facility**, the savings are determined by measuring energy use (utility meter) at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period. One or more ECMs might be included. Routine adjustments have to be used as required, using techniques such as simple comparison or regression analysis. Non-routine adjustments have to be used as required.

Multifaceted energy management program affecting many systems in a facility. For the energy savings calculation it is necessary to measure the energy use with the electric utility meters for a twelve month baseline period and throughout the reporting period. It is possible to explain the residential consumption with the next formula:

Electricity consumption = constant + X * number people + Y * HDD + Z * CDD

Saving = Baseline Energy – Reporting Period Energy ± Adjustments

Where X, Y and Z are the people-, heating- and cooling-dependent parts of the electricity consumption, respectively.

Example: Energy consumption of a university building. Figure 6 shows a screenshot of the ongoing commissioning system of the University of Stuttgart with commissioning comments from the energy manager. It can easily be seen that is a helpful tool which animates energy managers to interpret the consumption on an actual basis.

Patterns and dependencies are not very clear but we can see

- **Electricity** base load too high
- **Cold** no weekend set back
- **Heat** unreasonable heating during night time

ALLR5B - Verfügungsgebäude

Adresse: Allmandring 5B 70569 Stuttgart
Baujahr: 1997
Fläche: 8075 m²
Datenerfassung: seit 01.04.2004

Figure 6 : Screenshot of the commissioning system of the University of Stuttgart with ongoing commissioning comments from the energy manager

This option is applicable for energy savings > 10%* due to measuring the whole facility.

In **Option B, the Measurement of Key Parameters of ECM-affected systems** the savings are determined by field measurement of certain crucial performance parameter(s) which define the energy use of the system(s) affected by ECM. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the measured parameter, and the length of the reporting period. Routine and non-routine adjustments are calculated as required.

The energy savings calculation is done for each ECM:

Saving = Baseline Period – Reporting Period ± Adjustments

Example: A lighting retrofit where power draw is the key performance parameter that is measured periodically. Operating hours of the lights based on building schedules and occupant behaviour.

Before: Power = 60 W operation hours: 10 h/week

After EEM: Power = 15 W operation hours: 10 h/week

Savings: (60–15)*10=450Wh /Saving year: 450Wh*52weeks/year=23,4 kWh/year

This option is mainly used to determine energy savings for new behaviour or/and new equipment + submetering.

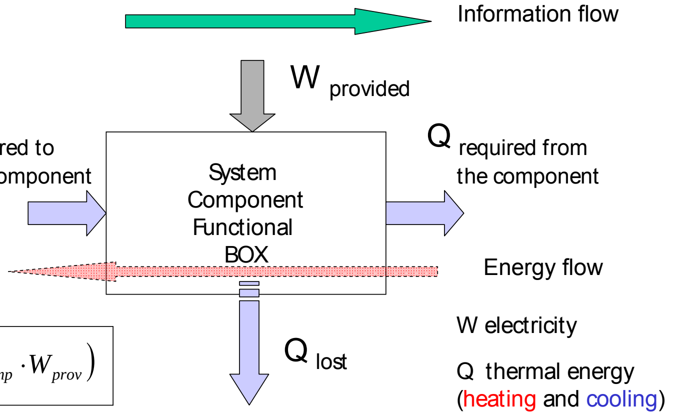
In **Option C, the Calibrated Simulation**, savings are determined through simulation of the energy use of the whole facility, or of a sub-facility. Simulation routines are demonstrated to adequately model actual energy performance measured in the facility. This option requires considerable skill in calibrated simulation if applied to the whole facility.

According to CEN 13790, each component of the system is modelled as an efficiency box which models the efficiency of a component depending on the operation mode. In general an efficiency box could be an emitter, a distribution circuit, a hot/cold storage or a generatorlike a boiler, chiller or a CHP unit. The same approach is made for heating, cooling, domestic hot water and ventilation systems. But also other appliances could be modelled in a similar way.

Each box can in principle be implemented with different level of complexity. The simplest one is to assign a constant efficiency (e.g. efficiency of the distribution circuit), whereas the sub-model for a boiler or a chiller could be more complex.

Figure 7 illustrates the principle input and output data as well as the calculation for a given sub-system (box) through the box characteristic equation. The output (service) of the box is characterised by $Q_{\text{required to}}$. Each sub-system considers an input of energy (electrical or thermal energy) $Q_{\text{required from}}$ and auxiliary electricity (W). The auxiliary electricity is converted to thermal energy and partially added to the system output.

- CEN Approach



Box Characteristic Equation

$$Q_{req\ from} = Q_{req\ to} - \left(Q_{Lost} - k_{Comp} \cdot W_{prov}\right)$$

$$k_{Comp} = \frac{\sum_{i=1}^{N} \left(\eta_{AUX} \cdot \dot{W}_{AUX}\right)_i}{\dot{W}_{provided}} \qquad Q_{Lost} = \left(\frac{1}{\eta_{component}} - 1\right) \cdot Q_{required\ to\ the\ component}$$

Figure 7: Simplified box model according to CEN 13790 (from BuildingEQ)

The outputs are the energy (electrical or thermal) that is delivered to the next connected component $Q_{\text{required to}}$ and the thermal losses Q_{lost}.

Similar models were developed in the scope of SmartCoDe and applied to optimise operation strategies. Models for typical EuPs and LEPs are also developed in SmartCoDe (Overview see attachment 6.4).

To generate the appropriate baseline, a model for each component where ECM is applied has to be developed. Then the level of comfort and associated $Q_{req\ from\ before}$ is determined and the model is calibrated using the measured consumption. Finally apply ECM to component and model and recalculate $Q_{req\ from\ after.}$.:

Saving = $Q_{\text{req from before}}$ - $Q_{\text{req from after}}$

The simulation option is primarily used to analyse special effects using these models.

Using **Option D, the Demand Response Methodology**, the benefits & impacts of this methodology are similar to the energy savings determination according option B:

Savings: baseline – consumption after demand response program ± Adjustments

Attention should be paid on the baseline, which has to be established in a different way for this case. To do this we define the Load Factor (LF). The Load Factor is defined as the value obtained by dividing the minimum power demand over the maximum power demand of a facility:

LF = (Min. power demand)/(Max. power demand)

Following the ideas of the 3e-HOUSES project we introduced the procedure described in Figure 8:

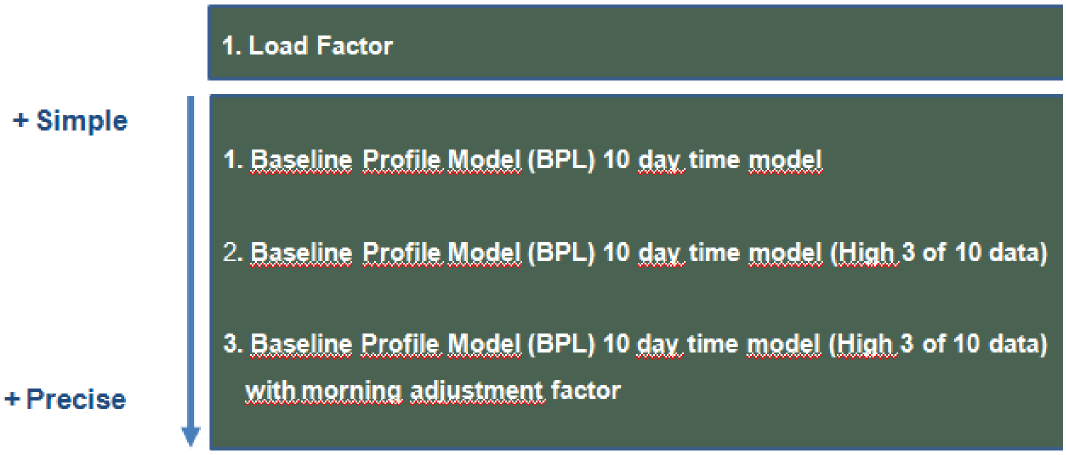


Figure 8: Demand response baseline methodology

In three levels the procedure allows three models rising from simple to precise:

1. Baseline Profile Model (BPL) 10 day time model

   It is generally accepted that a period of approximately 10 (non-event) business days reasonably represents consumption for normal operations and therefore makes up a preferred baseline window for resource adequacy and demand programs. Using a 10 day time window provides an appropriate balance – short enough to account for near – term trends and long enough to limit opportunities for manipulation.

Average calculation method for a 10 day period:

$b:(d1(t,h)+d2(t,h)+d3(t,h)+d4(t,h)+d5(t,h)+d6(t,h)+d7(t,h)+d8(t,h)+d9(t,h)+d10(t,h))/10$

(=average power demand for the number of the events of 10 days of the event)

2. Baseline Profile Model (BPL) 10 day time model (high 3 of 10 data)

   High 3 of 10 exclusion rules among the prevoius10 days, excluding event days and holidays

   $b: \max (1,3) (\sum dn(t,h))/3$

3. Baseline Profile Model (BPL) 10 day time model (high 3 of 10 data) with morning adjustment factor

   Customer demand is often heaviest on event days, capturing day-of realities in a customer load profile is essential to delivering accurate performance calculations. A simple way to address this need is through an adjustment based on day-of event conditions:

   $b': \max (1,3) (\sum dn(t,h))/3$

   $P: (d(t,h-1) - b(t,h-1) + d(t,h-2) - b(t,h-2))/2$

This Option is useful to document the effects of shifting the energy demand to other periods with less PE consumption.

In summary, it depends on the project and especially the project targets, which method to calculate the energy savings is appropriate. The two Demonstrator Sites in SmartCoDe fulfil two different targets – therefore different options were selected to document the effects.

2.2 Application to Almersberg Demonstrator

At **Almersberg** the effects of customary methods of the energy management (optimisation of the current systems, spare investments) and the influencing of the user's behaviour via the visualisation of the energy consumption was examined. These methods influence the energy consumption of single devices as well as the consumption of the whole facility in a relevant way, therefore we decided to use option A (measurement of whole facility) and option B (measurement of Key Parameters) to determine the energy savings.

In this chapter the different measurements and baselines ("fingerprints") are described, that were necessary to calculate the relevant baselines for the demonstrator.

2.2.1 Power consumption of the facility

The **consumption** was measured with meters from Elster and GMC ("Power_consumption"). The following Figures shows the consumption baselines (year 2010):

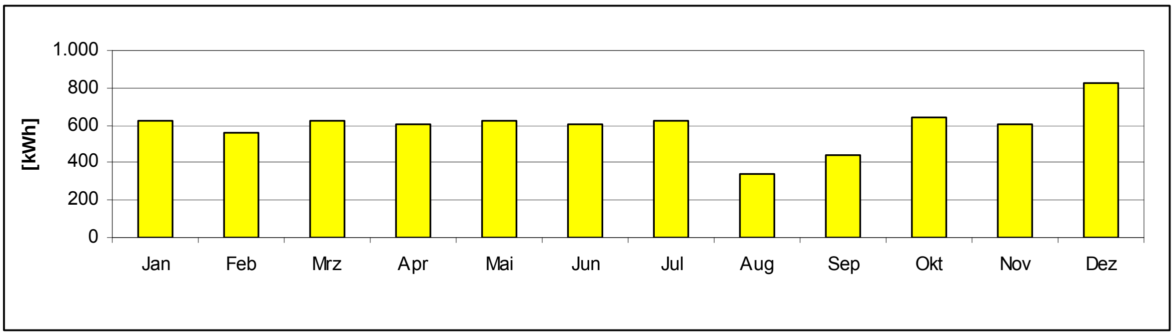


Figure 9: monthly power consumption facility (year 2010)[2]

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[2] 1/2010 to 7/2010 are interpolated values based on the yearly consumption; detailed measurement since 7/2010

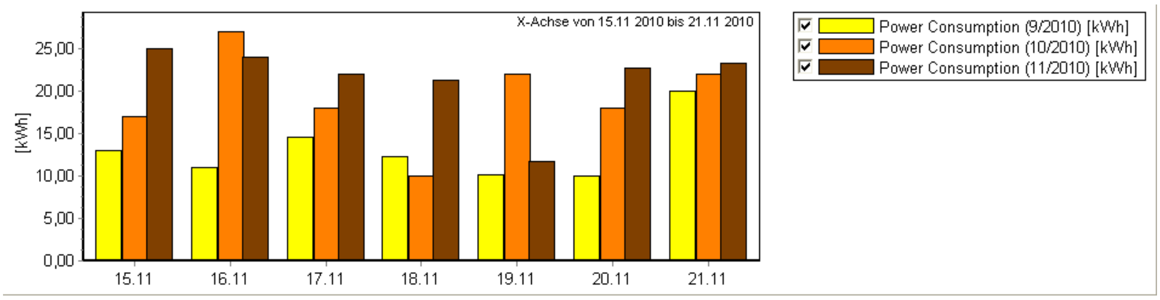


Figure 10: daily power consumption facility (Monday to Sunday 9-11/2010)

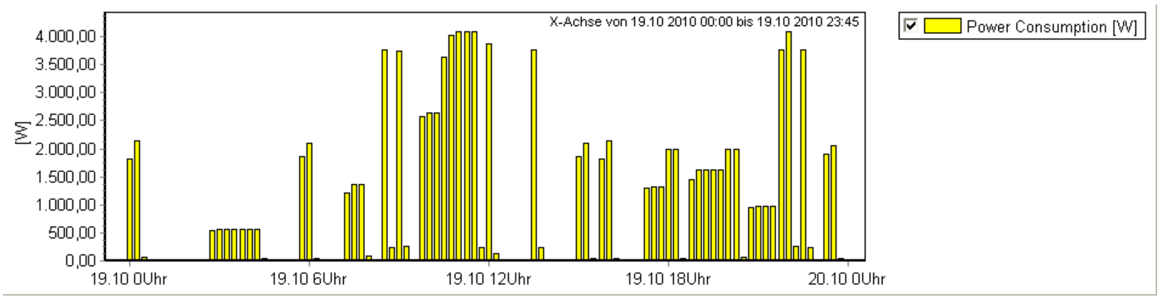


Figure 11: typical load curve facility (example: Tuesday 19.10.2012)

The Figures shows some typical aspects of power consumption at residential buildings: low energy consumption during summer holidays (Figure 9), rising energy consumption in autumn/winter times (Figure 10) and consumption peaks in the middle of the day and in the evening (Figure 11).

2.2.2 Power production (PV)

According to the LEP classification made in Task 1.1 the photovoltaic instalment is considered as VOLAEP.

The **produced power** is measured every 15 minutes by a meter from GMC. The following Figures show the distribution of the solar power over the year (Figure 12) and the production curve over the day (Figure 13).

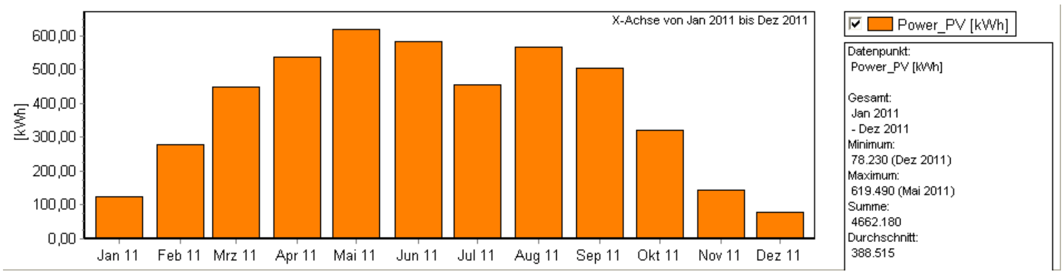


Figure 12: monthly energy production of the PV System

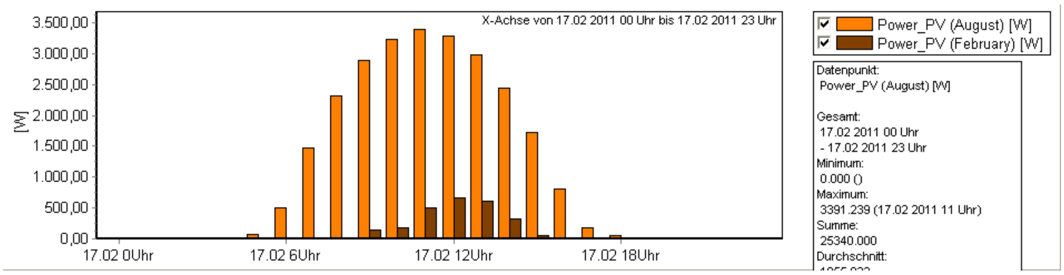


Figure 13: typical daily production curve of the PV System (here: February and August)

In addition, the **solar radiation** is measured by a Pyranometer (GSM/O). It detects almost 100% of the sunlight-spectra in the range from 380 nm to 2800 nm, and thus, comprises the uv-(ultraviolet radiation), vis-(visible radiation), and the part of the ir-(Infrared-radiation) light. This additional sensor enables the evaluation of the dependencies between the solar radiation and the produced power (see Figure 14).

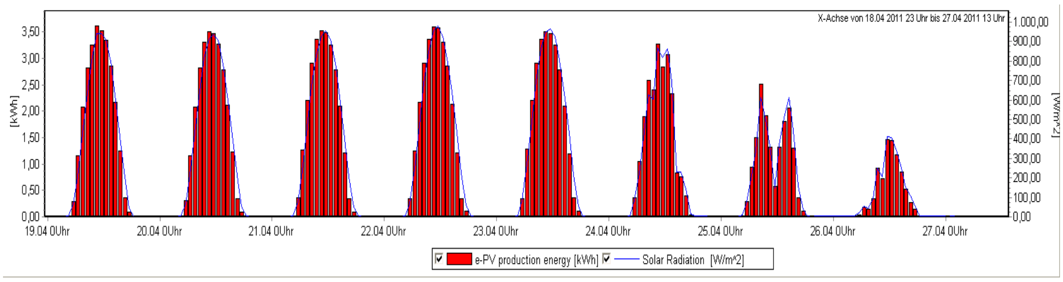


Figure 14: hourly PV production [kWh] in dependence of the solar radiation [W/m²] April 2011

With less influence to the production is the **outside temperature** as a factor measured with a PT 1000 sensor. As a result we observed some days in winter when the PV production is not directly proportional with the solar radiation.

2.2.3 *Power relevant aspects of the heating system*

Beside the local PV production we were also able to analyse the influence of the **Solar Thermic** device which is installed at the demonstrator's site. The installation was done in 1998 and it uses a vacuum tube type called VK 29 from Sonnenkraft. According to the LEP classification made in Task 1.1, Solar Thermic instalments are also is considered as VOLAEP.

Figure 15 shows the correlation between the average solar heat power production a week and the (daily) development of the solar radiation:

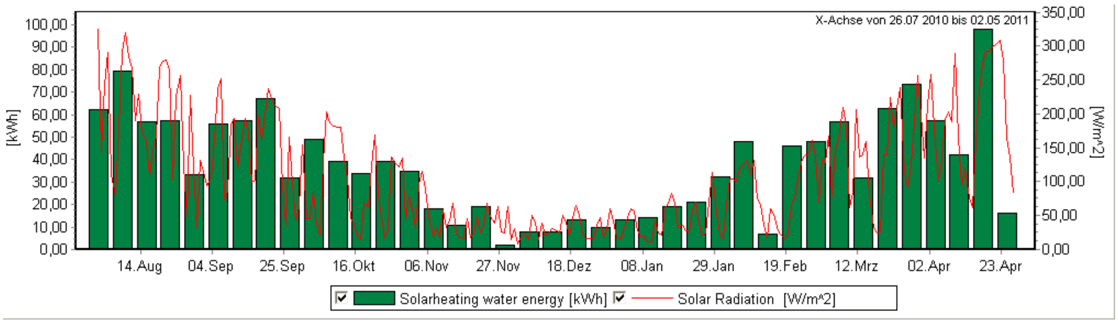


Figure 15: Solar heating [kWh] and solar radiation per week

There exists obviously a strong correlation between solar radiation and the heat production. In order to identify the parameters which influence the energy production, a PT 1000 was fixed on the roof underneath the panel and reflects (approximately) the **temperature of the panel**. The **temperature at the upper part of the solar boiler** is measured with an additional PT 1000. The preheated solar water is directly used for the e-Boiler and the Washing Machine.

As documented in chapter 1, in case of low energy from the Solar Panel the missing energy is produced by an **e-Boiler** (Elektro Bregenz 100l 1,5kW). The e-Boiler is according to the classification a virtually storable service (VSTSVC). It has two meters included: an electric meter and a heatmeter. The next Figure 16 shows the installed heatmeter (blue), the installed electric energy meter (red) from the e Boiler and the heat production from the Vacuum Solar panel (green):

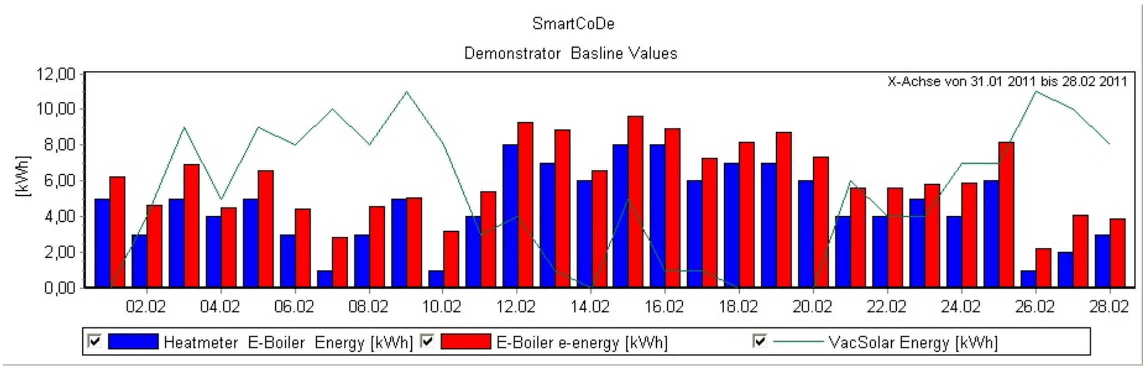


Figure 16 e-Boiler consumption per day in dependence to the supplied solar energy

For the SmartCoDe project also the consumption and behaviour of the **pumps for the distribution** was a relevant topic. The pumps are according to the classification variable services (VARSVC). Therefore an additional e-meter was installed to trace the consumption in the technical room.

Mainly the following EuPs are measured in the technical room:

- Vacuum solar pump (runs only when the Temp on the panel is 2 degree higher than the Solar boiler bottom temperature)
- Heating pump radiator (runs the whole winter season)
- Heating pump floor heating 1 (runs the whole winter season)
- Heating pump floor heating 2 (runs when guests are staying in the house)
- Heating pump storage Boiler (permanently switched off)

Additional equipment in the technical room witch was classified as constant service (CONSVC) with a relevant electric consumption is:

- Server Quiet Revolution Ltd (40 W, permanently switched on)
- Vaillant Control System unit (runs the whole winter season)
- Rendl biomass heat control unit (runs the whole winter season)

In Figure 17 the e consumption of the technical room is shown. On 12th November the heating system was manually switched on. Additionally the consumption (=peaks) of the solar pump (60 W) can be seen. The rest is permanent constant consumption

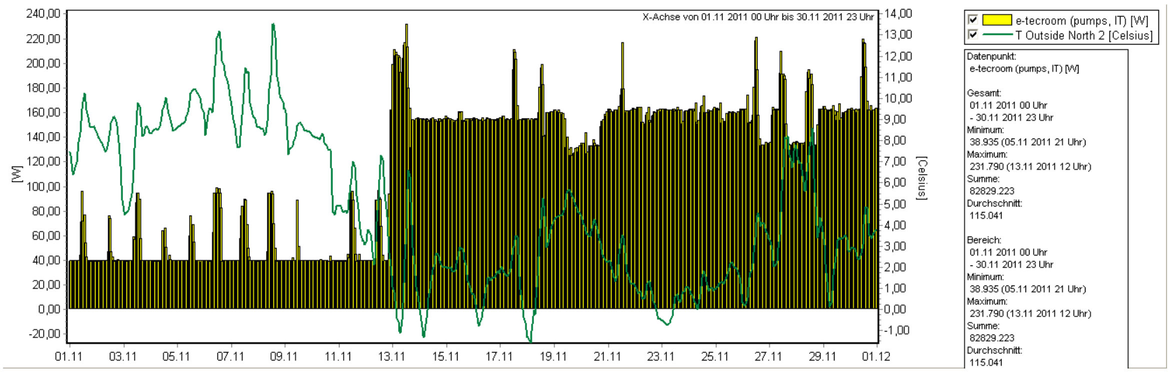


Figure 17 e-consumption technical room and outside temperature

2.2.4 Overview on the EuPs

The following EuPs were identified as relevant for detailed measuring and evaluation during the project:

- Dish-Washer
- Washing Machine
- 2 Ovens (AEG and BSH)
- Deep freezer

Over the year these EuPs have a part of about 40% on the electric consumption of the facility. In this chapter the Key-Parameters of these devices are documented as follows:

The **Dishwasher**, a Siemens Pianissimo 3,1kW, is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

The Dishwasher as seen in the next Figure is only once in the while running more than once in a day (Christmastime, Birthdays). It is not connected to the solar warm water supply and consumes per runtime period approximately 1,5kWh.

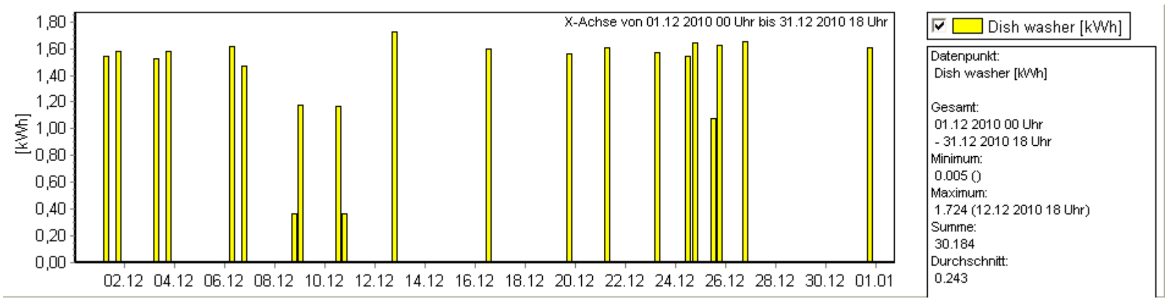


Figure 18 Dishwasher daily consumption

The consumption in detail for one run with 65 Degree Celsius (the washing program is almost not changed during the whole year). The following Figure shows a typical fingerprint of a runtime period:

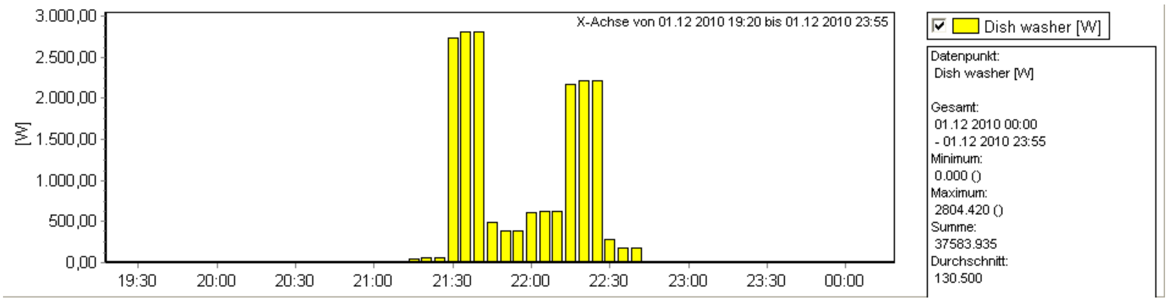


Figure 19 Dishwasher fingerprint

The **Washing Machine**, a AEG Lavamat 86820 2,15 kW, is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

The Washing Machine is connected to the solar boiler, therefore the consumption per washing is varying between aprox. 0,04 kWh and 1,2 kWh in dependence of the solar boiler temperature.

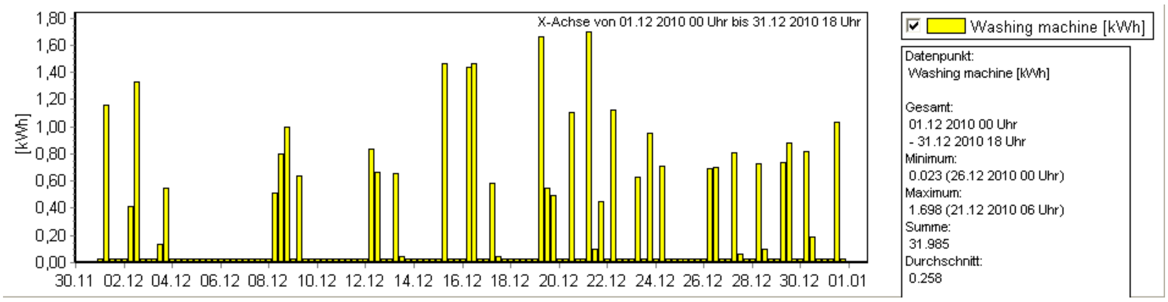


Figure 20 Washing Machine daily consumption

The consumption in wintertime is reasonable higher because of two reasons: the warm solar water is not available from the VAC Solar heating system which feeds the Washing Machine and more runtimes of the machine are done in wintertime.

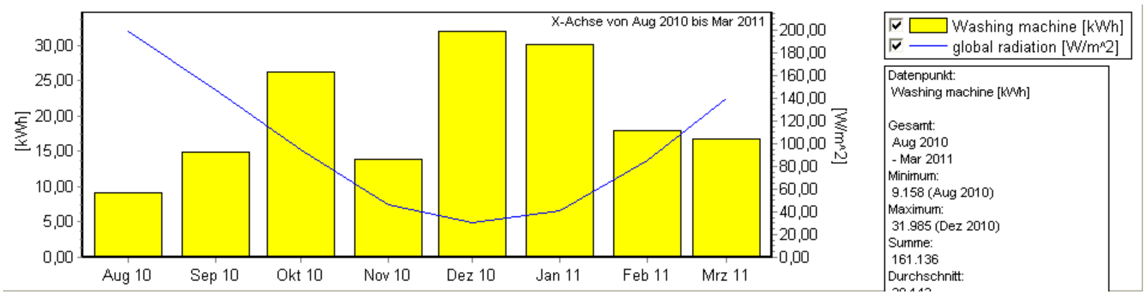


Figure 21 Washing machine and Solar radiation monthly

The consumption of single runs are dependent on the used Program and on the solar boiler temperature. In Figure 22 it is to be seen the consumption for the first run starting at aprox 10:20 am (with 30°Celsius 1000 rpm) and a second run at aprox 11:50am (with 60°Celsius

1600 rpm). For both runs the used water was pre heated from the solar system. The flow temperature was aprox 30°Celsius.

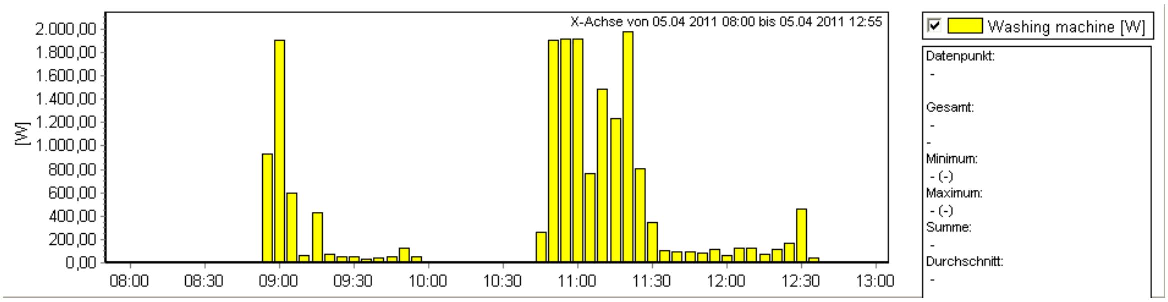


Figure 22: Washing Machine fingerprint - 2 runs: 30° 1000rpm / 60° 1600rpm

The **first Oven**, an AEG Competence, is according to the classification a custom control (CUSCON) device. It is measured by an e-Meter.

The energy consumption of the Oven in the kitchen is between 3 Wh and 1,5 kWh

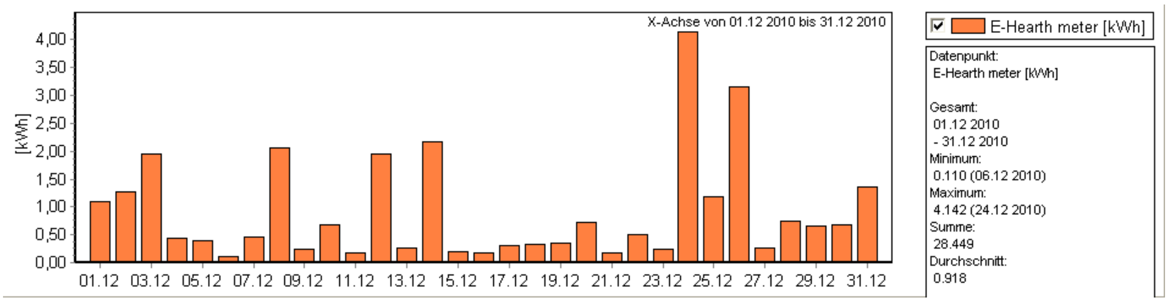


Figure 23 AEG-Oven daily consumption

The load curve heavily depends on the used parts of the oven. The required power ranges from 200 W to 2.800 W. The following fingerprint for example shows an intense use on 24th December:

SmartCoDe has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013]) under grant agreement n°247473

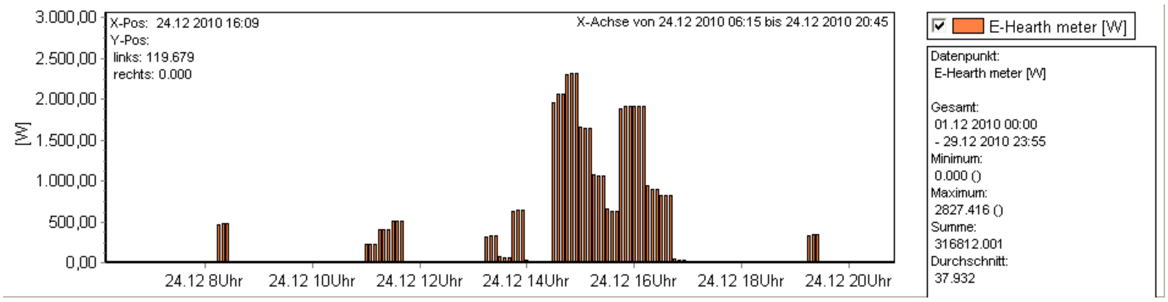


Figure 24 AEG-Oven fingerprint

The **second Oven** from BSH is also a custom control (CUSCON) device. It is measured by an own e-Meter.

The BSH Oven has a permanent consumption of about 0,5 kWh/day.

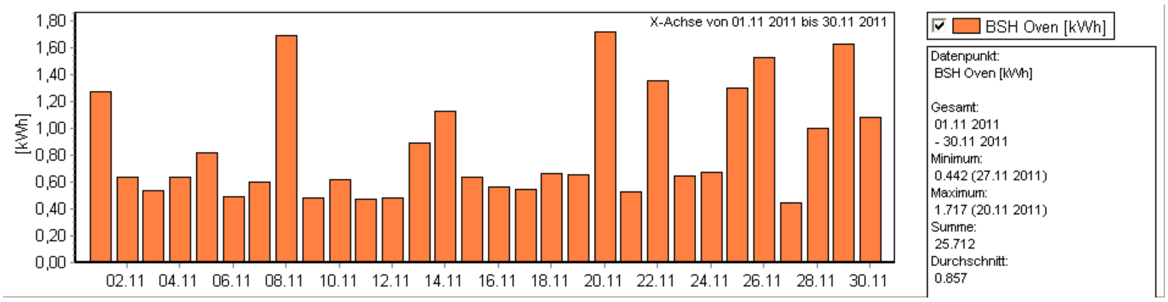


Figure 25 BSH-Oven daily consumption

The load curve heavily depends on the used parts of the oven. The required power ranges from 200 W (60 W permanent) to 1.800 W. The following fingerprint for example shows an intense use on 9th April:

SmartCoDe has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013]) under grant agreement n°247473

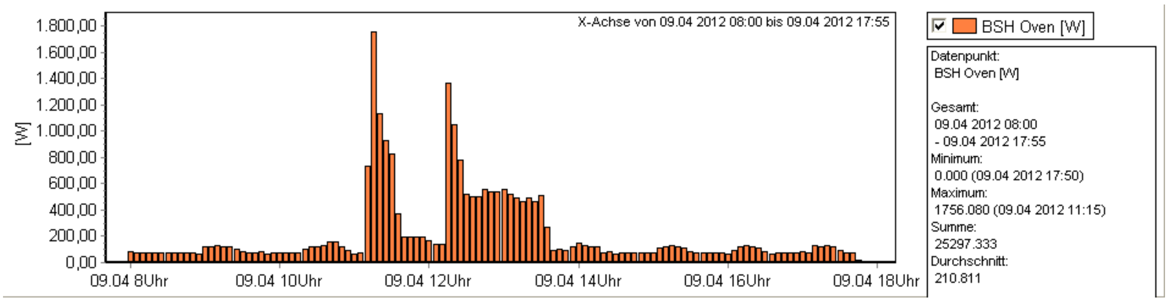


Figure 26 BSH-Oven fingerprint

The **Deepfreezer** is according to the classification a virtually storable service (VSTSVC) device. It is measured by an e-Meter.

The high efficient deepfreezer has a permanent consumption of about 1,5 kWh/day.

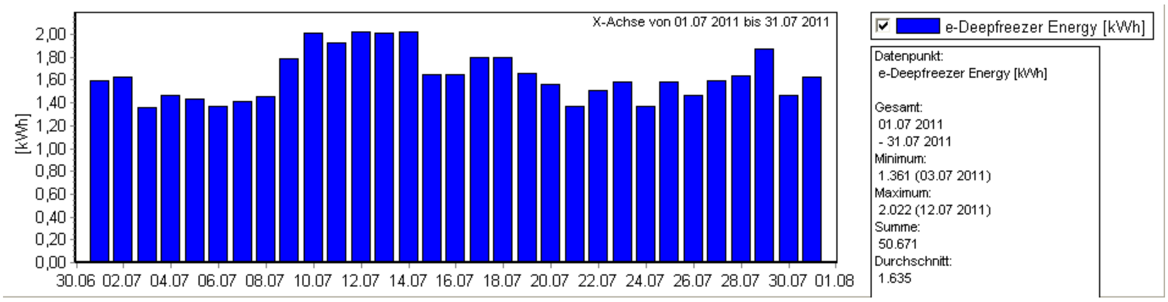


Figure 27 Deepfreezer daily consumption

The load curve depends on the usage (opening times, changing of content) and the outside temperature. The base load is about 80 W and can rise to 1.000 W.

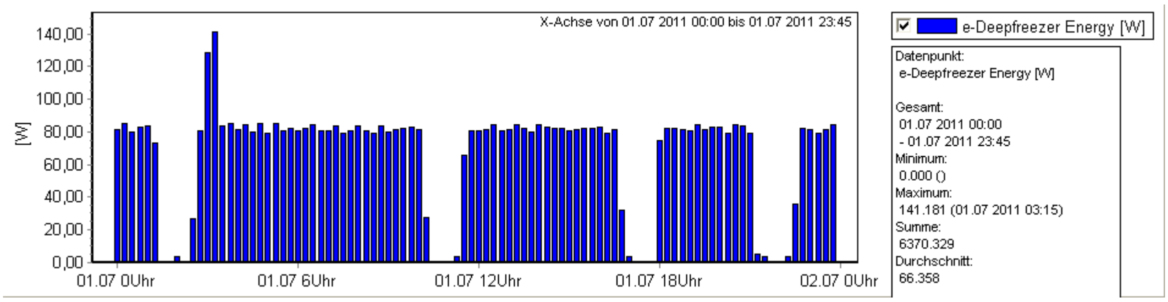


Figure 28 Deepfreezer fingerprint

2.2.5 Consumption and Production

The base load of the facility at Almersberg is about 0,2 kW. The total consumption was about 2.540 kWh.

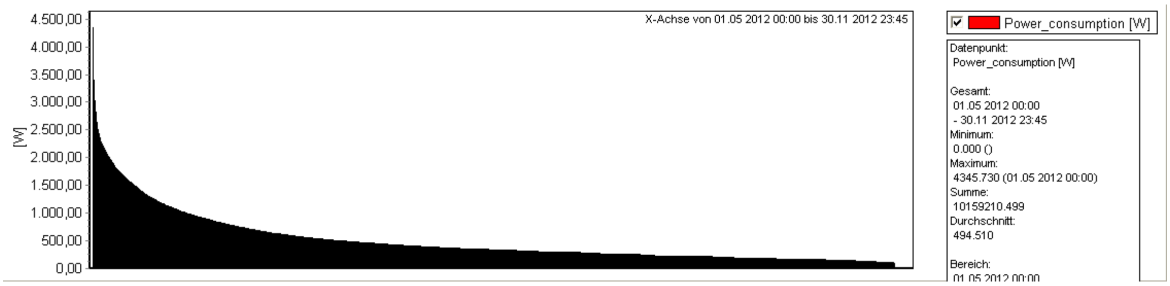


Figure 29: sorted consumption curve of the whole facility (5-11/2012)

In the same time the maximal measured output of the PV-System was about 4 kW. The middle value was about 600 W. Nearly 3.100 kWh was produced in this time.

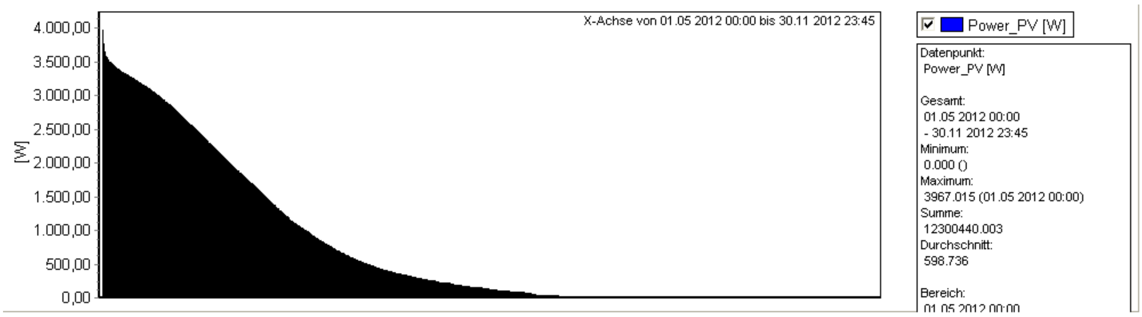


Figure 30: Output of PV-System (5-11/2012)

The following Figure shows the difference between consumption and production. Only 30% are used directly by the facility – the rest is sold to the net. On the other hand the facility buys 60% from the net. It is easy to see, that nearly all needed power could be produced by the PV-System if it would be possible to store the produced energy and/or to shift the consumers.

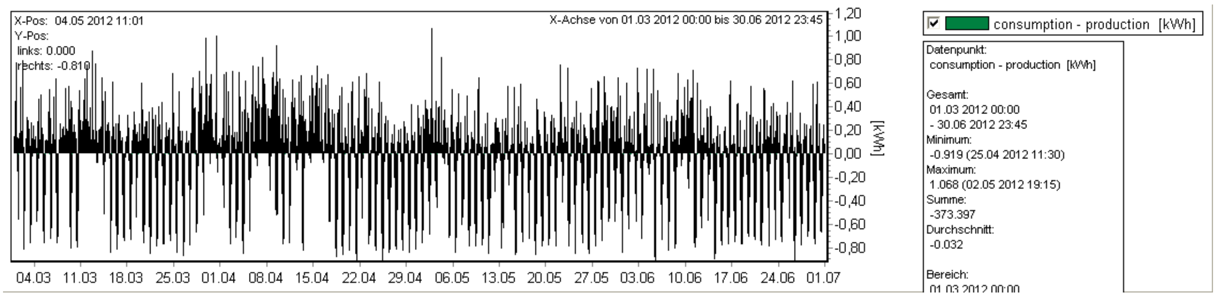


Figure 31: difference of consumption and production at Almersberg

2.3 Application to Buchberg Demonstrator

At **Buchberg** the focus was on decreasing the external use of power from the grid by optimising the usage of the energy produced by the wind turbine. These methods influence the load profile of single devices and of the whole facility and optimise the economical ratios, therefore in this case the combination of option B (measurement of Key Parameters), option

C (calibrated simulation) and option D (Demand Response methodology) was the appropriate methods to document the energy savings.

2.3.1 *Power consumption of the facility*

The consumption of the facility is measured via an interface to the e-meter of the EVU. The measurements started in September 2011.

The average daily power consumption on “non opening” days is about 100 to 120 kWh, on Opening Days the range is between 220 and 300 kWh.

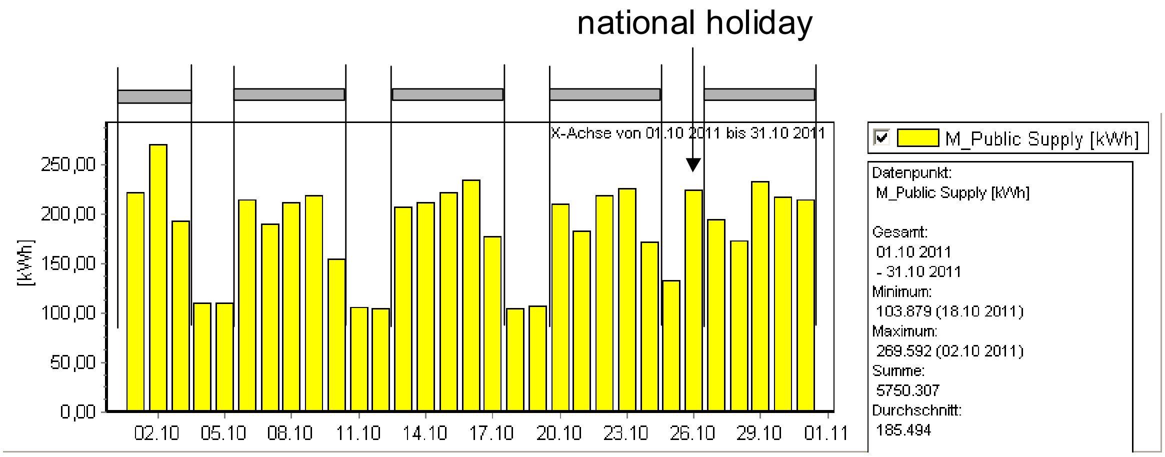


Figure 32: daily power consumption of facility, regular Opening Hours are Thursday to Monday

There is no relevant dependency on the season. The yearly consumption in 2011 was about 65.000 kWh.

The daily load curve on a typical Non-opening Day is shown in the following Figure. The load range is between 4.000 W and 12.000 W:

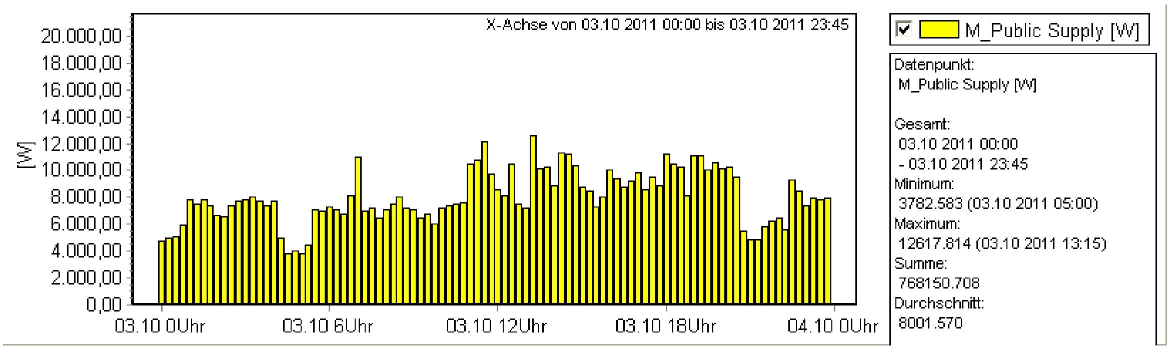


Figure 33: load curve on a typical Non-Opening Day

The load curve on an Opening Day ranges from 4.000 W to 18.000 W. Main consumption times are the typical lunch time from 10:00 to 13:00 and the evening (lights) between 17:00 and 20:00, where the restaurant is used:

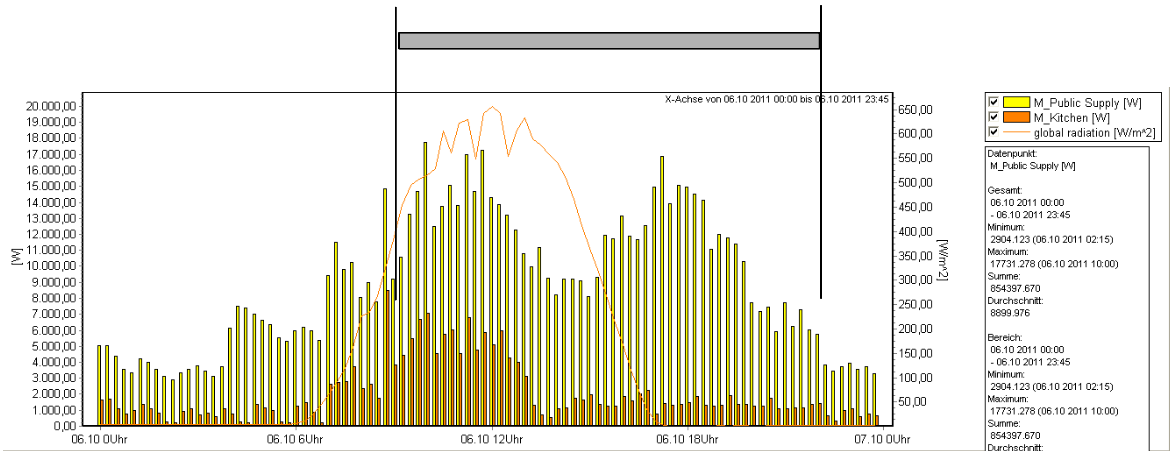
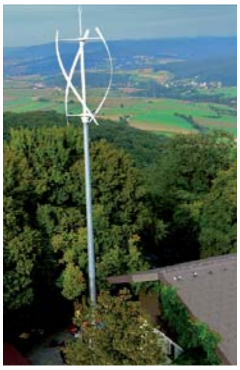


Figure 34: load curve on a typical Opening Day, Opening Time between 9 am to 22 pm with kitchen and global radiation

2.3.2 *Power production (wind turbine)*

In August 2011 the Qr5 Wind Turbine from Quiet Revolution starts its power production at Buchberg. The technical data are:



- Power: The peak power at 14m/s is 7.4kW aerodynamic | 6.2kW DC
  The BWEA rated power at 11m/s is 4.2kW aerodynamic | 3kW DC
- Output: 5,000 - 11,000 kWh per year (site wind dependant)
- Rotor Size: 5m tall, 3.1m diameter |Swept area 13.6m2 | Mass 450kg
- Material: Blades and spokes: Carbon and glass fiber
- Spool tube: Aluminium | Static tube: Steel
- Mast: Turbine is mounted on 15m tilt down mast
- Generator: Direct-drive permanent magnet synchronous generator integrated into the base of the rotor

The Qr5 rotor can use wind from all directions unlike traditional HAWTs which need to track the wind - therefore maximising efficiency:

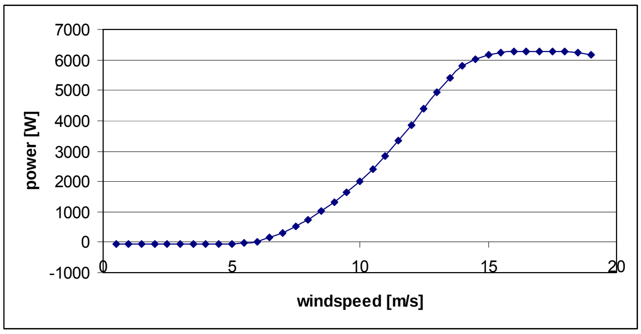


Figure 35: dependency between power production and windspeed (Qr5)

The following Figures show the power production together with the according windspeed[3]:

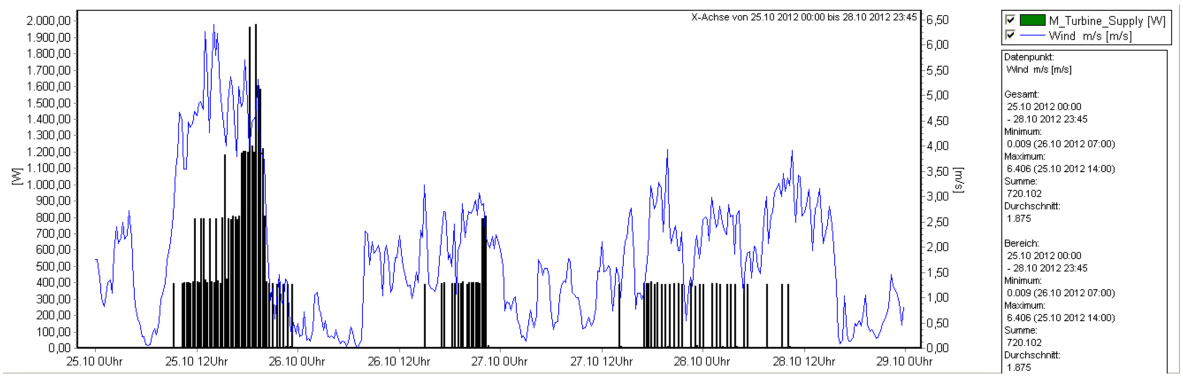


Figure 36: typical daily production curves of the Qr5

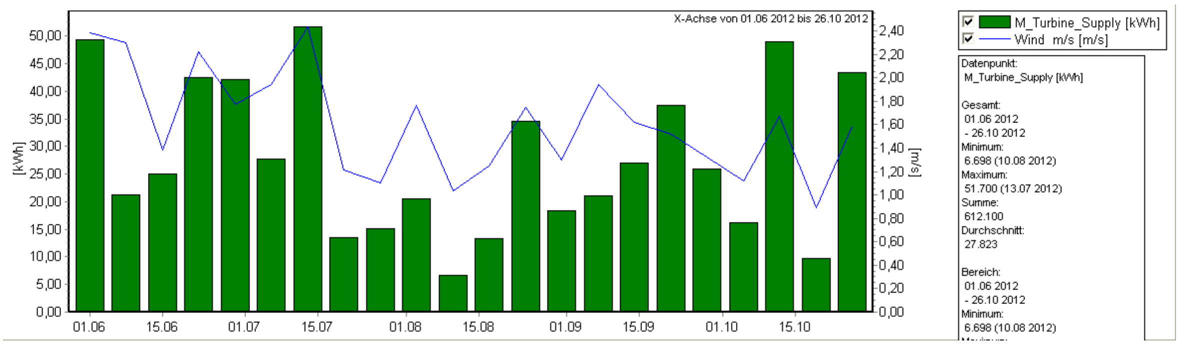


Figure 37: weekly power production of the Qr5 (6/2012 – 10/2012)

2.3.3 Overview on the EuPs

The following EuPs was identified as relevant for detailed measuring and evaluation during the project:

- 4 Deepfreezers

---

[3] windspeed measured at Almersberg

- Freeze-House
- 2 Washing machines
- 2 Dryers
- Oven

Over the year these EuPs have a part of about 33% on the electric consumption of the facility. In this chapter the Key-Parameters of these devices are documented as follows:

The **Deepfreezer 1**, a Whirlpool AFG 6512 G 0,2 kW, is according to the classification a virtual storage service (VSTSVC) device. It is measured by an e-Meter and an additional PT 1000 temperature-sensor.

This Deepfreezer has a permanent consumption of about 1,3 kWh/day with a middle outside temperature of 18 °C and a middle internal temperature of –25 °C.

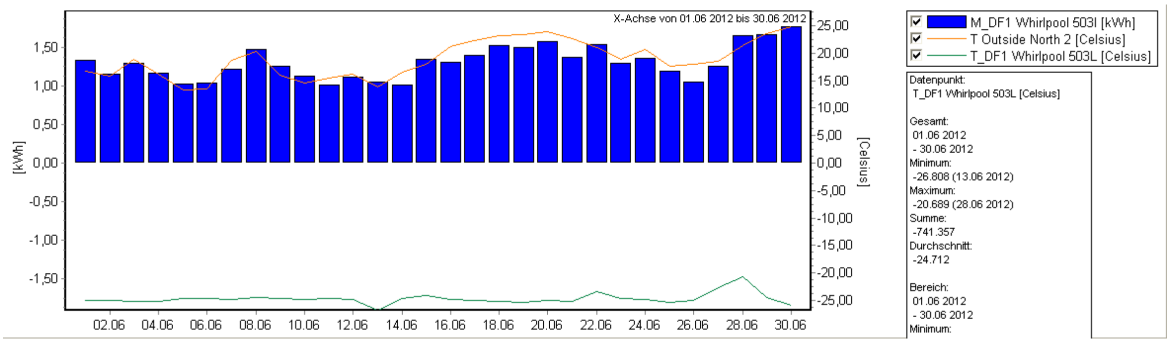


Figure 38 Deepfreezer 1 daily consumption

The load curve depends on the usage (opening times, changing of content) and the outside temperature. The performance purchase is about 75 W.

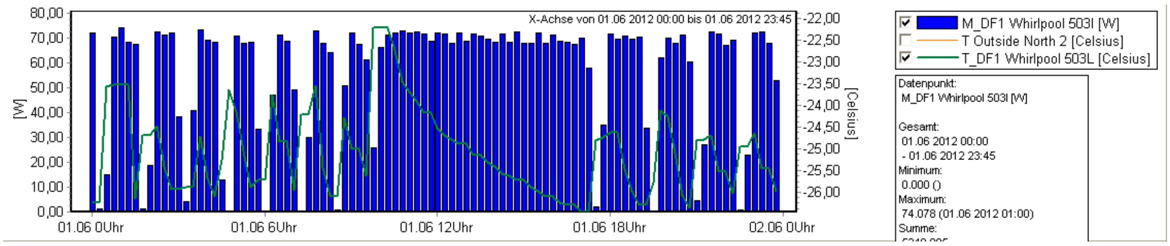


Figure 39 Deepfreezer 1 fingerprint (daily load curve) with internal temperature

The **Deepfreezer 2**, an Austria Haustechnik GTX 4755 0,22 kW, is according to the classification a virtual storage service (VSTSVC) device. It is measured by an e-Meter and an additional PT 1000 temperature-sensor.

This Deepfreezer has a permanent consumption of about 4,0 kWh/day with a middle outside temperature of 18 °C and a middle internal temperature of –22 °C.

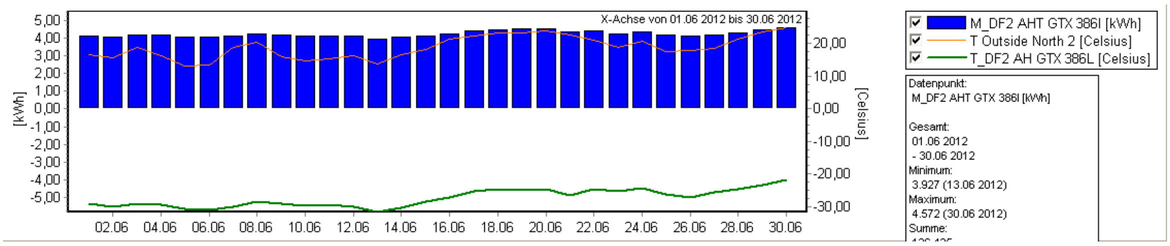


Figure 40 Deepfreezer 2 daily consumption

The load curve is nearly constant. The performance purchase is about 170 W.

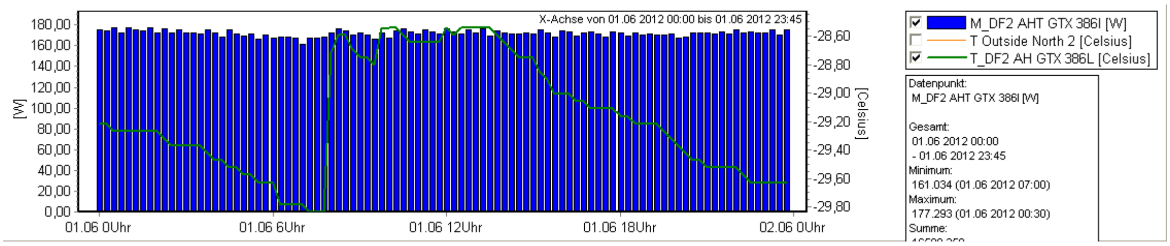


Figure 41 Deepfreezer 2 fingerprint (daily load curve) with internal temperature

The **Deepfreezer 3**, an AHT CC400 Type 807 Eskimo 0,3 kW, is according to the classification a virtual storage service (VSTSVC) device. It is measured by an e-Meter and an additional PT 1000 temperature-sensor.

This Deepfreezer has a permanent consumption of about 2,1 kWh/day with a middle outside temperature of 18 °C and a middle internal temperature of –13 °C.

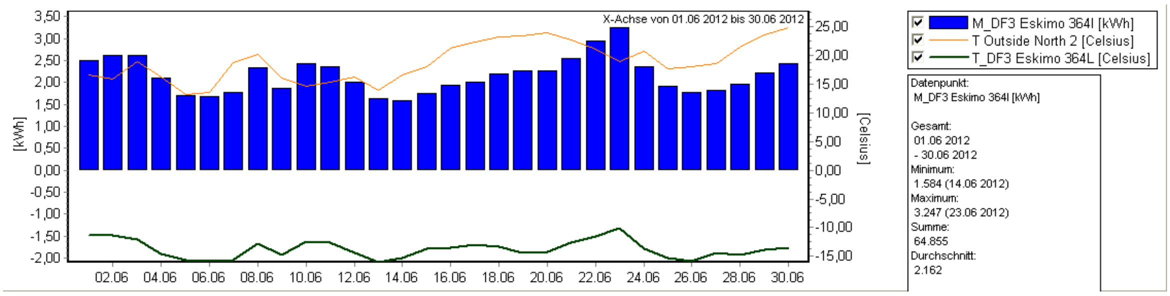


Figure 42 Deepfreezer 3 daily consumption

The load curve depends on the usage (opening times, changing of content) and the outside temperature. The performance purchase varies and is up to 300 W.

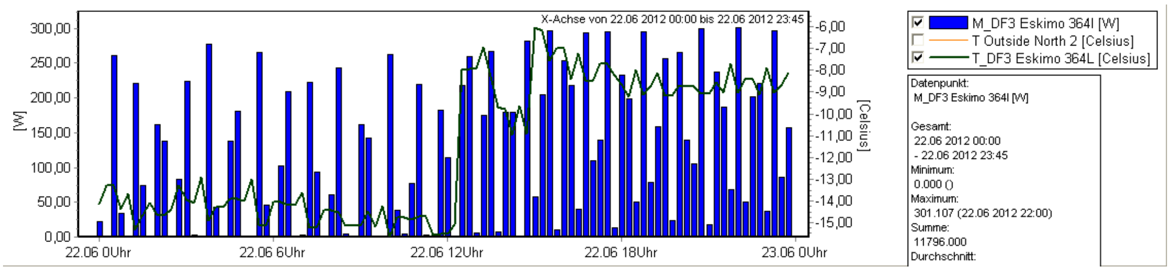


Figure 43 Deepfreezer 3 fingerprint (daily load curve) with internal temperature

The **Deepfreezer 4**, an ELIN GTI 0191 0,14 kW, is according to the classification a virtual storage service (VSTSVC) device. It is measured by an e-Meter and an additional PT 1000 temperature-sensor.

This Deepfreezer has a permanent consumption of about 2,1 kWh/day with a middle outside temperature of 18 °C and a middle internal temperature of –35 °C.

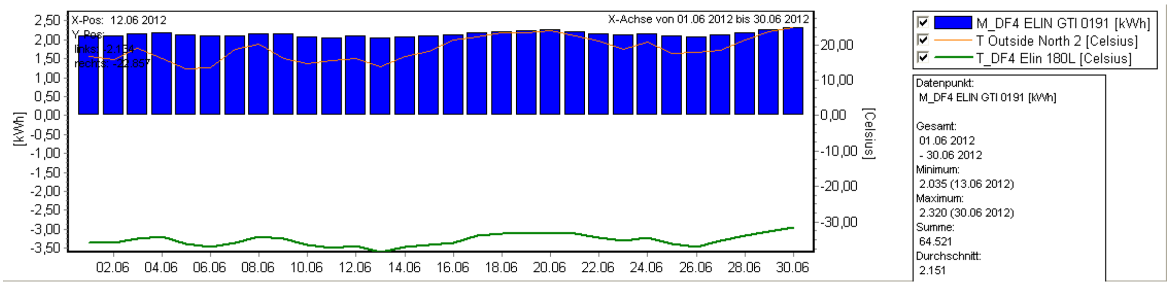


Figure 44 Deepfreezer 4 daily consumption

The load curve is nearly constant. The performance purchase is about 90 W.

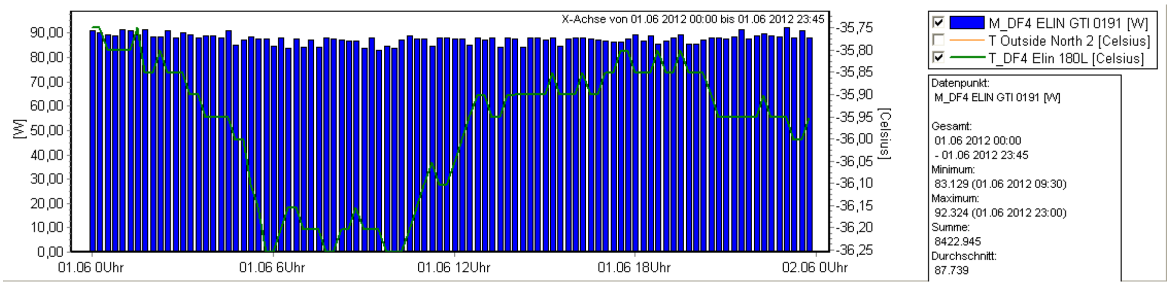


Figure 45 Deepfreezer 4 fingerprint (daily load curve) with internal temperature

The results of the measurements and especially the comparison of the temperature measurements with the temperatures measured by the installed SmartCoDe Nodes shows, that it is quite important, where in the deepfreezer the temperature sensor is placed. The following Figure shows the position of the sensors in the four deepfreezers:

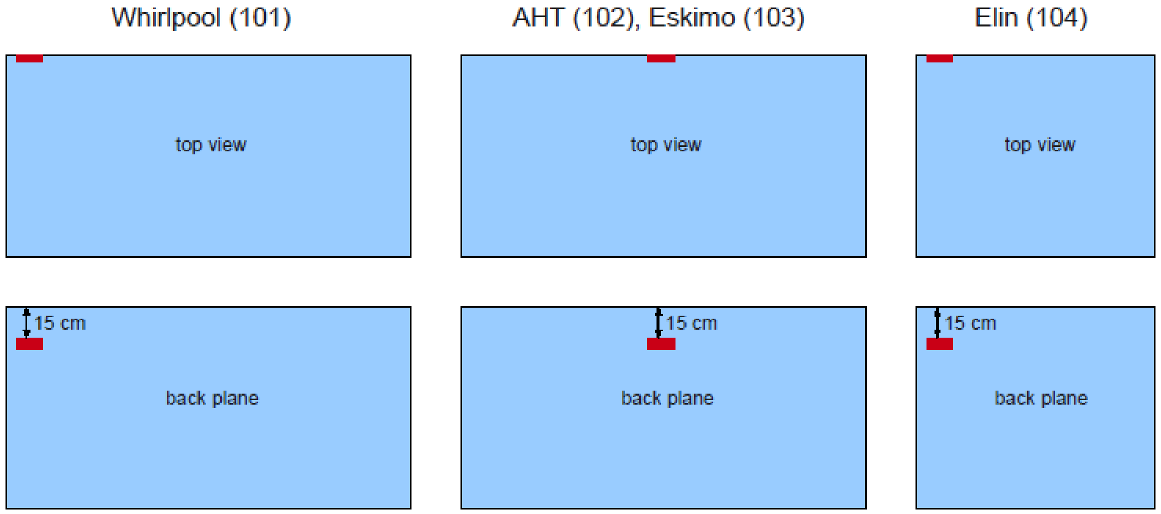
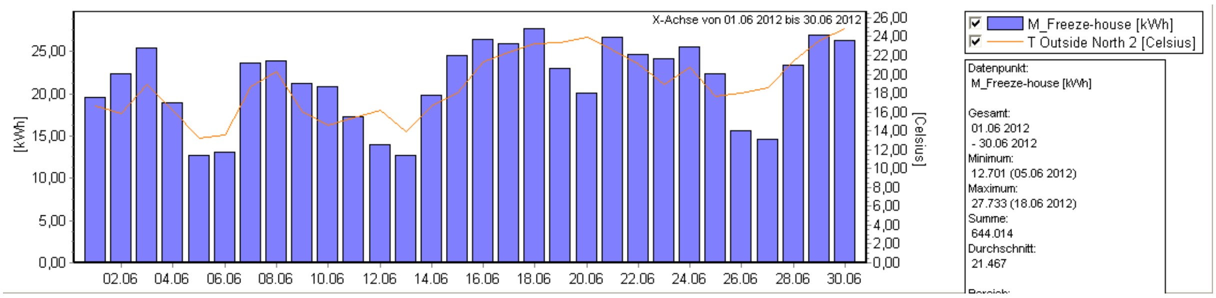


Figure 46: position of the temperature sensors in the deepfreezers

The **Freeze-House** is according to the classification a virtual storage service (VSTSVC) device. It is measured by an e-Meter.

This Freeze-House has a permanent consumption of about 22 kWh/day with a middle outside temperature of 19 °C.



```
Datenpunkt:
 M_Freeze-house [kWh]

Gesamt:
 01.06 2012
 - 30.06 2012
Minimum:
 12.701 (05.06 2012)
Maximum:
 27.733 (18.06 2012)
Summe:
 644.014
Durchschnitt:
 21.467
```

Figure 47: Freeze-House daily consumption (June)

The daily performance of the Freeze-House heavily depends on the outside temperature. The following Figure shows the dependency (0 °C / 450 W, 20 °C / 900 W):

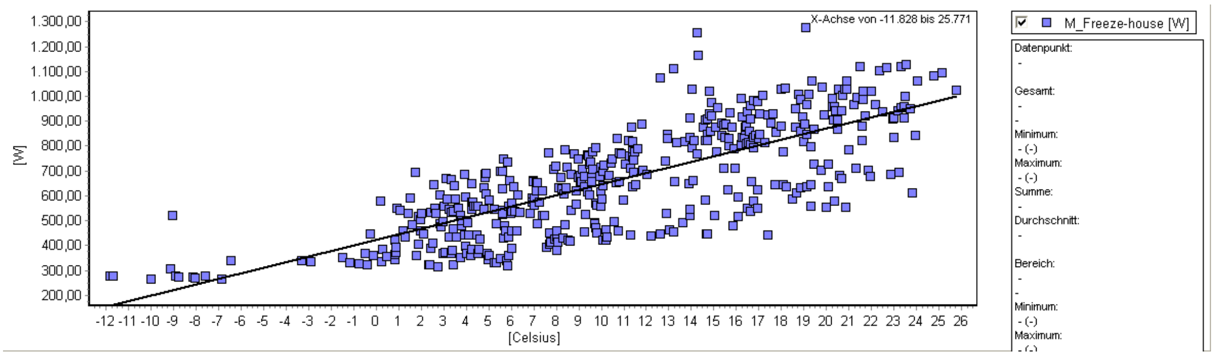
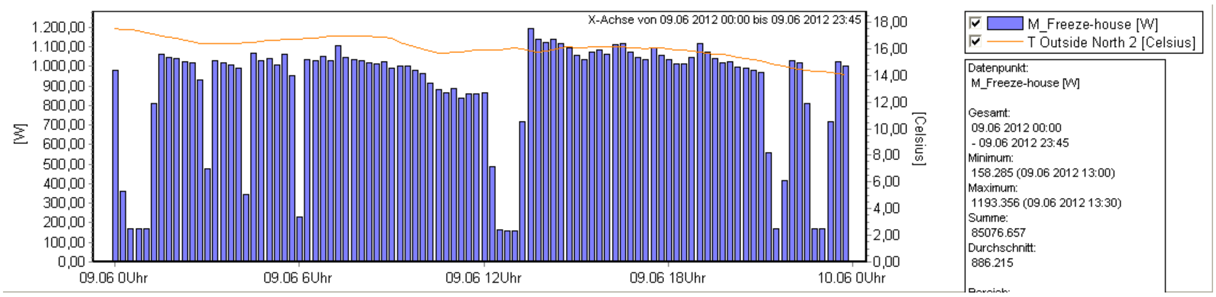


Figure 48: daily performance of the Freeze-House in dependence of the outside temperature

The load curve depends on the usage (opening times, changing of content) and the outside temperature. The performance purchase varies and is up to 1.500 W.



Datenpunkt:
M_Freeze-house [W]

Gesamt:
09.06 2012 00:00
- 09.06 2012 23:45
Minimum:
158.285 (09.06 2012 13:00)
Maximum:
1193.356 (09.06 2012 13:30)
Summe:
85076.657
Durchschnitt:
886.215

Figure 49 Freeze-House fingerprint (daily load curve) with outside temperature

The **Washing Machine 1**, a BSH WM16S750 2,3 kW, is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

This Washing Machine has an average consumption of about 1,6 kWh per washing cycle. With average 25 washing cycles per month the yearly consumption is about 480 kWh. The consumption is independent on the Opening Times.

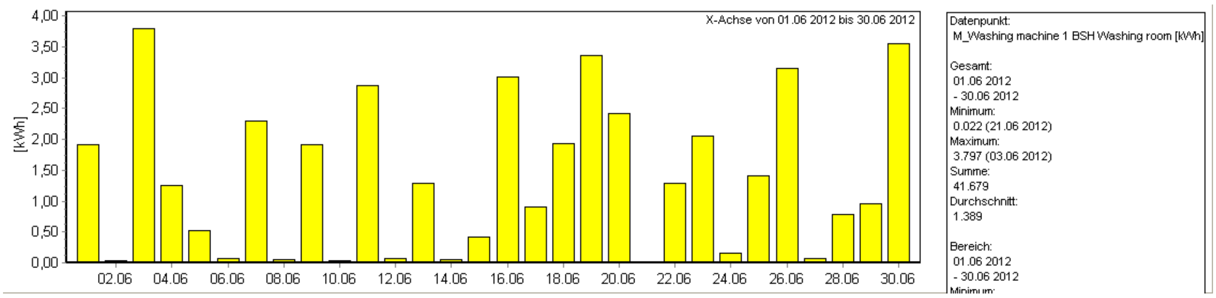


Figure 50 Washing Machine 1 daily consumption (average month)

The consumption of single runs are dependent on the used Program as shown in the next Figure. The performance purchase varies and is up to 1.900 W.

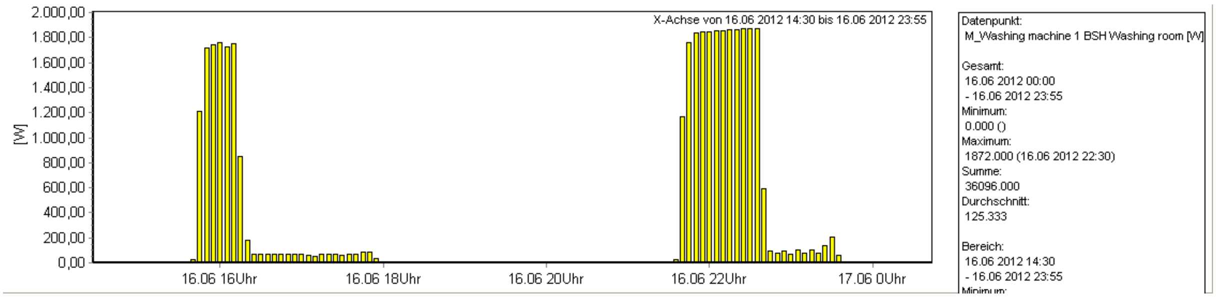


Figure 51 Washing Machine 1 fingerprint – load curves of two washing cycles

The **Washing Machine 2**, a Miele Meteor 1000 2,4 kW, is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

This Washing Machine has also an average consumption of about 1,6 kWh per washing cycle and a permanent consumption of about 0,5 kWh/day. With average 20 washing cycles per month the yearly consumption is about 560 kWh. The consumption is independent on the Opening Times.

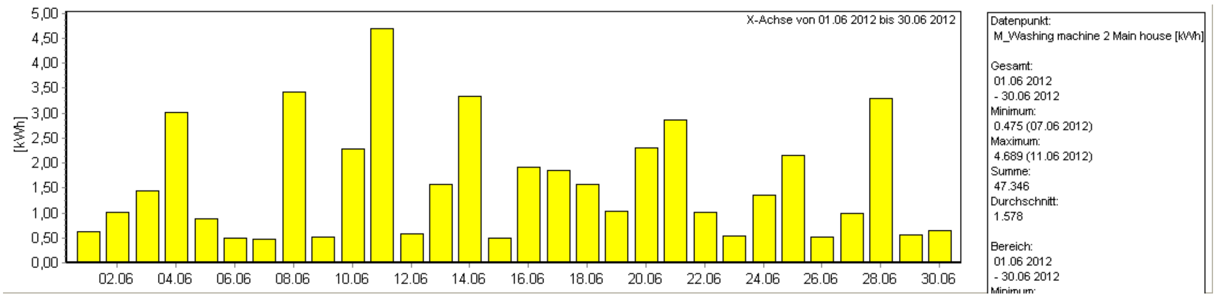


Figure 52 Washing Machine 2 daily consumption (average month)

The consumption of single runs are dependent on the used Program as shown in the next Figure. The performance purchase varies and is up to 2.200 W.

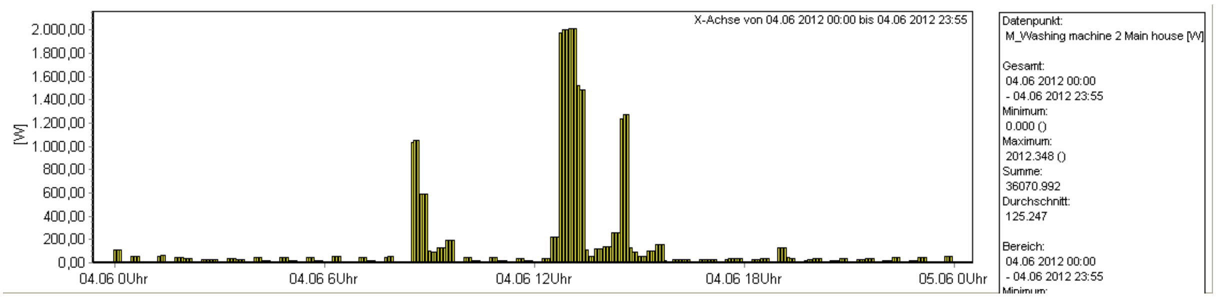


Figure 53 Washing Machine 2 fingerprint – load curves of two washing cycles

The **Dryer 1,** an Electrolux EDC 5310 4,4 kW is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

This Dryer has an average consumption of about 2,5 kWh per drying cycle. With average 15 drying cycles per month the yearly consumption is about 450 kWh. The consumption is independent on the Opening Times.

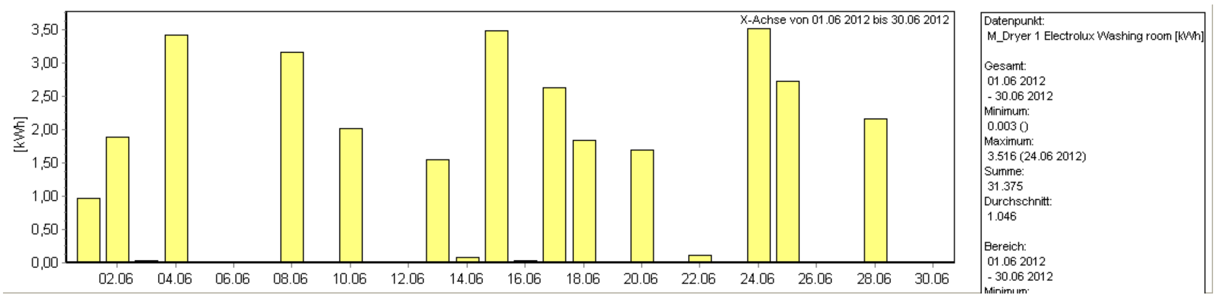


Figure 54 Dryer 1 daily consumption (average month)

The consumption of single runs are dependent on the used Program as shown in the next Figure. The performance purchase varies and is up to 2.050 W.

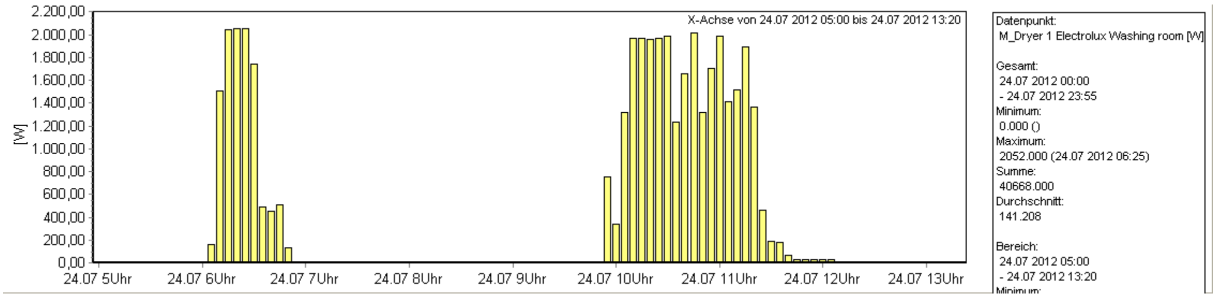


Figure 55: Dryer 1 fingerprint – load curves of two drying cycles

The **Dryer 2**, a BSH WDT60 1,5 kW, is according to the classification a schedulable service (SKDSVC). It is measured by an e-Meter.

This Dryer has an permanent consumption of about 0,05 kWh/day and an average consumption of about 2,1 kWh per drying cycle. With average 20 drying cycles per month the yearly consumption is about 520 kWh. The consumption is independent on the Opening Times.

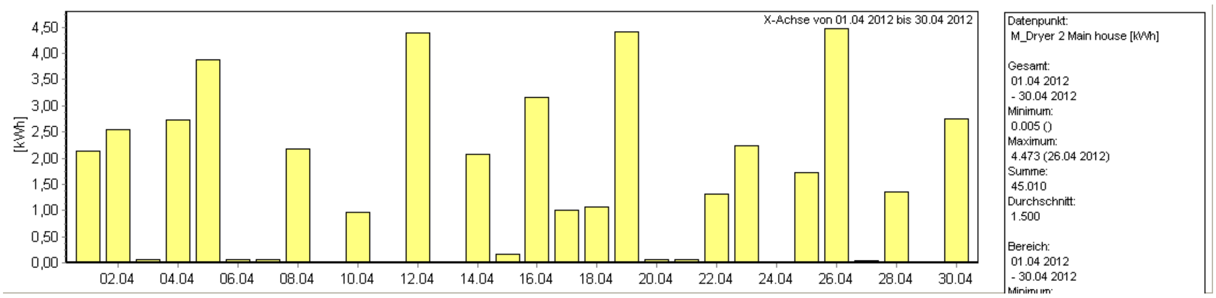


Figure 56 Dryer 2 daily consumption (average month)

The consumption of single runs are dependent on the used Program as shown in the next Figure. The performance purchase varies and is up to 1.540 W.

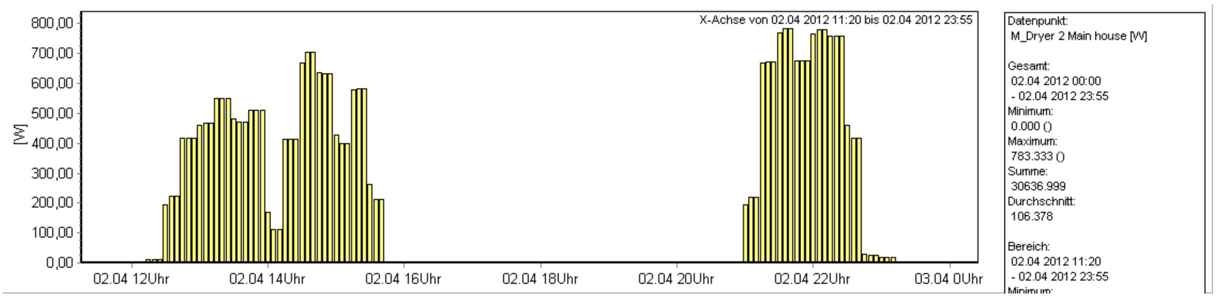


Figure 57: Dryer 2 fingerprint – load curves of two drying cycles

The **Oven**, a BSH HTSHBP7 3,7 kW, is according to the classification a custom control (CUSCON) device. It is measured by an e-Meter.

The average energy consumption of the Oven is about 55 kWh/month. The usage depends on the Opening Times as shown in the following Figure:

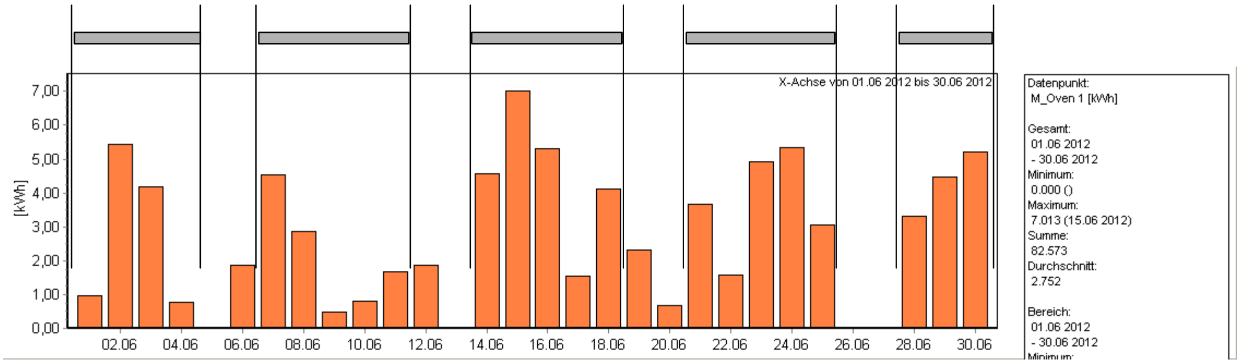


Figure 58: BSH-Oven daily consumption, , regular Opening Hours are Thursday to Monday

The load curve heavily depends on the used parts of the oven. The required power ranges from 20 W to 2.100 W.

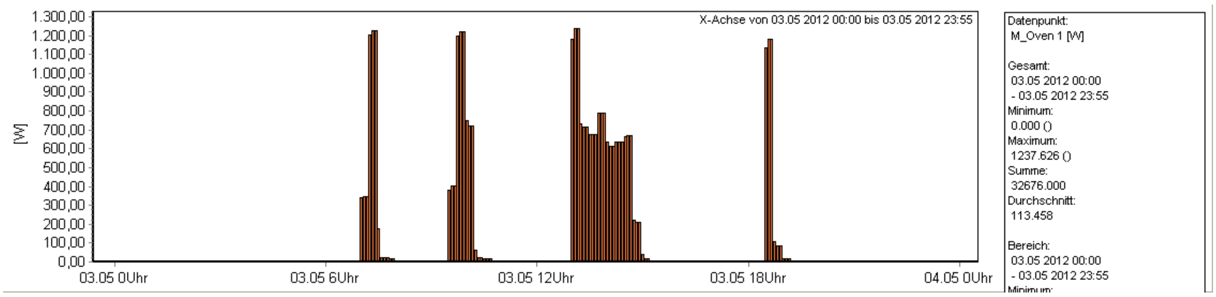
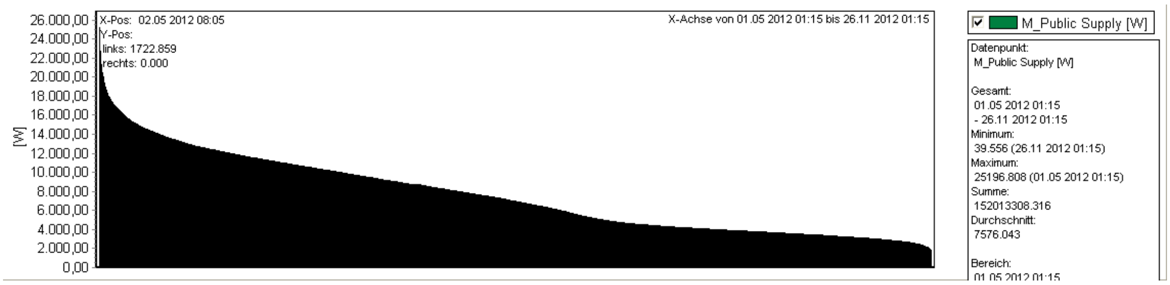


Figure 59: BSH-Oven fingerprint

2.3.4 Consumption and Production

The base load of the facility at Buchberg is about 3 kW:



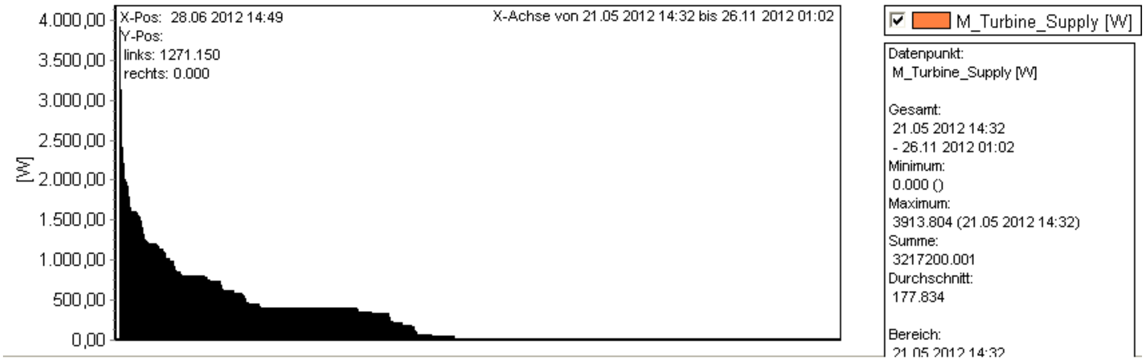
Datenpunkt:
M_Public Supply [W]

Gesamt:
01.05 2012 01:15
- 26.11 2012 01:15
Minimum:
39.556 (26.11 2012 01:15)
Maximum:
25196.808 (01.05 2012 01:15)
Summe:
152013308.316
Durchschnitt:
7576.043

Bereich:
01.05 2012 01:15

Figure 60: sorted consumption curve of the whole facility (5-11/2012)

In the same time the maximal measured output of the Wind Turbine was about 4 kW while most of the time the output is below 3 kW:



Datenpunkt:
M_Turbine_Supply [W]

Gesamt:
21.05 2012 14:32
- 26.11 2012 01:02
Minimum:
0.000 ()
Maximum:
3913.804 (21.05 2012 14:32)
Summe:
3217200.001
Durchschnitt:
177.834

Bereich:
21.05 2012 14:32

Figure 61: Output of Wind Turbine (5-11/2012)

Therefore all of the produced energy is used by the facility itself as shown in the following sample (orange is the turbine supply):

SmartCoDe has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013]) under grant agreement n°247473

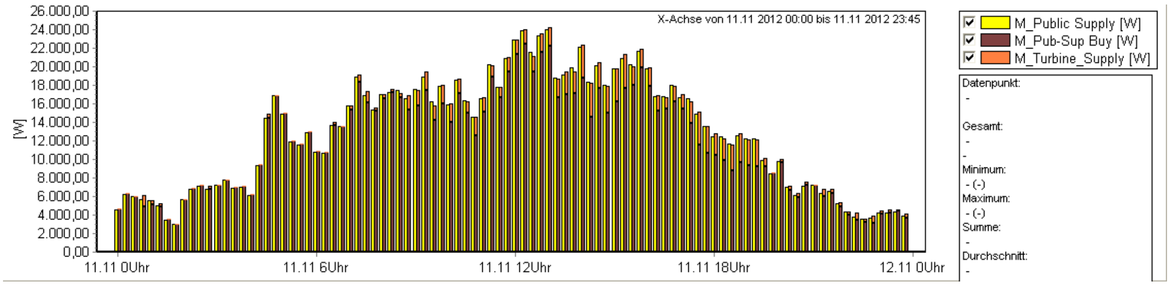


Figure 62: Used power in comparison to the turbine supply and additional power from the EVU

3 Energy Savings in SmartCoDe

In this chapter the results of the different energy savings approaches are described. The best method to lower the energy costs is to use as little energy as possible. Therefore we start with the energy savings which can be achieved by awareness campaigns in combination with modern energy controlling and visualisation systems. In a second step the energy savings that can be achieved by using the SmartCoDe technology are described.

3.1 Awareness and Savings

Energy Savings resulting from awareness can be divided into three groups: the classical energy savings like switching-off obvious unnecessary consumers, savings from the analysis of the situation which is possible as soon as additional energy controlling systems are available and finally manual load balancing which also uses modern visualisation technologies.

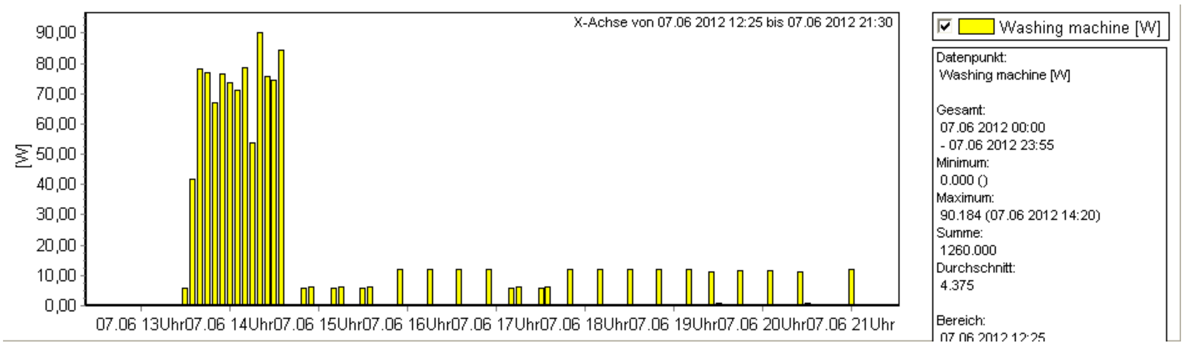
3.1.1 *Classical Energy Saving*

The following numbers and graphs are based on measurements at the Almersberg demonstrator location, the activities reflect the result of the generation of awareness at the owner side.

- switch off the heating pumps in non-heating periods
- switch off PC's that are not in use
- renewing of the e-Boiler
- renewing of the deepfreezer

The result was a reduction of the electric power consumption of the whole facility of about 43% in 2008.

As an additional activity in 4/2012 the old washing machine (AEG) was changed to a modern machine from BSH, type Vario Perfect S1675.



Datenpunkt:
Washing machine [W]

Gesamt:
07.06 2012 00:00
- 07.06 2012 23:55
Minimum:
0.000 ()
Maximum:
90.184 (07.06 2012 14:20)
Summe:
1260.000
Durchschnitt:
4.375

Bereich:
07.06 2012 12:25

Figure 63: fingerprint of the BSH washing machine

The men consumption per washing has been reduced to approx. 0,14 kWh which reflects a reduction in the consumption of about 56%. The peak load is reduced about 45% to a maximum of 1.000 W.

3.1.2 *Savings from Analysis*

With the installation of the EMU and its energy controlling functionality's the occupants of the facility were enabled to have a detailed view on the consumption and the different parameters/temperatures of the building systems.

The effect of energy savings due to energy analysis is shown using the examples of solar circle pump and heat pump:

The **pump of the solar circle** was running in step 3 with 60 Watt for the loading periods each time when there was sun. Beginning with 8th April the energy consumption of the solar pump could have been reduced in dependence of the temperature of the solar boiler.

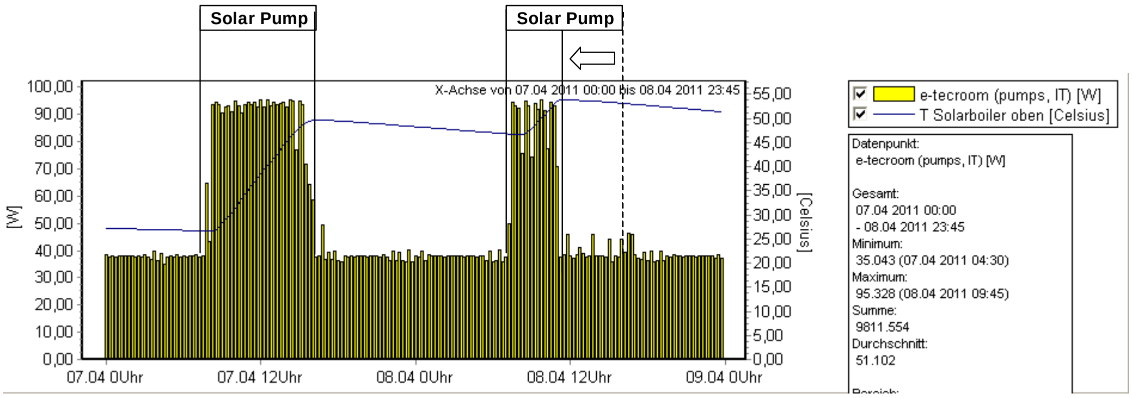


Figure 64: reduction of consumption of solar circle pump in dependency of the solar boiler temperature

The next example is a **heating pump**: A detailed analyze of the behavior of the pump together with the heat production of the biomass vessel showed, that there is saving potential in times when the wood heating system is not switched on.

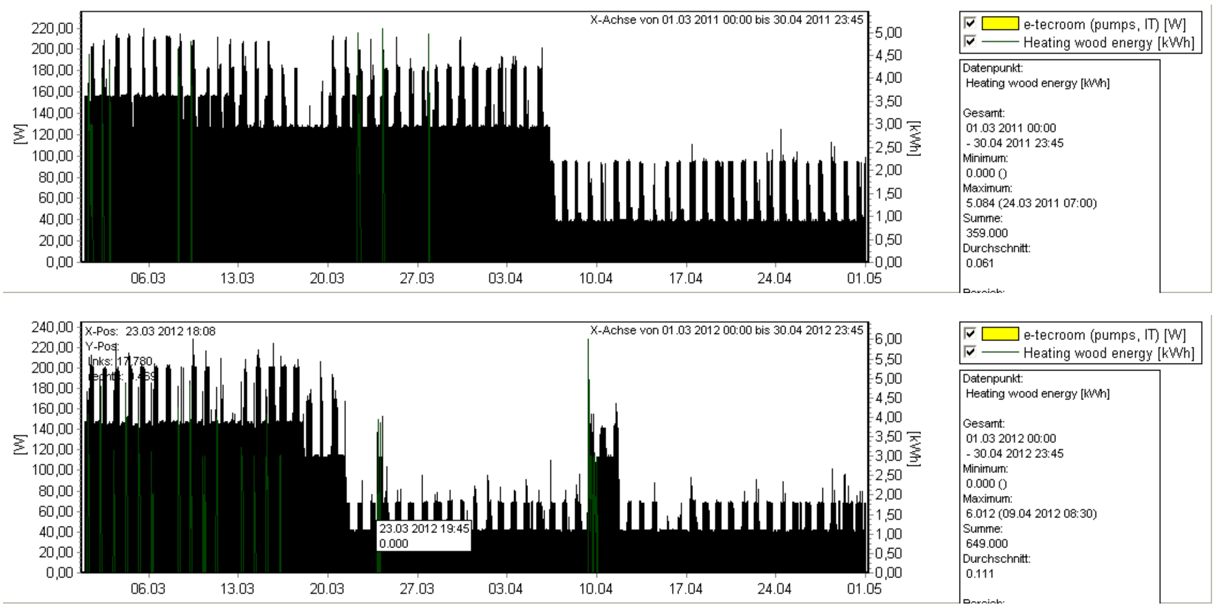


Figure 65a/b: electrical consumption and wood heating production before and after optimisation

The heating pump must not run always – the improvement was to control the heating pumps for the radiators and the floor heating system in dependence of the heat production of the biomass vessel.

Another optimisation (side-)effect was achieved by essentially replacing the faulty or over-convervative controllers of some of the fridges. For 3 of the 4 freezers, it turned out that their controllers would switch on their compressors for long terms without interruption, for example as shown in Figure 66. Not only does this enlarge the power consumption, the power consumed has also less effect since the freezer doesn't cool down anymore at some point. That is, a lot of energy is used to keep the freezer at a constant temperature, therefore the efficiency is very low.

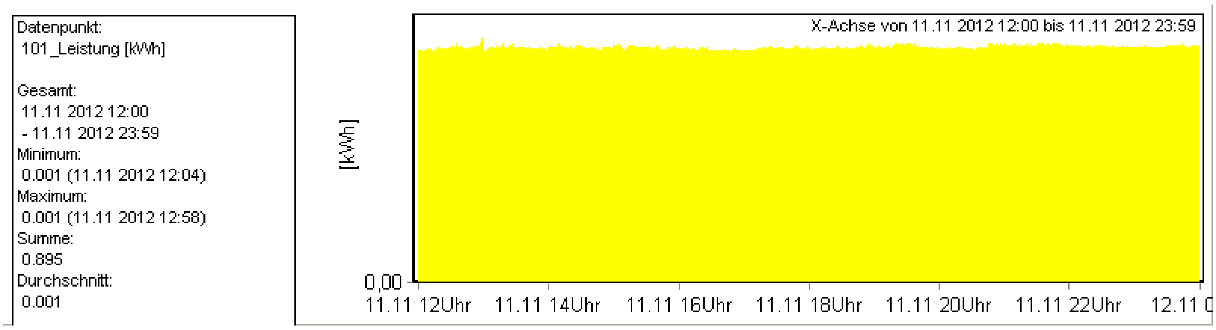
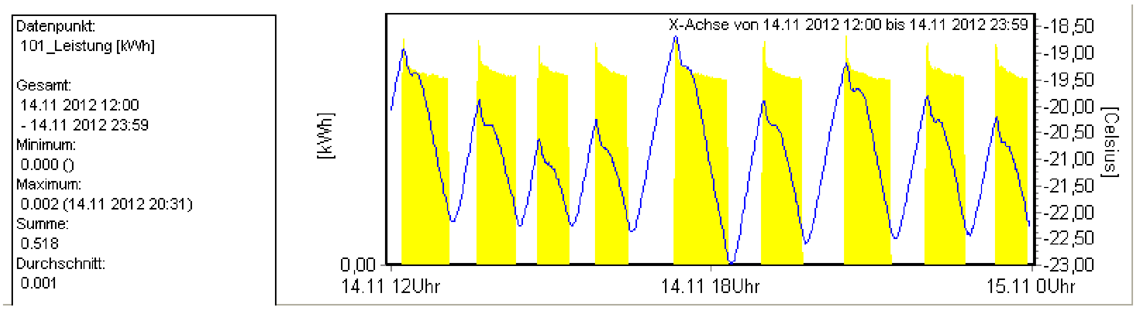


Figure 66 Freezer staying on permanently for 12 hours with own controller

While the reason for this was unclear, it was actually beneficial since this made it less likely that the freezers' own controllers would interfere with the control decisions of the SmartCoDe nodes. In any case, by using the SmartCoDe nodes the compressor was switched off again on a regular basis (see Figure 67), and this alone saves about 0.4 kWh in a 12 hour period for this particular freezer.



Datenpunkt:
101_Leistung [kWh]

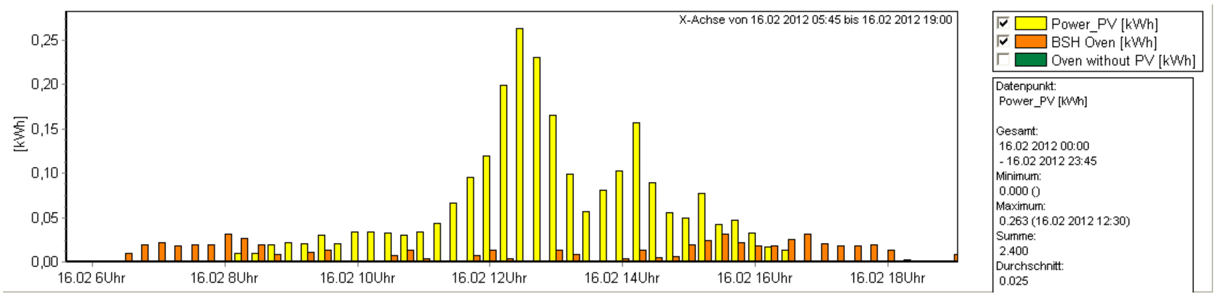
Gesamt:
14.11 2012 12:00
- 14.11 2012 23:59
Minimum:
0.000 ()
Maximum:
0.002 (14.11 2012 20:31)
Summe:
0.518
Durchschnitt:
0.001

Figure 67 Freezer is swiched off again by SmartCoDe node

3.1.3 *Manual Load Balancing*

A special case of saving energy on the basis of energy analysis is the continuous use of data from the energy controlling system to manually optimise the use of LEP in the building. To enable easy useage, the prototype of a Smart Phone Interface was developed which allows the user to see the current (and in further steps even the forecast) power from the LEP. This is especially helpful in cases where the user can influence the to use of specific EuP’s (e.g. CUSCON and SKDSVC).

As an example, the **oven** consumes approximately 280 kWh/p.a. of which where 155 kWh have been consumed in times when no energy from the LEP was available. That is an internal usage quote of about 45%. The following Figure shows the consumption curve of an oven and the production curve of the PV-System on 16th February:



Datenpunkt:
Power_PV [kWh]

Gesamt:
16.02 2012 00:00
- 16.02 2012 23:45
Minimum:
0.000 ()
Maximum:
0.263 (16.02 2012 12:30)
Summe:
2.400
Durchschnitt:
0.025

Figure 68: consumption curve of an oven and the production curve of the PV-System

On this day, the oven consumed 0,83 kWh, where 0,53 kWh was consumed in times, where there was no LEP power available. A small shift in the usage times (if possible) could raise the percentage of usage from 35% to over 90%.

Another example is the **usage of pre-heated water** which has the potential to reduce the electric power needed for a washing circle by up to 80%. The more effective solar-pre heating is used – the less additional electrical energy is required. The consequence: If solar preheating is available, not only the price of electric power is a criteria but also the availability of a storage capacity for pre-heated water. Or, in more simple words: the introduction of energy management into households enables the use of energy storage capacities like hot water tanks to store available surplus electrical energy.

In this context the sample of a washing cycle of a washing machine in Figure 5 shows that a small shift of about 4 hours can lower the consumption per cycle from 0,35 kWh to 0,12 kWh (65%) because the washing machine run has been shifted to the time when the pre-heating of the water boiler became effective (prerequisite: the washing machine has to be connected to the warm-water pipeline).

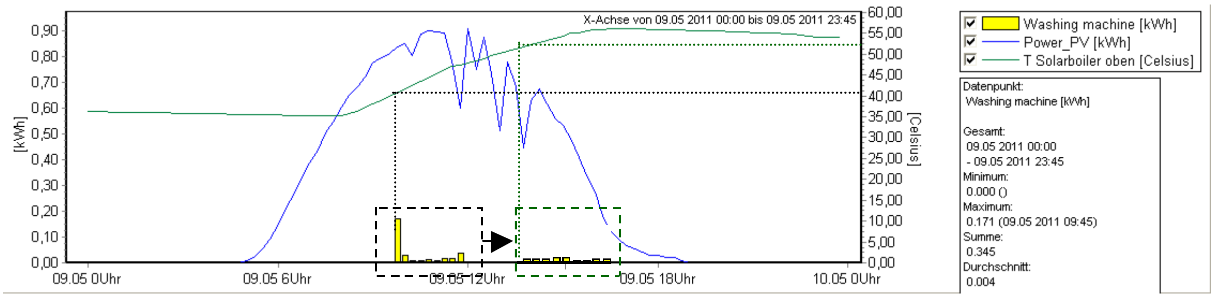


Figure 69: consumption of the washing machine in dependency of the solar boiler temperature

In further developments of the cost-function algorithms this combination has to be considered.

3.2Balancing the local energy load

Load balancing is an important sub-task in the SmartCoDe demand side management approach. One goal regarding demand side management is to increase the local EuPs combined power consumption at favourable times, e.g. when the wind turbine has an increased power output. However, we must also ensure that this increased consumption still stays within certain bounds. For example if *all* of the local EuPs choose to switch on resp. increase their power consumption in a favourable time period, the overall power drawn might surpass the power provided by the turbine by far. Therefore the power drawn from the grid might even increase above average, with the corresponding unfavourable results regarding e.g. monetary cost or grid stability.

The basis of the cost-profile protocol used is that appliances which send a load-plan are committed to this plan. This has a key advantage if we want to achieve load-balancing: We can use a *single cost-profile* for all load-plan committing appliances.

If a load plan is received by the EMU, it incorporates it into the new cost profile such that the cost in times of high load according to the load plan rises. This cost profile is then *broadcasted* to all load-plan committing appliances. Since the appliance which sent the last load-plan ignores the new cost profile until the current plan is executed, it will not be blocked by its last load plan. And when the next load-plan is computed, the cost-profile values affected by the last load plan are already outdated and are not broadcasted anymore.

These considerations led to the following *protocol* for a group of load-plan committing appliances:

- The EMU broadcasts a cost-profile to all appliances in the group. The base of this initial cost profile is not important in particular here. For example, it might reflect the power consumption of all other appliances in the network. It could also be based on a tariff more volatile (e.g. hourly-changing) then commonly used today. If the only goal is load-balancing, the initial cost-profile would be constant minimal, e.g. 0. For the demonstrator site, the initial cost profile is based on a forecast of the local wind turbine power output.

- At some point an appliance issues a load-plan to the EMU, e.g. when a freezer switches off the first time after finishing its learning phase and now computes a load-plan.
- The EMU incorporates the load-plan into the current cost-profile and broadcasts it.
- Eventually, other appliances will compute and send load-plans, giving rise to subsequent cost-profile updates.

The basic idea is that the cost profile inherently represents a power budget over time, and by incorporating a load plan into the next cost-profile update, a certain part of this budget is reserved for the appliance which made the plan.

3.2.1 *Lab example*

The example we show here was already presented in D 2.5 (see Figure 70). Unfortunately, not enough temperature sensors were available to produce another lab-example run since some sensors went defect and the rest is needed for the Buchberg demonstration site.

When the two fridges were run independently in usual bang-bang mode, the combined power consumption could reach about 200 Watts because sometimes their compressors were switched on at the same time. Since the fridges were of the same type, they even could run in lock-step for some time.

With the SmartCoDe cost-profile based load balancing algorithm in place, this situation could be circumvented, as Figure 70 clearly shows. Now the two fridges are never switched on at the same time. Note that the cost-profiles shown are the ones used by the respective node for their plan. Therefore the cost-profiles of the two nodes are different since they essentially represent the power consumption of the other node.

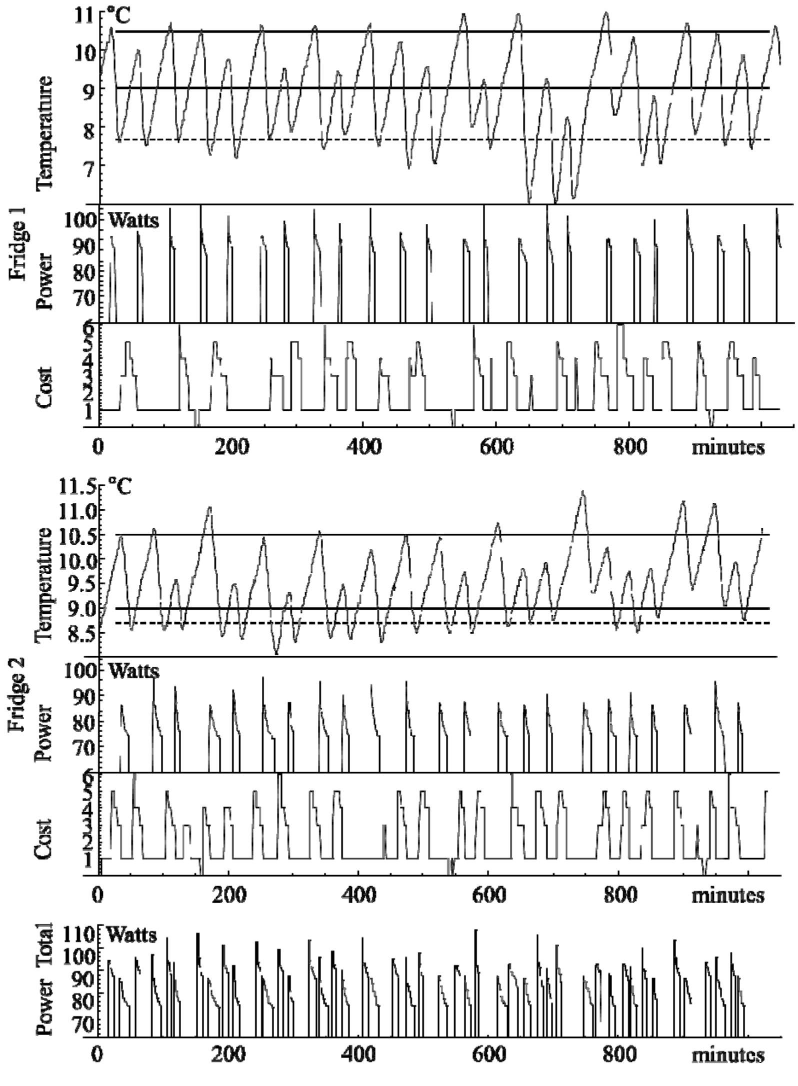


Figure 70 Temperature and power measurements of two fridges controlled with a load-plan based cost profile

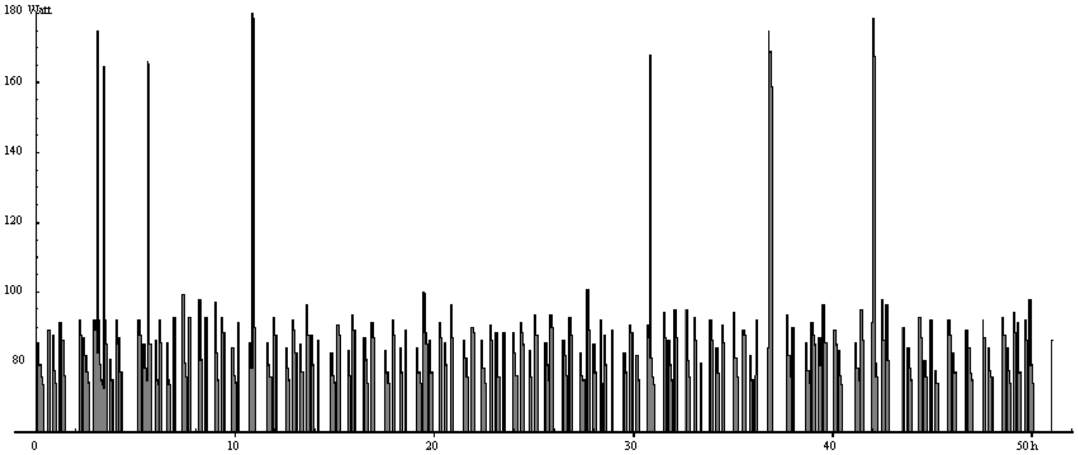


Figure 71 Long-term measurement of the total power consumption of the lab demonstrator

Figure 71 shows the total power consumption of the two fridges over a longer time period, indicating that the EM algorithm could prevent the two fridges from running at the same time for most of the time.

3.2.2 Demonstrator example

Figure 72 - Figure 75 show the temperature, power consumption and the cost-profile used by the four Buchberg Demonstration site freezers over a period of roughly 10 days. The data was logged with 1 Minute resolution. From about minute 10000 to 13000, the freezers where switched to the usual independent bang-bang operation, which can also be seen from the constant cost profiles in this period. During the rest of the time, the nodes planned their consumption with a cost-profile based on the load-plans of the other nodes, as well as the wind turbine forecast. Unfortunately, there was almost no forecast for a positive wind turbine power output except for a short time period before minute 8000. Therefore, during the time the cost-profile was used the nodes mainly balanced their load.

Note that the high temperature and the excessive on-period of node 101 after minute 10000 are probably caused by an event like opening the freezer and filling it with unfrozen goods.

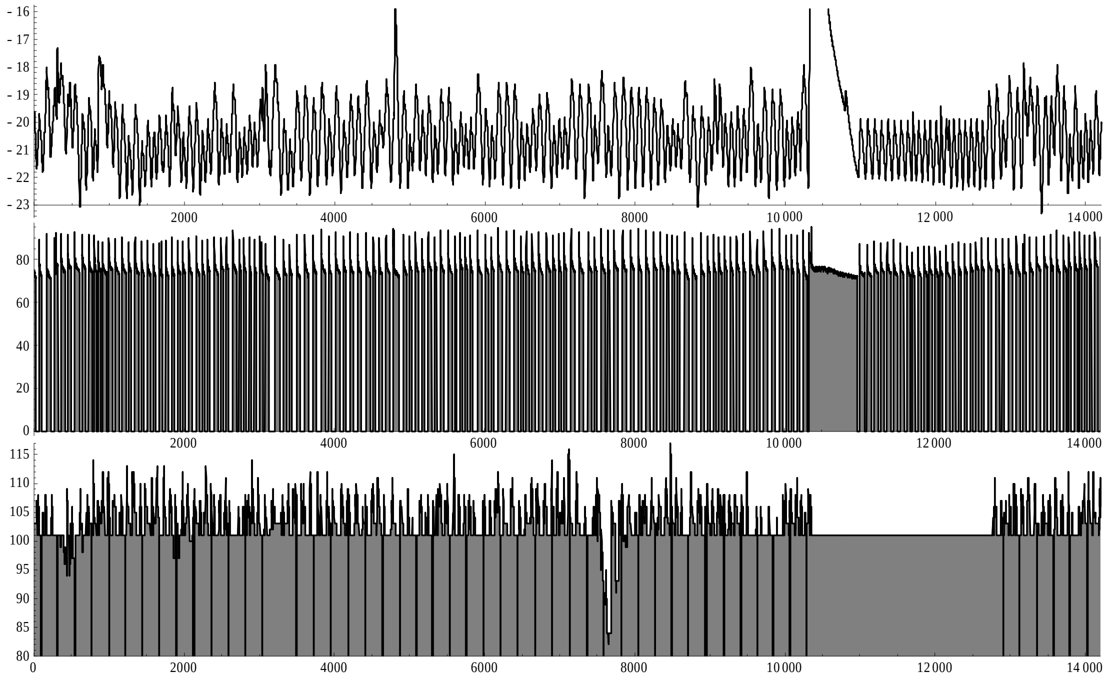


Figure 72 Freezer 101 Temperature (°C), Power (W) and used cost-profile over 10 days, timescale in minutes

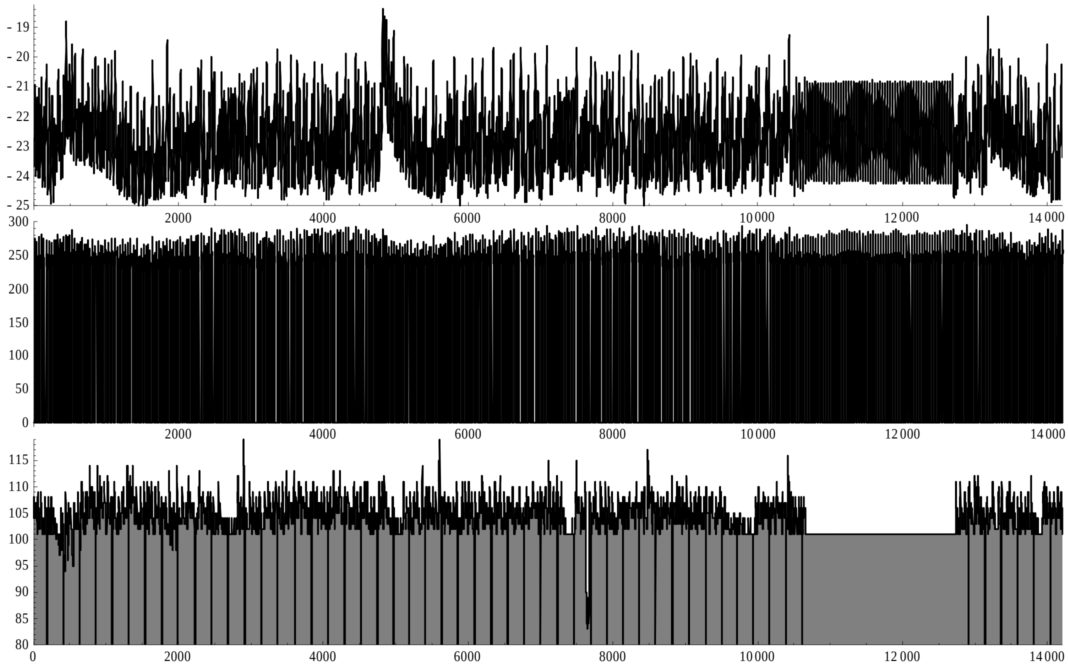


Figure 73 Freezer 102 Temperature (°C), Power (W) and used cost-profile over 10 days, timescale in minutes

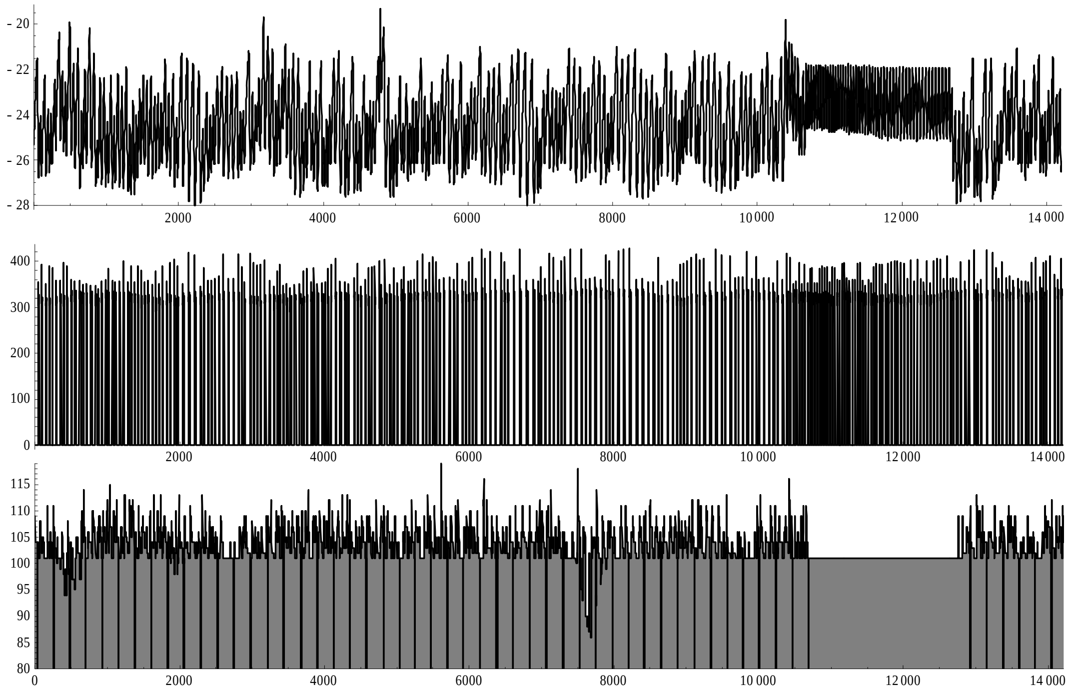


Figure 74 Freezer 103 Temperature (°C), Power (W) and used cost-profile over 10 days, timescale in minutes

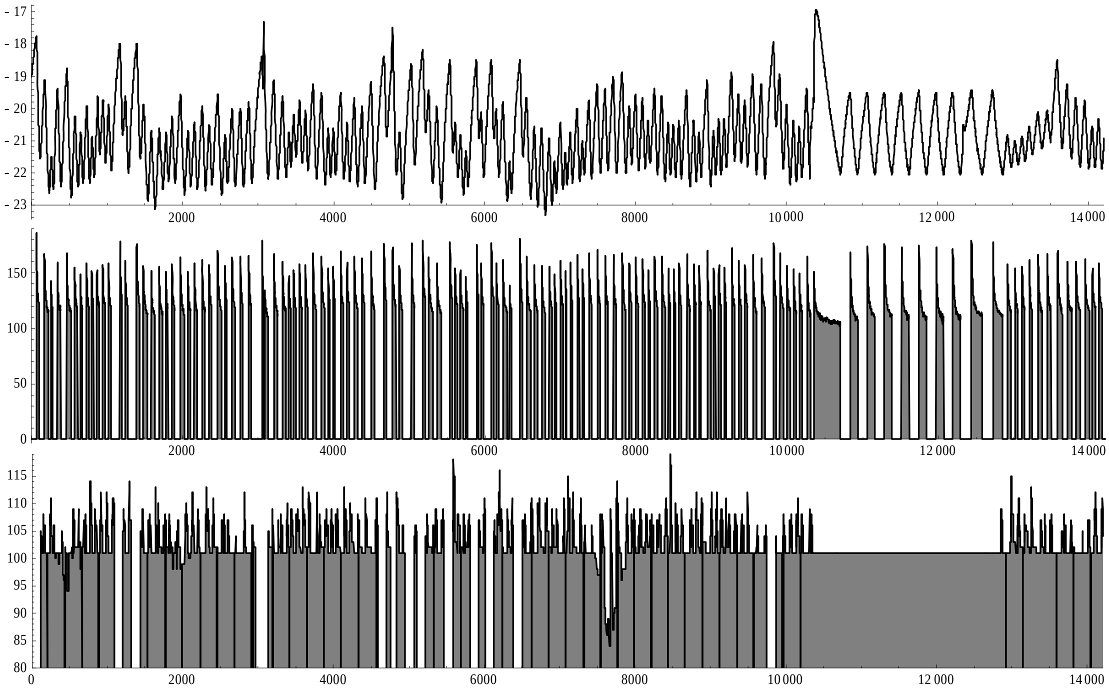


Figure 75 Freezer 104 Temperature (°C), Power (W) and used cost-profile over 10 days, timescale in minutes

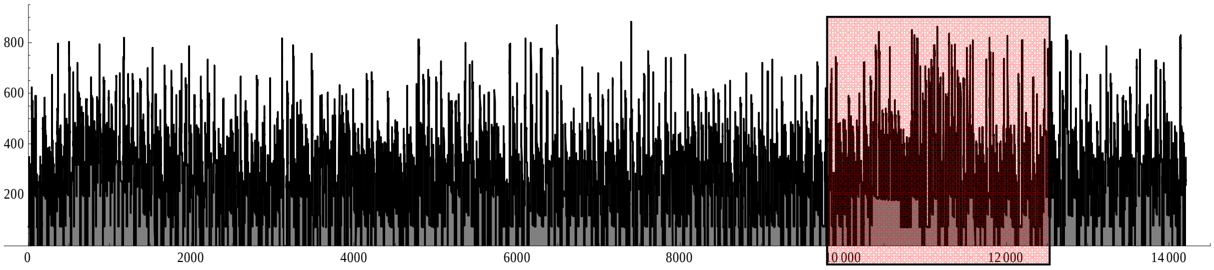


Figure 76 Combined power consumption of freezer 101-104

Figure 76 shows the overall power consumption of the four freezers. Since the load balancing effect is not obvious from this graph, the next two Figures provide a comparison of 3000 minutes of operation with (Figure 77) and without (Figure 78) load balancing. While Figure 77 is not exactly a smooth curve, it is nevertheless much less volatile than Figure 78. It shows less up- and downswings, as well as lesser large peaks and large valleys.

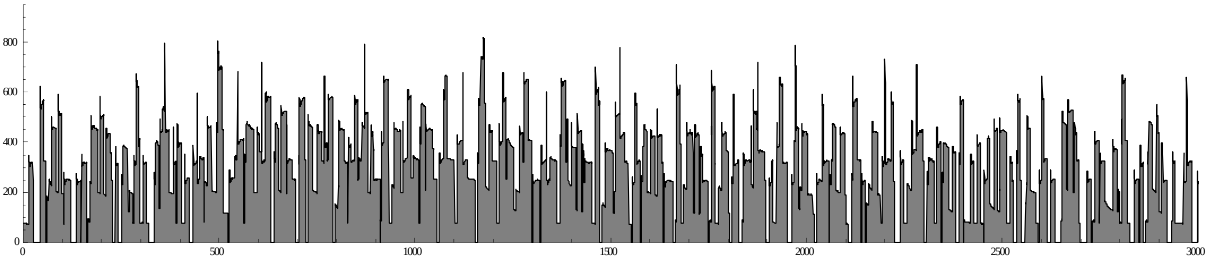


Figure 77 Combined power consumption of freezer 101-104 with load balancing (first 3000 minutes)

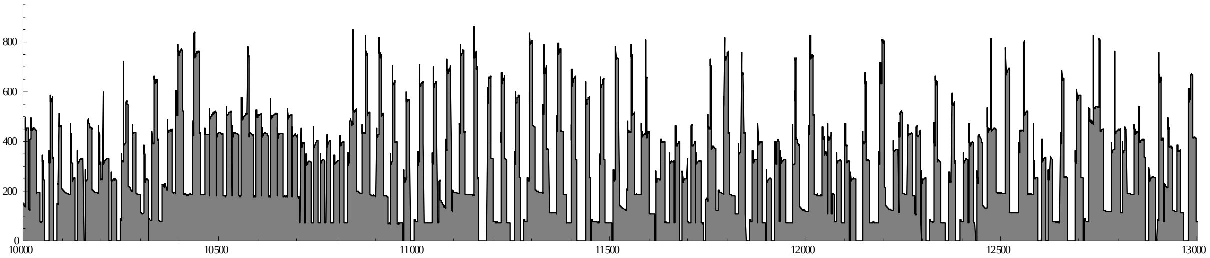


Figure 78 Combined power consumption of freezer 101-104 during period without load balancing

Figure 79 confirms this observation by showing the sample variance of the total power consumption of the 10 day period, which almost doubles during the bang-bang period (i.e. the period with SmartCoDe control switched-off). After the freezers go into cost-dependent planning mode again, the sample variance also drops again.

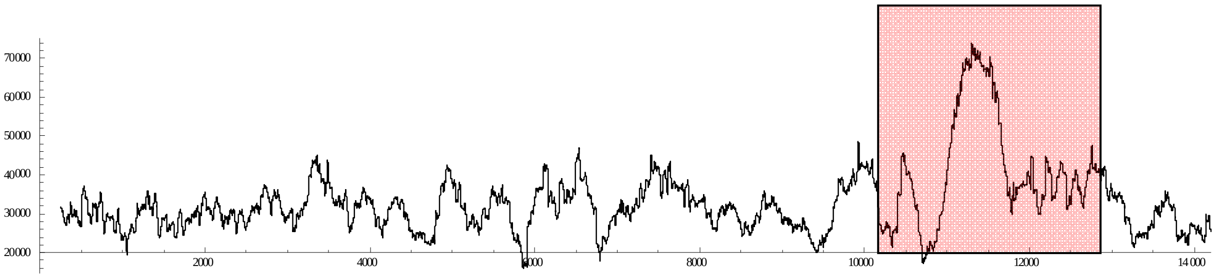


Figure 79 Sample variance of the combined power consumption

3.2.3 Simulation examples

The following plots show several load-balancing-simulations with a different number of fridges. Each simulation covers 5 days, with the first 2.5 days using (unbalanced) bang-bang control and the rest cost-profile dependent SmartCoDe control. For each Figure, the first plot shows the combined power consumption and the second plot the sample variance. The time axes are again minutes and the power axes are in watts.

Each simulated fridge has a random specification regarding temperature bounds, power consumption and thermal process, where the fridges of the lower-number experiment were re-used in the next one. I.e. the first two fridges in the 3 Fridge simulation are the same as in the 2 Fridge simulation and so on.

3.2.3.1 2 Fridges

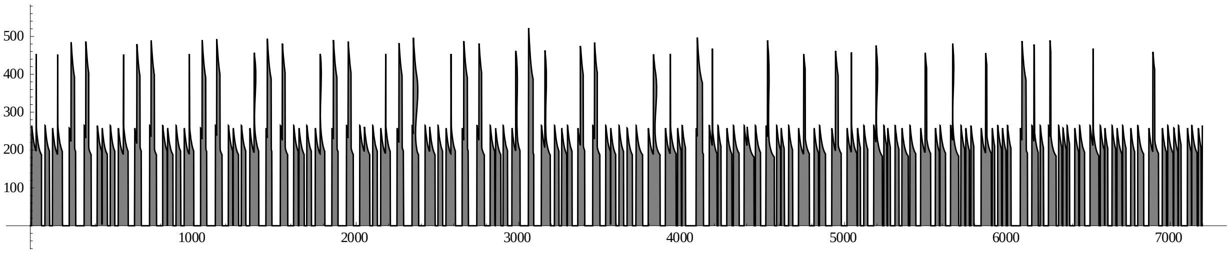


Figure 80 Simulated overall power consumption of 2 fridges

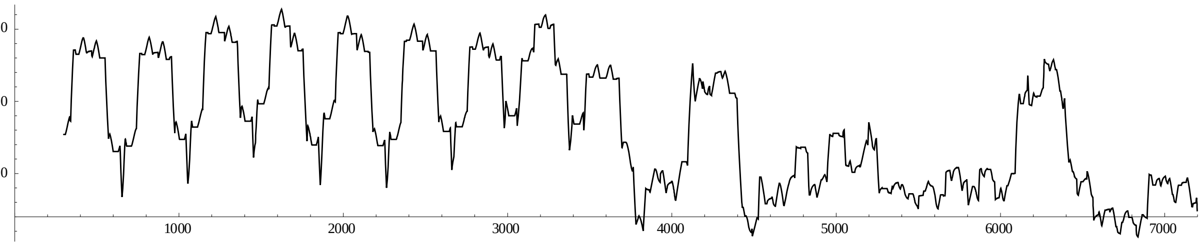


Figure 81 Sample variance of simulated overall power consumption of 2 fridges

3.2.3.2 3 Fridges

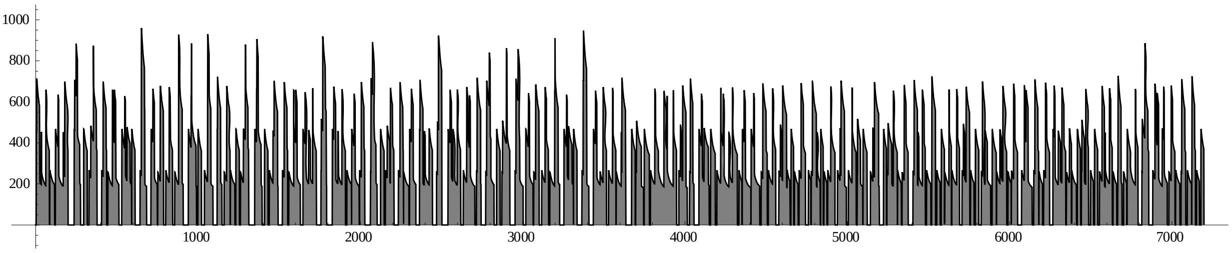


Figure 82 Simulated overall power consumption of 3 fridges

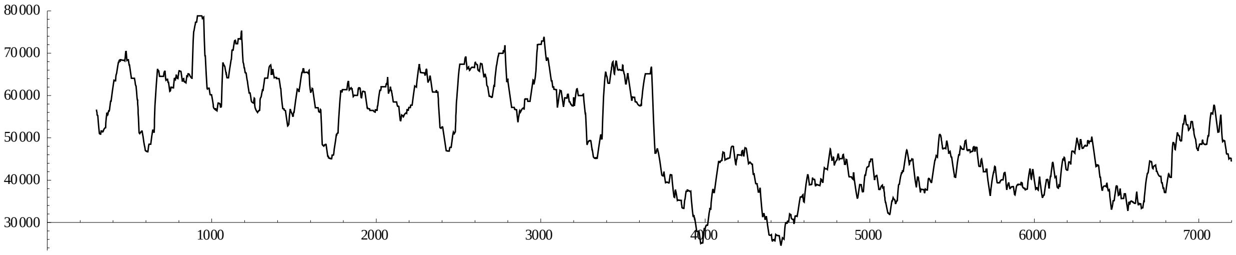


Figure 83 Sample variance of simulated overall power consumption of 3 fridges

3.2.3.3 4 Fridges

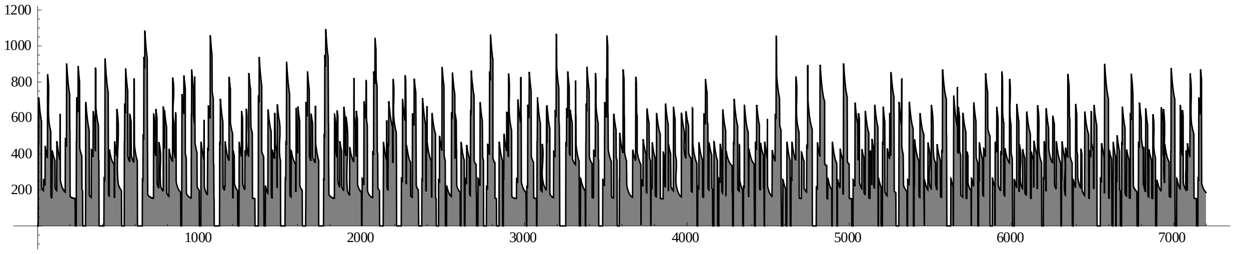


Figure 84 Simulated overall power consumption of 4 fridges

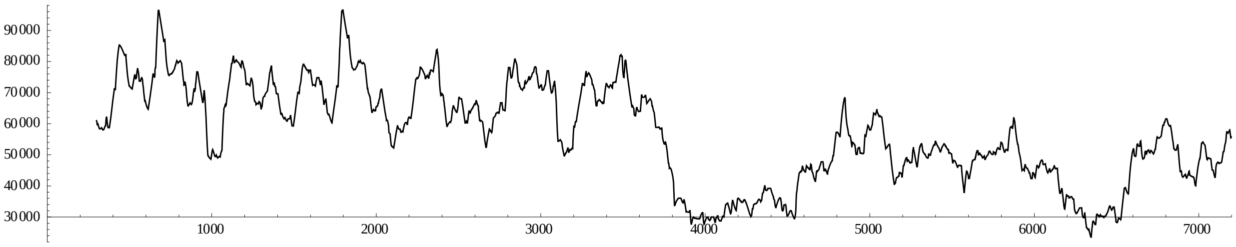


Figure 85 Sample variance of simulated overall power consumption of 4 fridges

3.2.3.4 10 Fridges

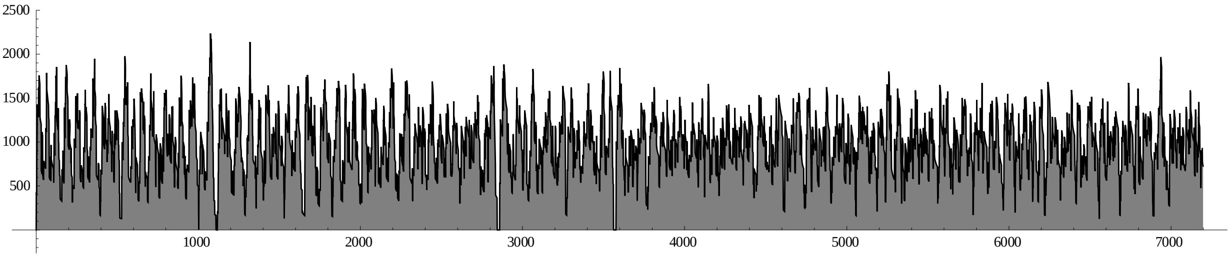


Figure 86 Simulated overall power consumption of 10 fridges

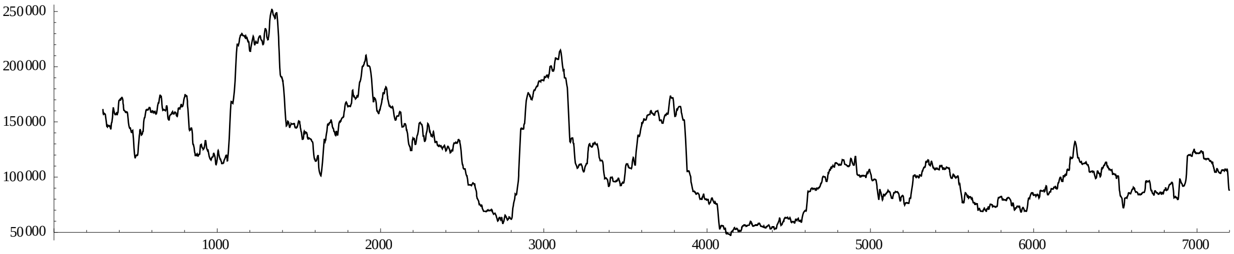


Figure 87 Sample variance of simulated overall power consumption of 10 fridges

3.2.3.5 15 Fridges

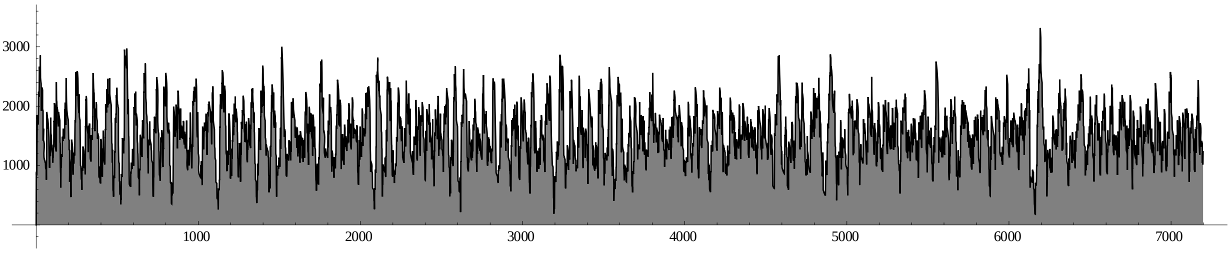


Figure 88 Simulated overall power consumption of 15 fridges

Figure 89 Sample variance of simulated overall power consumption of 15 fridges

3.2.3.6 20 Fridges

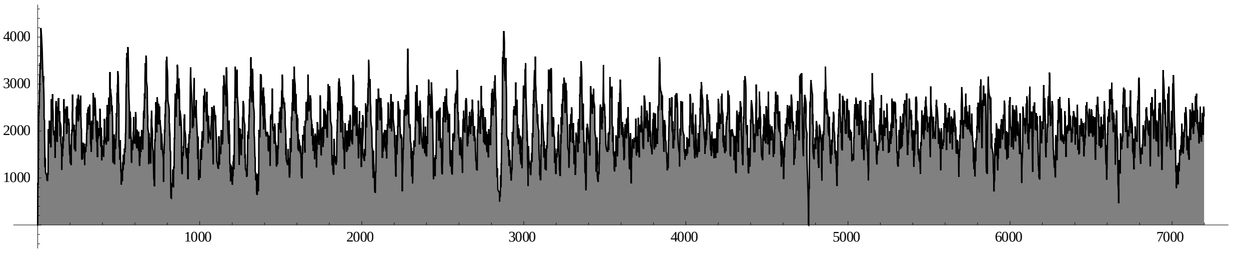


Figure 90 Simulated overall power consumption of 20 fridges

Figure 91 Sample variance of simulated overall power consumption of 20 fridges

3.2.3.7 Discussion

As it can be seen, the load balancing effect is also confirmed in several simulation scenarios. The load balancing effect becomes less obvious with a growing number of fridges when looking at the power plots, since the total power consumption becomes more random in nature itself with a growing number of fridges. However, as Table 9 indicates, the drop in average sample variance when moving from bang-bang control to SmartCoDe load balancing seems to remain stable, and even becomes a bit larger with a growing number of fridges.

For each number of fridges, 10 Simulations were made, again with random specifications as in the plots above. Table 9 also indicates the minimal and maximal variance drop of the 10 simulation runs. Over all the simulations, the average variance drop was 37%.

Number of fridges	Average drop in sample variance
2	27,94%
3	30,42%
4	36,47%
5	41,53%
6	36,00%
7	40,35%
8	41,22%
9	40,94%
10	36,85%
15	40,60%
20	34,69%

Table 9: average drop in sample variance aver several simulation runs

3.3 Shaping the local energy load

Using a SmartGridSwitch at Buchberg we were able to demonstrate the usability of our approach to shape the local energy load. The concept for the SmartGridSwitch covers the approach to have some devices to be managed directly by the EMU. The user can request run time for said devices by pressing a switch corresponding to his wished for time span on the smart grid switch which was defined and built in the reporting period:

- Yellow Button: Input one starts the machine immediately.
- Blue Button: Input two - The machine should be ready within 4 hours.
- Green Button: Inputs three - The machine should be ready within 12 hours and
- Red Button: Input four deletes the request.

Figure 92: SmartGridSwitch with user interface

The same functionality has been implemented for the SKDSVC appliances controlled by SmartCoDe-Nodes. Upon entering a deadline, the worst case load profile is sent to the coordinator which passes it on to the EMU which then computes a start time in exactly the same way as it does for the SmartGridSwitches. The start time is then sent back to the SmartCoDe-Nodes.

In order to evaluate the possibilities of shaping the loacl energy load in interaction with the user, a SmartgridSwitch was installed at Buchberg for Washing Machine 2. Currently the tarif models of the EVU are independent of the load profile, therefore we had to define an own cost profiles.

In Figure 93 the effect of using the “within 12 hours ready” button in combination with a three-step cost profile (6:00 to 20:00: 25 ct/kWh, 20:00 to 24:00: 20 ct/kWh, 0:00 to 6:00: 15 ct/kWh). The user pressed the green button at 18:20 (ready till 6:20), the Washing Machine starts at 0:00 while the tarif with the lowest cost and finished about 1:40.

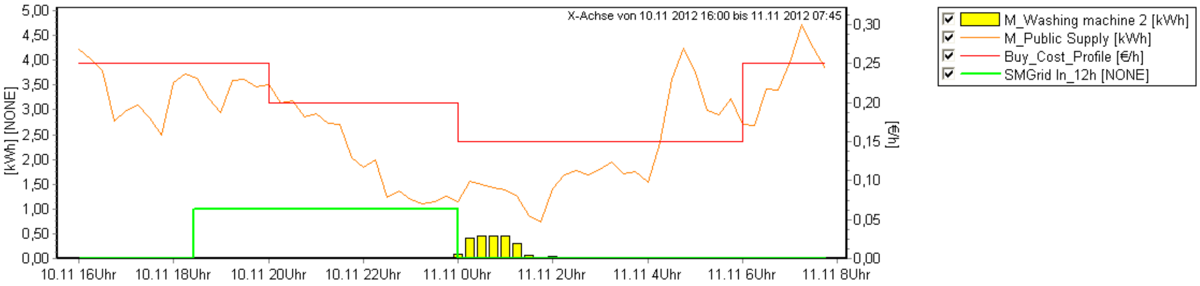


Figure 93: usage of SmartGridSwitch (ready within 12 h) in combination with a 3-step cost profile

In Figure 94 the effect of using the “within 4 hours ready” button in combination with the same three-step cost profile. The user pressed the blue button at 19:00 (ready till 23:00), the Washing Machine starts at 20:00 while the tarif with the middle cost and finished about 21:40.

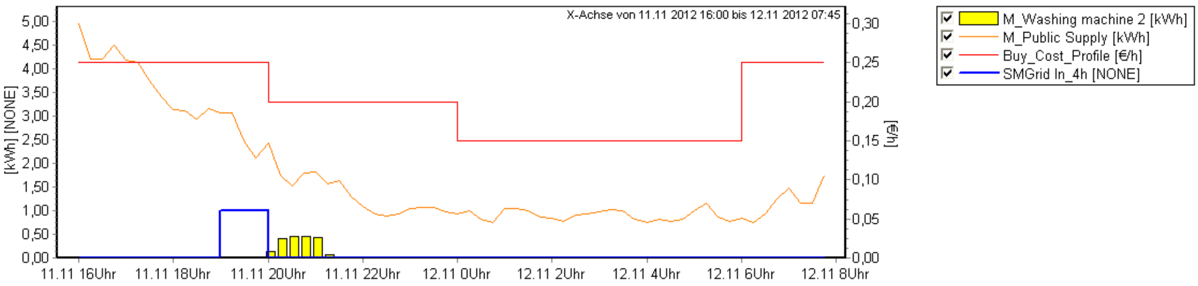


Figure 94: usage of SmartGridSwitch (ready within 4 h) in combination with a 3-step cost model

Using this concept it is possible to shift the consumption of SKDSVC appliances dependent on available LEP and the current tarif model within a timeframe of up to 12 hours with a good user acceptance.

4 From Simulation to Lab to Real World Environment

In this chapter we document the practical experience we gained with the forecast methods, criteria for EuPs and real world application of SmarCoDe nodes compared to theory and testing in laboratory conditions.

4.1 Power Generation Forecast Accuracy

In order to optimise the usage of locally produced energy it was necessary to develop forecast methods to predict the power curve a PV-installation or wind turbine will deliver over the following hours. In this chapter the practical experiences with the forecast routines are described.

4.1.1 *Wind Yield Forecast*

Work completed during year one and the year two of the project culminated in a model which develops correction factors for published wide-area forecasts to specific site conditions and a means to make the corrected forecast available in a manner that could be read and used by the energy management software.

The model is able to use the turbine's performance information to convert the forecast wind speeds into predictions of the power generated.

Since the forecast was published in Q2/2012 the work of integrating the results into the energy management system has been possible. In addition to the published forecast, each day a summary of the wind speeds and power produced on site for the 24 hour period is archived to Ennovatis server. Live data from the turbine can also be analysed using a web-interface to the monitoring computer linked directly to the turbine's control system.

As the forecasts have now been running since the early part of the year, further validation of the historical accuracy of the model has also been possible by comparing forecast data with actual data that the turbine saw during the period of the forecast.

In April 2012 the turbine was launched with a set of correction parameters derived from the previous quarter's worth of data. By July these were found to be following trends in the wind speed reasonably well – i.e. if the forecast was found to be suggesting a period of strengthening winds, wind speeds on site did by and large increase for the same period. However, the magnitude of the wind forecast was consistently lower than winds actually observed on site.

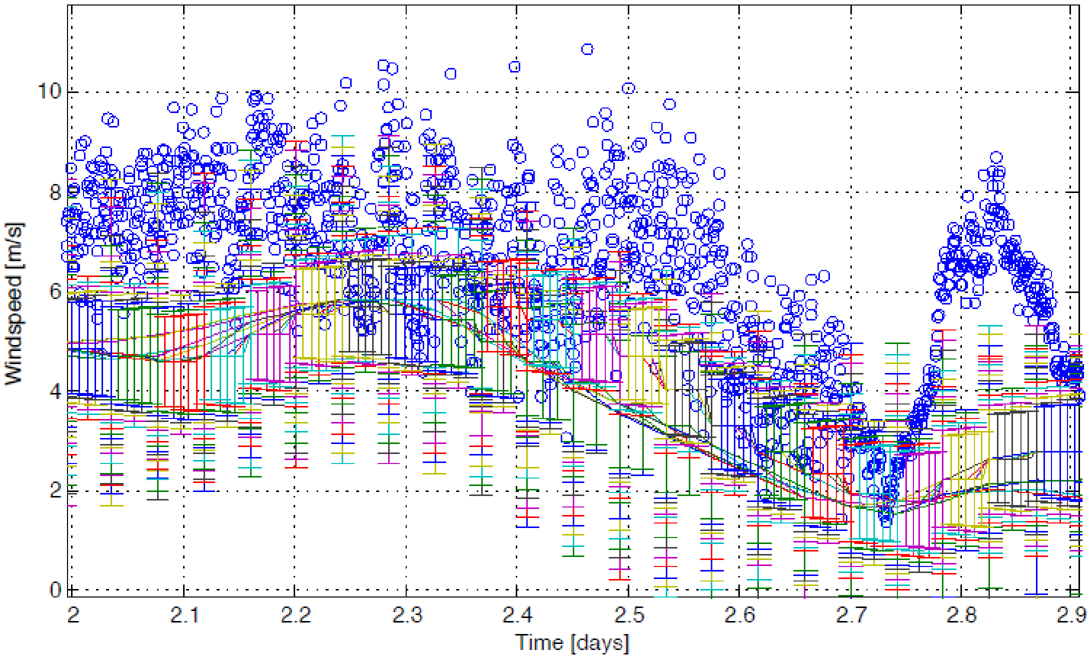


Figure 95: Sample data from July 2012 comparing measured data (blue circles) with forecast data (error bars) calculated with the original set of correction factors.

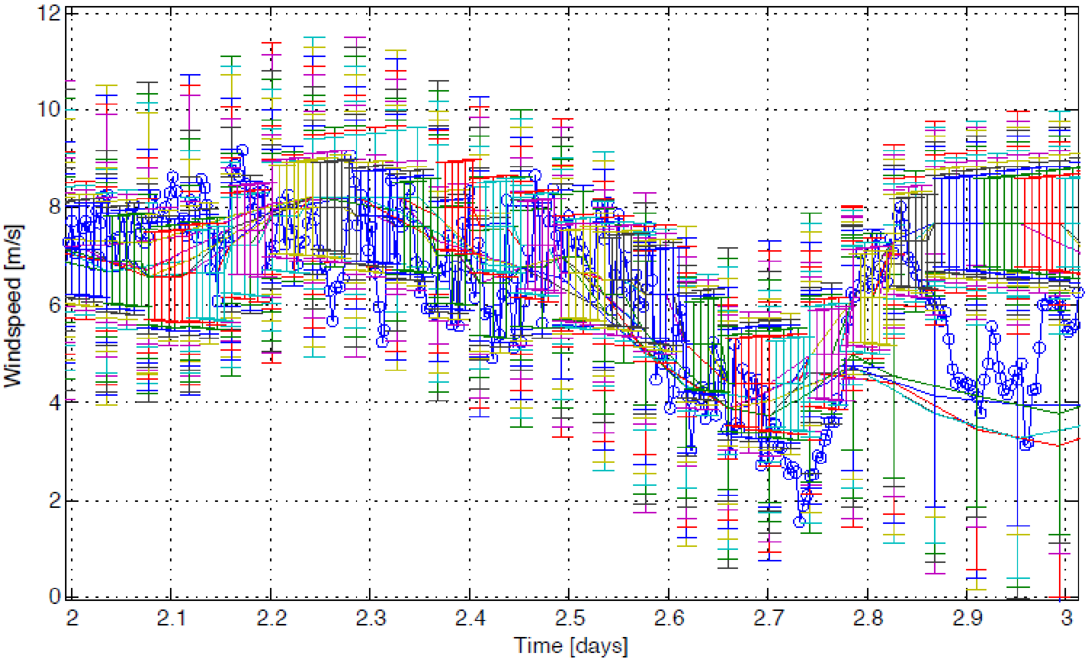


Figure 96: Sample data from July 2012 using updated correction factors

With the updated correction factors wind speeds generally stay within the range of values forecast.

SmartCoDe has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013]) under grant agreement n°247473

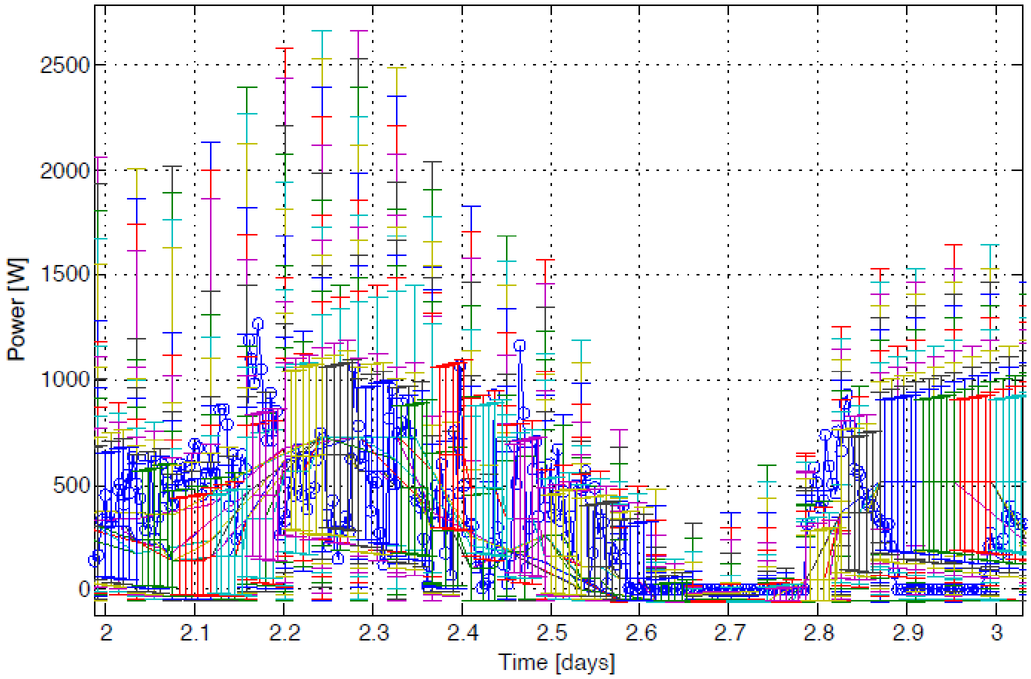


Figure 97: Sample power data from July 2012 showing power forecasts (error bars) and actual data (blue circles)

There is a greater deviation when the wind forecasts are converted into power. With power being proportional to the cube of the wind speed any difference between forecast and actual windspeed data is greatly exaggerated when this is converted to power. Actual power values rarely vary beyond the short term forecast predictions but the longer term forecasts do show greater deviation from actual values.

A similar correlation is seen when comparing data from September 2012 with the updated correction factors.

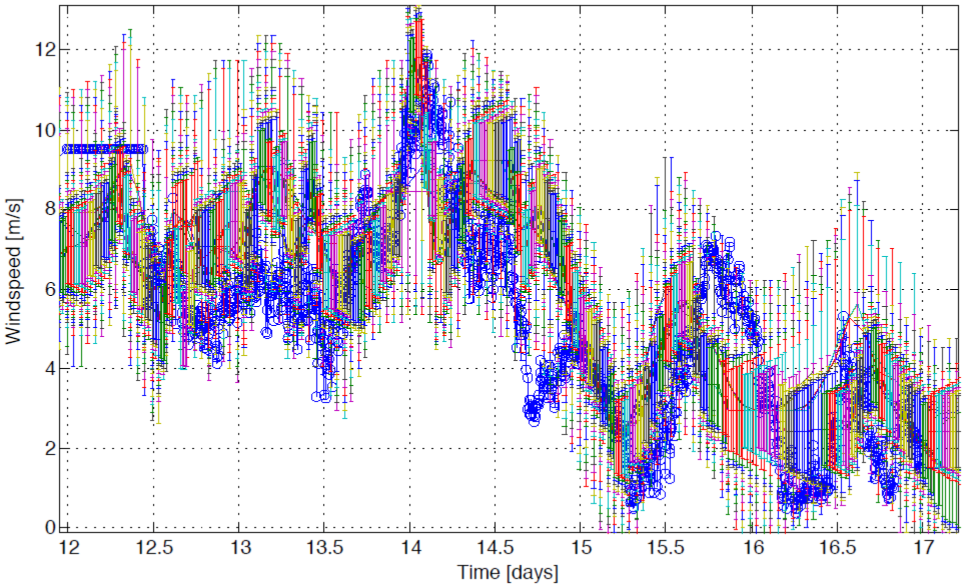


Figure 98: Wind speed forecast comparison for a period in September 2012

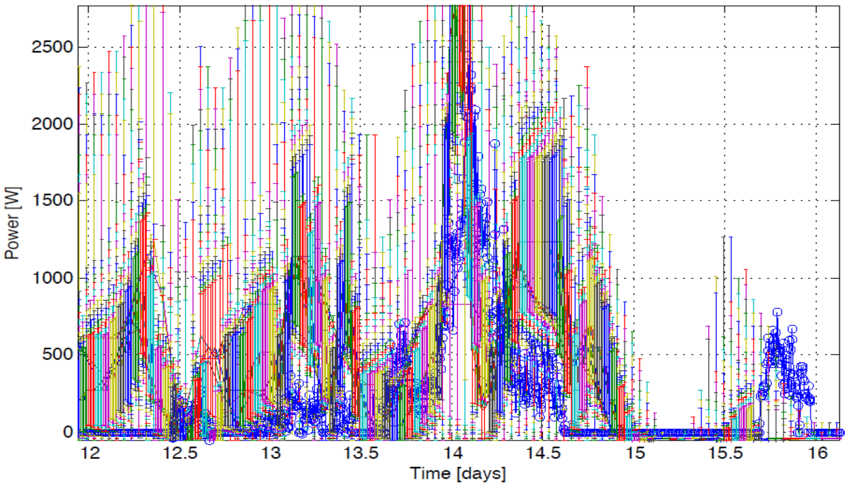


Figure 99: Power forecast comparison for a period in September 2012

Whilst it was hoped that correction factors derived from the first few months of observation on site and archiving of the weather forecasts would be useable throughout the year there appears to have been a significant shift in the correction factors between April and November. It is not clear from the period of observation to date whether this is a seasonal effect and that ideal correlation factors would return to values similar to those seen in the initial monitoring period or whether the changes in fact represent some other factor that has changed during the test period. A permanent change could arise due to the removal or addition of an obstruction local to the turbine, a change in the landscape nearby (clearing of forestry perhaps) or as a consequence of change in the method of weather forecast or the algorithms used.

To improve the accuracy of the forecasts going forward correlation factors could be obtained for a longer period and the scripts updated to use an appropriate correlation factor for the season.

However, as measurements over longer periods are impractical, and as the changes in correlation factor appear to be relatively slow, what is proposed going forward is a rolling update to the script which uses the previous week’s data to derive correlation factors for the week ahead.

This method would automatically make allowances for changes in the local topography or nearby obstructions and would provide some robustness in the system for unusual weather patterns.

The script running on the monitoring computer would have to be updated to automatically process and summarise the high resolution data recorded each day. This would be uploaded to the server where a new script would be needed to run the existing procedure to derive correction factors from the comparison between the summarised site data and the locally archived weather forecasts. Each day the correction factors used to adjust the forecasts would be updated based on the past 7 days worth of data.

4.1.2 Solar Yield Forecast

The solar power generation forecast was calculated within the EMU by a trigonometric formula. This formula calculated the direct sun beam on the PV-surface. With this it is possible to calculate the maximum PV power production by multiplication of the sun beam power with the maximum of the simulation output:

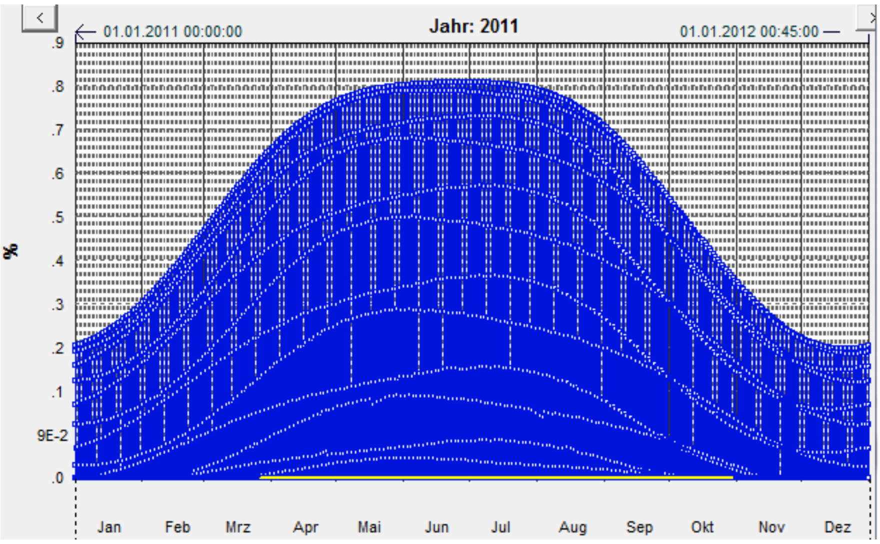


Figure 100: The theoretical maximum of the PV device plotted over the course of one year

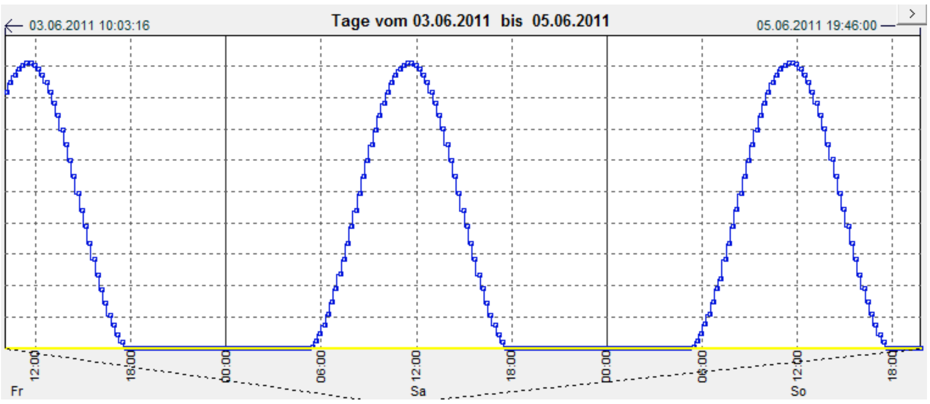


Figure 101: The theoretical maximum of the PV device in W plotted over three days in June 2011

By factoring this theoretical maximum with the PV-maximum on will get the following result:

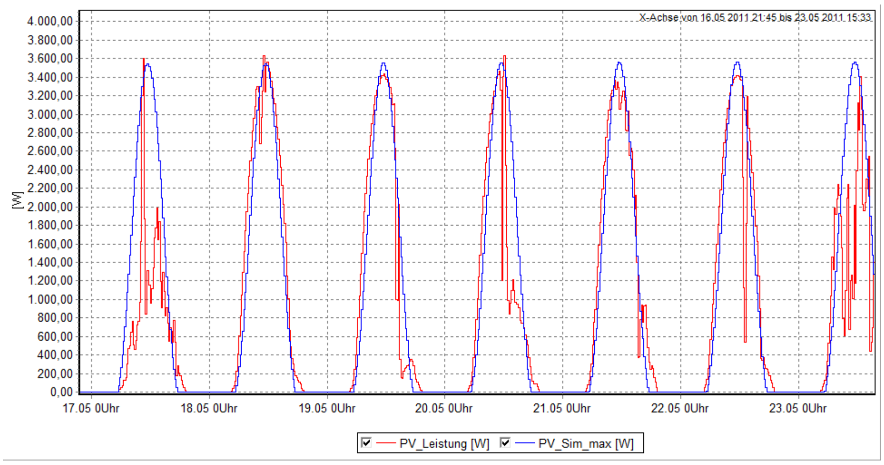


Figure 102: Comparison of theoretical maximum with measured data (good results)

Now while this looks good for several days, for others it is not working at all:

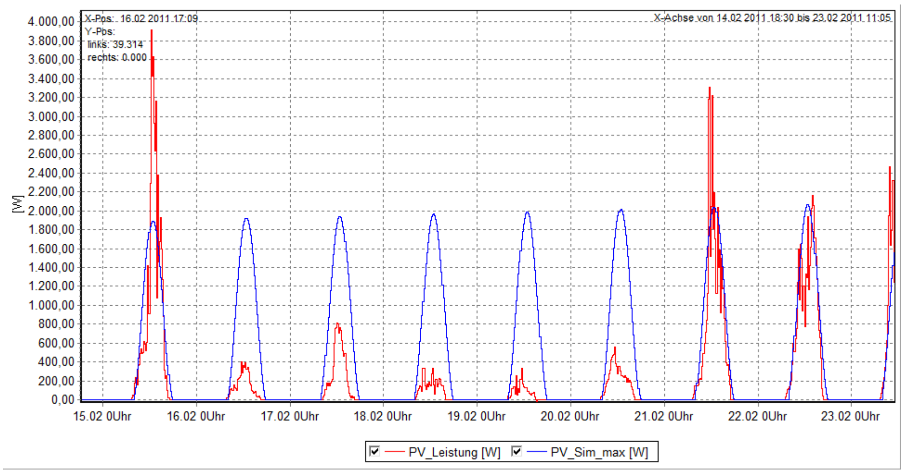


Figure 103: Comparison of theoretical maximum with measured data (problematic results)

Especially during spring and autumn the data did not correlate and the PV device mostly produced more energy as calculated. This was mostly because of underestimation of the diffuse sun beam, which lead to unaccounted additional PV-output.

To refine the PV power forecast, the output was now additionally corrected by the average cloud cover. The following graph shows the real measured PV-output compared to the corrected forecast:

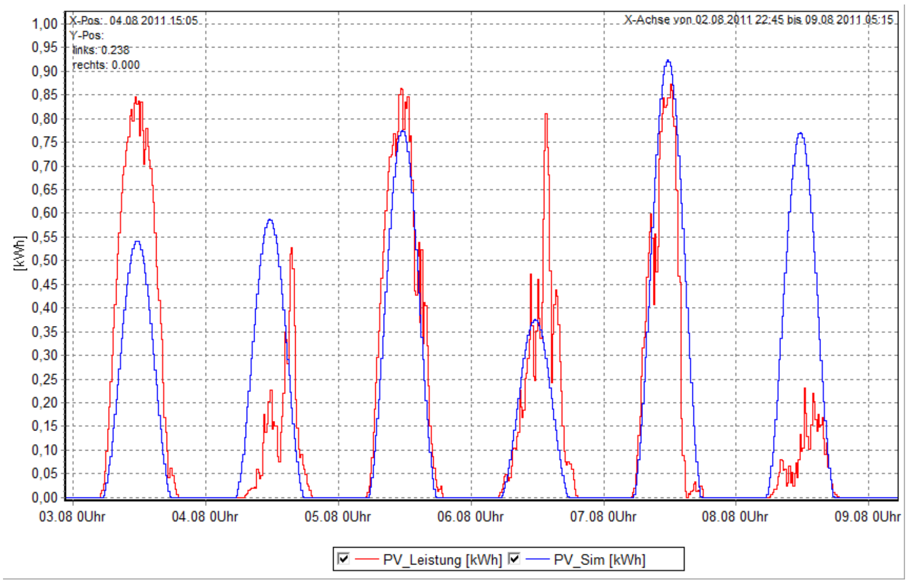


Figure 104: Comparison of corrected forecast with measured data (good results)

The approach works well during many periods. In others still, the results are not as good:

SmartCoDe has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013]) under grant agreement n°247473

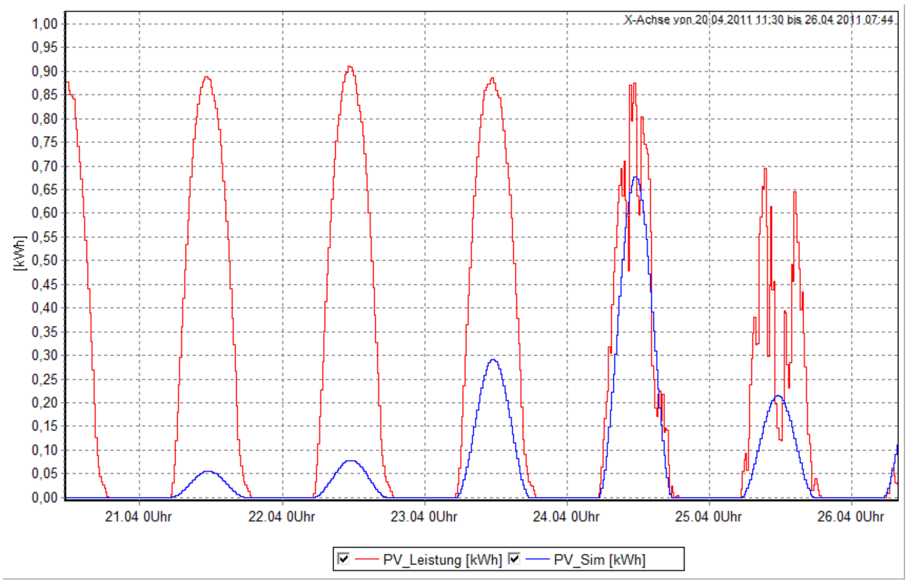


Figure 105: factoring Comparison of corrected forecast with measured data (problematic results)

To conclude, PV production can be forecast with trigonometric formulas. They fit easily into the computing means of the embedded device (EMU). The bigger problem is to get a good cloud cover forecast. Furthermore, forecasts are freely available only as daily averages. Nevertheless, for the needs of the SmartCoDe demonstrator the results are adequate.

4.2 Criteria for usable EuPs

In the following chapter we defined some criterias EuPs should fulfil to get optimal results in combination with SmartCoDe technology.

4.2.1 Fridges/Freezers (VSTSVC)

A crucial factor for VSTSVC appliances to be used for demand side management is the usual duty cycle. For example, in the extreme case where a freezers' compressor has to stay on all the time, there is obviously no room for load shifting.

The VSTSVC local cost-dependent control algorithm uses the usual duty-cycle during bang-bang operation as a basis for the load planning algorithm. Shortly after the compressor is switched off, the next off-on cycle is planned. To have room for cost-dependent adjustment, the usual off-cycle should be long (at least 30 minutes), and the usual on-cycle should also be considerably shorter than the off-cycle such that it doesn't block too large time periods for the operation of other appliances.

An example for a freezer which is sub-optimal in that respect is shown in Figure 106. This freezer has a usual duty cycle of 40 minutes off and 55 minutes on, that is a worse than 1:1 duty cycle. During summer, it was even worse and more in the range of 1:2. At least the 40 minutes off-cycle gives some room for cost-dependent adjustment.

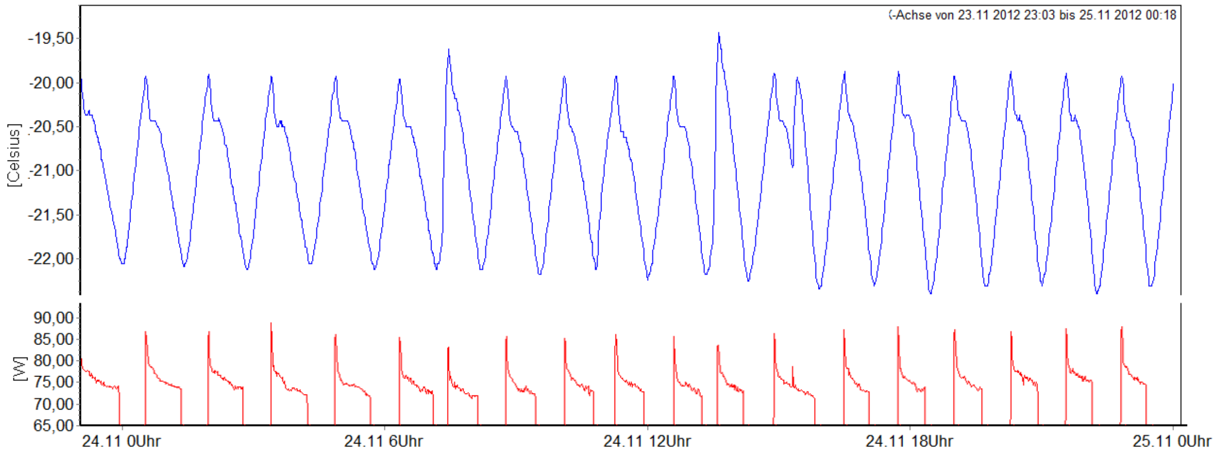


Figure 106 Buchberg Freezer 101 during bang-bang operation. The unusual values at about 15:00 are most likely caused by opening the freezer.

Figure 107 shows a better suited freezer for demand side management. This freezer has a usual duty cycle of 45 minutes off and 10 minutes on, i.e. a better than 4:1 duty cycle, which was also still in the 3:1 range during summer. Therefore, only short time periods are blocked by the operation of this freezer allowing more freedom in the planning of other appliances' operation.

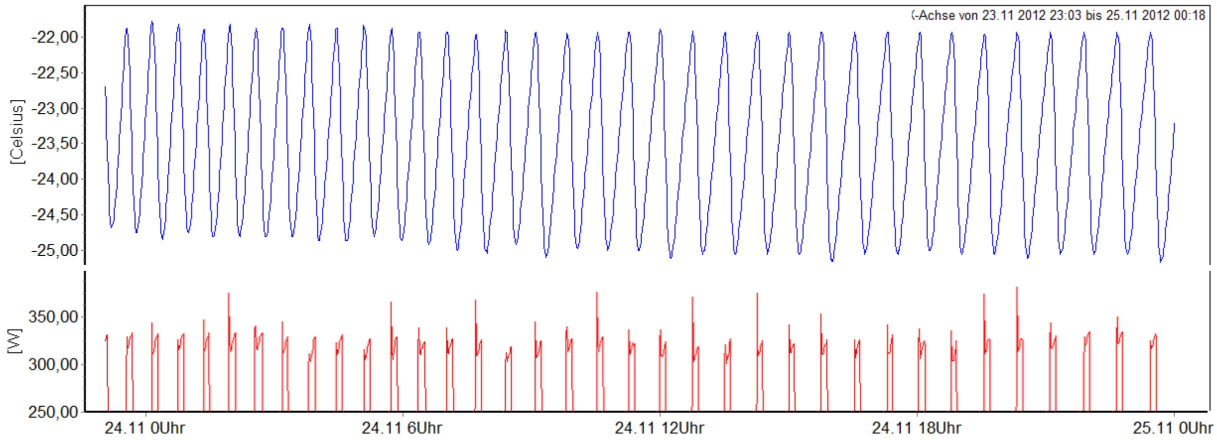


Figure 107 Buchberg Freezer 103 during bang-bang operation

To get such a duty cycle, there are essentially two factors:

- Good insulation since this prolongs the off-cycle
- A strong compressor since it cools down the fridge very quick and therefore shortens the on-cycle

However, a stronger compressor also has higher power consumption and therefore takes a big portion of the “power-cake” in the time slot when it’s active, so this is a trade-off. The possibility of using several power levels, like it is possible with inverters, would give more flexibility here. E.g. switch on with a high power-level during a very cheap and very short time period, but use a medium level during a longer but not so cheap period.

Another factor is temperature predictability. The SmartCoDe VSTSVC load planning algorithm only employs temperature prediction for the off-cycle, i.e. the warm-up phase. One reason for this is that the temperature forecast for the warm-up phase turned out to be much more reliable in some cases than for the cool-down phase. Figure 106 shows an example for this: Shortly after the cool-down starts, the temperature curve shows a small plateau before it proceeds to go down again. This actually means that the model function used for the temperature forecasting algorithm is not applicable here. The curve in Figure 107 however is fine in that respect.

With a better temperature predictability the load planning algorithm could be enhanced to cover more than one off-on cycle, which would obviously be advantageous.

4.2.2 *Washing machines (SKDSVC)*

While load plans for SKDSVC appliances are basically more straightforward and also more long-term than for VSTSVC, there is also much more knowledge required. The algorithm for VSTSVC developed in SmartCoDe is able to *learn* the important parameters (usual duty cycle and thermal process) and therefore can be employed in any fridge/freezer without further adjustment.

To provide a load plan for a washing machine, for example, there are much more factors to be considered:

- The program chosen by the user
- The water temperature
- The weight of the load

Out of this information, the EM-algorithm should be able to compute a load plan for the program. However, a lot of knowledge by the manufacturer is needed, possibly involving several series of experiments to get a formula for this. Ideally, the algorithm could also schedule some program interruptions where the opportunity presents itself. For example, they could be used to circumvent the relatively short activity periods of fridges/freezers.

The Bosch/Siemens washing machine and dryer interface used on the Buchberg demonstrator site is by far not sufficient for this. The interface between controller and the machine allows only turning the machine on after the user choose a deadline and pressed the start button, without the possibility to interrupt or stop the operation once it begins. There is no way to find out any details regarding duration and load profile of the specific washing program chosen by user. Instead, we use a worst-case load-plan, which is fine for a demonstration in the context of the SmartCoDe semi-decentralised EM-approach but by far not sufficient for effective demand side management.

4.3SmartCoDe Nodes in Theory and Practice

4.3.1 *Unforeseen resets of the SmartCoDe node*

In the lab, power interruptions are very rare, at most a few times a year. In such circumstances it is reasonable to keep internal data of the energy management algorithm in RAM only, e.g. temperature forecast coefficients mentioned in D-1.4 Section 5 [M. Damm et.a., 2011]. In the rare event of a power failure, performance would be degraded during several hours since the EM-algorithm would restart with the learning phase during which the appliance is unmanaged.

At the demonstration site, however, power fluctuations including voltage fluctuations and short interruptions turned out to be more frequent than anticipated. The ultra-low power supply is optimized for material costs, and designed to handle voltages of 230V +/- 10% and voltage drops of durations of less than 50ms - a common assumption for grid-powered appliances and assumed to be adequate. However, at the demonstration site the grid voltage would often drop below 180V for durations in the order of 750ms.

This is due to the semi-professional nature of the electrical installations as well as the remote rural location of the site. The power supply therefore provided too little safety margins against voltage drops and also against EMI due to switching heavy loads in a relatively weak grid. As a result, the SmartCoDe nodes experienced frequent resets caused by brownouts, and the energy optimization spent an unacceptable amount of time in the learning phase.

The issue was resolved by two measures:

- The energy management application was restructured to periodically save its internal state to non-volatile memory, starting with this procedure already in the learning phase. That way, even a reset during the learning phase could be handled without starting it from scratch. After the reset, the node first waits until it is synchronized in time again (time syncing is triggered after each start of a node). After that, a reboot handling method checks how long the node was powered down by comparing the time stamp of the last saved state to the current time, and then restores the state of the EM-algorithm accordingly, e.g. re-align the temperature measurements and dismissing recent (possibly corrupted) measurements in the learning phase.

- Resilience of the power-supply was improved by adding more robust line-filtering and a bigger storage capacitor for bridging voltage drops of a duration of up to one second.

4.3.2 *Issues of the wireless communication channel*

The material in the following sections has for the most part already been presented in D-3.3, Section 2.2. It is repeated here, however, because D-3.3 is confidential and the information comprised herein has value for the general public.

Early versions of the SmartCoDe energy management algorithm were running on close-to-target hardware under lab conditions as of September 2011 (general assembly meeting in Novi Sad). However, bringing the technology from the lab to the demonstration site proved more difficult and more time-consuming than anticipated by the project members.

4.3.2.1 ZigBee

ZigBee is believed to be a well-known and proven wireless networking technology. However, during winter 2011 and spring 2012 TUV and Tridonic identified numerous bugs in the ZigBee stack used for evaluation[4] and reported them back to solution vendor. While the SmartCoDe application matured in fall 2011 and already ran over extended periods of time in a laboratory setting, early attempts of installing SmartCoDe nodes at the Buchberg demonstration site failed within hours – the nodes quickly lost connectivity and did not regain them.
Bugs related to asymmetrical wireless links

NXP's stack failed to route around asymmetrical wireless links. Asymmetrical links occur when one node can receive packets from a second node, while the latter cannot receive packets from the first node. At the Buchberg demonstration site, the ZigBee routers use the high-RF-power variety of JN5148 modules in order to bridge the large distances between

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[4] NXP's ZigBee solution "JenStack" as distributed with the JN5148, ver. 1.5

some of the EuPs. The SmartCoDe nodes, however, use the normal variety. Mixing higher powered modules and lower powered modules results in a relatively high probability of asymmetrical links.

ZigBee PRO is designed to detect asymmetrical links and disregard them during route discovery. However, versions of the NXP stack from 2011 and early 2012 suffer from two distinct bugs with regards to route discovery in the presence of asymmetrical links:

- During route construction, the NXP stack checks for symmetry of candidate links at the wrong time, namely *after* already having poisoned the route discovery table with invalid candidates. At a later stage, it wrongly disregards good candidates, because they are trumped by the invalid ones.
- The second bug involves links that are symmetric at first and then change to being asymmetrical later. The code designed to expire failing symmetric links from the tables is simply broken due to a trivial programming bug in the stack code.

4.3.2.2 Re-joining of sleepy end-devices

SmartCoDe temperature sensors are battery powered and therefore power-cycle their transceiver to save power. In ZigBee, such nodes are called “sleepy end-devices”. While joining works as advertised, versions of the NXP stack from 2011 and early 2012 have issues whenever a sleepy end-device re-joins after a temporary network-outage. This happens at the Buchberg demonstrator whenever temperature sensors inside freezers get temporarily covered by frozen goods, or when brief power-outages cause short network-outages.

- On re-join of sleepy end-devices, ZigBee nodes with routing functionality corrupt their neighbour table, which leads to incorrect packet transmissions. If experienced by one or more ZigBee routers in a network, this leads to a slow but steady communication breakdown.
- Another issue not attributable to NXP’s implementation also has to do with sleepy end-devices in ZigBee – it can be considered a ZigBee specification bug: If a sleepy end-device, after a topology change, joins or re-joins a different ZigBee router, the original router under certain conditions fails to acknowledge the new route to the end-

device. This bug sometimes leaves SmartCoDe nodes unable to poll their temperature sensors. The issue can be coded around at the application layer.

4.3.2.3 Impact

The bugs described were not easily observable in the lab. They only appeared at the (remote) Buchberg site; hours, sometimes days after deployment. Whenever the demonstrator was brought live, several hours later after project members had long left the site, communication in the ZigBee network would get increasingly unreliable, but the system would continue to be semi-functional for several more hours until the last node became inaccessible. From there follows the big question: Is it a hardware or a software issue? If software, is it in the application or the stack?

The pace of any development task is critically dependent on the time between making a change to a system and observing its effect. In software development, this turnaround-time is typically seconds (compile / run), in embedded development minutes (compile / flash / run). At that time in the SmartCoDe project it was days, since accessing the Buchberg demonstrator site had to be organised regarding transportation.

Adding to that, the support received from the vendor NXP was less than optimal. From the time an accurate and detailed bug-report was filed, it typically took days to acknowledge and 30 to 60 days to fix. Research projects are not priority customers for big semiconductor companies like NXP.

Another problem was the fact that the SmartCoDe project did not have access to the source code of the NXP's ZigBee stack. Much time was spent debugging and reverse engineering different aspects of the stack in order to be able to accurately diagnose bugs and write accurate bug-reports.

The problems at the demonstration sites were only solved in the second quarter of 2012, after two things happened: The capabilities of the remote management infrastructure where significantly expanded beyond original plans, to capture a wider range of network performance parameters and events. And secondly, the wireless channel as present at the Buchberg site was recreated at TUV in meticulous detail.

Only in the lab was it possible to efficiently debug the system. The Buchberg demonstration site is a running restaurant business and it is therefore not possible to rapidly and repeatedly reconFigure and reset the system all the while keeping the impact on the business minimal. After all, the project is dependent on the co-operation of the landlord.

4.3.2.4 Lessons learned

The SmartCoDe project evaluated different ZigBee solutions in summer 2010. This was done by comparing the data-sheets, downloading and running the demo-applications and evaluating the development tools. . Even if ZigBee is an industry standard with a reputation for extensive and strict compliance testing and the chosen ZigBee solution passes ZigBee certification process, we developed and tested several demo applications in early project phases to minimise project risks.

Unfortunately, it seems that ZigBee certification process failed to uncover some obvious deficiencies in stack implementation. This problem is not related only to specific vendor, but it also means that certification process should be improved by ZigBee Alliance. On the other hand, real world applications can often stress algorithms and their implementation better than any certification or testing in laboratory conditions. This should be taken into account for future product evaluation.

Research and development has been based on commercial implementation of ZigBee Stack from existing, big and stable vendor. In time of evaluation, this was reasonable decision which could minimise risks, speed up development and allow to focus on project specific tasks. However, access to the source code would have greatly simplified bug hunting. Secondly, it would have enabled the project to integrate the whole stack as-is into the simulation environment, rather than developing a ZigBee simulation model which is of course useless for reproducing bugs of the closed-source implementation. This experience supports the opinion that research projects should under all circumstances try to use open-source technology.

4.3.2.5 Issues of the wireless channel in general

Apart from the issues we had regarding the concrete ZigBee stack used, we also experienced challenges connected to the use of wireless communication in general.

Router placement: The Buchberg demonstration site is a restaurant and therefore sensible to style and aesthetics. A ZigBee router placed openly in the lounge was considered rather problematic by the owners. Routers therefore had to be placed in positions sub-optimal from a wireless network perspective, which lead to some links being less reliable than optimal (and a higher probability of asymmetrical links).

Networks design: It turned out that the wireless network had to be designed more carefully than anticipated, just placing nodes at the spots where they are needed might not be enough for a *reliable* network, even if the nodes are able to connect when installed. In our case, we had to include an additional router because of some occasional obstructions issues (see below). Also, the connection between the coordinator and the central router turned out to be unreliable at times. The source of the latter wasn’t identified, but interference by WiFi equipment providing free internet access to the restaurant (which is used irregularly) might have played a role. The issue was solved by installing a high gain directional antenna at the coordinator pointing in direction of the central router.

Signal obstruction: The wireless channel changes over time in surprising and difficult to anticipate ways. One crucial router was placed at the bottom of a cabinet where it generally did a good job until the landlord one day decided to leave a bulky professional barbecue to dry right in front of said cabinet during after-hours. Needless to say, the project team was already half-way into the next bug-hunt until the real cause of the outage was learned by coincidence. Another source of signal obstruction was delivery vans occasionally parked between the buildings of the site. An additional router had to be installed to increase resilience of the particular link.

Obstruction of sensors: It took several experiments to find the ideal position of the temperature sensors inside the freezers and the right adhesive that would tolerate the low temperatures. The bigger problem, however, proved to be the personnel of the restaurant that on occasions excessively strains the sensor housing when resolutely hauling heavy bulk-sized containments of frozen goods (fries, vegetables, Schnitzel meat). This, however, is not a general problem of the approach but specific to the demonstration only. Wireless temperature sensors were only used to retro-fit freezers already on-site. In a full-scale application this wouldn't be an issue since the EuP would be directly integrated with the SmartCoDe node.

5 The big Picture

Having described the set-up, the methods, and concrete analysis results in the previous chapters, chapter five puts everything together and sets it into context to receive *the big picture*. The chapter summarises the results of the methods that have been applied and evaluated in the project and calculates the possible energy-reduction impact for the public, using as an example a roll-out of the described techniques and systems in Germany with approximately 40,3 million private households. The resulting energy savings on one side are compared against the costs of implementation of the system on the other side to allow an estimation of system amortisation times.

5.1Potential Impact on the public

Different approaches to achieve energy savings – ranging from the effects of awareness to the effects that can be achieved by using the automated SmartCoDe-Nodes – have been described in chapter 3. The effects of these approaches are now merged and the overall energy savings are calculated for the example of an average household and for different roll-out scenarios (1%, 10%, 20%) to the approx 40 million households in Germany.

The data that has been used for the example calculations is based on data from the VDE-ETG survey „Demand Side Integration“ [R. Apel et.al., 2012]. For the survey VDE has analysed and used the data from the 2012 publication of the Federal German Statistic Office on energy consumption in households and industry [Statistisches Bundesamt, 2012]. So for the example calculations we assume 40.3 million households in Germany with an average electrical power consumption of 3.600 kWh and an electricity price of 0,25 €/kWh. The following Figure shows the average penetration per appliance (“Durchdringung”) of these households with different types of electrical EuPs (from left to right: fridge, dishwasher, dryer, washing machine, heat pump, ventilation, heat storage at night, fridge/freezer combinations, hot water, freezer):

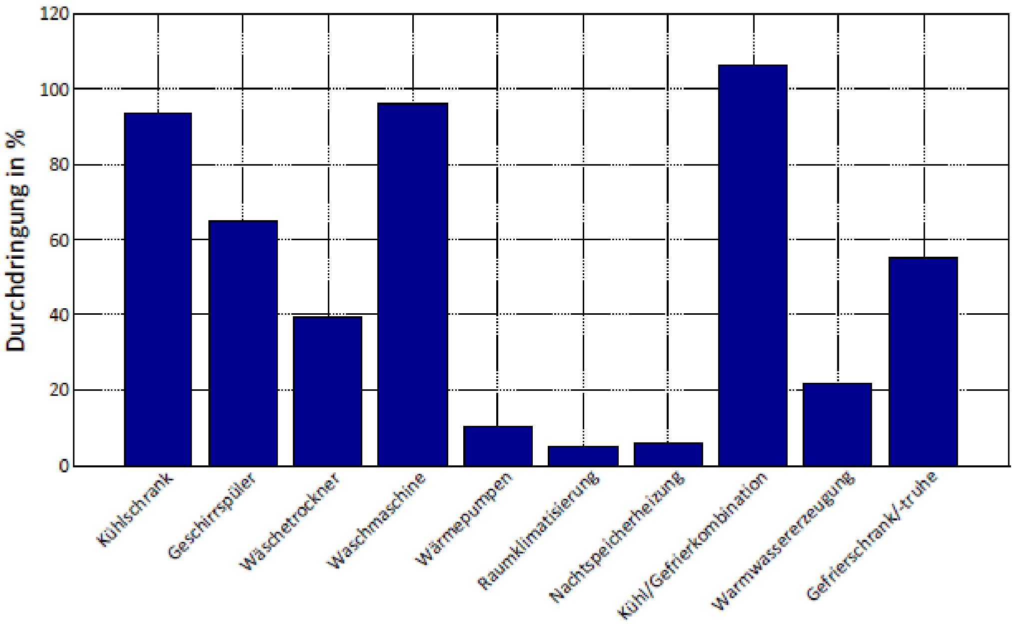

Figure 108: overview on EuP penetration in german hauseholds [R. Apel et.al., 2012].

5.1.1 *Effects from Awareness*

In chapter 3 we have documented that at the Almersberg demonstrator location using **“traditional” awareness** energy savings of about 43% are reasonable without using additional monitoring and visualisation techniques. The suggested measures ranged from the replacement of old and ineffective devices to a deliberate usage of PC, light and other devices that might be influenced directly.

For the potential calculated impact however we have used more conservative studies (e.g. KEMA, Bonn, 2009) which estimate the effects of awareness to be about 5% and an additional 15% for the replacement of inefficient devices.

<u>The potential energy savings for traditional awareness measures for the above described average household therefore totals to 720 kWh per annum.</u>

An unexpected discovery of the SmartCoDe project was the huge effects of using **pre-heated water** in connection with local renewable energy (e.g. PV) for the washing machine and the dishwasher. In chapter 3 we have shown that only with enabling the devices for this technology the consumed energy can be reduced by up to 35%. The required investment (components like a mixer to ensure the correct temperature for the program, even if the pre-heated water is hotter than needed) are estimated to be in the range of 100€. Taken that a Washing Machine has 146 washing cycles per annum and an average consumption per washing cycle of 0,9 kWh and a dishwasher has 198 cycles per annum and an average consumption of 1,1 kWh the potential energy savings sum up to a total of 94 kWh or 2,6% of the overall household consumption. Under the conditions defined previously the amortisation time of such an investment amounts to 4-5 years.

5.1.2 *Effects from Monitoring and Analysis*

With the installation of the SmartCoDe System a user also gets access to an effective appliance monitoring system that enables an additional energy saving potential.

The previous mentioned effect of the use of **pre-heated water** devices can be further improved to up to 60% by using the devices in times when the water storage capacity pre-heated by solar energy has reached a certain temperature threshold (see chapter 3.1.3 Manual Load Balancing). This additional effect raises the potential energy saving 158 kWh per year or 4,4% of the overall household consumption.

Even higher is the effect of the identification of inefficiencies in the **electrical components of the heating (and cooling) system**. The electric power for these systems has an average impact of 28,1% on the electrical energy consumption of an average household. Given the available analysis and monitoring capabilities and a low level of investment (e.g. additional timers, more thermostatic valve, ... up to a few hundred Euro), savings of about 30% are possible. For an average household these are 8% or 288 kWh per year.

In addition using the SmartCoDe-nodes for monitoring only we were able to **optimise an existing deepfreezer** manually without additional investments. The same effect would have been possible, if – after the analysis of the data – the old freezer control module would have been replaced. Average refrigerator or deepfreezer consumption is calculated with 345 kWh/year. Numbers from experience show that the replacement of a control module of one refrigerator saves up to 42%. For an average household this amounts to 133 kWh per annum or 3,7% of the overall household consumption.

The potential energy savings for monitoring and analysis measures for the above described average household therefore totals to 486 kWh per annum.

5.1.3 Effects from Balancing

In addition to awareness and monitoring / analysis measures the SmartCoDe project applied technologies to shift energy consumption and to use virtual storage capacities available a facility. There are several effects to such an approach. First, while shifting the load of household appliances to times when local renewable energy is available, energy consumption in terms of CO2 emission is reduced since the overall amount of energy received from the global grid is generated using fossil energy resources. Second, with information and control interfaces to the global grid are becoming available, the local resource can provide a stabilising service to the overall grid, i.e. grid peak loads can be reduced and overall grid load can be stabilised. The effect will be an improved utilisation of existing grid infrastructure.

End customer ICT interfaces to the global grid however are not yet available. The SmartCoDe project however has developed measure to enable household for the upcoming changes. In chapter 3 we have shown, that the SmartCoDe set-up is able to predict consumption and local generation and to shift available load in accordance to the information available at the local energy management unit. We have also shown the optional effect on the stability of the consumption curve, i.e. the system's schedule of the multiple fridge set-up received a reduction of sample variance between 30% and 40%.

For **shaping the prosumer curve** we evaluated two alternatives: Effects we can reach with manual load balancing and the effects we can reach with automatic load balancing.

Device	*Category*	*Percentage*	*Consumption*
Oven	CUSCON	7,90%	284 kWh
Dishwasher, Washing Machine, Dryer	SKDSVC	8,80%	317 kWh
Heating	VARSVC	16,40%	590 kWh
Light	VARSVC	7,10%	256 kWh
PC, Video, Audio	VARSVC	5,90%	212 kWh
Additional Devices	VARSVC	25%	900 kWh
Refrigerater and Deep freezers	VSTSVC	17,40%	626 kWh
Warmwater	VSTSVC	11,50%	414 kWh
Total			**3.600 kWh**

Table 10: overview on the power usage in an average household (source: VDEW)

With manual **load balancing** all EuPs are interesting, which can be directly be influenced by the user. These are especially the categories SKDSVC (schedulable service) and CUSCON (custom control). According to Table 10 this is a theoretical potential of about (7,9% + 8,8% =) 16,7% or 600 kWh per year.

At our demonstrator in Almersberg we have observed, that a mix of oven, dishwasher and washing machine are already be used for about 45% at times when energy from the local LEP is available. Therefore there is a potential of (55% of 16,7% =) 9,2% left for shifting. Considering the users behaviour it is possible to use up to 50% of this potential – depending on the benefit (e.g. lower costs through special energy tariffs) the user gets for his effort. Therefore we have an additional potential of (50% of 9,2% =) 4,6% - 2,4% for SKDSVC and 2,2% for CUSCON devices. This is 165 kWh per year and household.

The potential energy savings through manual load balancing for the above described average household therefore totals to 165 kWh per annum.

Using the SmartGridSwich we could evaluate, that for SKDSVC (schedulable service) there are good opportunities to shift the consumption load within a time frame of at least 12 hours and for VSTSVC (virtually storable services) within a time frame of at least 2 hours with **automatic load balancing**.

With this advanced techniques it is possible to use up to 90% of the potential for load balancing for SKDSVC. This effect raises the potential for load balancing from 2,4% to 4,4% and 157 kWh per year and household.

For VSTSVC there is according Table 10 a theoretical potential of about 28,9% or 1.040 kWh per year. In practice we have evaluated at our demonstrator in Almersberg, that in a mix with an e-Boiler and a deepfreezer already 35% are used in times with LEP. Therefore there is a potential of 18,8% left. Within the given timeframe, technical and comfort requests it is possible to use up to 25% of this potential. In sum this is a potential of 4,7% or 169 kWh per household.

The potential energy savings through automatic load balancing for the above described average household therefore totals to 241 kWh per annum.

The second target to reach was the **reduction of the variance** of the prosumer curve. In Chapter 3 we demonstrated with examples from the lab, the Buchberg demonstrator and simulation that the variance of the overall power consumption of a set of fridges and/or freezers (e.g. the ones in a neighbourhood or an apartment building) can be reduced by up to 40%. That is, power peaks and swings are reduced significantly with a resulting benefit to the local grid.

The example Plot in Figure 109 shows a portion of the combined power consumption of the 4 Buchberg freezers. In Chapter 3, we showed a load-balancing run where the variance could be reduced on average by 24%. Referred to the average power consumption of about 400W of the 4 freezers, this is a reduction of about 100W.

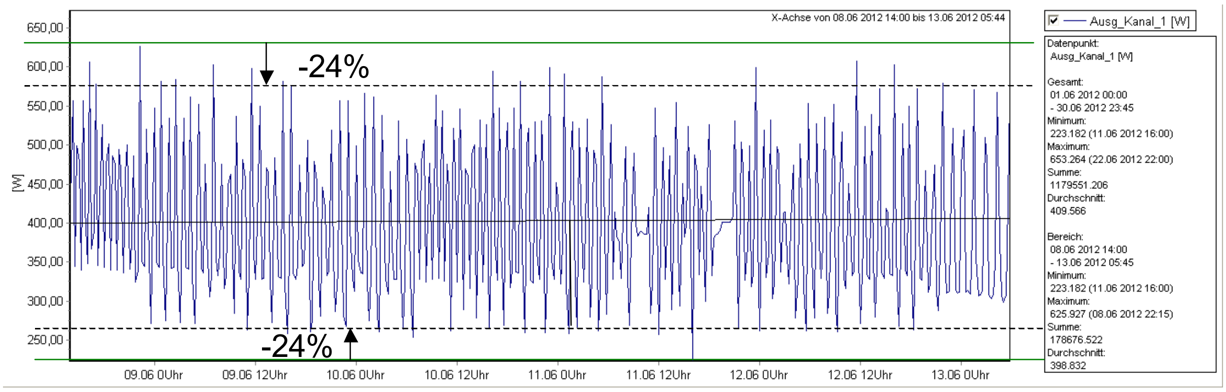

Figure 109: portion of the combined power consumption of the 4 Buchberg freezers

The potential reduction of grid peak loads resulting from SKDSVC and VSTSVC for the above described average household therefore totals to 24% referred to their average power consumption.

5.1.4 *Summarising the effects in total*

Table 11 summarise the results of the last three chapters and give an overview on the total effect of all efforts.

Nr	*Description*	*German Standard Household*			*Rollout to Germany*		
		Percentage	*Consumtion*	*Cost*	*Percentage of covered households*		
					1%	10%	20%
5.1.1.	Awareness						
	- deliberate usage	5,0%	180 kWh	45,00 €			
	- replacement in general	15,0%	540 kWh	135,00 €			
	- pre-heated water	2,6%	94 kWh	23,40 €			
	Total	**22,6%**	**814 kWh**	**203,40 €**	**329 GWh**	**3.287 GWh**	**6.574 GWh**
5.1.2.	Monitoring and Visualisation						
	- pre-heated water (additional)	1,8%	65 kWh	16,20 €			
	- optimization of heating system	8,0%	288 kWh	72,00 €			
	- optimize deepfreezer	3,7%	133 kWh	33,30 €			
	Total	**13,5%**	**486 kWh**	**121,50 €**	**196 GWh**	**1.963 GWh**	**3.927 GWh**
5.1.3.	Load Balancing						
	- manual load balancing						
	+ SKDSVC	2,4%	86 kWh				
	+ CUSCON	2,2%	79 kWh				
	- automatic load balancing						
	+ SKDSVC	2,0%	72 kWh				
	+ VSTSVC	4,7%	169 kWh				
	- reduction of the variance						
	Total	**11,3%**	**407 kWh**		**164 GWh**	**1.643 GWh**	**3.287 GWh**

Table 11: from the Household to the Rollout – overview on total effects

The possible effects of awareness are at least about 23% of the total power consumption. Together with the effects from monitoring and visualisation and the analysis of the data we have a total reduction potential of 36% and a reduction of the energy costs of about 325,- €

per year. For load balancing there is currently (for households without own LEP) no financial need, therefore it'll be one of the challenges for the future to change the tariff-models in a way that load balancing leads to a significant benefit.

A rollout of these systems to only 20% of the German households would lead to energy savings of about 10,5 TWh and a potential for load balancing of about 3.3 TWh.

5.2Estimation of the Costs

5.2.1 Description of Business Scenarios

The following sections analyse two scenarios.

The first one considers an early, low volume roll out of SmartCoDe technology (100.000 nodes). For this scenario it is assumed that all HW will be built by means of standard PCBs and discrete components. As white good appliances (like washing machines, refrigerators, etc.) are assumed to not provide digital smart remote control interfaces, wireless appliance control nodes need to provide full 220V power switching ability and power supply. For LED-lighting devices a simple architecture wireless node is assumed (no 220V to DC power supply, no 220V power switching ability).

The second scenario considers a mature market which can be supplied by high integration SmartCoDe technology (10.000.000 nodes). White good appliances are assumed to provide digital communication interfaces and DC power supply, therefore the complexity of the wireless controlling nodes can be significantly reduced, resulting in simple node architecture, similar to a node used for LED-lighting control. There is only a small portion of complex nodes assumed for the use in Smart Plugs

For both scenarios a general distinction is made between wireless controlling nodes (those nodes which are connected to end-devices like appliances, LED-lighting modules, sensors etc.) and infrastructure components like message forwarding/routing nodes, WSN2LAN gateway including Energy Management Unit EMU and SW-application for visualisation and remote control (APP for SmartPhones or Tablets). Infrastructure HW is assumed to be built by standard PCBs and discrete components.

The types of nodes considered in the following section are as follows:

- Complex SmartCoDe Enabled Sensor Node:

  a SmartCoDe node with high complex functionality, i.e. including 220V to DC power supply and 220V power switch. Node is built by using standard PCBs and discretes for the low volume scenario and built by using integration technologies for the high volume scenario. Node is used for white good appliance control and smart plugs in low volume scenario and for smart plugs only in high volume scenario.

- Simple SmartCoDe Enabled Sensor Node:

  a SmartCoDe node with low complex functionality, i.e. no 220V to DC power supply and 220V power switch. Node is built by using standard PCBs and discretes for the low volume scenario and built by using integration technologies for the high volume scenario. Node is used for LED-lighting modules in low volume scenario and for LED-lighting modules and white good appliances in high volume scenario.

- Simple Sensors:

  like temperature sensors, motion detection sensors

- Message forwarding/Router Nodes:

  This infrastructure node is used for range extension of the wireless sensor network

- Energy Management Unit including Gateway (WSN2LAN) node:

  This infrastructure node encapsulates both a gateway module, bridging the low power Wireless Sensor Network to LAN, and the Energy Management Unit

- Software Visualisation:

  APP on a SmartPhone or Tablet for visualisation and remote control of home appliances and lighting units.

5.2.2 *Low volume Cost Estimation*

Initial markets will start with retrofitting existing EuPs so that they become SmartCoDe enabled, hence a larger number of the typical fully featured and more expensive power plug adapter will be needed compared to embedded solutions directly built into the EuPs in further in the future scenarios.

The typical home use cases described in 5.2.1 are the basis for the cost estimation for low volume initial market assuming 100.000 SmartCoDe nodes deployed across Europe (or in core European countries where market entrance will start).

Product development costs are taken into consideration for the amount considered assuming the results and work done in the SmartCoDe Project can be used partly which will reduce development time and cost.

For the cost estimation of the given Nodes it is assumed that these will be ZigBee enabled.

For an initial market deployment, the following home use case is considered for an average house hold.

The average Number of installed devices considered is:

2x Router Nodes: Router only nodes for allowing full coverage of home network including remote locations where the energy meters typically are installed.

8x Complex SmartCoDe Enabled Sensor Nodes: These power plug adapters will connect, deep Freezer, Refrigerator, Dishwasher, Washing Machine, Electrical Heaters, Boiler, TV/HIFI, specific Lights connected by cable to the wall power plug.

4x Simple SmartCoDe Enabled Sensor Node: These reduced function sensor Nodes are installed in Lighting applications, within light Bulbs or Lamps which are used for a longer amount of time or can be automatically switched on and off with wireless motion sensors.

3x Simple Sensors: These are used for temperature measurement and/or motion detection allowing simple home automation functionality.

1x Energy Management Unit: Will interface to the SmartMeter the ZigBee Network and incorporate a Gateway.

1x Software Visualisation: It is assumed software will be provided for free as APP for Smart Phones or Tablets or a Web Interface for other devices.

The cost items for a complex SmartCoDe Sensor Node are split up as follow:

Complex Sensor Node	
Item	Net Price
Material Cost	€ 10,80
Mechanics Cost	€ 0,40
Direct Production Cost	€ 3,47
Other Product Cost	€ 3,40
Marketing / Sales	€ 10,12
Sum:	**€ 28,19**

Table 12: Cost Items for a complex SmartCoDe node for 100.000 units

The cost items for the Energy Management Unit Node are split up as follow:

Energy Mangement Unit	
Item	Net Price
Material Cost	€ 13,60
Mechanics Cost	€ 3,90
Direct Production Costs	€ 5,32
Other Product Costs	€ 16,42
Sales	€ 21,98
Sum:	**€ 61,22**

Table 13: Cost Items for the Energy Management node for 10.000 units

Material Cost:	Includes all the Bill of Material needed for Production
Mechanics Cost:	Includes all the mechanical parts such as plastics, metal parts, screws, packaging…
Direct Production Cost:	Includes assembly and initial costs directly related to production

Other Product Costs: Items such as warranty, financing and also the company's development costs are covered

The costs for the other note types of Table 1 were derived from the details of the above cost tables and are not shown in separate summary tables.

Based on the cost estimations for the different items in a household an average household scenario has been analysed with the following results:

Group	Item	Count	Production cost	Selling price	Sum	Description / Comment
SmartCoDe Nodes						
	Router Node	2		29,60 €	59,20 €	
	Complex Sensor Node	8		29,60 €	236,80 €	EuPs
	Simple Sensor Node	4		10,00 €	40,00 €	e.g. for lighting LEDs
EMU / other						
	EMU + Gateway	1	61,20 €	122,40 €	122,40 €	Interface to SmartMeter, Gateway Node
	Sensors	3	15,00 €	30,00 €	90,00 €	external temperaturem light, ...
	Software / Visualisation	1	- €	- €	- €	App for Tablets, Smart Phones etc.
					548,40 €	Package Cost
					24,45 €	Average cost / Node for LV
					181,60 €	Infrastructure cost / Household for LV

Table 14: Overview of Cost / Household for initial markets assuming low volume < 100.000

Figure 110 shows a split of the total package costs into the different cost items.

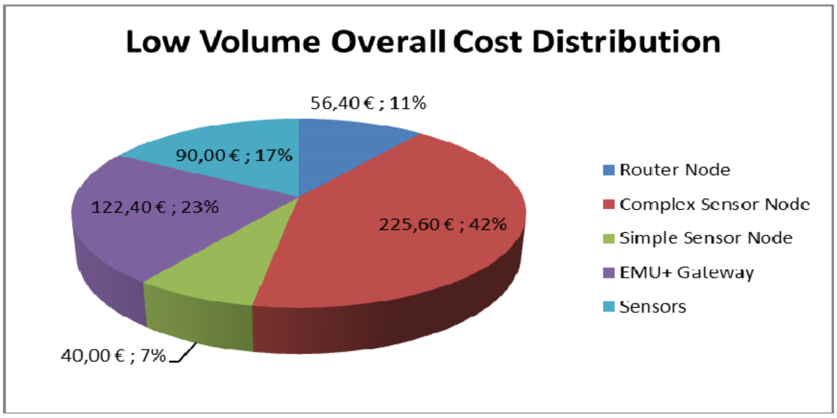

Figure 110: Low Volume (100.000 units) Overall Cost Distribution

5.2.3 High Volume Cost Estimation

For a mature market deployment (volume > 10.000.000), the following home use case is considered for an average house hold.

The average Number of installed devices considered is:

2x Router Nodes: Router only nodes for allowing full coverage of home network including remote locations where the energy meters typically are installed.

4x Complex SmartCoDe Enabled Sensor Nodes: These power plug adapters will connect wall power plug (Smart Plug).

8x Simple SmartCoDe Enabled Sensor Node: These reduced function sensor Nodes connect deep Freezer, Refrigerator, Dishwasher, Washing Machine, Electrical Heaters, Boiler, TV/HIFI, and are installed in Lighting applications, within light Bulbs or Lamps which are used for a longer amount of time or can be automatically switched on and off with wireless motion sensors.

3x Simple Sensors: These are used for temperature measurement and/or motion detection allowing simple home automation functionality.

1x Energy Management Unit: Will interface to the SmartMeter the ZigBee Network and incorporate a Gateway.

1x Software Visualisation: It is assumed software will be provided for free as APP for Smart Phones or Tablets or a Web Interface for other devices.

With these Figures and referencing to SmartCoDe deliverable *D3.1.2*, where production costs of highly integrated sensor nodes are estimated, an equivalent consideration (on the basis of 10.000.000 sold sensor nodes) as given for the low volume scenario has been performed for the high volume scenario as well. The analysis of an average household scenario, based on cost estimations for the different items in a household is given in the following table:

Group	Item	Count	Production cost	Selling price	Sum	Description/Comment
SmartCoDe Nodes						
	Gateway Node (integrated)	1	4,90 €	10,60 €	10,60 €	
	Router Node (integrated)	2	4,90 €	10,60 €	21,20 €	
	Complex Sensor Node	4	4,90 €	10,60 €	42,40 €	Smart Plugs
	Simple Sensor Node	8	2,50 €	5,30 €	42,40 €	Lighting-LEDs, EuPs (appliances)
EMU / other	EMU	1	40,00 €	80,00 €	80,00 €	Interface to SmartMeter, Gateway Node
	Sensors	3	3,00 €	6,00 €	18,00 €	external temperature, light, ...
	Software/Visulization	1	- €	- €	- €	App for Tablets, Smart Phones etc.
					214,60 €	Package Cost
					6,85 €	Average cost / Node for HV
					111,80 €	Infrastructure cost / Household for HV

Table 15: Overview of Cost / Household for mature markets assuming high volume > 10.000.000

Figure 111 shows a split of the total package costs into the different cost items.

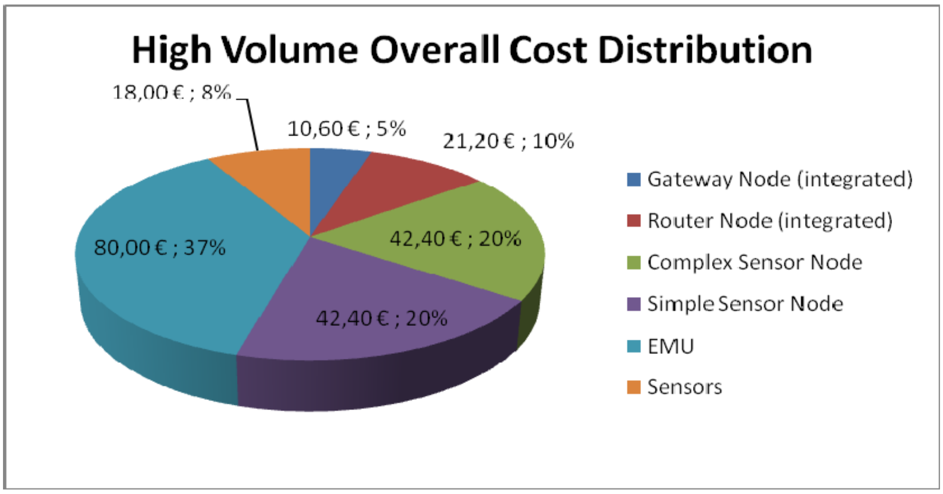

Figure 111: High Volume (10.000.000 units) Overall Cost Distribution

5.2.4 *Interpretation and Conclusion*

Summary of results – Low Volume Scenario:

The average cost / node over all SmartCoDe nodes not including the infrastructure is with more than 24€ much higher than achievable by mass deployment of a fully integrated solution, however one can see that the target price is already very attractive for at least a minor percentage of the households across Europe, i.e. those who are aware of energy saving possibilities and have not a big problem making 500€+ investment for an overall SmartCoDe enabled package.

The infrastructure cost is a one-time cost item that from a consumer perspective is high and might not be directly charged to the customer as other business models with some monthly services charges might be more appropriate. Due to the much smaller volumes (at most 1/10 of the SmartCoDe Nodes) the initial and development costs play a significant role in the overall costs.

Summary of results – High Volume Scenario:

For the high volume scenario the situation is different. While the share of infrastructure costs is still a dominant cost factor, the total cost of a package including 15 wireless nodes has become affordable (214,60€). This is due to the cost-benefit of the integrated sensor nodes and the assumed reduced complexity of white good controlling wireless nodes, resulting in average costs of 6,85€ per node (in comparison: 24,45€ per node for the low volume scenario). The business plan also shows much more upside potential due to the cheap costs of additional sensors, making extensions of a personal home automation network more attractive.

6 Attachement

6.1 References

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6.2 Definitions

Some definitions seem to be useful

Independent Variable: Characteristics of a facility's use or the environment which govern energy consumption: weather (Tª, humidity) and occupancy

Degree Day: is the measurement of the heating or cooling load on a facility created by outdoor T. It's defined relative to a base temperature - the outside temperature above which a building needs no heating

Measurement & Verification: The process of using measurements to reliably determine actual savings created by energy efficiency measures in facility

Routine adjustments: Adjustments for changes in selected independent variables that can be expected to happen throughout the baseline period

Non-Routine adjustments: (baseline adjustments): Adjustments for changes in parameters which cannot be predicted and that affect to demand

6.3 Abbreviations

b	Baseline Power
BPM	Baseline Profile Model
CDD	Cooling Degree Day

DHW	Domestic Hot Water
ECM	Energy Conserving Measure
EEM	Energy Efficiency Measure
EPBD	Energy Performance of heating Directive
EuP	Energy using Product
FEMP	Federal Energy Program
HDD	Heating Degree Day
IPMVP	International Performance Measurement & Verification Protocol
LEP	Local Energy Production
PE	Primary Energy
Q	Heat
SEC	Smart EuP Control with integrated circuit solution
W	electric auxiliary energy

6.4SmartCoDe models to describe EuPs

Class	Description	Parameters			Energy Management		Examples
		Configuration	Sensor input	Online input	Strategy	cost	
VARSVC	**Variable Service:** The appliance provides a user-variable service which is balanced with	tolerance bounds	current state of the service, e.g. illuminance	user demand, e.g. setpoint for illuminance	Minimise consumption by balancing the service with user demand, tolerance bounds and sensor	No	lighting controlled by illuminance level, dimmable
VSTSVC	**virtual storage service:** The appliance provides a inert, mostly thermal	temperature bounds / hysteresis	temperature	user demand, e.g. setpoint for temperature	Adjust temperature to user demand while exploiting the virtual storage property to minimise costs.	Yes	Fridge, Freezer, Heating, A/C, Water-boiler
SKDSVC	**Schedulable Service:** The appliance provides a service which can be	runtimes and power profiles of the different programs	none	deadline	Schedule program such that deadline is met and the program's load profile produces minimal costs.	Yes	washing machine, dryer, dishwasher, baking
ETOSVC	**Event-Timeout Service:** The appliance is control-led by sensor events and time-outs.	time span	sensor event, e.g. presence detection	none (indirectly through sensor input)	Control appliance according to sensor events and time-outs.	No	lighting controlled by presence detector
CHACON	**Charge Control:** The appliance charges a possibly removable device.	charging policy	current charge status, device	device removal re-insertion	Charge device such that costs are minimised, while obeying charging	Yes	battery chargers, hand-held vacuum, emergency
COMCON	**Complete Control:** Like CHACON, but the usage of the charged power can also be con-trolled.	charging policy, duty cycles, time slots	current charge status	none	Like CHACON, but also control the usage of the appliance cost-effectively while obeying to the given	Yes	robot vacuum, robot lawn-mower
CUSCON	**Custom Control:** device does not fit into other classes or has too high user inetraction to be controllable.	none	none	user demand	Automatic Energy Management probably not tolerable by user; custom schemes can be defined which are implemented by the	No	HiFi, PC, Oven

Table 16 SmartCoDe classification of EuPs