FLEXYNETS

D4.2 - Management of interaction with electricity and gas grid

Fifth generation, low temperature, high exergy district heating and cooling networks

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Table of Contents

1 Introduction

Historically, Demand Response (DR) programs in the electric sector have existed to ensure system reliability and prevent blackouts and brownouts. In recent years, DR has become a more dynamic resource that can also provide price mitigation and participate in providing ancillary services to utilities and grid operators. Until now, Europe has mainly seen commercial and industrial DR projects. Little has yet been done in the residential and the commercial sectors. Estimates suggest that for Europe as a whole, the potential contributions of households varies, depending on the time of year, between 20 GW to as much as 75 GW (Gils, 2014). Much of this potential, however, has yet to be tapped. Regarding DR, the required heating demand of households is not taken into account systematically, which can be coupled to the flow of electrical energy, e.g. by the use of heat pumps. The increase of self-consumption / self-sufficiency by coupling heat and electricity was already recognized and measured in 1997 (Benze, 2011) and further investigated in an accompanying project to the 'EEG Report 2011' (German Renewable Energy Act) (BMUB, 2011). However, the evaluation of the economic efficiency, the examination of the potentials of the building stock and the development and implementation of specific and optimized control algorithms are lacking. First product ideas that utilize the coupling of heat and electricity appear on the market, but are not mature in the system concept (Glen Dimplex Deutschland GmbH, 2012). This work package deals with the development of a strategy for the energy efficient integration of the DHC network with the electric and gas networks under different criteria (e.g. Economic/Market-driven, Network/Grid-driven) to tap the FLEXYNETS DR potential.

2 FLEXYNETS DR Potential

Within the FLEXYNETS approach, it is possible to realize several control and optimization strategies. Besides the basic operation what means, that the systems are operated heating demand driven, other operational modes are possible to suit the application of negative (consumption or the stop of production of electricity) and positive DR (production or the stop of consumption of electricity).

In many cases, the first goal is an **increase of self-consumption** within the boundaries of a FLEXYNETS grid**.** This offers often the best economic way due to the difference between feed-in tariffs / electricity market prices and end customer electricity prices. This would mean an electricity demand driven operation of e.g. CHP units utilizing thermal buffer storages. In addition, the operation of heat pumps and compression chillers can be scheduled, combined with a prediction of electricity demand, in a way, that they provide the best overlap of electricity production and consumption.

The utilization of the thermal storage capacity of the grid, buffer storages and building mass will provide a DR option to **shift the demand** of grid electricity or the grid infeed. This DR application enables participation in spot market trade (selling energy to the highest market price). By this, end customers could profit from **flexible heat pump and compression chiller tariffs** linked to the daily electricity price fluctuations.

Another attempt, that differs from the demand shift approach, is the **maximization of flexibility potential**. This is done by minimizing the amount of stored energy as well as by maximizing the demand within certain timespans according to prediction. This DR approach is suitable for a participation in power markets (e.g. secondary reserve) which are, compared to energy markets (spot market) more difficult to participate in but regarding a combined FLEXYNETS operation, show a potential which is barley tapped until today.

Systems in question for DR within FLEXYNETS

The following systems are considered:

- Heat pumps and compression chillers in combination with buffer storages. They allow negative DR (consumption of electricity during operation) and some positive DR (shut down when running). Direct power to heat systems are excluded due to their low efficiency.

- CHP systems, also including high temperature concentrating solar CHP, in combination with thermal buffer storages. Those systems allow at first positive DR focusing on their electricity output. A scheduled shut down of those systems while running for longer periods can also offer negative DR.

- PV systems are not considered due to the fact, that they only have a minor overlap with the FLEXYNETS concept (e.g. regarding electricity self-consumption). The same applies to low temperature solar thermal systems because they just have little impact on electricity consumption / production when they interfere with heat pumps when covering the thermal demand.

The FLEXYNETS approach will incorporate various systems that can offer a positive and negative DR potential. The systems will have a local energy management system that is within the constructed test environment developed by ENISYST. This controller can be e.g. connected to the manufacturer's system control (see Fig. 1). Optimized control strategies, based on weather forecast and historical data are delivered to the controller. From a certain point of view, the local controller works as an interface between the optimization algorithms in the virtual machine and the single building systems.

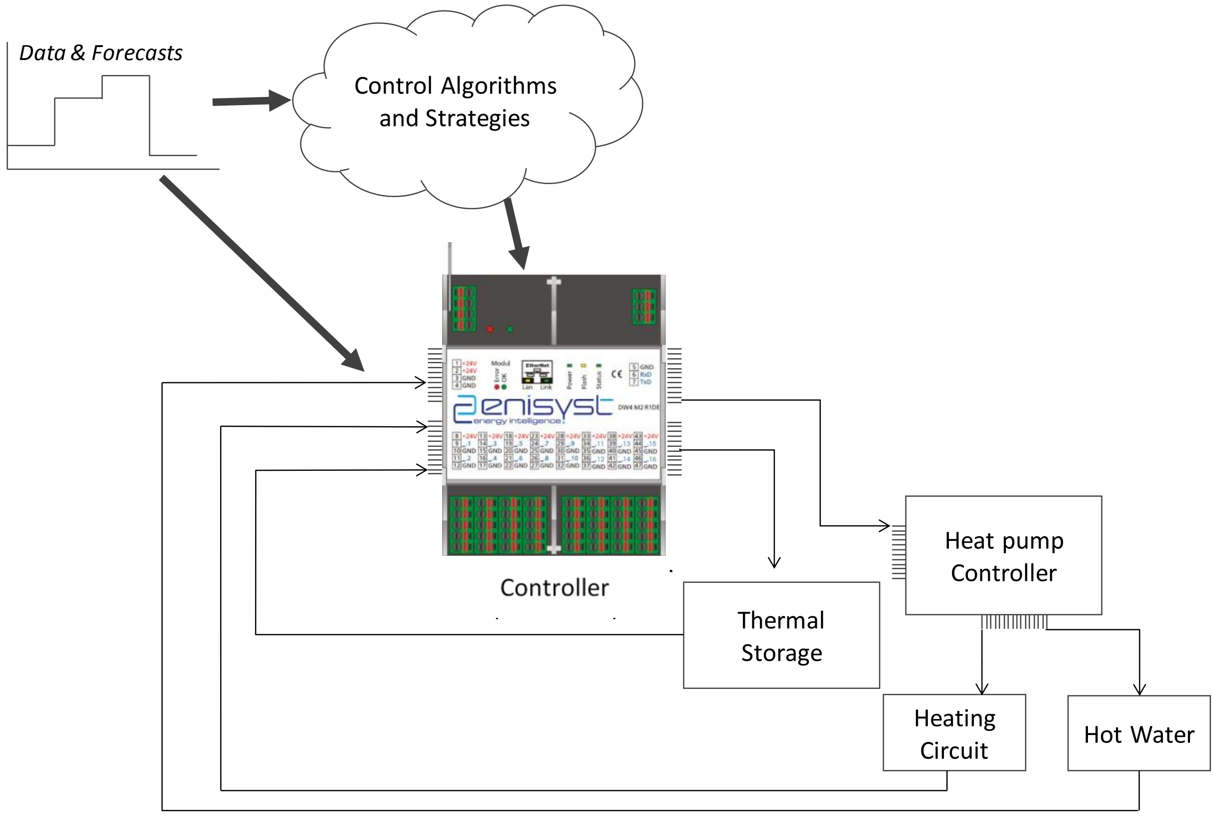

Fig. 1. Control scheme on building level

<u>Interfaces and Standards for DR control</u>

Various interfaces for DR controlled operation of building systems exist today. Examples are SG (Smart Grid) ready, VHP ready and EEBus. Thereby the SG ready label is the most suitable for heatpumps because it's used by 30 Manufacturers in more than 1.000 heat pump models (PV-Magazine, 2017). The interface was made public in 2013 by the German federal heat pump association (Bundesverband Wärmepumpe BWP). It defines four externally controllable modes of operation witch allow an increase or a reduction of heat pump power.

<u>Possible DR actions</u>

Self Consumption (electrical)

This can be achieved by an electricity production of the CHP units according to (household) electricity demand incorporating certain demand prediction methods like self-learning algorithms, etc. Thereby the produced electricity within a FLEXYNETS network would be at least partly consumed by the buildings connected to it.

The thermal storage possibilities can also be used to enlarge the CHP units running time by increasing temperature levels of buffer storages, the FLEXNYNETS network and of the buildings. Thereby the building mass can show a significant storage / flexibility potential, that is restrained by comfort reasons.

- Limitation of compression chiller / heat pump operation during times of high el. demand.
- Decrease of thermal storages temperatures.

Demand Shift (electrical)

- Electricity production of CHP according to market price signals → Utilization of thermal storages possibilities by increasing temperature levels of buffer storages, grid, buildings.
- Electricity consumption of heat pump / compression chiller according to market price signals (purchase at low prices, avoidance of operation at high prices) → Decrease of thermal storages temperatures.

Maximization of Flexibility Potential (electrical)

- Ensure the availability of flexibility for unpredictable activation calls → Average thermal storage capacities are kept at an average value that enables positive (loading of buffer storages by CHP) and negative DR (avoidance of heat pump / compression chiller operations). This could mean, that the storages are kept at a medium temperature level in the middle between the lowest and the highest temperature or some are kept at high and some at low level.

Gas Potential

- Possible DR actions regarding the interaction with the gas market can be demand shift of gas powered heat generation (CHP) according to market prices. This can also include a possible interaction with heat pump operation and other electrical consumers to enable self-consumption of CHP electricity.

3 Possible DR Market Participation: Electricity

3.1 Grid requirements and structure

Most European countries belong to the same wide area synchronous grid (see Fig. 2) that operates at the same, synchronized, frequency and in which electricity is exchanged between the countries. From a physical point of view, a stable grid frequency (50 Hz) in Europe is necessary for all AC electrical devices. The grid frequency is coupled to the amount of energy delivered to and drained from the grid. To date, energy storage capabilities are not deployable in a sufficient amount mostly due to economical (e.g. battery storages) but also due to ecological (e.g. hydroelectricity) reasons. Because of that, there has always to be a balance between energy production and consumption in the whole grid. For this purpose, electricity is offered in wholesale electricity markets. Those markets however differ. Most countries have their national market particularities and several energy exchanges are existent in Europe, e.g. EEX (European Energy Exchange) in central Europe, NASDAQ OMX Commodities Europe (formerly Nordpool) in northern Europe, IPEX (Italian Power Exchange) in Italy and OMIE on the Iberian Peninsula.

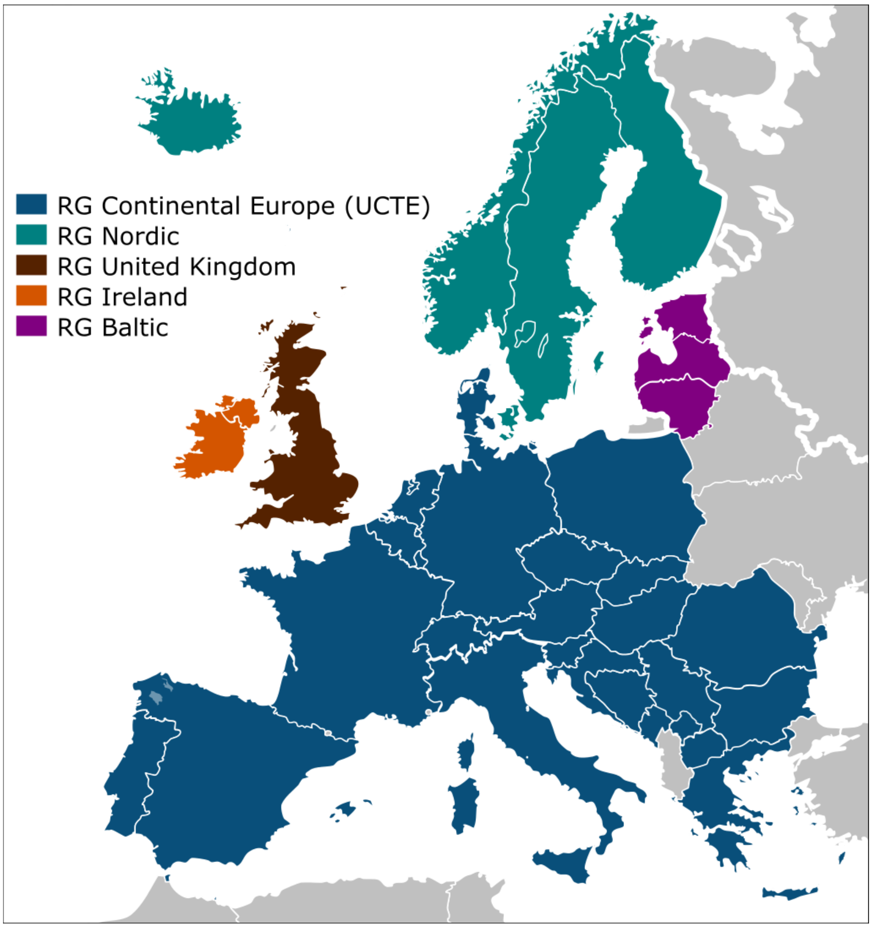

Fig. 2. Map of of European Transmission System Operators Organizations (Regional Groups)
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3.2 Price/Market-based interaction

The purpose of a price-based interaction ("Economic/Market-driven") is to lower the energy supply cost, increase available reserve and mitigate price volatility. Therefore, many business models for integrating DR resources into electricity grids exist (Aghaei & Alizadeh, 2013). DR can be implemented in a short or medium time interval. The price signals can be sent by the electricity market. Therefore, one has to clearly distinguish between different suitable market types e.g. energy market (day-ahead, intraday) and power/reserve market, see Fig. 3. An overview over the European countries electricity markets is given in Tab. 1. Today the increasing amount of variable renewable energy (VRE) changes the market structure. Often the required amount of power to balance can be predicted (e.g. VRE with weather forecast) what leads to short-term trading options (i.e. intraday) on the spot market. VRE lead to a more volatile production, therefore more balancing power is needed. This should lead to an increase in the balancing power price. But VRE with low costs also reduce spot and intraday market prices. This can bring the conventional power plants into the balancing market, what leads to a price drop. (Ocker, Braun, & Will, 2016)

Tab. 1 Overview of European power balancing markets
Source: (Ocker, Braun, & Will, 2016)

	Power market characteristics		Balancing power market characteristics			Auction characteristics	
	VRE share (2014)	**Latest possible trading option**	**FCR (automatic)**	**FRR (automatic)**	**RR**	**Pricing rule**	**Scoring rule**
Austria	7.3%	30min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; +-; w; m.-o.; Mo-Fr 8am- 8pm, rest; 5MW	PB&EB; +-; w; m.-o.; 42x4h; 5MW	PaB	lowest PBs
Belgium	9.2%	5min	TP; +-; m; n/a.; base, peak, offpeak; 1MW	PB&EB; +-; m; m.-o.; base, peak, offpeak; 5MW	PB&EB; +-; y; n/a.; base, peak, offpeak; 5MW	PaB	SP
Czech Republic	4.4%	Day-ahead	PB; s; d; n/a; 24x1h; n/a	PB; +-; d; p; 24x1h; n/a	PB; s; d; m.-o.; 24x1h; n/a	UP	lowest PBs
Denmark	44.7%	60min	PB; +-; d; n/a; 6x4h; 0,3MW	PB; s; m; p.; 24x1h; 0,3MW	PB&EB; +-; d; n/a; 24x1h; 10MW	UP (DK1), PaB&UP (DK2)	n/a
Estonia	8.7%	60min	provided by russian TSO	TP; n/a; n/a; m.-o.; 24x1h; 5MW	TP; +-; n/a; n/a; 24x1h; 5MW	PaB	n/a
Finland	1.4%	60min	n/a; s; n/a; n/a; 24x1h; 1MW	EB; +-; n/a; p; 24x1h; 10MW	non-existent	UP	n/a
France	5.6%	30min	compulsory, regulated prices	compulsory, regulated prices	TP; +-; y; m.-o.; n/a; 10MW	PaB	n/a
Germany	18.2%	30min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; +-; w; m.-o.; Mo-Fr 8am- 8pm, rest; 5MW	PB&EB; +-; d; m.-o.; 6x4h; 5MW	PaB	lowest PBs
Hungary	1.9%	120min	PB; +-; n/a; n/a; 24x1h; n/a	PB&EB; +-; n/a; m.-o.; 24x1h; n/a	PB&EB; +-; n/a; m.-o.; 24x1h; n/a	PaB	n/a
Iceland	0.0%	Day-ahead	TP; s; w; m.-o.; 24x1h; 1MW	TP; s; w; m.-o.; 24x1h; 1MW	TP; +-; w; m.-o.; 24x1h; 1MW	UP	lowest TPs
Italy	13.1%	250min	compulsory, regulated prices	EB; s; d; p; 24x1h; 1MW	EB; s; d; m.-o.; 24x1h; 1MW	PaB	n/a
Latvia	2.1%	60min	provided by russian TSO	manual: n/a; +-; n/a; m.-o.; 24x1h; n/a	non-existent	n/a	n/a
Lithuania	13.7%	60min	provided by russian TSO	manual: TP; n/a; d; m.-o.; 24x1h; 5MW	TP; n/a; d; m.-o.; 24x1h; 5MW	UP	lowest TPs
Netherlands	6.4%	5min	PB; s; w; m.-o.; 1x168h; 1MW	PB&EB; +-; d/y; m.-o.; n/a; 4MW	PB&EB; +-; d/y; m.-o.; n/a; 20MW	PaB & UP	lowest PBs (FCR), n/a
Norway	2.0%	60min	PB; s/+-; d/w; n/a; 24x1h; 1MW	PB&EB; +-; w; p; n/a; 1MW	non-existent	UP	n/a
Poland	6.0%	180min	EB; +-; n/a; n/a; 24x1h; n/a	EB; +-; n/a; n/a; 24x1h; n/a	EB; +-; n/a; m.-o.; 24x1h; n/a	UP	SP
Portugal	27.9%	195min	compulsory, no compensation	PB; +-; d; p; 24x1h; n/a	PB&EB; +-; d; m.-o.; 24x1h; n/a	UP	lowest PBs
Romania	18.4%	90min	compulsory, no compensation	TP; +-; d; m.-o.; 24x1h; n/a	TP; +-; d; m.-o.; 24x1h; n/a	UP	lowest TPs
Slovenia	2.1%	60min	compulsory, no compensation	PB&EB; n/a; y; p; 24x1h; n/a	PB&EB; n/a; y; m.-o.; 24x1h; n/a	PaB	n/a
Spain	28.3%	195min	compulsory, no compensation	PB; +-; d; p; 24x1h; n/a	PB&EB; +-; d; m.-o.; 24x1h; n/a	UP	lowest PBs
Sweden	9.2%	60min	PB&EB; s; d/w; n/a; 24x1h; n/a	PB&EB; +-; w; p; n/a; n/a	non-existent	PaB	n/a
Switzerland	1.6%[3]	60min	PB; s; w; m.-o.; 1x168h; 1MW	PB; s; w; p.; n/a; 5MW	PB; +-; w; n/a; 6x4h; 1MW	PaB	lowest PBs (FCR), SP (FRR, RR)
Serbia	0,0%	Day-ahead	non-existent	TP; +-; d; p; 24x1h; n/a	TP; +-; d; n/a; 24x1h; n/a	UP	lowest TPs
United Kingdom	11.9%	75min	PB&EB; +-; m; n/a; Mo-Fr, Sa, Su; 10MW	PB&EB; +-; m; n/a; Mo-Fr, Sa, Su ; 10MW	PB&EB; s; m; n/a; Mo-Fr, Sa, Su; 50MW	PaB	n/a

manual=manual activation; **PB**=power bid and/or **EB**=energy bid or **TP**=total price; **s**=symmetric product (no distinction between positive and negative balancing energy) or **±**=distinction between positive and negative balancing power; procurement: **d**=daily, **w**=weekly, **m**=monthly or **y**=yearly; **m.-o.**=merit-order activation of balancing energy or **p**=pro-ratio/parallel activation of balancing energy; **24x1h**=24 one-hour time slices per day; **5MW**=minimum power offer is 5MW; **PaB**=Pay-as-Bid pricing or **UP**=Uniform pricing (for EB and/or PB); **SP**=Stochastic Programming or lowest **PBs/TPs**=lowest capacity bids/total prices are considered until balancing demand is met; **n/a**=parameter not available

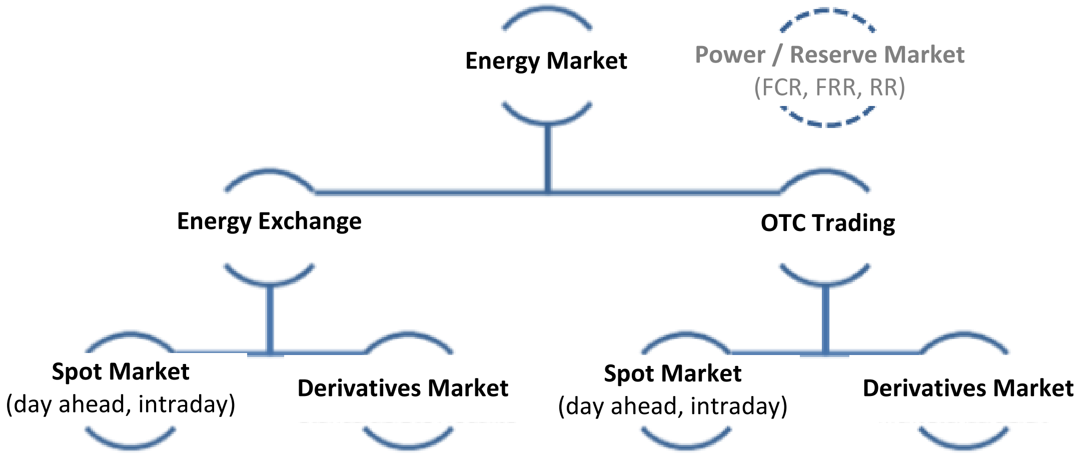


Fig. 3. Overview of different electricity market types

3.2.1 Energy markets

Within energy markets power is provided over a period (e.g. delivery of one MW electrical power over an hour). In the energy market various subdivisions exist. E.g. in the EEX (European Energy Exchange) there exists the power derivatives Market, which is hardly interesting for DR operations because of the necessary long-term planning, the day-ahead spot market and the intraday spot market. In the day-ahead market, the service of the energy supply is traded (positive power over hours or blocks of several hours) which can be bought or sold. In order to use the switchable system as often as possible, the effort for activation should be low (regarding monetary conditions, organization and time effort of modified operations). For DR operations it is possible to use the price spreads between those hours. Consumers then work as a functional storage. The Intraday spot market within the EEX implies the purchase and sale of electricity (hours and 15 min) up to 45 min before performance. Thereby for DR operations, the very short-term use of the price spreads between hours and quarter hours is possible. In most European countries there are intraday trading options for electricity but with different levels of reaction time. In more than 50 % of the European countries the markets have trading options of 60 min or less before delivery but e.g. in southern European countries (Portugal, Spain and Italy) there is only the possibility to trade up to 195 min before delivery. All those energy markets components are traded at different energy exchanges and via OTC (Over The Counter) trading directly in between the market participants. (Gobmaier, Bernhard, & Roon, 2012)

3.2.2 Power Markets

In power markets the seller is paid for the provided power. Depending on market demand, the likelihood and frequency of activations varies widely, partly the seller is also payed for the provided energy. Power markets usually consist of FCR (Frequency Containment Reserve), FRR (Frequency Restoration Reserve) and RR (Replacement Reserve) (European Comission, 2016). Capacity markets, which are controversial and exist in some European countries, could also be a rewarding option for demand response operations. Subsequently, in the US, the largest part of the DR economical gains are achieved in the capacity markets (Bayer, 2014). Participation in the balancing power markets requires prequalification by the TSOs, which ensures that the offered services can also be provided. For switchable loads, this is usually only possible in a pool. Unlike it is the case for power plants, for switchable loads, often no standards for prequalification exist. Often, the minimum power output limit and the duration of power support are barriers for them. Most switchable consumers enable a load shift of several hours and thereby they behave like electricity storages because they sell electricity when turned off and later on buy more electricity to catch up. Only a small number of switchable consumer do not have to catch up after a shutdown (e.g. industrial production reduction) and can thus resell already purchased electricity without countertrade.

Frequency Containment Reserve (FCR)

The Frequency Containment Process is intended to stabilize the grid frequency after a disturbance. For this purpose, weekly sales of offers with a duration of one week are carried out one week in advance. A participating plant must be able to switch on and off the offered power stepless and also to keep the power output for the entire week. Thereby an automatic control of the grid frequency is conducted. The energy is not refunded. Positive and negative power call-ups usually equalize. Almost all European countries differentiate between positive and negative balancing power. On the contrary, the Frequency Containment Reserve cooperation between Austria, Germany, the Netherlands and Switzerland operates FCR without the distinction of positive and negative. (Ocker, Braun, & Will, 2016)

Frequency Restoration Reserve (FRR)

The Frequency Restoration Process controls the frequency towards its setpoint value by activation of FRR and replaces the activated FCR. It is traded within weekly auctions over the duration of one week, one week in advance. To create an incentive to participate in balance markets, suppliers of balancing power need to be compensated for delivering power and for keeping power available for its delivery. Therefore suppliers can place bids on power (€/MW) and energy bids (€/MWh) (Ocker, Braun, & Will, 2016). In Germany Transmission System Operators (TSOs) contract negative secondary reserve weekly in a two-component pay-as-bid auction open to pre-qualified plants and DR-capable sites. The first component is the capacity price, which determines whether a bidder is contracted for a given week. The second component is the energy price (also pay-as-bid), which determines the order of activation of the bidders as they are called upon to provide their contracted capacity at a given moment during the contract period. E.g. in Germany, peak excluding weekends (HT) and off-peak including weekends (NT) are auctioned separately; contracts are for whole weeks, beginning Monday at 00:00 and ending Sunday evening. Auctions are held on the Wednesday preceding the respective contracted calendar week. The plants power output must be able to be controlled at least in discrete steps. FRR services are typically activated centrally in an automatic or manual way.

In future it is planned to integrate the European balance markets stepwise. TSOs from Coordinated Balancing Areas (CoBAs) will then be able to exchange FRR products between areas (ENTSO-E, 2014).

Replacement Reserve (RR)

The Reserve Replacement Process replaces the activated FRR and/or supports the FRR activation. In Great Britain and Ireland the RR replaces both, FCR and FRR. E.g. in Germany RR is traded within daily sales of 4-hour blocks for the next day with distinction on the positive and negative power. It must be ensured, that the offered power can be maintained during the whole block.

An overview of the activation sequence of FCR, FRR and RR is given in Fig. 4.

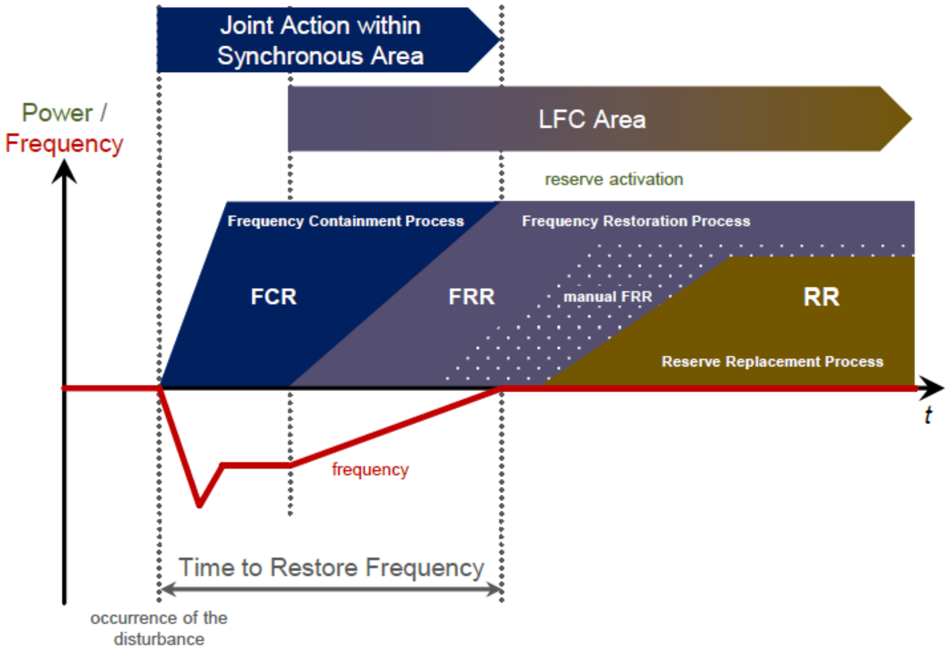


Fig. 4. Dynamic hierarchy of load-frequency control processes
Source: (ENTSO-E, 2013)

3.3 Suitable markets for FLEXYNETS applications

Tab 2 gives a comparison of markets and their usability for DR, which applies to the majority of consumers.

Tab. 2 Comparison of electricity markets and their usability for DR
Source (Gobmaier, Bernhard, & Roon, 2012)

	Feed-in	Effort	Daily use	Modulating	Reaction time	Max. duration
FCR	pos. & neg.	very low	plant can run continuous with reduced output	continuous	high (15s), usually only possible if plant is already running	1 week, (hydr. Plants 4h)
FRR	pos. or neg.	low	-	discrete stages	fast start possible (30s – 15min) or plant is already running	12h to 60h
RR	pos. or neg.	moderate	-	discrete stages	start in 15min (scheduled product)	4h
Day-Ahead	pos.: purchase or sale	low	low, demand occurs on a great number of days	no	only according to schedule, power delivery within 15min	1h or product duration
Intraday (hourly)	pos.: purchase or sale	low	low, demand occurs on a great number of days	no	up to 45min before power delivery according to schedule	1h
Intraday (15min)	pos.: purchase or sale	low	low, demand occurs on a great number of days	no	up to 45min before power delivery according to schedule	15min
Capacity market	positive	high	plant must be switched off until demand occurs	no	low, several hours or days until power delivery	days up to weeks

3.3.1 Spot Market

Day ahead

Participation in the trade is only suitable if the demand occurs often but not continuously (e.g. daily charging of an electric vehicle). The offered amount of power must be provided for the whole time, a modulation of the power output is not necessary. There are only minor requirements regarding reaction time. Within the day-ahead market, products with a duration of one hour, four hours, 12 hours (peak and off peak) and 24 hours (base) are traded. Within FLEXYNETS, these conditions could be served with the operation of distributed heat pumps, chillers and CHP systems as a virtual power plant together with local utility companies or other aggregators. The goal would be to optimize load profiles in order to use lower electricity prices based on spot prices in the day-ahead auction (e.g. EPEX). For the required load shifting, dynamic simulation tools together with weather forecast data are needed in order to actively use available technical thermal storages and the thermal mass of the connected buildings.

Intraday

The intraday market can be described as a corrector market because its time intervals between trade and activation and the activation period are significantly lower. Thereby it allows the market players to update their offers. The requirements for a participation in the intraday market are similar to those of the day ahead market. Therefore, a participation in the intraday market is useful as a complement to the participation of aggregated FLEXYNETS systems in the day ahead market to modify day ahead offers when forecast errors occur.

3.3.2 Reserve Market

Frequency Containment Reserve (FCR)

Tab 2 shows, that the FCR market demands positive as well as negative power according to the specific offer. Therefore this market is only suitable for switchable loads with low control effort since almost continuously calls with only a part of the offered maximum power occur. Because of the required high reaction rate and the requirement of the ability to provide positive and negative power, this market is only suitable for those systems that are already running permanently and thereby are able to short-term increase or decrease their power. Within FLEXYNETS, scalable CHP could be suitable to this market.

Frequency Restoration Reserve (FRR)

Power demand in the Frequency Restoration Reserve has high fluctuations and the period of a demand for negative power from the grid is highly dependent on the demand in the grid itself and on the configuration of plants and other participants in the market. The offered power has to be at least 5MW.

Based on weekly auction results as well as on immediate demand overall in the German Grid Control Cooperation (Netzregelverbund) for 2014 it can be seen, that the average duration of individual activations of negative power is dependent on the particular energy price bid.

In Fig. 5 positive energy prices indicate payment to the grid for power. Negative prices indicate payment from the grid to consume more power or to reduce the power production. The significant decrease in the duration of activations from bids of +25 €/MWh to 0 €/MWh shows that the volatility of demand from the grid increases as marginal costs of providing flexibility increase.

Due to this volatility the incorporation of many FLEXYNETS systems, including household heat pumps, is limited. It also implies that DR capable actors which have only a limited amount of possible activations in a certain timespan due to system restrictions will require specific innovative control methods on aggregator level.

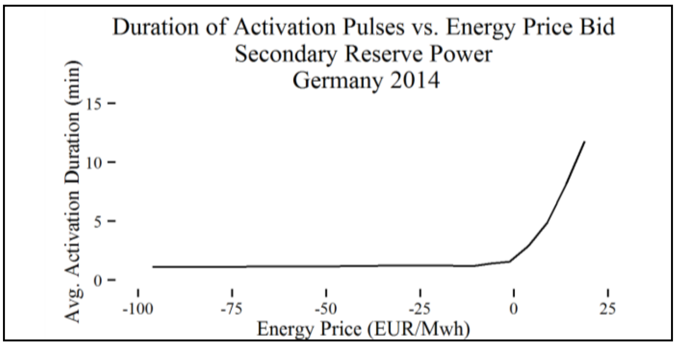


Fig. 5. Average duration of activation pulses vs. energy price bids 2014, own calculations

In the Frequency Restoration Reserve, the order in which bidders are activated by the TSO is also dependent on energy price bids (merit order list). First, cheaper bids are activated, then followed by bidders with increasing costs, until the required grid balance is restored. Very cheap providers of negative reserve will be activated very often. More expensive capacities will be activated much less often (not dependent on the duration of each activation).

Fig. 6 shows the frequency of activations (independent from activation duration) depending on the energy price (2014 market data).

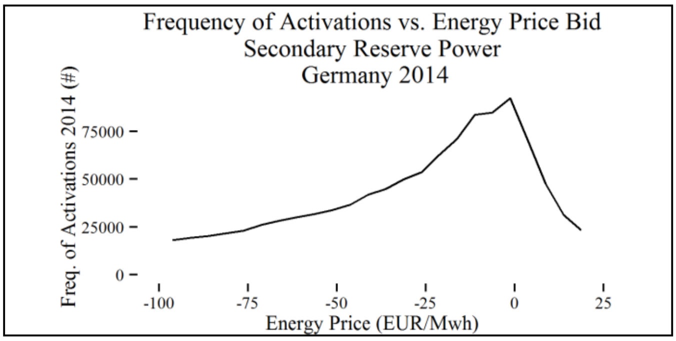


Fig. 6. Frequency of activations of secondary reserve according to energy price bid, own calculations

FLEXYNETS typical systems such as heat pumps, compression chillers and CHP systems in DR settings will have to manage with those requirements. Thereby system design related problems exist. The cycle times of heat pumps, which are at minimum 10 minutes, are longer than average secondary reserve power activations (seconds to a few minutes). A reduction of the heat pumps cycle times in permanent operation would lower the lifetime of the heat pumps compressor significantly (Curtis & Pine, 2012). Additionally, the start-up losses noticeably reduce efficiency (Green, 2012). The same problems apply to CHP systems where the minimum cycle times of CHP of one hour are even higher (Wirtschaftsministerium Baden-Württemberg, 2009). The use of on-site heating rods for direct power to heat operations could be an alternative for short timed activation periods, thus the efficiency is significantly lower. This all implies, that state-of-the-art control and bidding strategies coupled with control systems are essential.

Replacement Reserve (RR)

The RR replaces the activated FRR and / or supports the activation of FRR. In Germany it is traded in 4 hour blocks for the next day with a distinction between negative and positive power. Thereby it has to be ensured, that the offered power can be delivered for the whole time. To be able to participate in the RR market, the offered power has to be at least 5MW. Thereby, for smaller systems only an aggregated approach, as virtual power plant, is practicable (Next Kraftwerke GmbH, 2017). To participate in the RR market, compared to FRR, longer activation times and shorter timespans of a possible engagement have to be fulfilled. Contrary to the FRR the trades are scheduled. This and the fact, that the activations time spans are longer makes RR more suitable for heat pumps.

3.4 Requirements for electrical DR

3.4.1 Infrastructure

To participate in the previously mentioned electricity and power markets, DR systems must comply with distributed signals from the TSO (Transmission System Operator). Measurement of changes in demand must occur, what requires an accurate metering and communication infrastructure. It is necessary, that baseline loads are determined and the deviation from this baseline that appears during a demand response activation is measured in order to calculate the total change in demand. Meter specifications depend on time intervals of participations (e.g. 15 min, 5 min to seconds in FCR). Telemetry requirements differ. For some DR applications after-the-fact metering is sufficient, others require up to four-second real time telemetry equipment to ensure the system operators to track, that the contracted adjustment in demand is achieved. For smaller systems, advanced metering and communication systems can be unproportioned expensive and may not always be necessary. As metering accuracy increases, so do costs. (Hurley, Peterson, & Whited, 2013)

3.4.2 Regulations and barriers

Laws and regulations vary from country to country or at least from balancing area to balancing area.

Often the market access is difficult especially for smaller participants. E.g. participation in the balancing power markets requires prequalification by the TSOs, to ensure that the offered services can also be provided. For switchable loads this is usually only possible in a pool. Thereby it could be possible to provide such a pool by combining the DR measures of various FLEXYNETS networks. The problem that often, the minimum power output limit and the duration of power support are barriers for small DR applications, could also be addresses with such a pool.

Further barriers to implement DR into markets are, that often the technical requirements are written from generation point of view (pre-qualifications, general conditions of market products), the economic incentives to participate are too weak and some participation requirements can only be met by a very small number of very large consumers (ENERNOC, 2014).

3.5 Flexibility Potential of FLEXYNETS subsystems

Various types of prosumers show a potential regarding switchable electricity generation and / or consumption. Thereby they can utilize different thermal buffer storage options to increase their flexibility. This potential is explained below.

3.5.1 Storage potential

Thermal buffer storage

Thermal buffer storages, generally installed together with heat pumps to extend the heat pumps running time, show a flexibility potential, which can be easily tapped by increasing / decreasing the temperature level, to which the storage is loaded. E.g. an increase of the temperature level of a 1000 litres thermal buffer storage tank by 10 K leads to a thermal storage capacity of 11.6 kWh. Unfortunately, this leads to higher thermal losses (which can still partly be credited to the building) and to a lower COP of the heat pump (see Fig. 7).

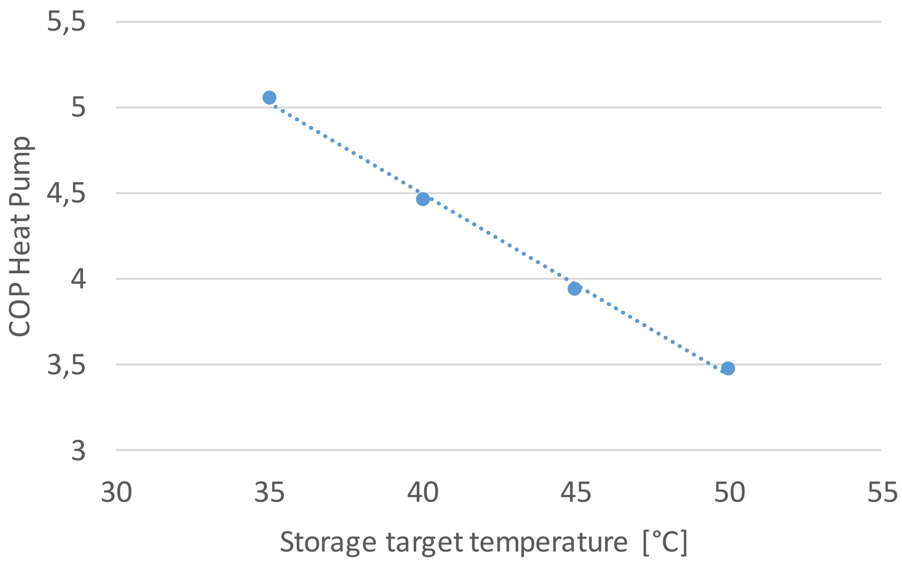


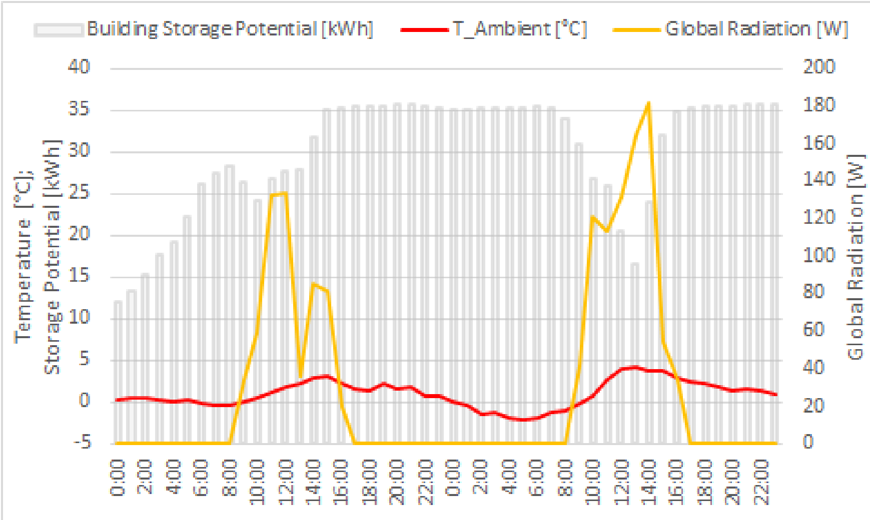
Fig. 7. Heat pump COP dependent on buffer storage temperature

Buildings

The thermal storage capacity of buildings and thus the flexibility potential which is offered by increasing or lowering the room temperature by a minor step is also worth considering. However, comfort criteria must be considered carefully. To examine the storage potential of the building mass, simulations focusing on a multi family residential building (317 m² living area, 20 kW_{th} heat pump) were carried out. Thereby, for every hour during a day, the storable energy in the building was examined for a temperature increase by 2 K. This means that 24 simulation runs were carried out per day. A comparison of the daily potential for different seasons (winter, spring) is shown in

Fig. 8. Thereby the set point temperatures stayed the same for night and day. The initial parameters were set to the corresponding values of the input data.

January



March

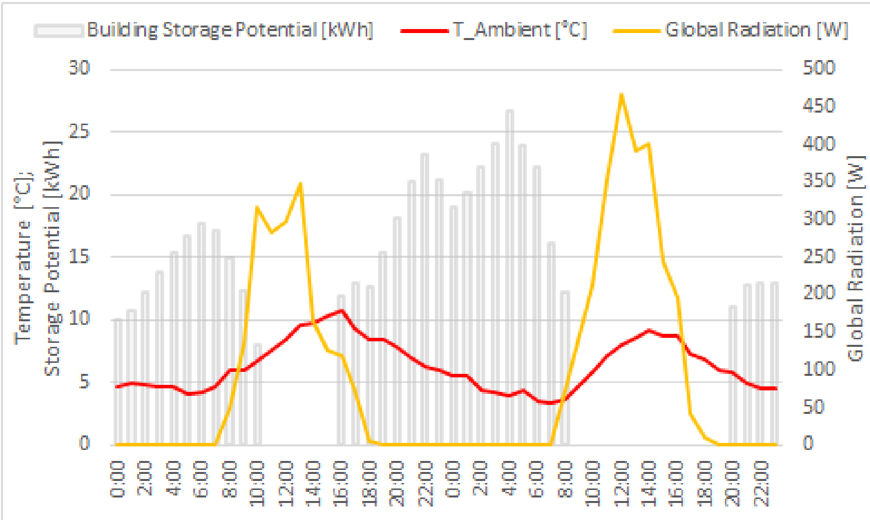


Fig. 8. Thermal storage potential of building mass

It shows, as expected, that the storage potential is affected by the heating demand (ambient temperature), but solar gains can also have a noticeable impact. The room temperature can exceed the set point temperature fast when direct radiation enters.

Power and runtime

Tab. 3 shows an example of the negative DR potential of a heat pump cluster (six decentral heat pumps, each in one single family residential building). All buildings have thermal buffer storages (size and hydraulics vary from building to building). Starting from thermal buffer storages and buildings at heating activation setpoint temperature (20 °C building with 2 K hysteresis, 35 °C buffer storage for space heating and 45 °C buffer storage for DHW with 5 K hysteresis each) the negative overall DR potential relying on heat pumps is 16.6 kW with a maximum runtime of 114.1 min. Thereby the maximum runtime is limited by the building that reaches at first the maximum temperature. The maximum storable amount of thermal energy is 41.7 kWh resulting in 10.4 kWh of electricity to be converted.

Tab. 3 Negative heat pump DR potential of a residential building cluster

Residential buildings negative DR	
overall max. power heat pump [kW]	**16,6**
max. duration at overall heat pump max. power [min]	**114,1**
min duration at overall heat pump max. power [min]	**10,0**
storable amount of thermal energy [kWh]	**41,7**
convertable amount of electrical energy [kWh]	**10,4**
Building ID	Building 1
max. power heat pump [kW]	4,0
storable amount of thermal energy [kWh]	7,6
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	114,1
Building ID	Building 2
max. power heat pump [kW]	2,1
storable amount of thermal energy [kWh]	4,1
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	119,8
Building ID	Building 3
max. power heat pump [kW]	4,5
storable amount of thermal energy [kWh]	11,5
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	153,3
Building ID	Building 4
max. power heat pump [kW]	1,5
storable amount of thermal energy [kWh]	4,0
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	160,2
Building ID	Building 5
max. power heat pump [kW]	1,9
storable amount of thermal energy [kWh]	6,1
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	190,5
Building ID	Building 6
max. power heat pump [kW]	2,6
storable amount of thermal energy [kWh]	8,4
min. duration @Pmax [min]	10,0
max. duration @Pmax [min]	194,6

3.5.2 Self Consumption

Simulations for the same previously mentioned building type, in combination with a PV-system, show that the optimized charging of the hot water storage (targeted heat pump operation in dependence of PV-gain) could at maximum lead to an increase of up to 30.3 % regarding the self-consumption rate. This lowers the heat pumps COP significantly. A more moderate charging of the thermal buffer storage leads to an improvement of the self-consumption rate of 10 % (Pietruschka, Brennenstuhl, Matthiss, & Binder, 2015). This self-consumption potential is also relevant, when it comes to the electricity created by CHP units (Widmann, Lödige, Toradmal, & Thomas, 2017). Fig. 9 shows a daily heat pump operation during winter times optimized for, in this case PV, self consumption.

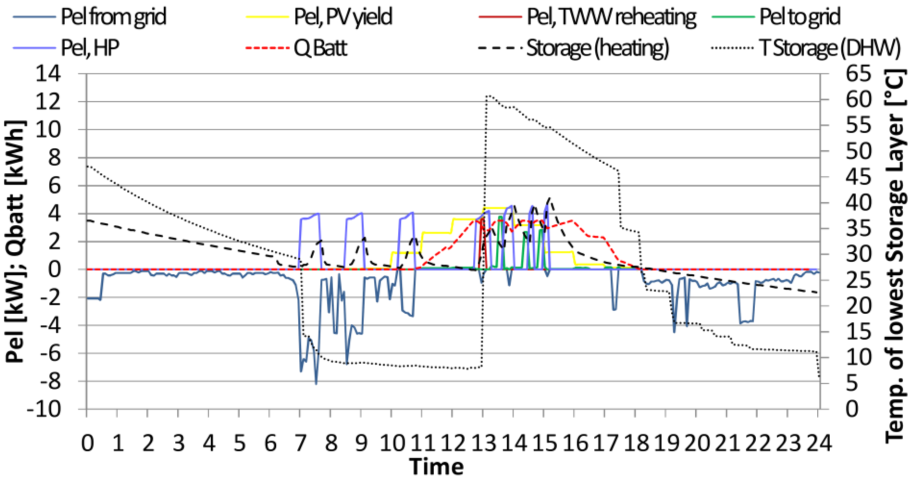


Fig. 9. Heat Pump operation optimized for self-consumption in a residential building (Pietruschka, Brennenstuhl, Matthiss, & Binder, 2015)

3.5.3 Day Ahead, Intraday / Flexible electricity tariffs

The price fluctuations as they occur within the day ahead and intraday market (see Fig. 10) show a good potential for DR operations of the systems considered within FLEXYNETS. Especially participation in the intraday market only requires demand and operational prediction times of several hours.

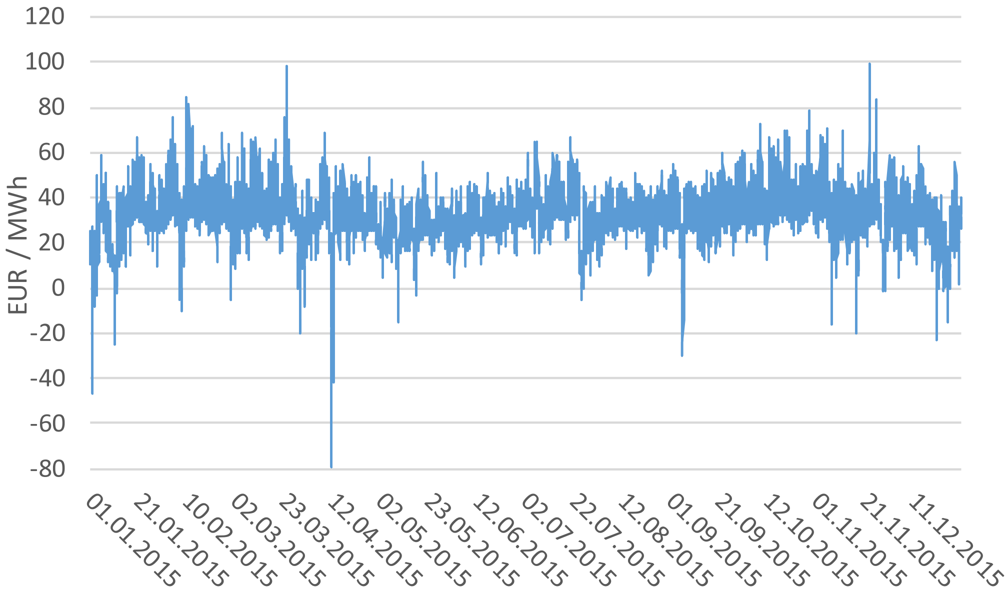


Fig. 10. Fluctuations of day ahead market prices in Germany, 2015

The fluctuations in the spot market trade could enable **flexible electricity tariffs** in future. This will enable the FLEXYNETS prosumers to benefit more easily from fluctuating electricity prices, for both, production and demand. This will also skip the need of a virtual power plant to offer minimum power limits or trade a minimum amount of electricity, enabling one FLEXYNETS setting to act as one virtual power plant without the need to aggregate up more systems to meet minimum requirements.

This also means, that a balance has to be found in between flexible tariffs and the electricity production within FLEXYNETS going together with self-consumption. Regarding FLEXYNETS control this leads to a two-dimensional optimization problem (see also chapter 5.2).

3.5.4 FRR

To test the both physical and financial viability of utilizing household heat pumps to provide flexible power on the FRR market a full scale physical model (heat pump supplying a residential building, combined with thermal buffer storages) was interconnection with historical FRR activation calls. For negative FRR, the control strategy is that the thermal buffers are loaded by 10 K higher than normal. It has been shown, that there is a good potential. It was possible to supply up to 48 % of the heat pumps' electricity demand by FRR resulting in an additional electricity demand with FRR (due to lower COP and thermal losses) of up to 7 % (see also Fig. 11), which is acceptable. Due to short time activations, a heat pump pool operation is necessary to stay within in the minimum running time of the heat pump which should be at least several minutes to avoid reduction in the heat pumps life time. (Brennenstuhl, Pietruschka, Yadack, & Eicker, 2017)
An integrated communication and control strategy, as it is proposed within FLEXYNETS, could enable this approach on aggregated operation for the various prosumers.

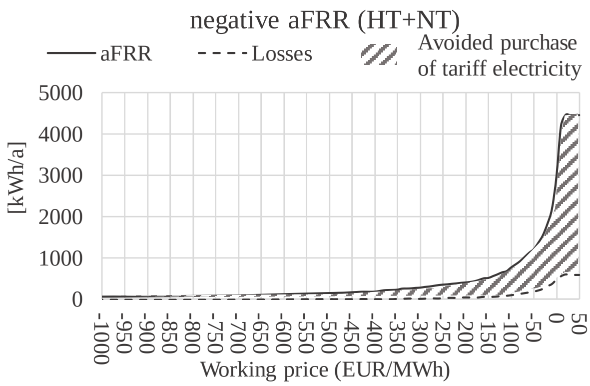


Fig. 11. Coincidence of aFRR purchase and resulting thermal losses (Brennenstuhl, Pietruschka, Yadack, & Eicker, 2017).

3.5.5 DR with Power to Heat and Battery Storage

In general, heat pumps enable DR without any further investments into battery storages, which still can be considered as rather expensive. Prices for small decentral storages are in 2017 above 1.150 €/kWh. Battery storages for PV-self comsumption are about to become economical without subsidies in Germany in the year 2018 (PV-Magazine, 2017). Battery storages solely for grid stability measures are not yet economical and partly the regulatory framework is also a problem (Bundesverband Erneuerbare Energie e.V., 2015). It can be said that it makes economically no sense to install smaller decentral battery storages solely for participation in energy and power markets. In opposite, a combined use of battery storages for an increased self consumption and market participation could increase the rentability. E.g. Fig. 12 shows the annual electricity flows of a single houshold with heat pump, PV system, thermal buffer storages and 5 kWh battery storage. Thereby energy from the FRR market is used for heat pump operation. The battery storage helps to shift the houshold electricity demand and thus, the self consumption rate almost stays the same.

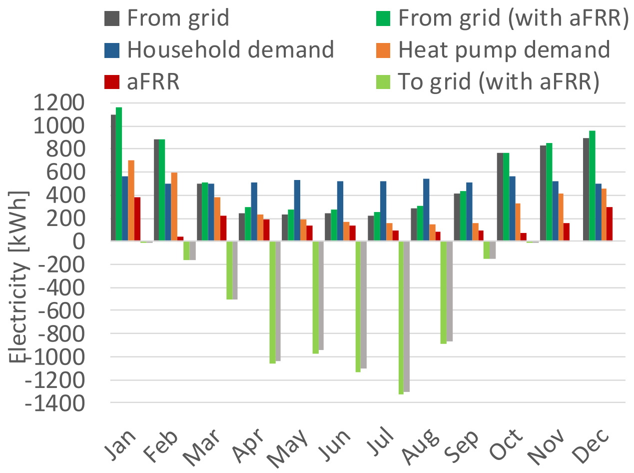


Fig. 12. Coincidence of FRR purchase and resulting thermal losses (Brennenstuhl, Pietruschka, Yadack, & Eicker, 2017).

4 Possible DR Market Participation: Gas

4.1 Grid requirements and structure

Most European countries are dependent on natural gas imports, mainly through pipelines. This makes them vulnerable to the market power of foreign producers/countries. Liquified Natural Gas (LGN) offers the possibility to reduce this dependency on a few producers, limited by distance. Compared to electricity, natural gas is storable for a longer period and large storage capacities exist throughout Europe. This facilitates supply control according to the demand. Producers, traders and consumers sell gas at the wholesale gas market for the day or for future date delivery. Trading is facilitated at a hub. This might be a major pipeline junction (e.g. Zeebrugge in Belgium and CEGH in Austria) or a fictitious hub (e.g. as NBP, TTF, Gaspool, NCG, PSV, the PEG and TIGF) (European Comission, 2014).

4.2 Priced/Market-based interaction

Trading activity in the natural gas market has increased strongly in recent years. Since the natural gas markets deregulations, it has become one of the most volatile markets (Lin & Jr., 2013). Fluctuations are highly dependent on the weather and the season.

Price spikes like in Fig. 13 can occur during winter times load peaks and during summer, when pipeline maintenance limits capacity. Hereby DR could be an option instead of building additional pipeline capacity that might avoid high investment costs (The Brattle Group, Brown Rudnick LLP, 2014).

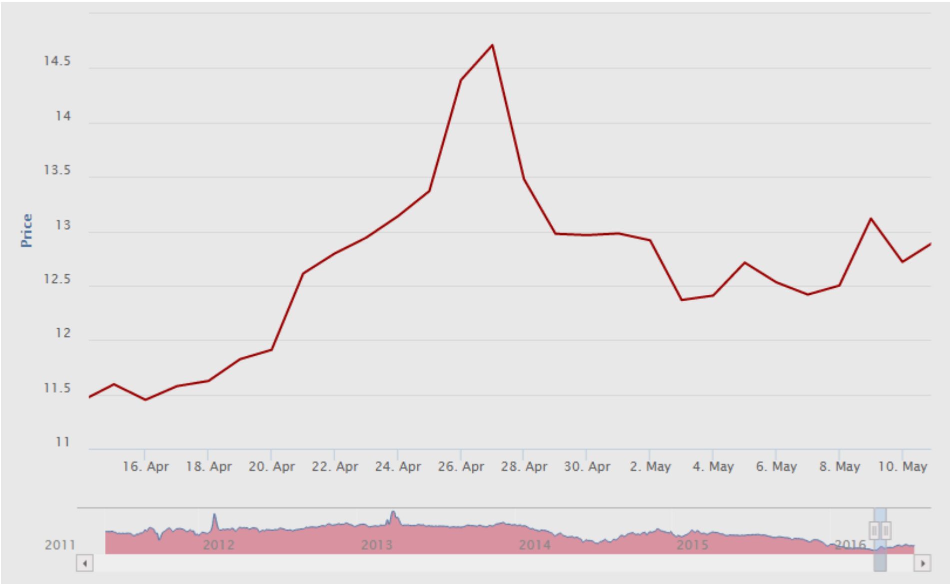


Fig. 13. EEX Daily Reference Price Natural Gas (EUR/MWh)
Source: European Energy Exchange (EEX)

4.3 Requirements and barriers

To implement DR within gas grids, similar options in comparison to DR within the electrical grid have to be considered. Thermal buffer storage capacities and/or the availability of a backup heat generation source (e.g. heat pumps, waste heat or biomass boilers within a FLEXYNETS grid) could be measures to allow the intended load shift. Under acceptance of a loss in comfort, programmable and centrally controllable thermostats could also be an option to shift loads within buildings which are monovalent heated by a gas driven heating system. Predictive control algorithms, based on weather forecast data, also taking into account user behavior, are essential. Problems are, that compared to electricity grids, no clear market models for DR settings within gas grids exist. Apart from DR market models which might result in price signals, all technically necessary framework conditions already exist today. Subsidies to the necessary infrastructure for end-users (smart meters, thermostats, etc.) could here lead to an increased acceptance.

4.4 FLEXYNETS potential

Regarding the FLEXYNETS gas DR potential one has to distinguish between the following:

- A price driven operation based on short time fluctuations of gas price e.g. in dependence on weather
- Seasonal fluctuations of gas price (high demand in winter)
- DR operations under technical criteria like reduction of transport capabilities (probably maintenance in summer, technical problems) and also gas price increases / supply constraints due to higher circumstances (e.g. political conditions)

Therefore within FLEXYNETS it is relevant to determine the load shift potential under direct gas price criteria and under investment cost reduction criteria (lower pipeline expansion or backup investments). For both, an exact demand prognosis in cooperating with a thermal production shift towards other systems, from gas boilers / gas driven CHP to heat pumps, biomass, etc. or a time shift together with preloading of thermal buffer storages is necessary to avoid supply bottlenecks. Also activation of thermal building mass capacity as thermal short time storage could be an option. One has to distinguish whether a short term load shift of e.g. a few hours to compensate daily fluctuations or a long term load shift resulting in different system operations for e.g. several days to weeks is necessary. Short term shifts could be compensated with storage capabilities; long term shifts would require alternate thermal generation or seasonal storage.

5 FLEXYNETS implementation

The substations designed in FLEXYNETS incorporate different combined or multi-energy supply units (CHP, ORC systems, heat pumps) that act as linkages between gas, electricity and heat distribution networks. To develop a strategy for the energy efficient integration of the DHC network with the electric and gas grids, the three systems have to be considered as an integrated whole.

However, the network model developed by ZAFH – as well as the majority of tools available – addresses only an individual energy network and is not capable to model multi-vector networks with the required level of detail for integrated design or operational analysis of district energy systems.

The interaction of electricity, gas and heat networks in FLEXYNETS is very tight and modelling of all subsystems as a whole is expected to play an important role for more efficient utilization of distributed energy and for more flexibility in equalizing the fluctuations from the renewable energy.

A literature screening shows two tendencies in this context. There are studies making use of decomposed electric-hydraulic-thermal calculation methods. The electrical, thermal and gas power flows were calculated independently and linked through generating units. Here the energy supply systems were usually considered as individual sub-systems with separate energy vectors. Independent planning and operation of those separate energy networks will unlikely yield an overall optimum, since synergies between the different energy vectors cannot be exploited (Liu, Wu, Jenkins, & Bagdanavicius, 2016).

Other more advanced models use integrated calculations techniques and some approaches for modelling the integration of different energy systems have been published. Examples include energy hubs, multi-energy systems and distributed multi-generation, intelligent energy systems, community energy, smart energy systems, and integrated energy systems (Liu, Wu, Jenkins, & Bagdanavicius, 2016). These models are generally complicated and time intensive.

Within FLEXYNETS it is intended to consider the dynamics of electricity and gas grids as boundary condition during the dynamic optimization. The electric and gas grids will be modeled as large sinks / sources characterized by e.g.:

- Market information (energy price)
- Predictable dynamics (weather forecast, price evolution etc.)

The Optimizer within the high-level DH controller will follow the variations/tendencies to efficiently manage the demand side (mainly storage) and exploit the synergies between all energy carriers.

5.1 Identification of the necessary information to be exchanged

This information is directly linked to the boundaries cited above. The following KPIs are identified to be used to assess the interaction behavior:

Technical

- Ramp up speed
- Minimum / maximum running time (e.g. heat pumps have to run at least for approximately 10 min)
- Maximal negative / positive DR power (electrical; gas)
- Positive / negative flexibility potential (kWh)

- Seasonal differences

Economical

- Levelized costs of electricity (LCoE)
- Fixed end user tariffs for purchase of electricity and gas
- Fluctuating electricity and gas prices at energy exchange
- Earnings and costs of participation in power markets (e.g. earnings for utilization, the provided power; costs of additional energy consumption due to lower efficiency / thermal losses)
- Costs of metering and communication equipment required for market participation

5.2 Development of control algorithms

For a price or technical based interaction in between the FLEXYNETS district heating and cooling grid and the electrical or gas grid, prediction of energy demand and availability of the prosumers based on their distribution and typology, on weather forecast data and pricing evolution along a daytime is essential.

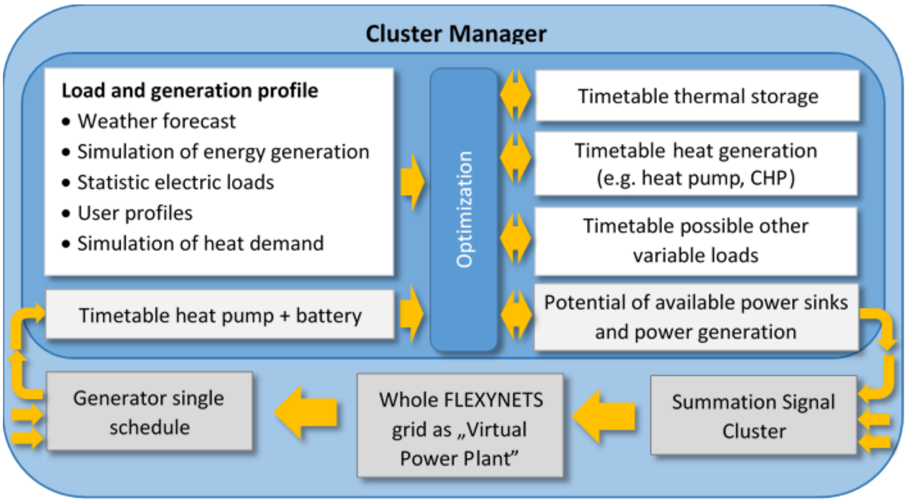


Fig. 14. Flow chart of a building cluster manager optimization routine.

The system design is such that the energy service provider will create schedules for the whole building cluster. These can be written via a secure connection to a (cloud based) database, which will be also accessed by an inter-building controller, a so-called cluster manager (see Fig. 14). The cluster manager will generate control instructions for each prosumer in real time (e.g. 5 s interval electrically and 30 s interval thermally) and on black box Model Predictive Control (MPC) simulations at the individual building level. The local controllers operate the prosumers systems to these control instructions. In addition, user interfaces in the selected buildings could motivate the users to adapt their electricity consumption to the DR needs and would allow them to decide to what extent the building mass can also be used as further storage capacity. Activation of this option would allow the control system to vary the room temperature in a certain range within comfort limits. Possible photovoltaic and solar thermal yield can be predicted by a commercial company or with an irradiation prediction model, relying on publicly available forecast data (temperature, cloud index, humidity).

5.2.1 Prediction of local energy production and consumption

The thermal heating and cooling demand will be predicted in the following way. Weather forecast data, e.g. from cost-free weather data provider, will be an input source for a thermal demand prediction model. To this purpose, black box models will be utilized.

Solar thermal / PV generation yield will be predicted in a similar way. Solar radiation data will be either provided by a commercial forecast data provider, or by public available weather forecast data (cloud index, humidity, temperature) and an already developed algorithm which predicts the hourly solar radiation with this input data.

Together with the predicted heating and cooling demand, also the electricity production of CHP and the electricity consumption of heat pumps and compression chillers can be determined. Together with the PV electricity production, forecasts on the total amount of electricity surplus or demand can be calculated.

5.2.2 Description of the Model Predictive Control structure

The advanced control is divided in three consecutive steps: forecast, planning and real-time operation. Firstly, the forecast are obtained with the method described in the previous section and then passed to the planning phase, which uses also the current state from the system to establish a schedule for the operation of each unit owned by the network manager (NM). Only generation units and their corresponding storages are considered in this section. The schedule for each unit consists of 12 hourly values corresponding to the amount of thermal energy and/or electricity they need to produce. The real time controller uses then these values as target to run correctly the different actuators such as valves, pumps, burners etc. This controller also reacts to the deviations from the situation assumed in the planning phase due to unpredicted perturbation and by uncertain predictions, which typically arise in the real system. Fig. 15 gives an overview of this control.

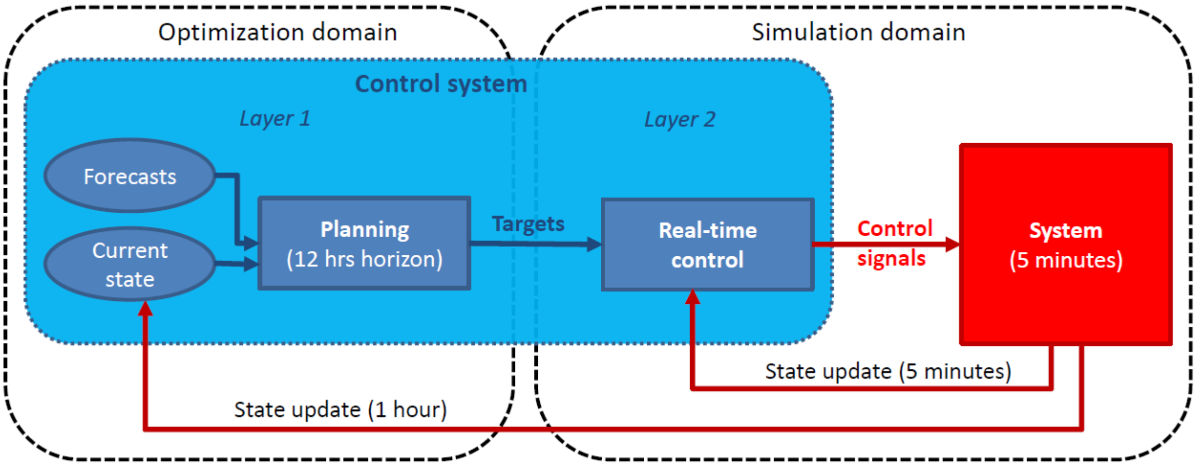


Fig. 15. Schematic overview of the advanced control logic. (Vivian, Jobard, Ben Hassine, Pietrushka, & Hurink, 2017)

The planning phase consists of an optimization problem that schedules the units according to a specific cost function depending on the application and the set target. One can however, define two optimization strategies:

1. Economically driven: The optimizer tries to minimize the net economic costs for running the system.
2. Environmentally driven: The CO2 emission and/or the primary energy consumption of the system are minimized in this case.

The optimization problem is formulated as a Mixed Integer Linear Programming (MILP) problem. A detailed description can be found in (Vivian, Jobard, Ben Hassine, Pietrushka, & Hurink, 2017).

5.2.3 Optimal planning

In this Section, only the output of the economically driven optimization is discussed. We consider here a network composed of consumer with heat pumps, a main generation plant consisting of a combined heat and power (CHP) unit, a central storage (CS) and a modulating gas boiler (GB). Several waste heat substations are distributed along the network, these are considered as non-balancing (the network manager does not have the ability to control them).

The objective function of the optimization aims to minimize the overall operational costs of the system, as given in (1).

$$f = c_{gas}Q_{chp,in} - p_{el,sell}(W_{chp} - W_{chp,self}) + x_{su}SUC_{chp} + c_{gas}Q_{gb} + c_{wh}(Q_{rec,1} + Q_{rec,2}) + p_{el,buy}\left(COP^{-1}\sum_{c=1}^{NC} D_c - W_{chp,self}\right) \quad (1)$$

Where

- c_{gas}, c_{wh} are respectivilly the buying cost for gas and waste heat
- $p_{el,sell}$ and $p_{el,buy}$ are the selling and buying price, the electricity sold to the grid are usual spot market price
- $Q_{chp,in}$, Q_{gb} are the required energy input to run the CHP and the gas boiler (GB)
- $Q_{rec,1}$ and $Q_{rec,2}$ are the recovered heat from the waste heat substation 1 and 2
- W_{chp} and $W_{chp,self}$ are the total CHP produced electricity and the self-consumed part
- x_{su} and SUC_{chp} are resp. the startup signal and the startup cost for the CHP unit
- COP is the overall Coefficient of Performance of the heat pump pool
- D_c is the Energy demand of the consumer on the building side

Tab. 4 Economic parameters used in the case-study

Parameter	Value [€/MWh]
c_{gas}	50
$p_{el,buy}$	175
$p_{el,sell}$[1]	μ = 32.5, σ = 14.4
c_{wh}	10

[1] https://www.epexspot.com/en/market-data/

Fig. 16 and Fig. 17 show respectively for one typical winter and summer day:

a) The heat demand, electricity price and waste heat availability, which are considered here as ideal and
b) The planned electricity production and self-consumed energy of the CHP plant, the CS and network supply temperature and the supply heat to the network for each heat supplier type.

As seen in the first graph of Fig. 16 (b), the CHP produces around 1100kW electricity corresponding to a part load ration of 0.5. The corresponding thermal output of the CHP and the WH recovered does not cover the total demand during the first three hours. Consequently, the temperature of the central is foreseen to decrease (see Fig. 16 (b) 2nd graph). This will allow a higher production during off-peak hours between hour 6 and 7, when the electricity price is higher. The CHP is running at full capacity and produces excess electricity, which is sold at a good price to the grid. During the first three hours, the gas boiler stays off because of sufficient heat availability. Then, the gas boiler switches on at hour 4 when the WH is forecasted to inject less heat to the network. From hour 8 to hour 11, the GB lowers its production and the CS takes over as it has been charged during the off-peak hours. The remaining part is covered by the WH sources. The optimizer sets the network temperature at a stable temperature of 20°C in order to maximize the share of electricity self-consumption and to maximize the waste heat recovered from the low temperature sources.

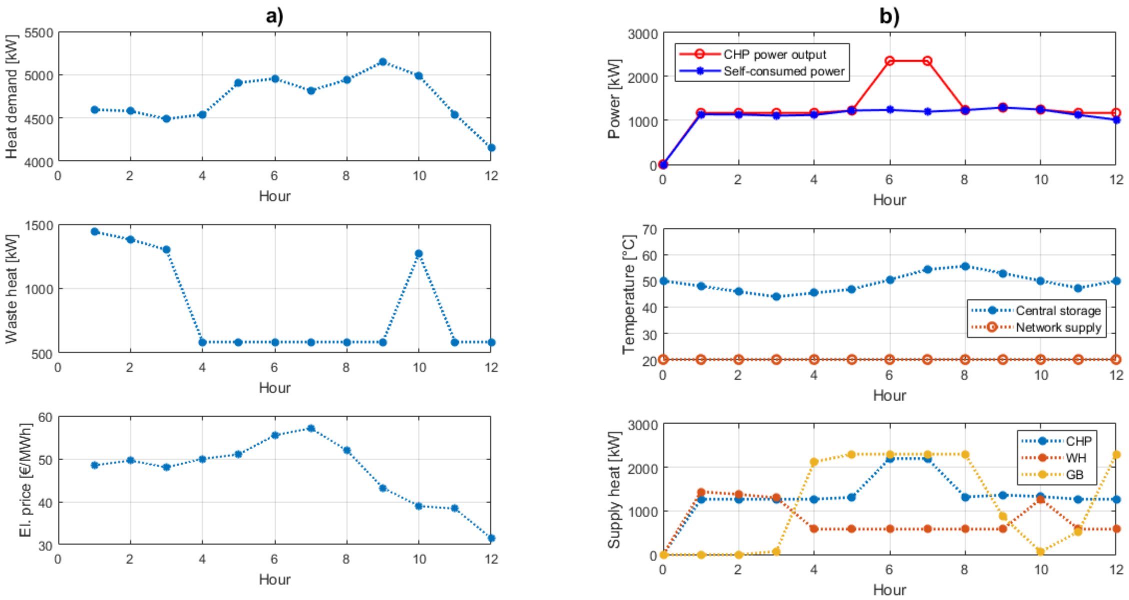


Fig. 16. (a) Forecast and (b) optimization output for a typical winter day. (Vivian, Jobard, Ben Hassine, Pietrushka, & Hurink, 2017)

As shown in Fig. 17 and due to the low heat demand and the high share of available waste heat, the share of electricity self-consumption is not sufficiently high to justify switching on the CHP. The optimal strategy is to cover the building demand only with the waste heat sources. Since the CHP is not running, there is no more need to maximize the self-consumption of produced electricity. This leads to an increase of the network temperature from 20°C to 30°C. The network acts in this case as a buffer. This strategy is in the end driven by the high electricity purchase price and the availability of free heat. Other simulations, not shown here, showed that when the available waste heat is not sufficient to cover the heat demand, the gas boiler is switched on.

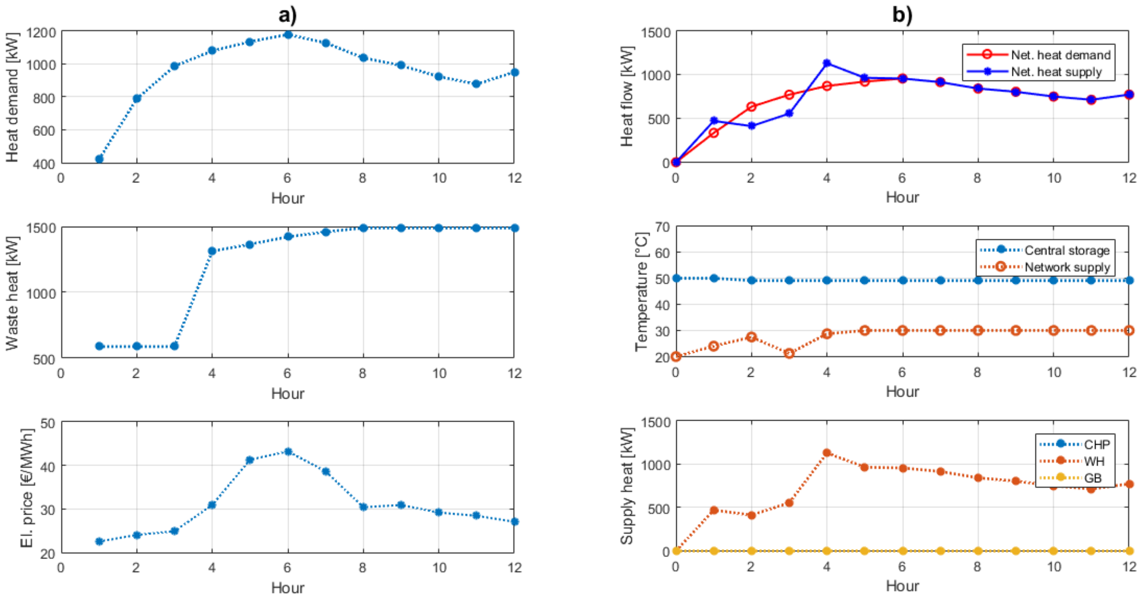


Fig. 17. (a) Forecast and (b) optimization output in a typical summer day. (Vivian, Jobard, Ben Hassine, Pietrushka, & Hurink, 2017)

5.2.4 Simulation test environment

A simulation test environment has been implemented in TRNSYS 17 in order to test and develop the MPC strategy. The simulation reproduces the behavior of the physical system with a higher level of detail and provides a sufficient time resolution for the real time controller with a simulation time step of 5 minutes. The planning and the real-time control are implemented in MATLAB and linked to TRNSYS 17 via Type 155.

Tab. 5 compares the level of detail of the main models used for the modelling of the system.

Tab. 5 Summary of the main models used in TRNSYS and in the MILP optimization problem

	TRNSYS model	**MILP model**
District Heating network	spHeat (Ben Hassine & Eicker, 2013) Finite Element Model	Fully mixed thermal storage
Central Storage	Finite Element model with stratification (8 nodes)	Fully mixed thermal storage
Substation Heat pumps	Performance Map model	Linear Performance Curve
CHP Unit	Nonlinear Performance curve	Linear Performance Curve

6 Conclusions

The examined criteria and measures for the management of interaction with electricity grids can be divided into the following categories:

Technical

The systems which are in question are heat pumps and compression chillers combined with buffer storages for negative and some positive DR, CHP systems, including high temperature concentrating solar CHP in combination with thermal buffer storages for positive DR and also negative DR (system shutdown). Thereby operational goals are an increase of self-consumption (of self-produced electricity), a demand shift for interaction with spot market trade / flexible electricity tariffs and the maximization of flexibility potential for interaction with price signals that are hard to predict (e.g. power markets). To achieve those targets within a FLEXYNETS network the storage potential of thermal buffer storages, building mass (under comfort restrictions) and of the network by itself can be tapped. Thereby the key performance indicators are ramp up speed, minimum / maximum running time, maximal negative / positive DR power (electrical; gas), positive / negative flexibility potential and seasonal differences.

Economical

Different markets are suitable for FLEXYNETS DR strategies, but there are limitations due to activation times, minimum power, minimum amount of energy, economics and prediction times. Future changes in energy markets might lead to general conditions more suitable to smaller systems providing DR. A wider spread of smart metering and communication equipment also enables flexible energy tariffs (mainly electricity). Those flexible tariffs can e.g. be based on fluctuations in the spot market trade. This will enable the FLEXYNETS prosumers to benefit more easily from varying electricity prices, for both, production and demand. This will also skip the need of a virtual power plant to offer minimum power limits or trade a minimum amount of electricity, enabling one FLEXYNETS setting to act as one virtual power plant without the need to aggregate up more systems to meet minimum requirements.

Regarding the now existing markets it can be said, that the actual spot and power market structure (FRR and RR) can be served by the FLEXYNETS concept but economics are questionable. Power markets might get more attractive if the guidelines change to serve better smaller systems capable of DR.

Regarding the onsite production and consumption of electricity, the combined production and consumption can save investments in grid infrastructure and can reduce the need to balance the grid.

Economical key performance indicators are levelized costs of electricity (LCoE), fixed end user tariffs for purchase of electricity and gas, fluctuating electricity and gas prices at energy exchanges, earnings and costs of participation in power markets and costs of metering and communication equipment required for market participation

Control

To fulfill the technical and economical requirements, an advanced control is developed within FLEXYNETS. This advanced control is divided in three consecutive steps: forecast, planning and real-time operation. At first the forecast is obtained and then passed to the planning phase, which uses also the current state of the system to establish a schedule for the operation of each units included in the network manager. The schedule for each unit consists of 12 hourly values corresponding to the amount of thermal energy and / or electricity they need to produce. Thereby goals can be economically driven – the optimizer tries to minimize the net economic costs for running the system – or environmentally driven – the CO2 emission and / or the primary energy consumption of the system are minimized in this case.

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