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E-HUB

*Energy-Hub for residential and commercial districts and transport*

SEVENTH FRAMEWORK PROGRAMME

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# D4.1: An ICT architecture for energy management in district energy grids

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# Content

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## Notations, abbreviations and acronyms

Table 0-1: Notations, abbreviations and acronyms

| | |
|---|---|
| AB | Apartment Building |
| ANSI | American National Standards Institute |
| ASHRAE | American Society of Heating, Refrigeration and Air-Conditioning Engineers |
| CEN | European Committee for Standardization |
| CENELEC | European Committee For Electro technical Standardization |
| CHP | Combined Heat and Power |
| DG | Distributed Generation of electricity (or heat) |
| DR | Demand Response |
| DSM | Demand Side Management |
| DSO | Distribution System Operator |
| EMS | Energy Management System |
| EPRI | Electric Power Research Institute |
| ESP | Energy Service Provider |
| ESS | Electrical Substation |
| ETSI | European Telecommunications Standards Institute |
| HB | Heat Buffer |
| HE | Heat Exchanger |
| HES | Home Electronic System |
| HEMB | Home Energy Management Box |
| HGI | Home Gateway Initiative |
| HHC | Household Concentrator |
| HHD | Household Demand |
| HP | Heat Pump |
| H2G DEWG | Home-to-Grid Domain Expert Working Group |
| IEC | International Electrotechnical Commission |
| IEEE | Institute of Electrical and Electronics Engineers |
| IETF | Internet Engineering Task Force |

| | |
|---|---|
| ITU-T | International Telecommunication Union Telecommunication Standardisation sector |
| LAN | Local Area Network |
| MCI | Modular Communication Interface |
| NIST | National Institute of Standards and Technology (USA) |
| OGEMA | Open Gateway Energy Management Alliance |
| PV | Photovoltaic |
| ROI | Return of Investment |
| RTU | Remote Terminal Unit |
| SGD | Smart Grids Device |
| SGIP | Smart Grid Interoperability Panel |
| SoC | State of Charge |
| SWH | Solar Water Heating |
| UCM | Universal Communication Module |
| USNAP | Universal Smart Network Access Port |
| WAN | Wide Area Network |
| WP | Work Package |

# Executive summary

*Description of the work*

The aim of this document is to define an overall ICT architecture for energy management in district energy systems comprising both electricity and heat. The district energy system will be built around a number of renewable energy sources and will focus on the optimal utilization of all energy flows. The architecture will be used to develop market based control tools for matching the supply and demand of electricity and heat on the district level and will be implemented in a real life demonstration project called Tweewaters.

In concordance with the definition of a Smart Grid reference architecture as defined in [1] the following viewpoints are applied in the process of building an overall e-hub ICT architecture:

1. ***Conceptual Architecture***
2. ***Functional Architecture***
3. ***Information Architecture***
4. ***Information Security Architecture***
5. ***Communication Architecture***

These architectures form the backbone of this document.

First, the major stakeholders of an e-hub system are identified together with their requirements.

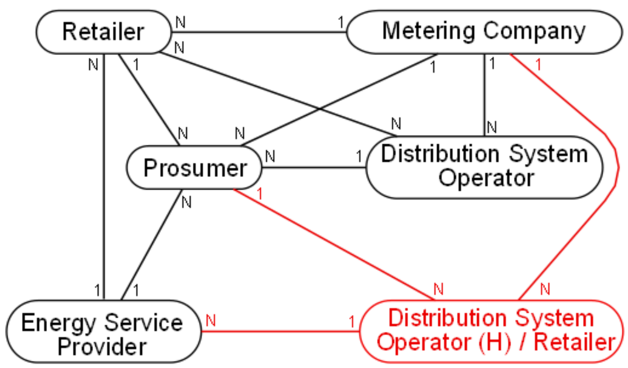



Figure 0-1: Conceptual Architecture E-hub (H = heat)

The **conceptual architecture**, a high-level overview consisting of the stakeholders, their business needs and the interactions between the stakeholders, gives an insight in the overall system the district Energy Management System (EMS) will be part of. Not all business actors mentioned in the model (Figure 0-1) may need to interact with the e-hub energy management system. Nor will all interactions between these stakeholders pass via the e-hub energy management system. However, having the whole picture will contribute to a more accurate and less error prone design. One major requirement shown in the model is the fact the architecture must be able to handle multiple commodities. The red boxes and lines represent the stakeholders for the heat system additional to the electricity system roles (black boxes and lines).

Secondly **the functional architecture** is discussed. It comprehends the functionality of the e-hub energy management system together with its internal and external interfaces.

The architecture of this control platform needs to be open and flexible for efficient integration of the latest state-of-the-art technologies. To implement the user requirements and assure the interoperability of the different components of the district system a generic control platform is required in which appliances, generators, storage units and controllers, based on different technologies, can be integrated and communicate with each other.

Several architectural guidelines are applied to the functional architecture resulting in important functional architecture guidelines:

- ***Clear Vision***: in this context this means "The generic control platform and its communication network need to follow and be in-line with the physical architecture, the pipes and wires, if not physically than at least virtually".
- ***Holistic Thinking***: Taking the total system as a basis brings us to: "Communication and control should follow the physical architecture, from top to bottom of the total system".
- ***Modularity***: "Define components in the Energy Management System that are connected by clear consistent and simple interfaces".
- ***Every System Consists of Subsystems***: "Ensure scalability and design according to the real world hierarchy".
- ***KISS (Keep It Simple and Straightforward)***: **"**More complexity than necessary will result in sub-optimal systems".
- ***Be Open to the Future***: In our architecture, this means "be as independent as possible of control algorithms, for example by using open and existing interfaces".
- ***Plan Ahead for Reuse:*** "Make sure it works for electricity and heat and cold, than check if it could be reused for gas and hydrogen, or others energy carriers and infrastructures".

Several examples are included in this document to explain the meaning and importance of these guidelines. For instance

Figure 0-2 illustrates the result of applying the functional architecture guidelines to the Tweewaters demonstration district. It shows a distributed control architecture with two levels of control and this for the heat system as well as for the electricity system. Communication follows the wires and pipes resulting for example in a concentrator at the house level and a controller on top.

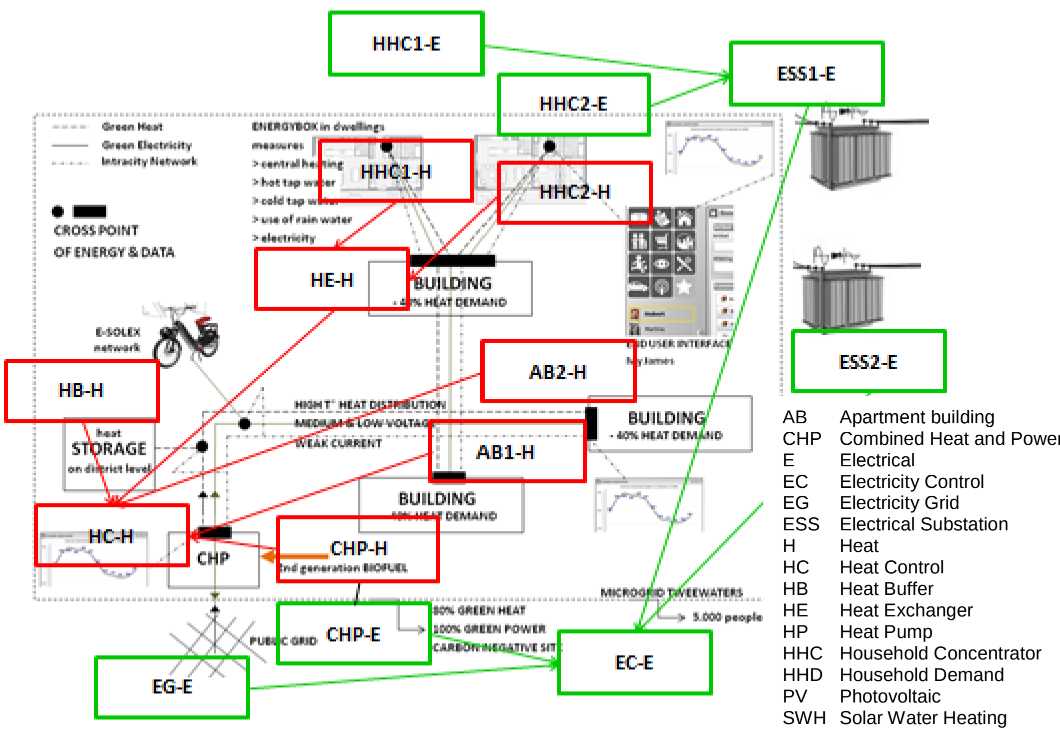
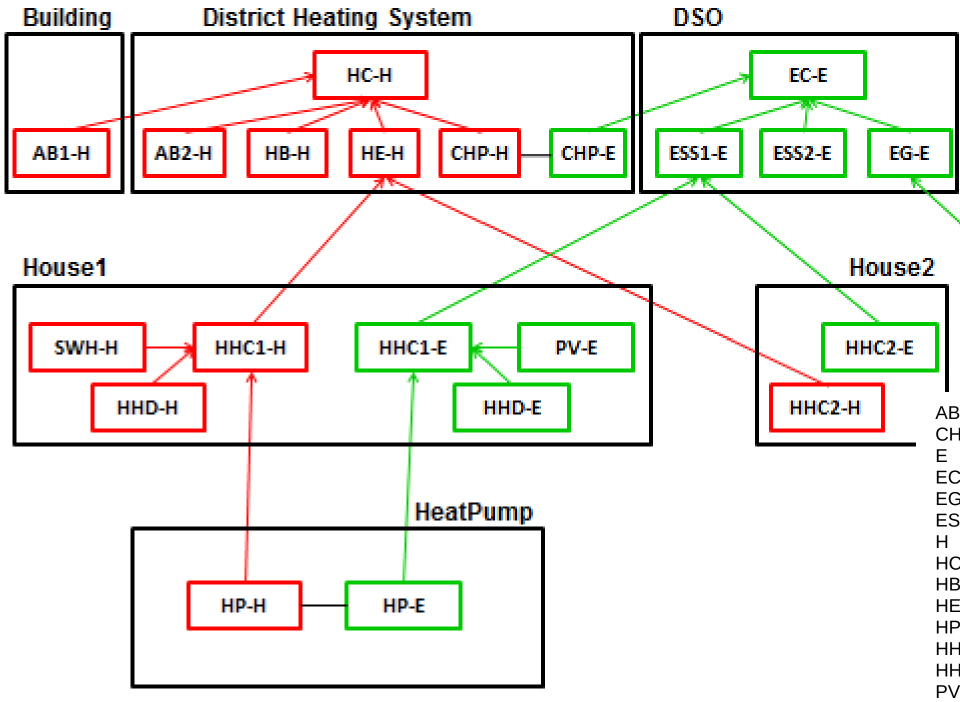



Figure 0-2: District example with heat and electricity control on dwelling and district level

This results in a software architecture as shown in Figure 0-3. The software is hierarchically structured and divided in different software modules. These modules can be clustered and run on one physical component or location.




| | |
|---|---|
| AB | Apartment building |
| CHP | Combined Heat and Power |
| E | Electrical |
| EC | Electricity Control |
| EG | Electricity Grid |
| ESS | Electrical Substation |
| H | Heat |
| HC | Heat Control |
| HB | Heat Buffer |
| HE | Heat Exchanger |
| HP | Heat Pump |
| HHC | Household Concentrator |
| HHD | Household Demand |
| PV | Photovoltaic |
| SWH | Solar Water Heating |

Figure 0-3: Software modules can be clustered and run on one component or location

By distributing the control and taking the control decisions as low as possible in the hierarchy the architecture results in a simple design complying for instance with the KISS guideline.

In the **information architecture** a formal representation of the information that is exchanged between the different stakeholders is described and applied to several use cases.

In order to achieve the goal of controlling and optimizing the electricity and heating system, a market-based multi-agent system (MAS) is proposed. In this concept each participating device is represented by either a consumer, producer or consumer/producer agent. These agents communicate the supply and/or demand needs of each device to the market. This is performed through a bid function. The market is represented by an agent aggregating all individual bids in order to achieve a balance (match) between supply and demand. This agent is called an auctioneer or prioritizer. The market can be a local market, covering for instance a house, or at a higher level a global market covering a district. In the market a price/priority is established such that demand and supply of electricity are matched. Each device is then allowed to supply or consume an amount of electricity that corresponds to the price and its bid function. This price/priority represents the willingness of the device to receive or deliver the given power. In other words, the price/priority may be seen as a kind of artificial price. For example, if the price/priority of the device is high, the device is willing to pay a high price to get electricity or heat allocated to it. Conversely, if the price/priority is low, the device is only willing to pay a small price for receiving the requested electricity or heat.

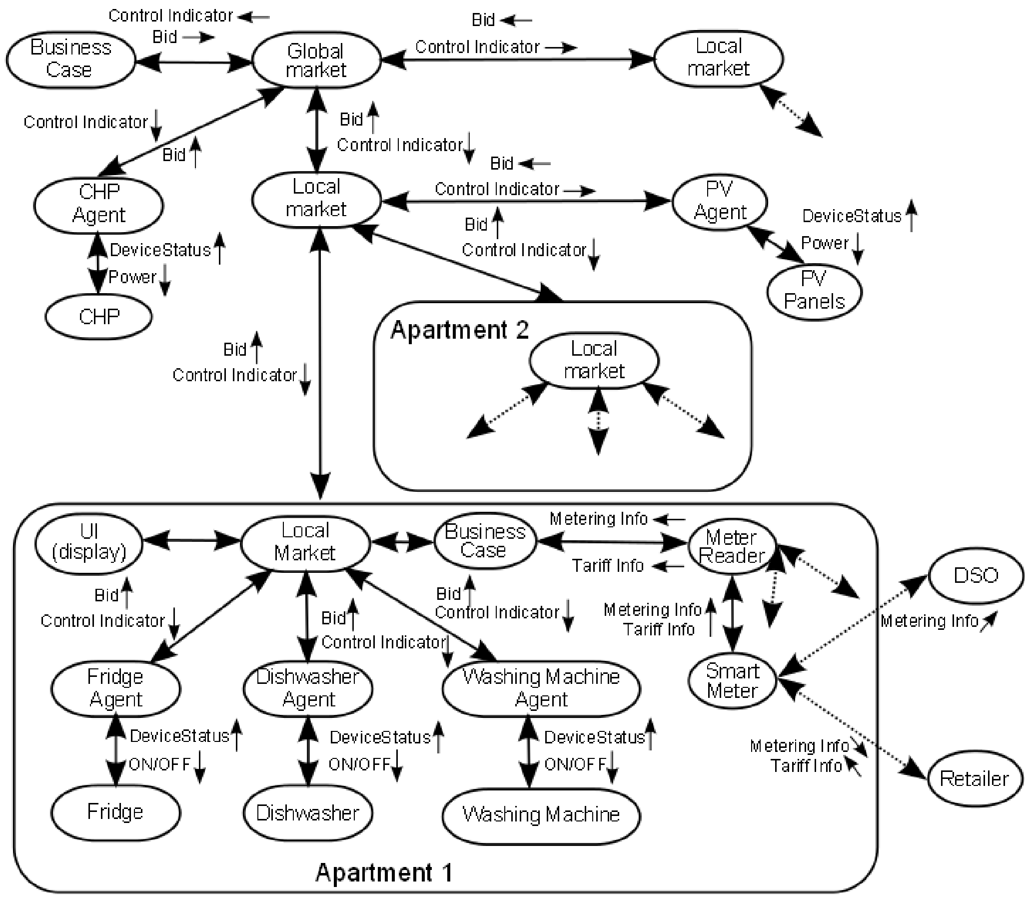



Figure 0-4: General information data flow with a business agent in the top left corner representing a particular business case

An extra component shown in Figure 0-4 is called the business agent. This component can be seen as an agent, that also will send bids, but these bids are used to impose the business objectives onto the system.

To investigate the information flow and the representation of the information exchanged in a market-based multi-agent control concept two implementations of a MAS, the “Intelligator”, developed by VITO and the “PowerMatcher”, developed by TNO, are discussed and compared. Two main phases can be distinguished in the operation of the systems, namely the start-up phase when the agents register themselves at the system, and the working phase when the agents exchange bids and allocations with the system. The start-up phase is similar in both systems. In the working phase there is a slight difference in controlling the appliances. This shows in the communication messages sent from the market towards the agents.

By means of several use cases the information flow in the MAS concept is further explored and illustrated.

It is of high importance that this information is exchanged in a secure way. This is discussed in the ***Information Security Architecture.*** The goal of the security architecture is to describe the security controls (security countermeasures), how they are positioned, and how they relate to the overall architecture. An analysis of the e-hub Energy Management System is performed to identify the most important risks to be mitigated, resulting in a set of architecture guidelines for the E-hub Energy Management System:

- Use a zoned network infrastructure where each zone provides a network for a specific group of devices. The zones should be separated by means of network security devices like firewalls.

- Use a decentralized architecture, so control-loops operate in a local area without direct control by a master system.
- To cope with privacy investigate if the system can operate successfully with anonymized data (that is not linked to a specific user or household).
- A lot of components in the e-hub energy management system are located at or nearby the location of physical users. Electricity and heat-devices and their control systems must be physically secured from unauthorized access.

The **communication architecture** is the last architecture which is addressed. As the EMS system will interact with lot of actors like smart meters, distributed energy resources, building management systems and even actors in the Smart Grid, the focus is on interoperability. Standards are one way to deal with this topic, but there are a lot of communication technologies (and standards) and all have to fit together.

Besides promoting standards for the communication, the ICT architecture must be designed in such a way that it can handle:

- Different communication technologies. New communication technologies may emerge and it must be possible to integrate these technologies into the architecture with minimal effort. Abstraction layers and adaptors is one of several techniques to tackle this.
- Different information models may be used throughout the system. If for the control communication one information model isn't possible (due to the fact that control systems with different information models may have to be integrated), translation functions have to be foreseen. One can translate between several models or one can translate all models to one common model.

From the viewpoint of the communication architecture two techniques were applied to ensure it is technology agnostic. This way the control system can operate without knowing the details of the underlying communication technology. First a Universal Communication Module (UCM) is used to decouple the communication of a device from the smart grid device (SGD) itself (Figure 0-5). It is good practice to implement this tactic to increase the extensibility of the system. It enables easy switching of the physical communication media, e.g. one UCM for power line communication, one for Ethernet, etc. Secondly at the device level a generic interface is defined to make it control system independent. An adapter will handle the transformation of the device state and characteristics into the desired format of the control solution. This adapter will be device type and control system dependent. For reusability and extensibility, the adapter will be implemented at the control system (RTU) and not at the device level.

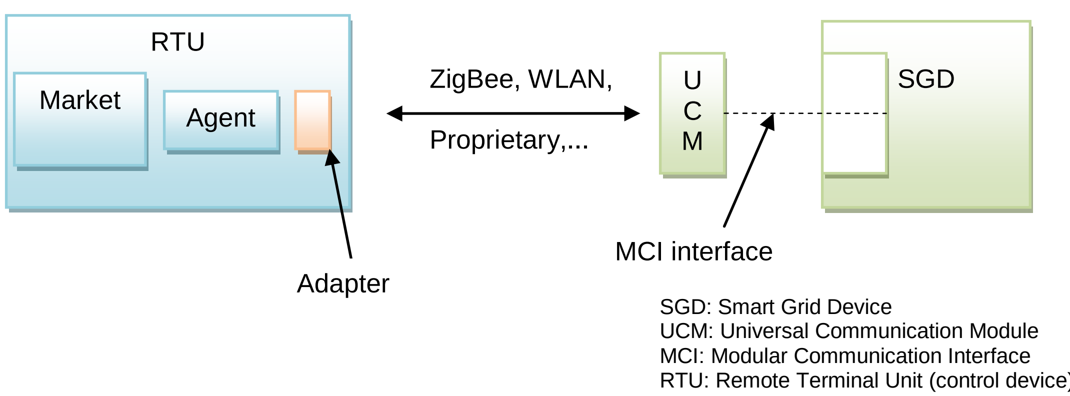



Figure 0-5:Use of a standard Universal Communication Module (UCM)

Implementing an EMS which is capable of optimizing consumption and production of both heat and electricity is a big challenge in the e-hub project. The focus in this project is on the control architecture, and simulation of the systems' control behavior is of the highest importance. Taking into account the simulation requirement an EMS based on the generic ICT architecture discussed in this document will be developed. This ICT architecture, extended with a software architecture, will be implemented in task 4.3

“Development of the EMS” and tested in task T4.5. The EMS in the field trial (WP5) will apply the architectural principles discussed in this document.

*Resources allocated*

Partners’ contributions dedicated to this deliverable reached total 22 PM and have been split into the following efforts:

- VITO has worked on the conceptual architecture, the information data architecture, the communication architecture and writing of D4.1, spending on it 7.65 PM.
- TNO has worked on the functional architecture, the information security architecture, the performance evaluation and writing of D4.1, spending on it 9.5 PM.
- VTT has worked on the user requirements and reviewing of D4.1, spending on it 3 PM
- Acciona has worked on reviewing D4.1, spending on it 0.8 PM
- TPG has worked on reviewing D4.1, spending on it 0.5 PM
- Ertzberg has given input for the requirements, spending 0.15 PM.

# 1 Introduction

## 1.1 e-hub

The 'e-hub: Energy-Hub for residential and commercial districts and transport' project is funded under the specific program "Cooperation" in the FP7 framework; and more specifically within the "Energy efficient Buildings (EeB) initiative (FP7-2010-NMP-ENV-ENERGY-ICT-EeB) with the aim of developing a concept able to utilize the full potential of renewable energies, covering up to 100% of the energy demand at district level. The scope is to build up the e-hub system and to develop technologies that are necessary to realize the system, to develop business models in order to overcome institutional and financial barriers, and to perform a feasibility study/case study consecutively to be applied in real life situation.

The aim of the e-hub project is to develop a concept able to implement / utilize the large share of renewable energies, similar to an energy station, in which energy and information streams are interconnected/converted into each other and/or stored. The e-hub would exchange energy via the energy grids between the different actors, depending on their role (once consumer and once supplier). These would exchange information with the e-hub, depending on their energy needs and energy production rates, in order for the available energy to be distributed efficiently. The e-hub concept would hold for all types of energy flows: primarily heating/cooling and electricity, and may connect not only households, but also (electrical) cars and commercial/industrial buildings.

## 1.2 Scope of the document

This document is part of WP4: "Development of Energy Management System".

The objectives of WP4 are:

- To implement the requirements for an e-hub as a system as defined in WP1 into an energy system architecture, with specifications on ICT requirement;
- To develop a (as much as possible) technology independent active demand response system for district level heating and electricity;
- To integrate the Business strategies as defined in WP6 in a global control system;
- To simulate the district in terms of energy management.

Task 4.1 is part of work package 4 and defines the overall architecture of the Energy Management System for e-hub. This architecture will be implemented in T4.3, tested for different scenarios in T4.5 and applied to the field trial in WP5 (Reference architecture).

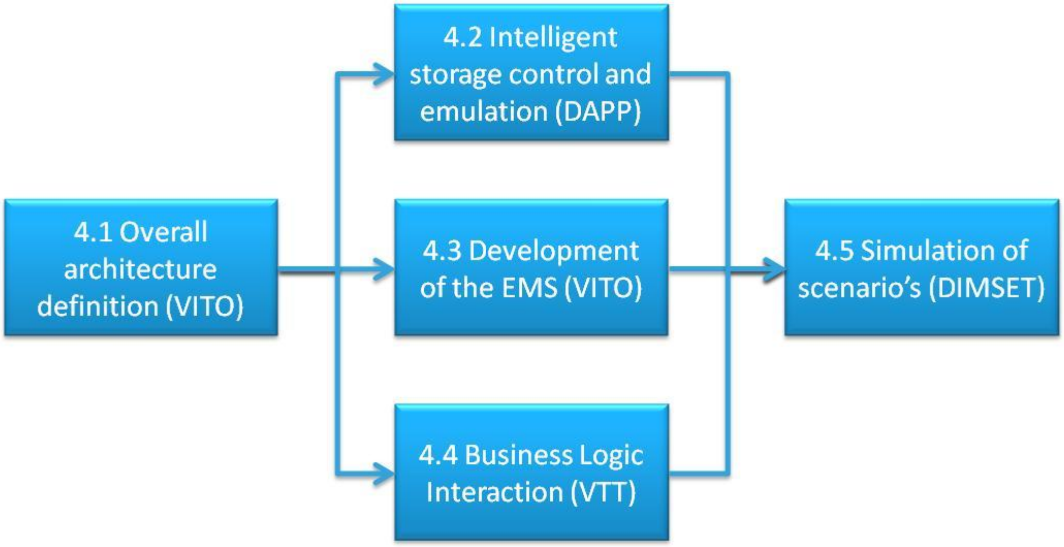



Figure 1-1: Overview of the task in the work package

The major challenge of e-hub from technical viewpoint is to interconnect a variety of networks: the electricity network, the heat network, the cold network and not at least the communication network. And this in such a way that it will support the business needs of a variety of stakeholders, ensuring at the same time that the networks will be reliable and secure.

The first step in defining the overall architecture is to identify the stakeholders and their needs. This is described in chapter 2 System requirements.

In concordance with the definition of a Smart Grid reference architecture as defined in [1] several ways to consider the e-hub architecture are applied. In essence, the purpose of an architecture is to allow for the separation of a complex system into entities that can be isolated from each other according to some principles, thus making possible the description of the whole system in terms of the separate entities and their relationships.

The following viewpoints are applied in the process of building an overall e-hub architecture:

1. ***Conceptual Architecture*:** A high-level presentation of the major stakeholders or the major domains in the system and their interactions. This is described in chapter 0.
2. ***Functional Architecture*:** An arrangement of functions and their sub-functions and interfaces (internal and external) that defines the execution sequencing, the conditions for control or data flow, and the performance requirements to satisfy the requirements baseline. This is described in chapter 0.
3. ***Information Architecture*:** An abstract but formal representation of entities including their properties, relationships and the operations that can be performed on them. This is described in chapter 5.
4. ***Information Security Architecture***: A description of all aspects of the system that relate to information security, along with a set of principles to guide the design. A security architecture describes how the system is put together to satisfy the security requirements. This is described in chapter 6.
5. ***Communication Architecture*:** A specialization of the former focusing on connectivity. As the system will interact with smart meters, distributed energy resources, building management systems and so on, also actors in the Smart Grid, this chapter focuses on the standards available for communication with these actors. This is described in chapter 8.

These architectures form the backbone of this document. They are necessary, in various degrees, to complete the description of an overall architecture.

# 2 System requirements

This section aims to present the major stakeholders involved in an e-hub system and the requirements of those stakeholders.

## 2.1 Methods for gathering user requirements

The user requirements presented in this document are based on

- a workshop performed in a Task 4.1 meeting at TNO (10-11 Oct 2011) (VTT, VITO, TNO);
- an analysis of existing documents (VTT);
- knowledge from past experience (VTT);
- comments by other partners;
- validation of requirements by an interview with Ertzberg (a service provider, generation company, project developer) (VITO)

## 2.2 Major stakeholders

The following users/stakeholders were chosen to be considered in this subtask (definitions mainly after ESMA glossary):

- End users (consumers / prosumers)
  - Occupants of a residential building. They consume energy and may also produce energy.
- Energy service provider
  - A natural or legal person that delivers energy services and / or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in doing so. The payment for the services delivered is based (either wholly or in part) on the achievement of energy efficiency improvements and on the meeting of the other agreed performance criteria.
  - Synonym: Energy service company (ESCO)
- DSO (Distribution System Operator)
  - DSO manages and operates a distribution network for energy (electricity, gas, heat) or water. DSO has operators, control rooms and various ICT systems for distribution management and automation. In the competitive electricity market the distribution of electricity is usually a natural monopoly controlled by the regulating authorities.
  - Synonym: Distribution Network Operator (DNO)
- DG (Distributed Generation of electricity) company in the district
  - DG refers to power generation connected to the electricity distribution network. Nowadays running of most DG is scheduled (or dispatched) without taking into account the situation in the power system and the electricity networks. Increasing penetration of DG will make is necessary to increasingly use DG as controllable resources for the electricity market, for the power system and for the distribution network. Synonyms to DG: dispersed generation, embedded generation
- Energy retailer
  - An actor in the competitive electricity market that connects retail market customers with the bulk market.
  - Synonyms: Retail Energy Supply Company (RESC), Retail Energy Supplier and often supplier is used, when the context is strictly the electricity retail market.
- Metering operator
  - Metering operator operates the billing meters. This activity includes installation, maintenance and replacement of meters. In some countries billing metering is unbundled and competitive and in some countries metering is part of the electricity distribution

monopoly. Also in the latter case separate meter operators are common, because many distribution operators outsource the metering. In some countries (e.g. UK) the metering operator is split further into MAP (Meter asset provider) and MAM (meter asset manager). Actually, MAP and MAM refer to the same function (provision of meters) but for electricity and gas respectively.
    - Synonyms: Meter Operator(MO, MOP)
- Research and business development
    - Included as a separate stakeholder to take into account the special requirements of the e-hub field test.

## 2.3 Overview of requirements of different stakeholders

This table gives an overview of requirements but does not present all the requirements of different stakeholders in section 2.4. The aim of the overview is to illustrate how the requirements are shared between the stakeholders.

Table 2-1: Overview of requirements

| Req # | Requirement | Description | Stakeholders |
|---|---|---|---|
| **1.1** | ROI / savings | The benefits cover the costs | all |
| **1.2** | Ease and efficiency of use (usability) | End user is in control. End user can choose simple overview or detailed information. User interfaces suitable for different end users and purposes | all |
| **1.3** | Maintain comfort | Indoor conditions are maintained at comfortable level, i.e. indoor thermal conditions, indoor air quality and lighting conditions are not sacrificed for energy saving (without acceptance by the occupants). Effective personal control over indoor conditions (not sacrificed to save energy) | end users |
| **1.4** | Privacy | End user information and consumption data only to those who are authorised by the end user. | end users |
| | | Sensitive business data only to the parties authorised by the stakeholder | all |
| **1.5** | Data security | Adequate data security for providing needed availability, confidentiality and privacy | all |
| **1.6** | Access and ownership of data | Data access and ownership must conform to legislation | all |
| | | Multi-commodity of data: consumption data is produced and shared by several stakeholders | all |
| | | Consumer has right to get for free all data of his/her consumption etc. | end users |
| | | Consumer decides who has access to his/her data | end users |
| | | Measurement data for billing and settlement collected and stored as required by laws | all |
| **1.7** | Conformance to energy markets | Does not prevent stakeholder access to competitive market | service providers |
| | | One and only one actor responsible for each electricity balance | all electricity market actors |

| | | | |
|---|---|---|---|
| | | Billing and settlement according to energy market rules (electricity, gas, heat) | all energy market actors |
| **1.8** | Simple but adequate connections to electricity market | Indirectly able to take advantage of fast price variations in the electricity markets but hides complexities of the electricity market from e-hub actors | end users, service providers etc. |
| **1.9** | No lock in to vendors or service providers | Enables competition. Modular system with open interfaces | all (but not necessarily favourable by vendors/service providers) |
| **1.10** | Harmonised and stable interfaces | Conformance to standards. Full documentation and free use of the interfaces | all |
| **1.11** | Saves energy and environment | Reduce negative impacts on environment such as CO2 emissions (at overall system level) | all |
| **1.12** | Supports balance management | Reduces imbalance costs | end users, DG, retailer, DSO, operator of e-hub |
| | | Helps management of district power balance and of load in the connection to main grid | end users, DG, retailer, DSO, operator of e-hub |
| **1.13** | Supports islanded operation of the district | In islanded operation local generation supports critical loads and balancing loads during black outs of the electricity infrastructure. (e-hub does not implement island operation but helps it) | end users, DG, retailer, DSO, operator of e-hub |
| **1.14** | Good prediction of balance, load and flexibility | Prediction of loads and flexibility about 24-48 hours ahead | all |
| **1.15** | Good monitoring and control of balance, load and flexibility | Needed for balance management (12) and ROI (1) | all |
| **1.16** | Reliability, availability | Small enough down time per year and longest individual service interruption | all |
| **1.17** | Maintainability, scalability | Repair, upgrading, extension and scale increase can be done with acceptable costs | all |

Quantitative performance requirements are not even roughly defined in this document. For e-hub, response time and availability at modest costs now seem to be more critical performance requirements than bandwidth. Software and communication architecture design choices can affect them. Such design choices include appropriate decentralisation of intelligence, exploiting and adding redundancies, prioritising, data concentrators, alarm filtering, communication protocols, physical communication media and data security architecture.

## 2.4 Requirements of different stakeholders

### 2.4.1 End users (consumers / prosumers)

Table 2-2: Requirements of end users (consumers / prosumers)

| Description of requirements | Priority | Testability |
|---|---|---|
| 2.1 ROI / savings<br>• Savings compared to a regular system | High | Average |
| 2.2 Relevant information on energy consumption<br>• Real time information on energy consumption / cost<br>• History data of energy consumption / cost<br>• Normative information (comparisons with others) on energy consumption / cost<br>• Amount of primary energy consumption reduction<br>• Projection of estimated future energy consumption / cost<br>• Real time information to show when it is favourable to consume or delay consumption<br>• How much did you gain by using this system (benchmarking)? | High | Good |
| 2.3 Relevant information on own energy production<br>• Real time information on energy production / value<br>• History data of energy production / value<br>• Projection of estimated future energy production / value<br>• Real time information to show when it is favourable to produce or delay production<br>• How much did you gain by using this system (benchmarking)? | High | Good |
| 2.4 Ease and efficiency of use (usability)<br>• Appropriate level of automation (user is in control but can leave some tasks for automation; automation takes care of routines, constant monitoring and control and fast responses), see Note 1<br>• Fits to the user and purpose (passive consumers, active consumers, experts, homes, mobile users)<br>• Different levels of detail of information (only the most relevant information is presented in the main window, most important functions are the easiest to use etc.)<br>• Easy overview of the current operation and settings (for example, the user should be able to check if for instance the refrigerator is currently involved in an active demand action)<br>• Highly usable user interface (easy to learn, acceptable default settings, efficient in everyday use etc.)<br>• Capability to control the system outside the home environment | High | Rather good |

| | | |
|---|---|---|
| 2.5 Maintain comfort<br>• Indoor conditions are maintained at comfortable, safe and healthy level, i.e. indoor thermal conditions, indoor air quality are lighting conditions are not sacrificed to save energy (without acceptance by the consumer)<br>• Effective personal control over indoor conditions (not sacrificed to save energy) | High | Good |
| 2.6 Safety and security<br>• End user information and consumption data only to those who are authorised by the end user<br>• Availability of the e-hub system is not compromised (by external or internal attacks, security updates, etc.<br>• Protection of control actions and data against unauthorised access and user errors. | High | Average |
| 2.7 Control over his installations, costs and systems<br>• No vendor lock in, Note 2<br>• Modular system (and easy installation of new appliances, no expertise required, e.g. plug-and-play)<br>• Open standard interfaces and data models<br>• Simple and understandable contracts | High | Average |

Note 1. This issue and related user interface requirements are to be studied in Task 4.3 by interviews, questionnaires, user interface prototyping or other relevant methods. This work will produce more detail regarding these requirements. In field tests users will have an override button for disabling active demand control. It is to be decided how to react when the end user uses the shutdown button too frequently.

Note 2. In the Tweewaters demonstration, the end user can switch to another energy retailer but in this case the end user will not be allowed to integrate an HEMB other than the one provided by Ertzberg.

### 2.4.2 Energy service provider

Table 2-3: Requirements of Energy Service Provider

| Description of requirements | Priority | Testability |
|---|---|---|
| 3.1 ROI / savings | High | Average |
| 3.2 Collect data/information about the users (monitoring and control)<br>• Types of family<br>• Configuration<br>• Prediction of user consumption<br>• Billing information<br>• Means to control the amount of energy and its timing with a high time-frequency (pricing, time of use pricing/control, dynamic pricing, controllable power limits) | High | Good |
| 3.3 Scalability, upgradability, maintainability | High | Average |

### 2.4.3 DSO (Distribution System Operator)

Table 2-4: Requirements of DSO (Distribution System Operator)

| Description of requirements | Priority | Testability |
|---|---|---|
| 4.1 Limit investment costs | High | Average |
| 4.2 Reduction of administrative overhead | High | Average |
| 4.3 Don't overload the system. Longer lifetime of network components. Peak load management, see Note 1 | High | Good |
| 4.4 Management of voltage quality and reactive power (electricity) | Rather high | As good as power quality monitoring system |
| 4.5 Pressure management (gas) | Rather high | Good |
| 4.6 Shut off an entire neighbourhood safely (Controlled partial shutdown) | High | Good |
| 4.7 Shut off lower priority consumption (Controlled partial shutdown) | High | Good |
| 4.8 Prediction of energy use (also including control responses) | High | Good |
| 4.9 Reliability of the EMS / distribution system | High | Average |
| 4.10 Helps management of district power balance and management of load in the connection to main grid. | Rather high | Good |
| 4.11 Register transmission losses | High | Good |

Note 1: Traditionally the management of peak loads was based on limiting peak loads. One of the main benefits of smart grids and demand response (enabled by e-hub) is that the loading of the network component can be managed dynamically and more accurately than with peak load limiting. The transfer capacity of the network can be utilised more accurately, when the power flows and loads on different network components are taken into account dynamically. Applying average based static peak load limiting conflicts with smart dynamic management of network capacity.

Note 2: In the e-hub context islanded operation does not represent an economic added value and an extremely limited technical added value within the current network setting. Therefore Islanded operation is not selected as a requirement of the DSO.

### 2.4.4 DG (Distributed Generation of electricity) company in the district

Table 2-5: Requirements of the DG company in the district

| Description of requirements | Priority | Testability |
|---|---|---|
| 5.1 ROI / savings<br>• Most profitable production as possible<br>• Imbalance cost reduction | High | Average |
| 5.2 Good prediction of the energy consumption, range of flexibility and responses to control actions | High | Average |
| 5.3 Good control of balance with a high time-frequency (generation + purchase - consumption - sales) | High | Average |

### 2.4.5 Energy retailer

Table 2-6: Requirements of Energy retailer

| Description of requirements | Priority | Testability |
|---|---|---|
| 6.1 ROI / savings<br>• Price and volume risk management<br>• Imbalance cost reduction | High | Average |
| 6.2 Good prediction of the energy consumption, range of flexibility and responses to control actions | High | Average |
| 6.3 Good control of balance (purchase - consumption) | High | Average |

### 2.4.6 Metering operator

Table 2-7: Requirements of metering operator

| Description of requirements | Priority | Testability |
|---|---|---|
| 7.1 Harmonised and stable open standard interfaces | Rather high | Good |

Note: Smart meters are owned by the DSO in the Tweewaters case

### 2.4.7 Research and Business development

Table 2-8: Requirements of Research and Business Development

| Description | Priority | Testability |
|---|---|---|
| 8.1Availability of data, easy access to data<br>• Real time information on energy consumption / cost<br>• Projection of estimated future energy consumption / cost | High | Average |

| | | |
|---|---|---|
| • History data of energy consumption / cost<br>• Usability and adaptability<br>• Possibilities to collect data on how the system is used in the field tests (which parts are used, how often, etc. for example by click stream data)<br>• Harmonized and stable open standard interfaces | | |
| 8.2 Possibilities for field test for identifying and calibrating the models used in analyses | High | Good |

# 3 Conceptual architecture

This section discusses the conceptual architecture of the e-hub project. The conceptual architecture comprises a high-level overview of the major stakeholders and the relationships of the total system and the interactions between them.

## 3.1 Overview

Taking into account the stakeholders defined in section 2.2, the conceptual architecture is given in Figure 3-1, the lines between the different actors represent their relations. As shown an end user is represented by a prosumer, the energy service provider and metering company are responsible for both electricity and heat. For the metering company this implies that it will measure both electricity and heat instead of a separate metering company for every commodity. Only the relevant stakeholders for the ICT architecture are shown in the figure, the whole sale markets are not shown in this figure because they will be discussed in WP6.The following subsections describe the relationships and interaction between the different stakeholders for both electricity and heat networks.

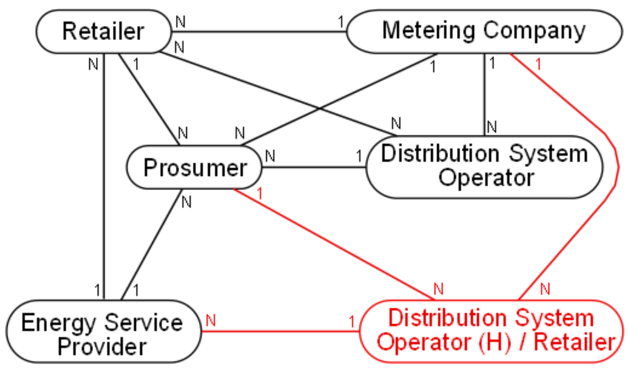



Figure 3-1: Conceptual Architecture E-hub (H = heat)

## 3.2 Relationships and interaction (Electricity)

The relationships are described in general in order to fit the different models of the European countries. The interactions differ per country, therefore the lists given in the subsections are examples for some specific countries. These examples are not exhaustive neither are they applicable to each country.

### 3.2.1 Prosumer (end-user) – Retailer (N – 1)

An end user is in contact with only one retailer whereas one retailer can have/has many end users. Their interactions include:

- A contract between the end user and the retailer
    - Day/Night tariff, Single tariff, Time of Use (ToU), …
- The retailer sends billing information to the end user
- The retailer sends load control signals to the end user (direct or indirect, commands or incentives)
    - Can also be implemented by using an ESP for achieving this e.g. the ESP sends the commands to the prosumers.

### 3.2.2 Prosumer (end-user) – DSO (N – 1)

An end user is connected to one DSO whereas the DSO can have/has multiple end users. Some examples of their interactions are:

- End user has a contract with the DSO regarding the connection with the grid
    - To connect to the electricity grid, an end user has to sign a contract with the DSO. The connection with the grid can be billed separately (by the DSO) from the main electricity bill (by the retailer).

### 3.2.3 Prosumer (end-user) – ESP (N – 1)

Examples of possible interactions of an end user with an ESP are amongst other:

- Billing information
  - Instead of receiving billing information directly from the retailer, it is possible to receive the information from the ESP (e.g. Tweewaters demo project)
- Power consumption information
  - Analogue to the billing information, the power consumption information can be provided to the end user by the ESP
- DSM information

### 3.2.4 Retailer – ESP (N – 1)

Instead of the retailer sending load control signals directly to the end users, this can be achieved by means of an ESP. This way the retailer informs the ESP about the objective of the automated DR so the control system algorithm can be updated to achieve the objective given by the retailer.

### 3.2.5 Retailer – DSO (N – N)

A retailer has a connection with one or more DSO's and vice versa. Their interactions are related to:

- Deciding on access rules and regulations (the retailer informs the DSO regarding its supply points)
- Processing information of DSO for billing purposes
  - In case the DSO reads out the meters, the consumption information of the end users is communicated to the retailer so they can send the billing information to their customers

### 3.2.6 Metering company – End User (1 – N)

A metering company interacts with multiple end users. It reads out the electricity meters installed at its customers, for example:

- Automated Meter Reading (AMR) clients, which are metered at a 15 minutes interval for electricity.
- Monthly Meter Reading (MMR) clients, metered at monthly intervals
- Yearly Meter Reading (YMR) clients, metered only once a year or at a 2-year interval

### 3.2.7 Metering company – DSO (1 – N)

A metering company is hired by a DSO in order to read out the meters installed at its customers. One metering company can of course be hired by different DSO's, their interactions exist of:

- A contract between the metering company and the DSO to read out the meters
- The read out metering info is exchanged with the DSO

### 3.2.8 Metering Company – Retailer

A metering company is connected to all the retailers which are suppliers on the specific distribution grid. They give the retailer the read out meter data of the customers in its portfolio.

## 3.3 Relationships and interaction (Heat)

The relationships and interactions between the stakeholders related to the heat network differ from the ones of the electricity grid. In one single heat network only one DSO, the operator of the heat network which is also the retailer, is present.

### 3.3.1 End user – DSO (N – 1)

An end user is connected to one DSO whereas the DSO can have/has multiple end users. Some examples of their interactions are:

- End user has a contract with the DSO regarding the connection with the heat network

- Exchanging information related to the purchase of heat
- A supply contract

### 3.3.2 End user – ESP (N – 1)

Examples of possible interactions of an end user with an ESP are amongst other:

- Billing information
- Heat consumption information
- DSM information

### 3.3.3 DSO – ESP (N – N)

A DSO can interact with one or more ESP (’s) and vice versa. Exchanged information includes:

- Metering information (in case the ESP is a Metering Company)
- DSM Business Case information

## 3.4 Relevance

The conceptual architecture, consisting of the stakeholders, their business needs (see 2.3) and the interactions between the stakeholders, gives an insight in the overall system the district EMS will be part of. Not all business actors mentioned in the model may need to interact with the e-hub energy management system. Nor will all interactions between these stakeholders pass via the e-hub energy management system. However, having the whole picture will contribute to a more accurate and less error prone design.

# 4 Functional architecture

This chapter describes the functional architecture of the e-hub control platform, the basis of the e-hub Energy Management System. As described in the description of work of e-hub in task 4.1 the overall architecture will be defined, to assure the interoperability of the different components of the district system and to enable implementation of all the user requirements. For that the definition of a generic control platform is required, in which appliances, generators, storage units and controllers, based on different technologies, can be integrated and communicate to each other, some examples of these appliances are given in the following list:

- Water heater,
- Heat pump,
- Washing machine
- Dishwasher,
- Tumble dryer,
- Fridge,
- Battery,
- CHP,
- ...

The architecture of this control platform needs to be open and flexible for efficient integration of the latest state-of-the-art technologies.

An important part of this overall architecture is the functional architecture that will describe the arrangement of functions and their sub-functions and interfaces (internal and external) that enable the execution of the control defined by the control platform. It will also show the data flows and communication links.

## 4.1 Architecture Principles

Before describing the functional architecture, we will first list the architecture principles that we apply to this functional architecture. The architecture principles are based on our experience and literature about architectures. These principles are:

- ***Holistic Thinking*****:** Take the total and complete system as a basis, this makes it more likely that the architecture complies with all the system and user requirements.
- ***Clear Vision*****:** It is essential for a successful architecture definition to have a clear vision and be consistent in that vision and base the architecture on that vision.
- ***Conceptual Clarity:*** Define glossary and data models using standards as much as possible.
- ***Modularity*****:** This makes it easy to replace for example devices by other devices without changing the complete design or other parts of the system.
- ***Every System Consists of Subsystems*****:** This enables to connect a complex subsystem without directly taking the complexity of this subsystem into account higher up in the hierarchy.
- ***KISS (Keep It Simple and Straightforward)*****:** The more complex the solution, the more difficult it gets to follow the guidelines and maintain the consistency of the design, so we need to keep it simple and straightforward, this also prevents too many exceptions.
- ***Be Open to the Future*****:** The architecture should enable new and future algorithms to be implemented, preferably the architecture should be totally algorithm independent.
- ***Plan Ahead for Reuse*****:** Need to be able to handle different technologies or energy carriers when they would arise in the future.

## 4.2 Functional Architecture Guidelines

Based on these architecture principles we will now define the resulting functional architecture guidelines.

***Clear Vision*:** In this context our vision is: “The generic control platform and its communication network need to follow and be in-line with the physical architecture, the pipes and wires, if not physically than at least virtually”. This is based on our experience in various projects on Energy Management Systems (EMS). All EMS use an energy infrastructure that consists of physical connections for heat, gas or electricity. Besides that these systems very often have a hierarchy, most from central production (via energy markets) to decentralised demand, although more and more distributed generation is seen especially in electricity grids. Hierarchy can also be found in cities, for example from districts to streets, to buildings and houses. Bringing in ownership and stakeholders like building management and housing owners further shows the fit with this vision, and the easier mapping to real-life physical situations.

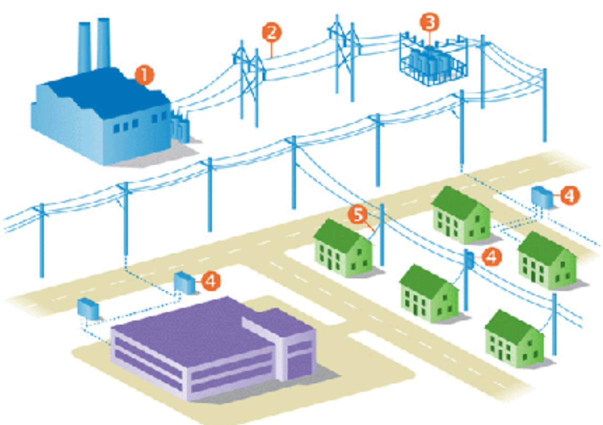


Figure 4-1: Electricity system with wires

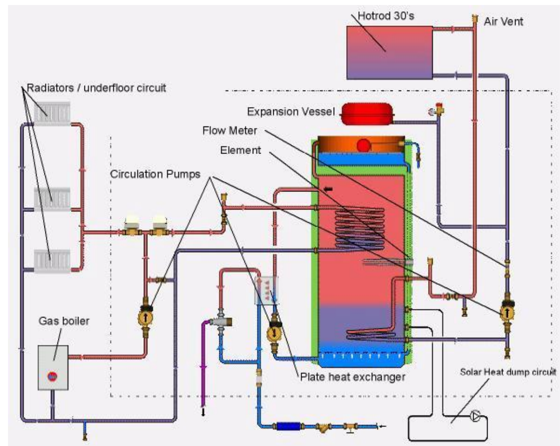



Figure 4-2: Heat system with pipes

***Holistic Thinking*:** Taking the total system as a basis, and combining this with our vision brings us to: Communication and control should follow the physical architecture, from top to bottom of the total system. This is logical, also because where connections are, the connected devices need to communicate to the next layer their energy availability, needs and flexibility, since they are able to exchange energy (they are connected to each other). See the two figures above for examples of systems.

***Modularity*:** Define components in the Energy Management System that are connected by clear consistent interfaces. Clear consistent and simple interfaces will enable all devices like even household appliances to be equipped with the local intelligence to participate in the control. This makes it easy to add or replace devices without changing the complete design. This enables multiple devices from multiple vendors to be connected.

***Every System Consists of Subsystems*:** Ensure scalability and design according to the real world hierarchy. For example a district consists of streets, apartment buildings, houses, and individual components and equipment like heat pumps. This also prevents everything to communicate with everything, and it prevents to many communication links.

***KISS (Keep It Simple and Straightforward)*:** More complexity than necessary will result in sub-optimal systems. This seems obvious and a no brainer, but for example taking the control decisions as low in the hierarchy as possible creates a faster and more reliable system since subsystems can in such a situation operate on their own. Simple does not mean limited or restricted, it also can mean more universal and generic.

***Be Open to the Future*:** In our architecture, this means being as independent as possible of control algorithms, for example by using open and existing interfaces. This algorithm independency creates lots of flexibility (for coupling and integrating heat and electricity energy management systems) and makes the system future-proof, since energy management algorithms and technologies are still in development.

***Plan Ahead for Reuse*:** Make sure it works for electricity and heat and cold, than check if it could be reused for gas and hydrogen, or others energy carriers and infrastructures.

## 4.3 Functional Architecture Guidelines in an example on district level

To show in more detail what these functional architecture guidelines mean we will work out an example on district level, where we base ourselves on a picture from the DoW, the energy layout of the Tweewaters demonstration district (see the next figure).

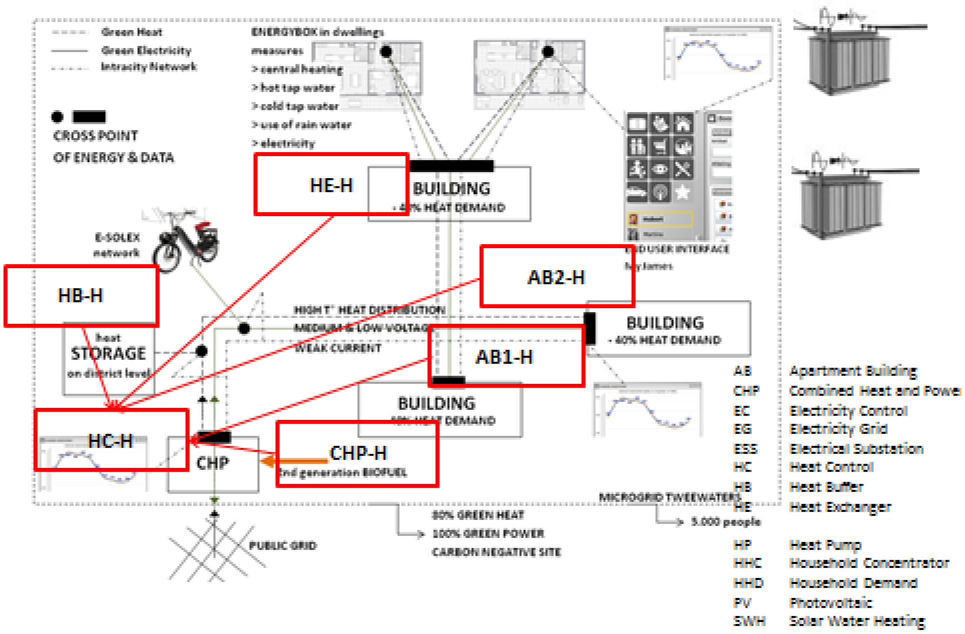



Figure 4-3: Energy layout of Tweewaters demonstration district

In this example the heat from the Combined Heat and Power (CHP), the Heat Buffer (HB), and the 3 buildings (for example 2 Apartment Buildings (ABs) and 1 Heat Exchanger (HE) for 2 houses) need to be controlled and managed, since they are on one heat distribution system. This control can be done by the unit Heat Control (HC) in such a way that the energy needs of the different components are fulfilled. Following the vision and guideline that communication and control should follow and be in-line with the physical architecture, meaning pipes and wires, we come to the following communication links between the mentioned components (see next figure). The arrows point to the components higher up in the hierarchy. The communication is expected to be bidirectional in the end. In this picture we have already added two Electrical Substations (ESSs) that we will use later.

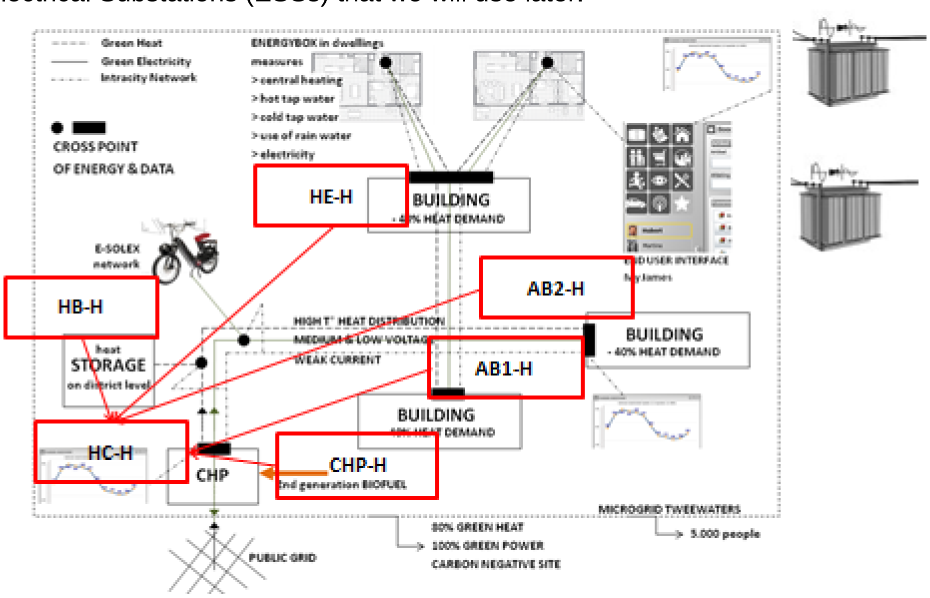



Figure 4-4: District example with top level heat control

The communication in the picture ensures that the Heat Control, who will act as master and initiator of the communication, has the required information from the heat of the buildings and the status of the heat buffer. This is sufficient basis for the HC to decide on the heat to be produced / consumed in this cluster.

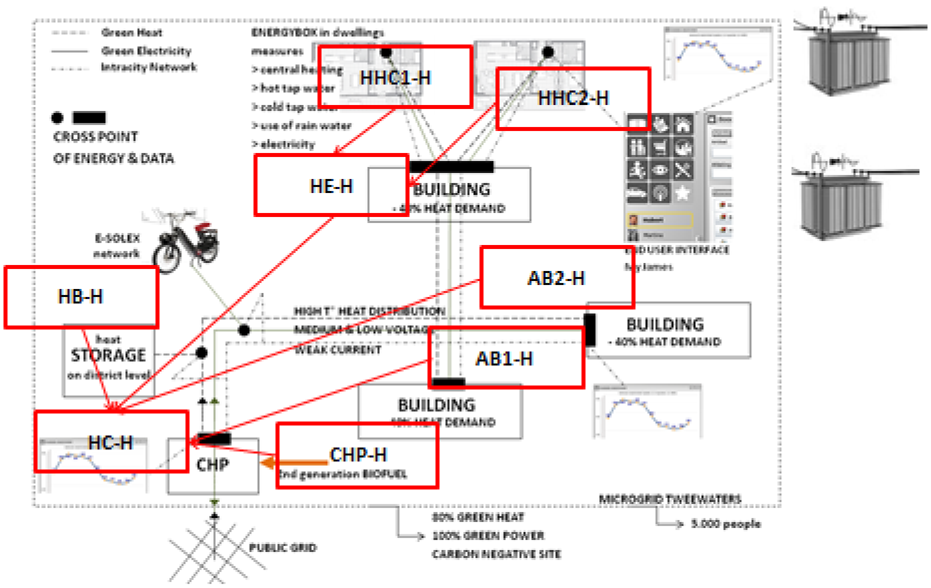



Figure 4-5: District example with two levels of heat control

The previous figure shows the extension to the next level. In this case, 2 households are connected to the heat exchanger. This is what we meant by “the guideline every system consists of subsystems”. We ensure scalability with this. Now the heat exchanger will act as master, initiator and concentrator in the communication towards the houses. It has the required information from the heat of the households (heat demands), can accumulate these and communicate that with the HC (its master on a higher level). This prevents that the top level HC needs to communicate directly with all the households, thus avoiding additional complexity. But still, the HC receives the heat demand of all systems and devices coupled to his infrastructure.

We now repeat the process for the electricity domain, but add directly two levels. See in the figure below the example case on district level with control of the electricity domain added. This is in line with our guideline of making sure it works for electricity and heat, and is likely applicable for other energy carriers.

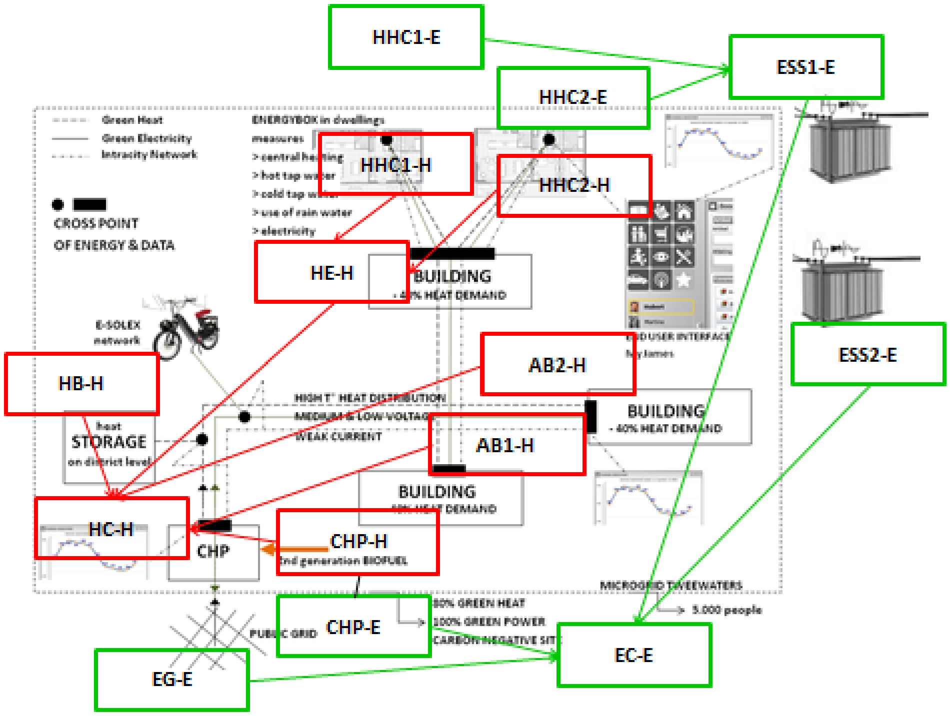



Figure 4-6: District example with two levels of heat and electricity control

Here we see the master Electricity Control for electricity communicating with the Electricity Grids (EG), the two Electrical Substations and the CHP, who produces both heat and electricity. The Electrical Substation number 1 communicates with the two connected households. Now it becomes also visible that one physical component (CHP, HP) can have multiple control elements that communicate in different domains but also to each other. This is also a result of the modularity guideline. It is the responsibility of the components, for example a CHP, to ensure the required communication between multiple modules in the same component. The interfaces should be clear and consistent, as for both heat and electricity required or available energy (heat or electricity) is communicated upward and a priority signal (or price) is communicated downwards. Several algorithms and control systems are based on that. This follows the guideline, “Be Open to the Future”, stay as independent as possible of control algorithms.

Let’s now descend further in for example household 1. As depicted in the next figure we take a house with a Heat Pump (HP), Photovoltaic (PV) solar cells, Solar Water Heating (SWH), and Household Demand (HHD) for heat and electricity.

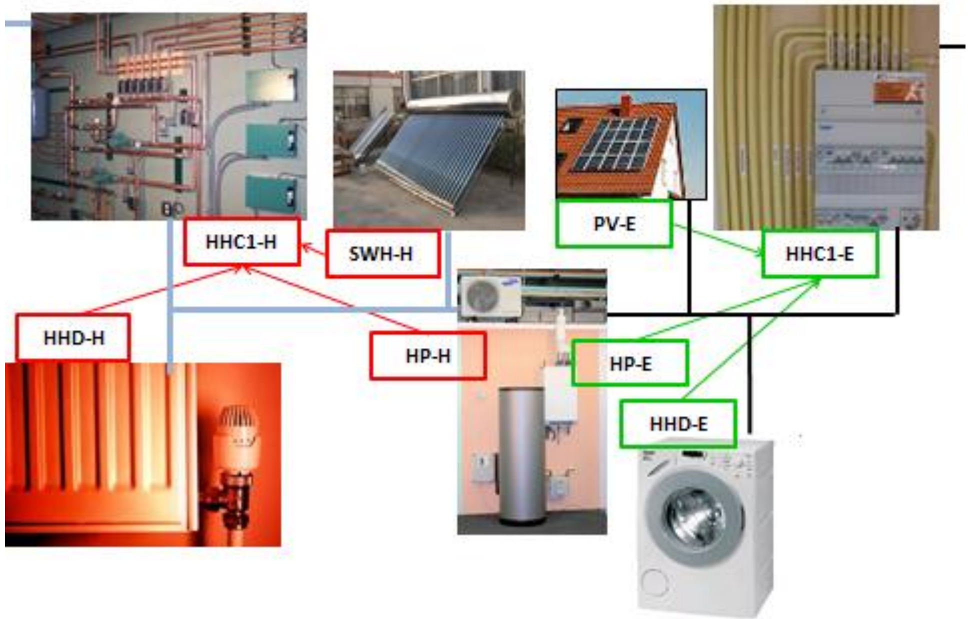



Figure 4-7: Household example with heat and electricity

We again apply the guideline of following the pipes and wires for communication. This means that the Household Concentrator for heat masters the communication with the heat demand, the Solar Water Heating and the Heat Pump. Then the Household Concentrator for electricity masters the communication with the electricity demand (e.g. household appliances like washing machine, dishwasher, dryer, fridge, freezer, etc.), the PV solar cells and again the Heat Pump. This also complies with our guideline: from top to bottom of the total system. We now have defined several connections and several software modules. The next picture shows these modules in their software hierarchy, a different way of presentation but not a different communication.

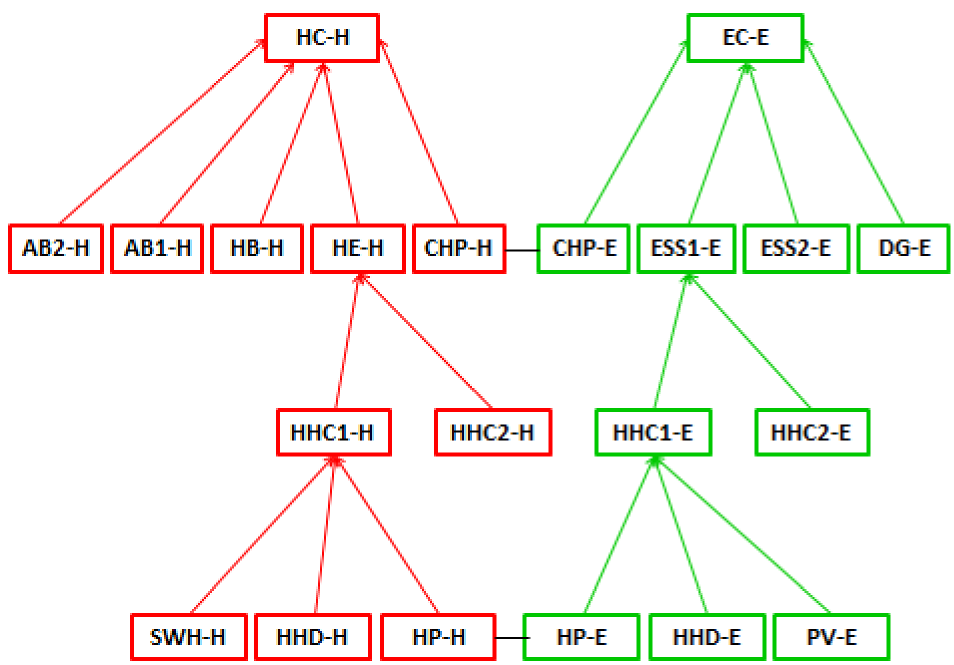



Figure 4-8: Software hierarchy and the different modules

This structure seems rather complex but several software modules can be clustered and run on one physical component or location. This is also aligned with possible owners and operators of these systems, as shown in the figure below.

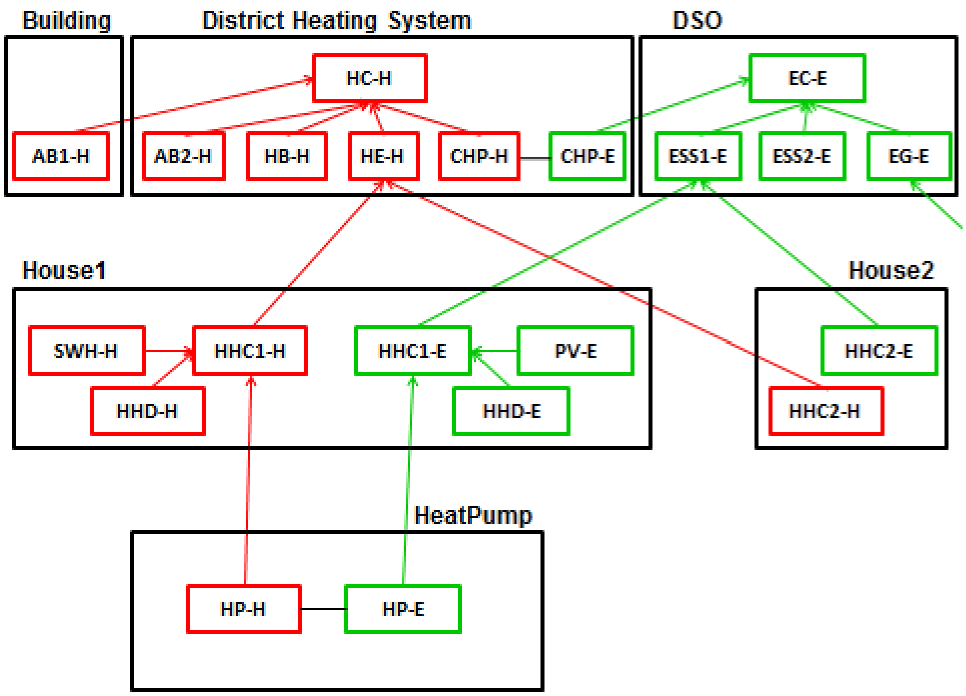



Figure 4-9: Software modules can be clustered and run on one component or location

This is based on the assumption that the district heating system covers and includes management of the heat exchanger, heat buffer and one of the apartment buildings. Maybe one apartment building is owned by another owner, who has chosen to manage his own energy demand inside the building. Several software modules in house 1 are combined in for example a house energy management system, but likely the heat pump has its own control system due to restrictions of the equipment itself, which are often proprietary and therefore under control of the manufacturer's software implementation.

Not directly visible in this last figure is the application of the keep it simple guideline, like taking the control decisions as low in the hierarchy as possible, this is preventing communication overhead and control complexity. Control is done by the device itself making the decision to switch on or off. Details about this approach are given in chapter 5.

Figure 4-9 shows the software modules clustered and running on one component, and the communication between these components. This becomes a complete energy management system when these different clusters manage and control their energy management and operational requirements. To illustrate the point, here is the list of energy management requirements that the different clusters will manage and control:

- The District Heating System needs to provide the heat required by Apartment Building 1, and the Heat Exchanger that is coupled to the two households. It will also make sure that Apartment Building 2 is heated to the required temperature, but it can optimize the moment for delivering this heat in combination with the Heat Buffer and for example the price it will receive for the generated electricity (and heat). How this optimization is performed (active demand response algorithms like HeatMatcher, Intelligator or PowerMatcher) will be worked out later in task 4.3 of this project (Development of technology independent active demand response energy management system).

- The system in Apartment Building 1 will heat the building to the required temperature, but is able to negotiate, agree and decide with the District Heating System at which time and price it received the heat.
- Distribution System Operator (DSO) will safeguard the maximum electricity capacity it can provide, and act as a communication hub between the CHP and the electricity market.
- The system in house 1, which will heat it to the required temperature, is also able to negotiate, agree and decide with the District Heating System at which time and price it receives the heat, but also has the same negotiation with the Heat Pump in this house. Further is also negotiates, agrees and decides on electricity it consumes or produces via an electrical substation.
- The Heap Pump in house 1 communicates and negotiates with the HEMB (Home Energy Management Box) on heat and electricity, and as mentioned before, the way this optimization is performed will be worked out later in task 4.3 of this project.

Besides the communication between the different clusters, some of these clusters (like the District Heating System) will gather information from "elsewhere", for example weather forecasts on sunshine, temperature and wind. The same holds for measurement and logging information on for example energy used. This is not yet drawn in the picture above. This paragraph shows how the overall system can function, but also that the detailed control and algorithms inside the different clusters need to be worked out separately.

## 4.3.1 Functional Architecture example on district level mapped to PowerMatcher

PowerMatcher technology is a distributed energy/electricity system architecture and communication protocol, which facilitates implementation of standardized, scalable Smart Grids, that can include both conventional and renewable energy sources (see also http://www.powermatcher.net/in-a-nutshell/).

Here we will show that the functional architecture defined above is compatible with more specific implementations for energy management, in this case PowerMatcher for energy in the electricity domain. The following picture shows how de devices and their agents can communicate to each other.

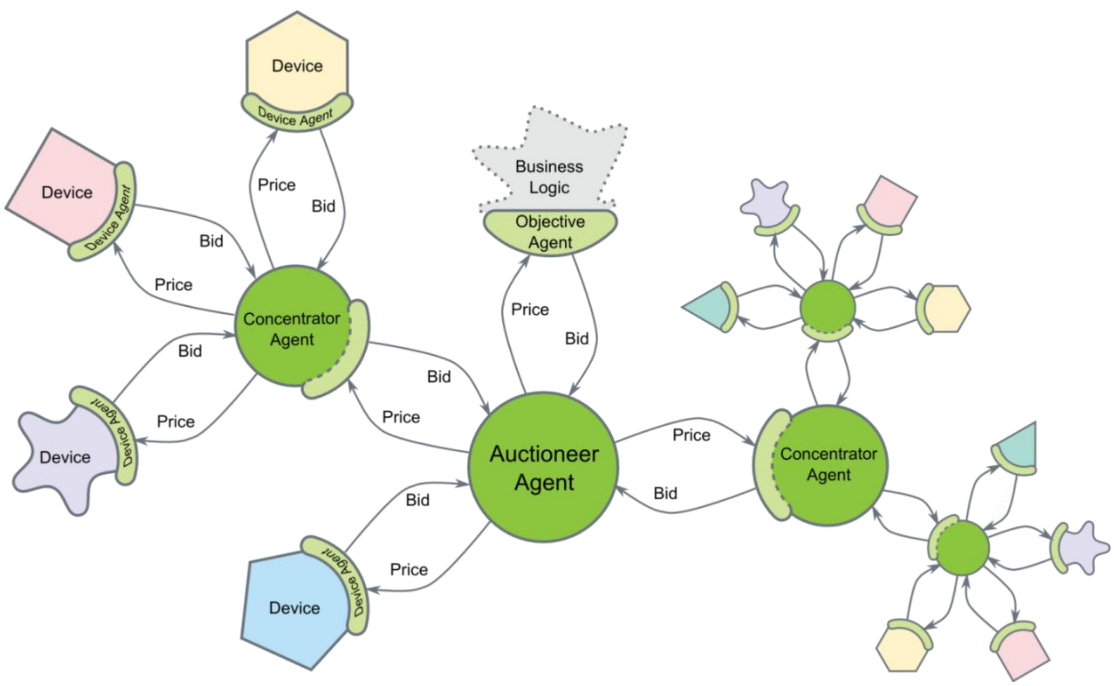



Figure 4-10: PowerMatcher agent architecture and communication

The following picture show the PowerMatcher agents (only the electricity domain, the original environment of PowerMatcher) drawn in the e-hub functional architecture, which shows that this functional architecture fits very nicely with the PowerMatcher technology and its systems architecture and also, its communication protocol, which is bid (availability/requirement) and price (priority) based.

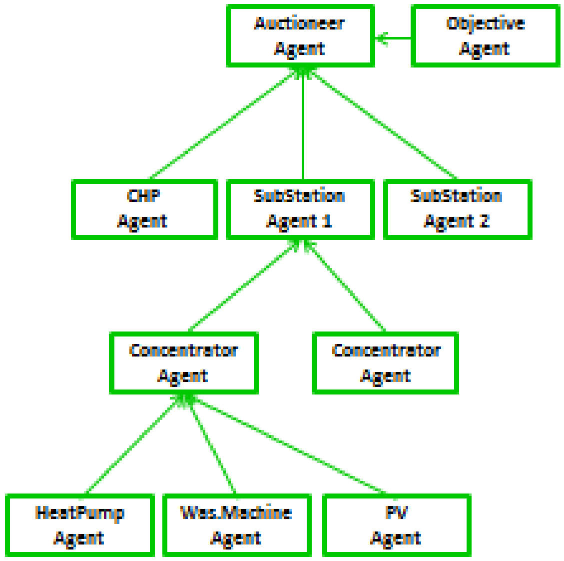



Figure 4-11: PowerMatcher agents drawn in their hierarchy

More information on the PowerMatcher concept can be found in section 5.1 and 5.2.

## 4.3.2 Functional Architecture example on district level mapped to Intelligator

Intelligator technology is a distributed energy/electricity system architecture and communication protocol, which facilitates implementation of standardized, scalable Smart Grids, which can include both conventional and renewable energy sources.

Here we will show that the functional architecture defined above is compatible with more specific implementations for energy management, in this case Intelligator for energy in the electricity domain. The following picture shows how de devices and their agents can communicate to each other.

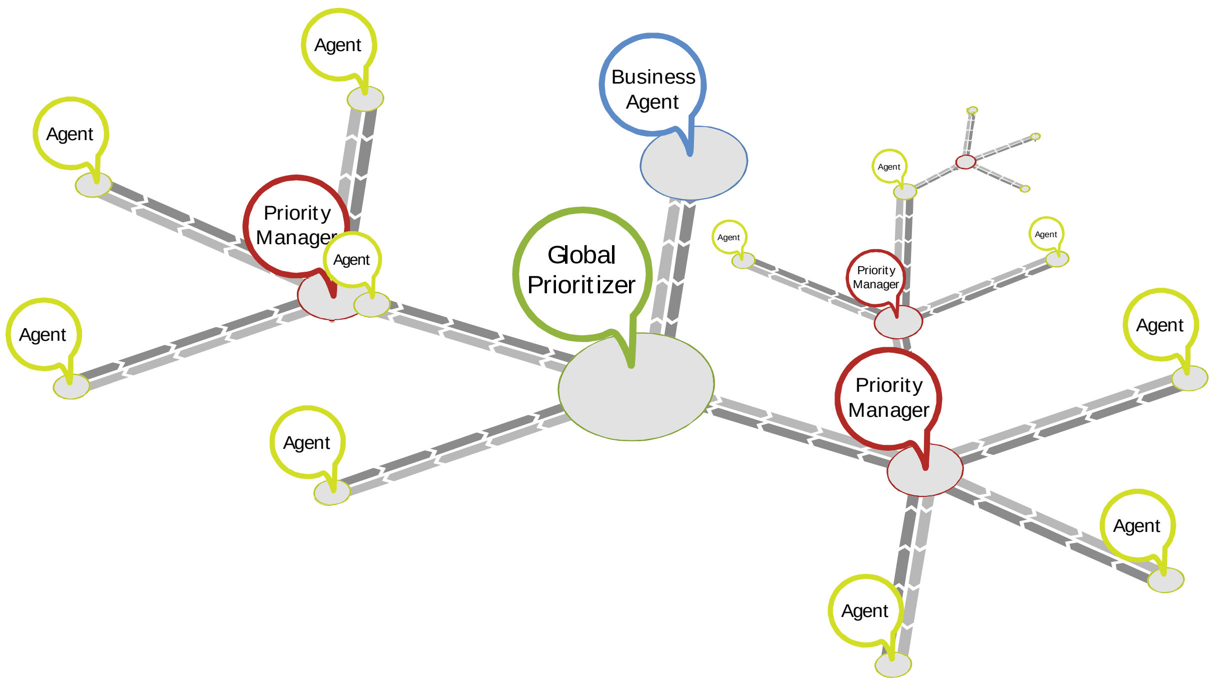



Figure 4-12: Intelligator agent architecture and communication

The following picture show the Intelligator agents (only the electricity domain, the original environment of Intelligator) drawn in the e-hub functional architecture, which shows that this functional architecture fits very nicely with the Intelligator technology and its systems architecture and also, its communication protocol, which is bid (availability/requirement) and priority (price) based.

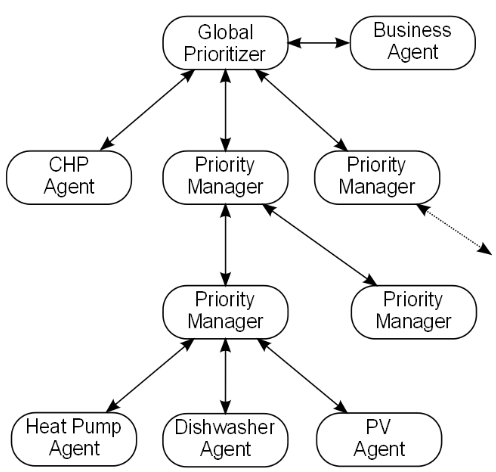



Figure 4-13: Hierarchy of Intelligator Agents

More information on the Intelligator concept can be found in section 5.1 and 5.2.

# 5 Information Data Architecture

Figure 3-1 in chapter 0 shows an overview of all the actors and stakeholders in the e-hub system together with a discussion about their relationships and interactions. This section focuses on the type of information that is being exchanged between these actors themselves and between the different system components.

As an introduction, a general overview of a possible control system concept is given. Two possible implementations are given, e.g. PowerMatcher and Intelligator. Thereafter the high level goals of the overall system are discussed. Although the information exchange is kept as generic as possible, the control concept will have its effect on the type of exchanged data.

## 5.1 Market-based multi-agent control

In order to achieve the goal of controlling and optimizing the electricity and heating system, a market-based multi-agent system (MAS) can be used. More background information on the MAS concept can be found in [27] and [28]. In this concept each participating device is represented by either a consumer, producer or consumer/producer agent. These agents communicate the supply and/or demand needs of each device represented to the market. this is performed through a bid function. The bid function is plotted into a x-y chart, showing the priority in the x-axis, and the power demand/supply in the y-xis. This price/priority represents the willingness of the device to receive or deliver the given power. In other words, the priority may be seen as a kind of artificial price. For example, if the priority of the device is high, the device is willing to pay a high price to get electricity or heat allocated to it. Conversely, if the priority is low, the device is only willing to pay a small price for receiving the requested electricity or heat.

All agents communicate their bid function to a central auctioneer/prioritizer and a price/priority is established where demand and supply of electricity are matched. Each device is then allowed to supply or consume an amount of electricity that corresponds to the price and its bid function.

As an illustration, in Figure 5-1 following agents are shown:

- An agent to represent the heat pump
- An agent to represent the renewable energy source (wind turbine / pv panel)
- An agent to represent a fixed ( uncontrollable) load
- An agent to represent the electricity grid

In this specific case, the heat pump's bid function describes the electricity price/priority of the heat pump agent. In case of a low price/priority the agent will switch the heat pump on. In case of a higher priority the agent will switch it off. In terms of electricity grid, it is only willing to deliver electricity at high priority, as shown in the second graph from the left in Figure 5-1. This ensures that, at low priorities, the heat pump will only switch on when there is sufficient renewable production. This is due to the grid which is not willing to deliver the electricity at these low priorities. Next, the bid function representing the uncontrollable load shows a straight line, this stems from the fact that it needs its power at all priorities. Same applies to the PV/wind production, which is also uncontrollable and thus needs to distribute its power whenever it becomes available. More details about these bid functions are given in section 5.1.1.

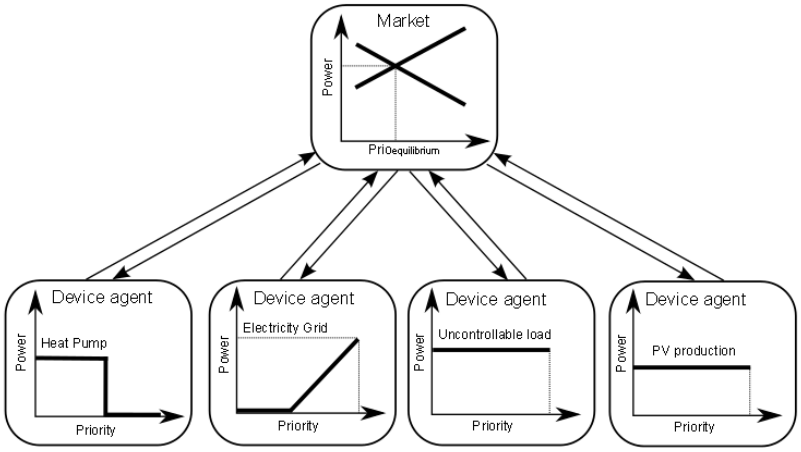



Figure 5-1: Overview of four different bid functions

In Figure 5-1, different agents are connected to the market, where all supply and demand functions are aggregated in order to obtain an equilibrium point. At this point the supply of electricity/heat matches the demand. Based on the priority, $Prio_{equilibrium}$ related to this equilibrium point, the agents will control their device correspondingly. This comes down to switching on all devices which have a higher priority as $Prio_{equilibrium}$ and switching off all devices which have a lower priority as $Prio_{equilibrium}$.

### 5.1.1 Bid curves

As displayed in Figure 5-2 the bid curve represents the demand or supply of the current status of the device. A demand function reflects the urgency of having a certain capacity for a commodity as a demander or the eagerness of supplying this demand as a generator. Within PowerMatcher implementation context, bids have a certain price range. It's worth noting that in this context, the prices are purely artificial, for instance, they are not connected to the market for electricity. In the Intelligator implementation the name price is replaced with priority. However, in this section, only the price terminology is used for simplicity. This section is still analogue applicable to the Intelligator bid functions. Powermatcher/Intelligator systems control electricity, but the same applies for other commodities as heat and cold.

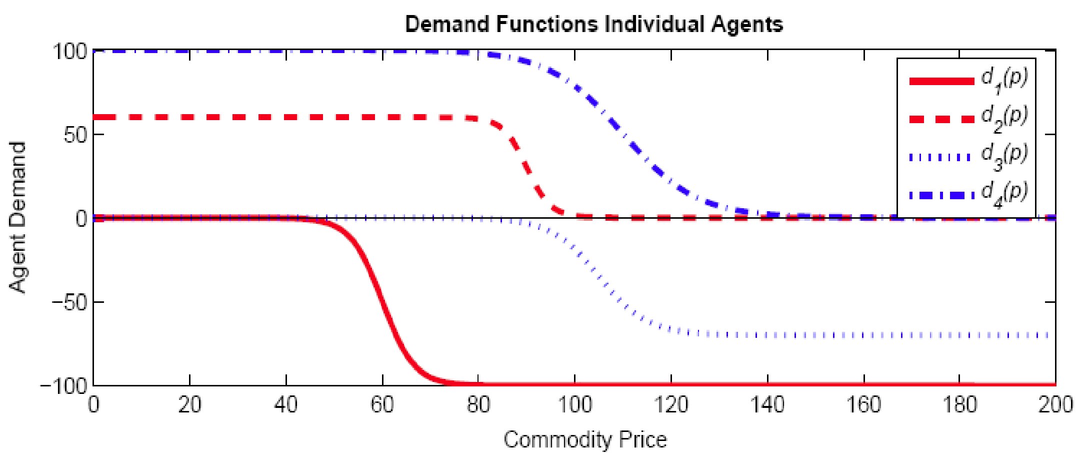



Figure 5-2: Individual bid functions: positive bid functions refer to electricity demand while negative functions refer to electricity production.

The figure above illustrates the demand curve mechanism. In this figure, four demand functions are shown: $d_1$, $d_2$, $d_3$ and $d_4$. The demand and price range are dependent upon the device involved and the application respectively. Curve $d_4$ represents an installation, which gradually stops wanting to buy from 80 price units onwards. At 140 price units, the agent's primary process no longer can afford to buy the commodity. Starting from a wanted capacity of 100 units (e.g. for electricity Watts), it can be seen that there is a gradual decrease in capacity, if the commodity price becomes too high. Curve $d_2$ represents a smaller maximum demand requiring device. The demand articulation, the steepness of the curve when going from maximum to minimum capacity, is more pronounced. Curves $d_1$ and $d_3$ represent two generators having 'negative' demands, meaning production of 100 and 70 units respectively. Demand curves will not always be very smoothly declining or ascending. On/off installation/device types will have discrete graphs. This is also the case for devices, which operate most energy efficiently at full power like heat pumps and micro-CHPs. Must-run devices like solar cells and wind turbines will have horizontal demand curves to be sure to get their production consumed at any price. Finally, storage units like batteries in a electricity context, may deliver curves with consumption power at low prices and production power at high prices.

If a cluster would consist of a device having a demander represented by $d_4$ in the figure and a supplier represented by $d_1$, supply and demand are equal at a commodity price of 80 units. This price, then, would be sent back to the device agents, which on their turn would allocate their maximum power, reconciliating at 80 units after delivery. For the two curves representing a smaller supplier and demander the equilibrium can be seen to be at slightly below 100 units, with only partial allocation.

## 5.2 Comparison between Intelligator and PowerMatcher

This section discusses two different implementations of the market-based multi-agent control concept:

- Intelligator
- PowerMatcher

In particular the differences between the two systems are discussed together with their consequences on the information data architecture. Two main phases can be distinguished in the operation of the systems, namely the start-up phase when the agents register themselves at the system, and afterwards, the normal working phase when the agents exchange bids and allocations with the system. The start-up phase is similar in both systems except for some naming conventions of the different system components. In normal operation however, there is a slight difference in controlling the appliances. The main difference is in the communication details, illustrated in Table 5-1 below.

Figure 5-3 shows an overview of the general information exchanged in both control systems. In this figure, the market shown in Figure 5-1 is hierarchically split into a global market and a local market. The local markets can be seen as the markets per household, apartment etc. which will communicate with a global market on a higher level in the system. This approach enables good scalability and makes it easy to extend existing systems. Apart from the information given in the previous section there is also an extra component shown in this image, which is called the business agent. This component can be seen as an agent, that also will send bids, however these bids are not based on some kind of device status but they are based on the business objective of the system.

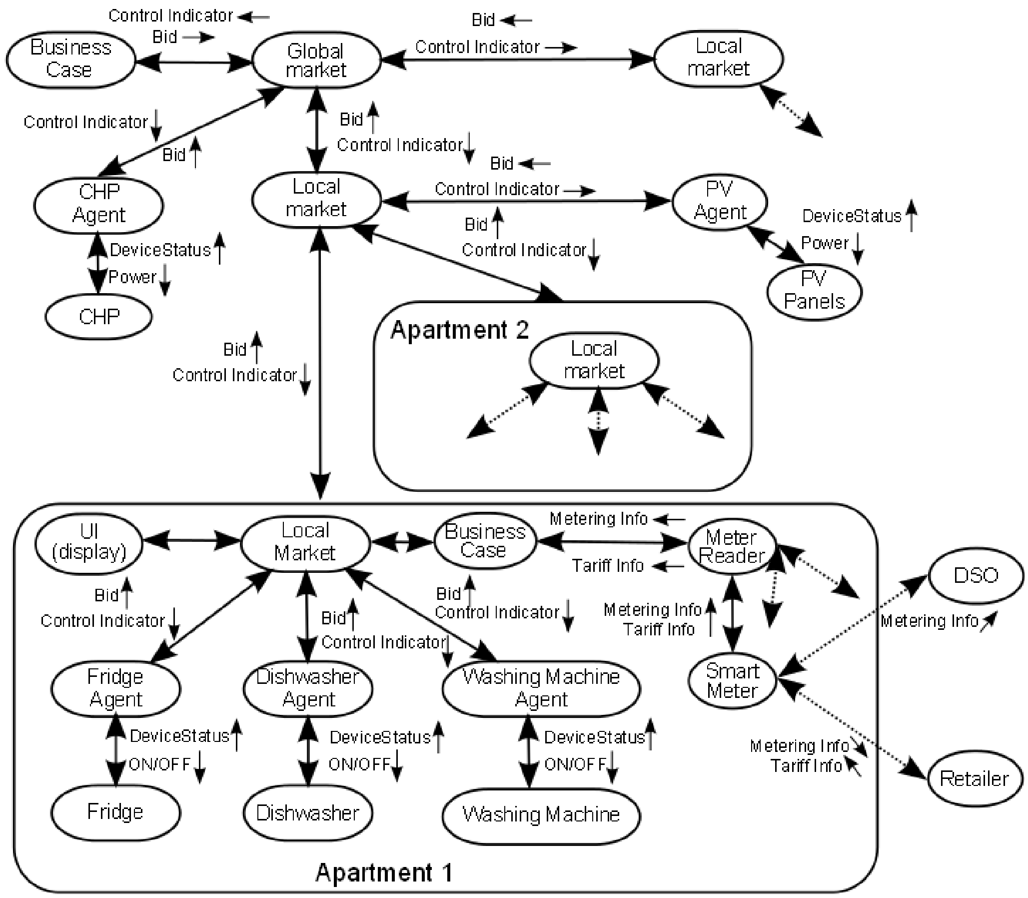



Figure 5-3: General information data flow

Because the actual control of the devices will work differently in both systems, a control indicator message is used in the previous figure. This control indicator is represented by an allocation message in the Intelligator implementation and by a price message in the PowerMatcher system. The following table gives an overview of the major differences - terms in bold – in the implementation between the two systems.

Table 5-1: Differences Intelligator and PowerMatcher

| Description | Intelligator | PowerMatcher |
|---|---|---|
| Naming Conventions | Agent Management System (AMS)<br><br>YellowPages (YP)<br><br>**PriorityManager (PM)** *(Figure 5-3: local market)*<br><br>**Global Prioritizer (GP) )** *(Figure 5-3: global market)*<br><br>**Business Agent )** *(Figure 5-3: business case)* | Agent Management System (AMS)<br><br>YellowPages (YP)<br><br>**Concentrator** *(Figure 5-3: local market)*<br><br>**Matcher/Auctioneer )** *(Figure 5-3: global market)*<br><br>**Objective Agent** *(Figure 5-3: business case)* |
| Bid | Requested Power<br>**Priority** | Requested Power<br>**Price** |
| Message from agent to PM/ Concentrator | Bid<br>• Agent id<br>• Commodity | Bid<br>• Agent id<br>• Commodity |

| | | |
|---|---|---|
| | • Currency<br>• **Price step**<br>• Minimum price<br>• Maximum price<br>• Demand<br>• Bid round id<br>• **Timestamp** | • Price basis<br>  ○ **Price steps**<br>  ○ Minimum price<br>  ○ Maximum price<br>  ○ **Significance**<br>  ○ Currency<br>• Demand<br>• Bid number |
| Message from PM/ Concentrator to agent | **Allocation** *(Figure 5-3: control indicator)*<br>• **Agent id**<br>• **Allocation**<br>• **Bid round id**<br>• Commodity<br>• **Currency**<br>• Price<br>• **Timestamp** | **Price** *(Figure 5-3: control indicator)*<br>• CurrentPrice<br>• Commodity |
| | | |

As shown in Table 5-1, the main difference is situated in the information exchanged between PM/Concentrator and the device agent. As mentioned above Intelligator sends an allocation to the device agents whereas PowerMatcher sends the equilibrium price/priority to the agents. Sending allocations to the agents implies that the device will be switched on/off by PM/Concentrator in contrast with sending prices/priorities to the device agents where the agents will decide, based on the received price/priority, if their device will be switched on/off.

Next a short description is given of the variables which are included in the bid message of the PowerMatcher implementation:

- ***Agent Id:*** is the unique identity of the agent. At agent startup this Id is given to the agent.
- ***Commodity:*** is the name of the 'good' which is traded on the electronic market. Examples of such goods are: "electricity", "heat", "cold";
- ***Pricebasis:*** is included in every Bid message
  - *Price steps, minimum price and maximum price* define the X-axis of the bid curve;
  - *Significance* defines the number of fractional digits in the price;
  - *Currency* is the unit of price, for example "Euro";
- ***Demand:*** is an array of doubles what represents the bid curve;
- ***Bid number:*** that is incremented by the agent at sending a Bid. This bid number is only used for logging purposes.

A couple of differences exist with the 'Bid' message of Intelligator. Intelligator does not send the total number of price steps. Instead it sends the step size of one step. The significance variable is not included in the Intelligator message. However, it does implement a 'Timestamp' which is not included in PowerMatcher. Moreover, the bid round id which is the counterpart of the bid number, is used by Intelligator to check whether the received bid is the most recent one. This is necessary because of the asynchronous type of communication which does not guarantee chronological receipt of messages.

## 5.3 Overall goals and global use case

Figure 5-3 shows the information data flow from the point of view of the smart control algorithm. The smart control will be implemented by an ESP, meaning this information flow can be seen as a part of the information flow between the end user and the ESP. To assess the information architecture, it is helpful to view the system by use case view. The Use case view defines the use cases of the system. A use case defines a scenario from a user perspective, showing how the system is used. In this section a high level global use case is given, which is then split up in several lower level use cases. In the end, a sequence diagram of one lower level use case is discussed.

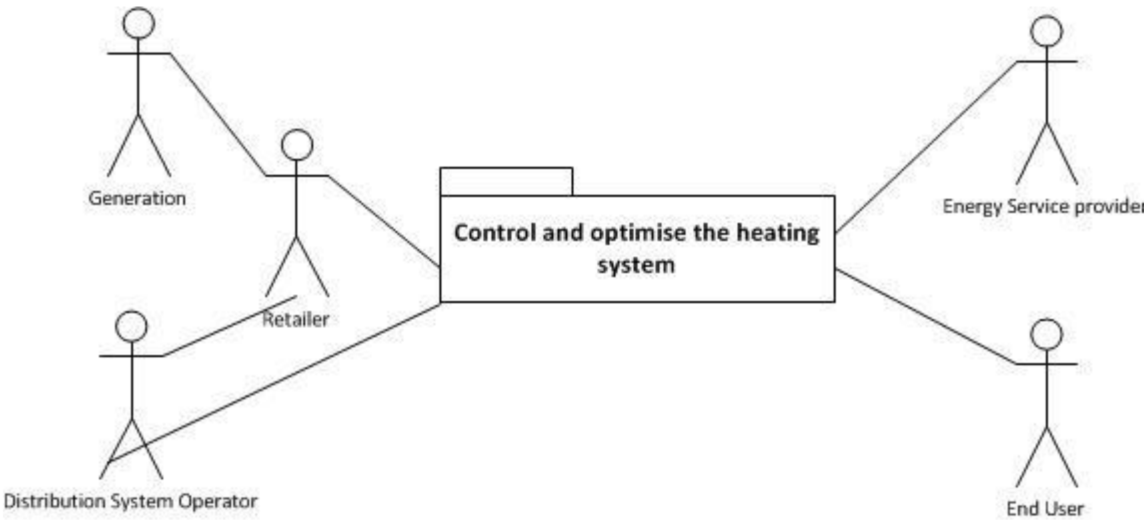



Figure 5-4: High level use case of heating system control

The next figure shows the use case on the highest level for heating according to the conceptual architecture: “Control and Optimization of heating systems”. It refers to keeping the electricity system up and running and optimizing it with respect energy efficiency on district level and cost for in principle each stakeholder. The division of cost reduction between the stakeholders will depend on the settlement between the involved stakeholders.

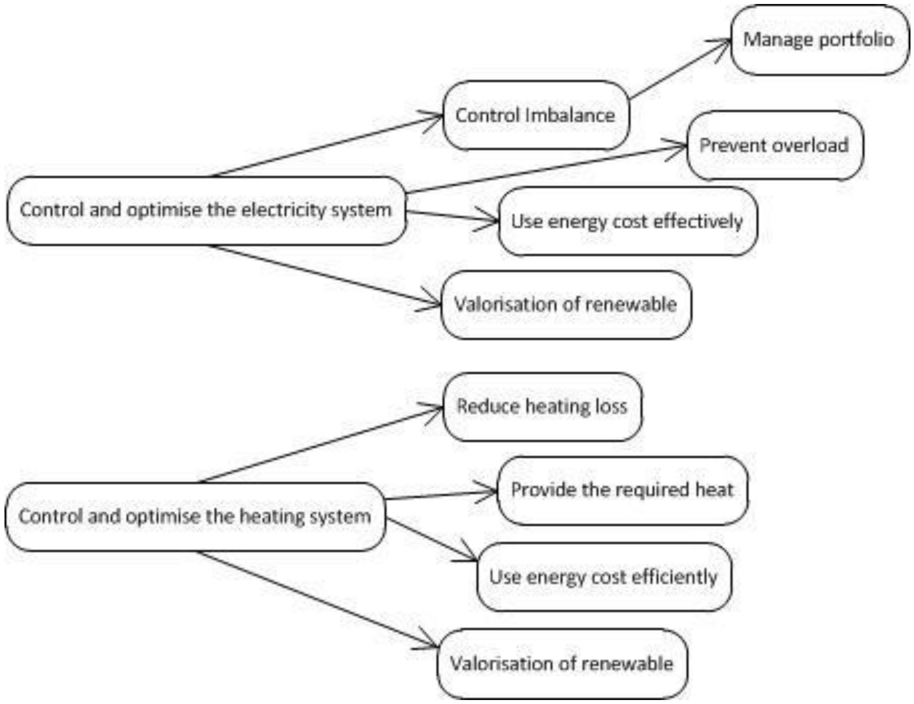



Figure 5-5: Overview of different use cases based on KPI's

Table 5-2: Description of different lower level use cases

| Use Case | Description |
|---|---|
| Control imbalance | Refers to reducing imbalance in the grid |
| Use energy cost effectively | This refers to using energy as cost efficiently as possible by the end user |
| Minimize energy cost for end users | Optimize the consumption/production of the end users to ensure a minimisation of the costs |
| Valorisation of renewables | Use renewable energy as efficient as possible in terms of financial benefit and/or contribution to loss reduction |
| Manage portfolio | This use case refers to optimise exploitation of all generators and consumers in the portfolio of the retailer |
| Prevent overload | Prevent overload of the electrical network |
| Reduce heating loss | Refers to managing heat buffers and flexibility to reduce heat loss in buffers and pipes |
| Provide the required heat | Provide user comfort by supplying the required heat |

As an illustration of a Use Case, Figure 5-6 shows a sequence diagram of preventing overload of the electricity grid by applying smart control to a heat pump. Table 5-3 gives an overview of the different messages which are being exchanged between the actors and system components.

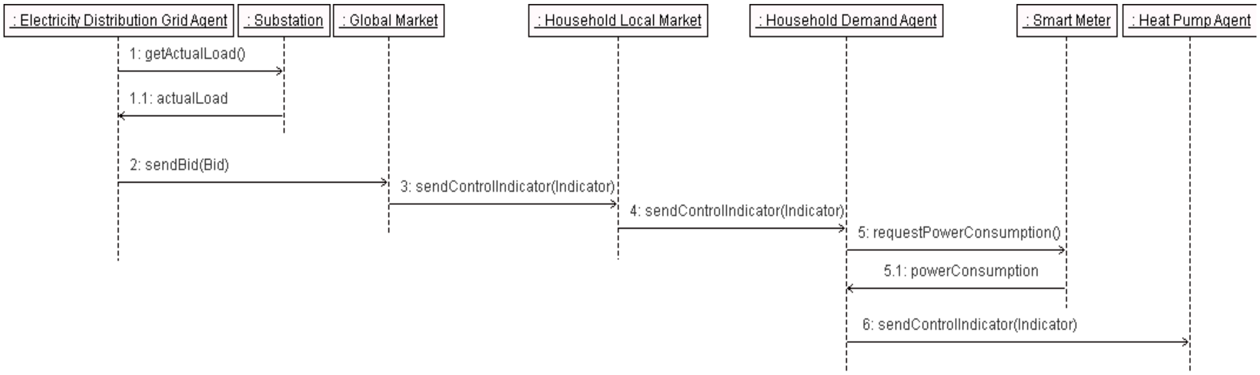



Figure 5-6: Sequence Diagram use case: overload prevention of the electricity grid

Table 5-3: Description sequence diagram messages

| Message | Description |
|---|---|
| **1 – Request Load** | The distribution electrical grid agent interfaces with the substation to request its actual load |
| **1.1 – Load Substation** | The actual load is sent to the distribution grid agent |
| **2 – New Bid** | The distribution grid agent sends a bid to the market |
| **3 – Control Indicator** | The Auctioneer sends a control indicator (allocation or price/priority) to the household concentrator |
| **4 – Control Indicator** | The Household concentrator sends a control indicator (allocation or price/priority) to the Household demand agent |
| **5 – Request electricity use** | The Household demand agent interfaces to the smart meter to request the power consumption of the household (this way the amount of uncontrollable load in the household can be determined) |
| **5.1 – Electricity use** | The Smart Meter sends the power to the Household demand agent |
| **7 – Control Indicator** | The Household concentrator sends a control indicator (allocation or price/priority) to the Heat Pump agent |

Note: Having multiple levels in the system and passing messages over multiple levels is the way to cope with scalability. Via a few of these delegations many (thousands of) devices can be reached.

## 5.4 Information flow

The following sections will discuss the information flow shown in Figure 5-3 based on more concrete and detailed use case examples.

### 5.4.1 Information between device and device agent

The communication between a device and its agent is bidirectional. A device can communicate its status to its agent and an agent can communicate the amount of power which is allocated to the device. The physical control of the device will be based on the allocation it receives from its agent.

The information exchanged from the device to its agent dependents on the type of the device which is controlled. In total nine major types can be distinguished:

- On/Off consumer: a power consuming device which can be either on or off (washing machine, fridge, …). It may have a variable consumption profile, but in terms of control it can only be on or off;
- On/Off producer: a power producing device which can be either on or off (generator, …);

- On/Off consumer/producer: a power producing and consuming device which can either consume or produce energy both at one specific level of power, it can also do nothing and thus is switched off (battery, …);
- Modulating consumer: a power consuming device which has different levels of power consumption (electrical heater, …);
- Modulating producer: a power producing device which has different levels of power production (CHP, …);
- Modulating consumer/producer: a power producing and consuming device which has different levels of power production and consumption (battery, …);
- Uncontrollable consumer: an on/off or modulating consumer which is uncontrollable with regards to the EMS (TV, microwave, …). These devices are not shiftable in time;
- Uncontrollable producer: an on/off or modulating producer which is uncontrollable with regards to the EMS (PV, wind turbine, …);
- Uncontrollable consumer/producer: an on/off or modulating consumer and producer which is uncontrollable with regards to the EMS (PV, wind turbine, …).

Table 5-4: Data exchanged between device and agent

| | Device to Agent | Agent to Device |
|---|---|---|
| **On/Off Consumer/Producer** | Priority<br>Requested Power | Allocation |
| **Modulating Consumer/Producer** | Priority<br>Requested Power | Allocation |
| **Uncontrollable Consumer/Producer** | Requested Power | Allocation |

As an example of interaction between a device and its device agent two use cases are given:

- Programming a smart household appliance
- Configuring a thermostat to keep the indoor temperature between certain boundaries

#### 5.4.1.1 Use case: programming a smart household appliance

Figure 5-7 shows the sequence diagram of the first use case.

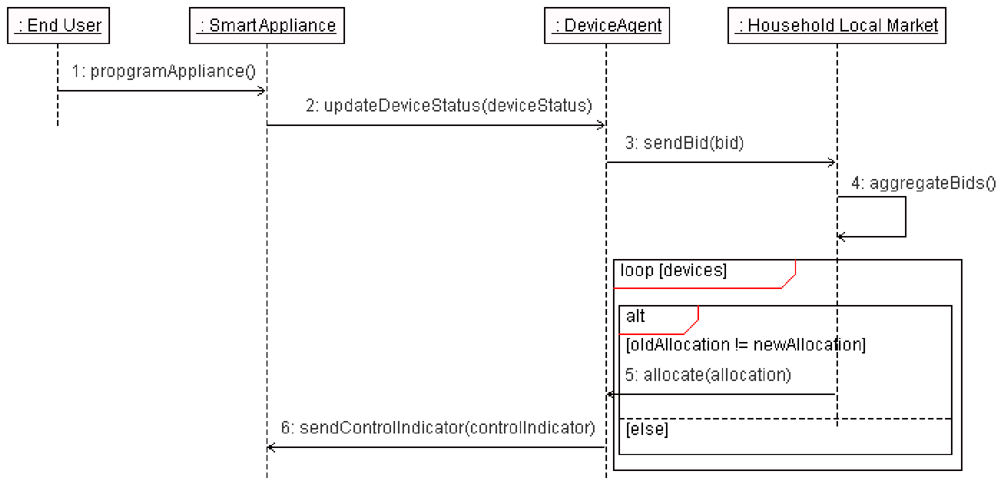



Figure 5-7: Use case 1 - Programming smart household appliance

| **Use case :** | **Programming smart household appliance** | | |
|---|---|---|---|
| **Goal:** | The end user programs a smart household appliance with a certain amount of flexibility in order to participate in the DSM. The appliance will execute its cycle within the predefined boundaries. | | |
| **Summary** | The end user programs a smart household appliance (for example a washing machine) and configures a deadline when it has to be ready. The appliance will participate in the DSM control system and will execute its cycle at a favourable moment, before the deadline has been reached. | | |
| **Main actor** : | End User | **Secondary actor(s)** | DSM control |
| **regular** | 1 – End user sets up the washing program and the deadline when the program has to be finished.<br>2 – The smart appliance pushes its configured device details to its agent.<br>3 – The agent converts this information into a bid function and sends it to its local market.<br>4 – The local market receives this bid curve and calculates a new equilibrium point. Depending on the difference with the previous one, this is also propagated to a higher level market.<br>5 – The local market sends a new allocation to the registered devices based on this new equilibrium point (only when the allocation has changed)<br>6 – As the deadline approaches, the priority of the washing machine increases. A substantial increase of the priority is pushed to the agent which in turn sends out a new bid function to the priority manager.<br>7 – The washing machine's priority is higher than the equilibrium priority and thus the washing machine's agent receives an | | |

| | |
|---|---|
| | allocation.<br>8 – The agent pushes this allocation to the washing machine which will start executing its cycle.<br>9 – The washing machine starts and changes its status to the highest priority because once started it has to finish its cycle at once. This new device status is again pushed to the agent which in turn sends a new bid function to the local market.<br>10 – The washing machine ends its cycle before the deadline has been reached<br>11 – The washing machine's priority changes to 0, this is pushed to its agent which will send a new bidding function to the priority manager |
| **alternative** | |
| **Conditions** | |
| **pre:** | - The smart appliance is connected to an agent which represents its status<br>- The smart appliance agent has to be registered at the DSM control system |
| **post:** | - The device has executed its programmed cycle within the configured boundaries |
| **Exceptions** | |

Use case 1: Programming smart household appliance

### 5.4.1.2 Use case: configuring a thermostat

The sequence diagram is similar to Figure 5-7, but instead of a smart appliance the end user programs a thermostat. When the thermostat is programmed an update will be sent to the device agent. The agent will use this information to compose a new bid function and send it to the local market.

| **Use case :** | **Configure thermostat to keep indoor temperature between the desired boundaries** | | |
|---|---|---|---|
| **Goal:** | Control heat pump so that the indoor temperature in house stays within the configured boundaries | | |
| **Summary** | The ESP receives the set point and indoor temperature from the household thermostat. Based on this information, the bid function related to the heating system is updated. This will result in a new control indicator which will have its effect on the smart control actions which are executed. | | |
| **Main actor** : | End user, ESP | **Secondary actor(s)** | - |
| **Scenarios:** | | | |

| | |
|---|---|
| **regular** | 1 – The interface of the agent representative for the end user reads the thermostats' set point and indoor temperature, and sends these parameter values to the end user agent<br><br>2 –The end user agent updates according to this new information its bid function and sends it to the local market<br><br>3- The local market calculates a new equilibrium (price) and sends the aggregated bid curve to the global market<br><br>4- The global market calculates a new equilibrium point in the heating system<br><br>5- According to the new information more or less heat is delivered in the heating system<br><br>6- Heating devices that are allocated send their information to the ESP |
| **alternative** | - |
| **Conditions** | |
| **pre:** | - Thermostats must be installed at end users<br>- The system must be able to read out the thermostat |
| **post:** | - The temperature in the house is kept between the desired boundaries of the newly set temperature set point |
| **Exceptions** | |

Use case 2: Configure new temperature set point in thermostat

## 5.4.2 Information between device agent and market

Based on the device details, the device's agent creates a bid function which it communicates to the market it is connected to. The market adds all the bid functions it has received and calculates an equilibrium point. Based on this equilibrium point an allocation is calculated for every registered device, this allocation will be sent to its respective device agent. A market (local) can also act as an agent for another market (local or global) which resides one level higher in the hierarchy. In this case the information exchanged is identical to the one of a normal device agent.

Table 5-5: Data exchanged between agent and market

| | Agent to market | Market to agent |
|---|---|---|
| Device agent | Bid | Allocation |
| Market | Bid | Allocation |

As an example of interaction between a device agent and the market, the use case "reducing heating loss by buffers automatically" is described in the next section.

### 5.4.2.1 Use case: Reducing heating loss by buffers automatically

Figure 5-8 shows the sequence diagram of this use case.

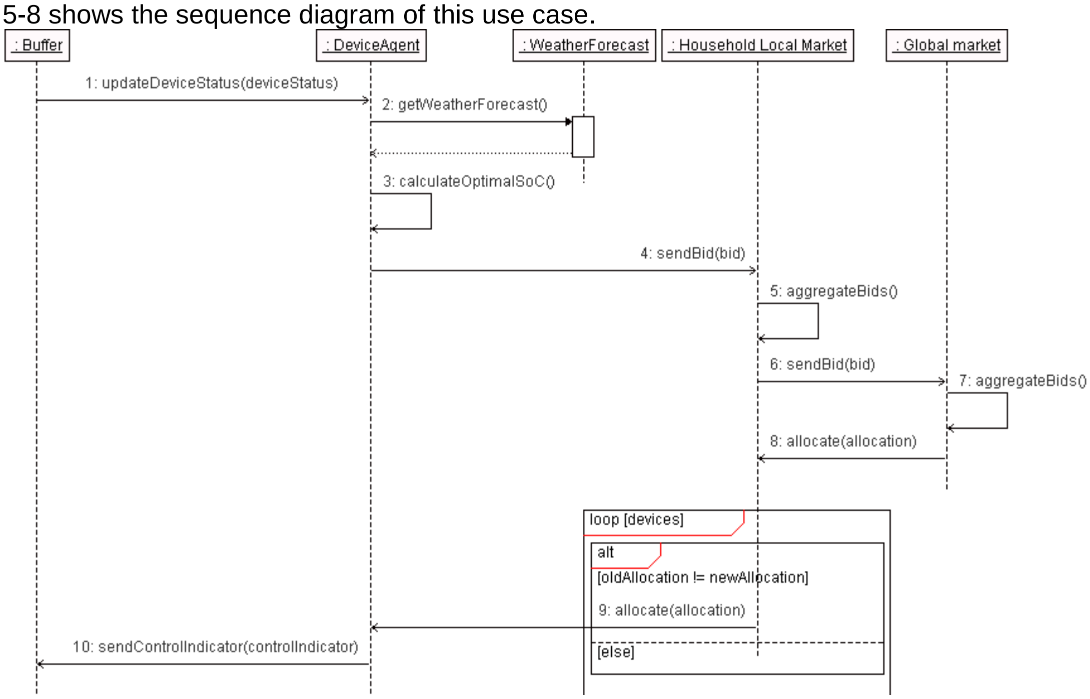



Figure 5-8: Use case 3 - Reducing heating loss by buffers automatically

| Use case : | Reduce heating loss by buffers automatically | | |
|---|---|---|---|
| **Goal:** | Automatic optimization of energy efficiency of heat buffers | | |
| **Summary** | The ESP manages the load of the heat buffers in order to reduce heat loss by the buffers. According to the weather forecast the optimal load of the heat buffer is calculated. Based on this information, the bid function for the heat buffer is updated. This will result in a new control indicator which will have its effect on the smart control actions which are executed. | | |
| **Main actor** : | ESP | **Secondary actor(s)** | End user |

| | | |
|---|---|---|
| **Scenarios:** | | |
| **regular** | 1 – The weather forecast for the current day is retrieved and the expected outdoor temperature and solar radiation are saved.<br><br>2 – According to the expected outdoor temperature and solar radiation an optimal buffer load is calculated<br><br>3 –The buffer updates according to this new information its bid function and sends it to the local market<br><br>4- The local market calculates a new equilibrium point and sends the aggregated bid curve to the auctioneer<br><br>5- The global market calculates a new equilibrium point in the heating system<br><br>6- According to the new information more or less heat is delivered to the buffer<br><br>7- Heating devices that are allocated send their information to the ESP | |
| **alternative** | - | |
| **Conditions** | | |
| **pre:** | - | Weather forecast must be available |
| | - | An algorithm must be present, able to translate the expected weather data to predict an optimal buffer load |
| **post:** | - | The energy efficiency of the buffers is optimized by automatic control of the SoC of the heat buffer |
| **Exceptions** | | |

Use case 3: Automatic heating loss reduction in buffers

## 5.4.3 Information between smart meter and meter reader

On a household level the meter reader will read out the consumption/production and the tariff information from the smart meter. Different components can connect with the meter reader to get this information which is used for example in the automatic control system, to know the exact real-time load, to update the business case agent's bid function, to show the end user his real-time consumption/production behavior, etc. In Figure 5-3, the business case agent is only connected to the meter reader for simplicity.

Table 5-6: Data between smart meter and meter reader

| Smart Meter to Meter Reader | Meter Reader to Smart Meter |
|---|---|
| Consumption/Production data<br>Tariff Information | - |

As an example of the data information exchanged between a smart meter and an ESP the use case "Updating the control strategy based on new information available at the smart meter" is described in the next section.

### 5.4.3.1 Use case: Updating the control strategy based on new information available at the smart meter

Figure 5-9 shows the sequence diagram of this use case.

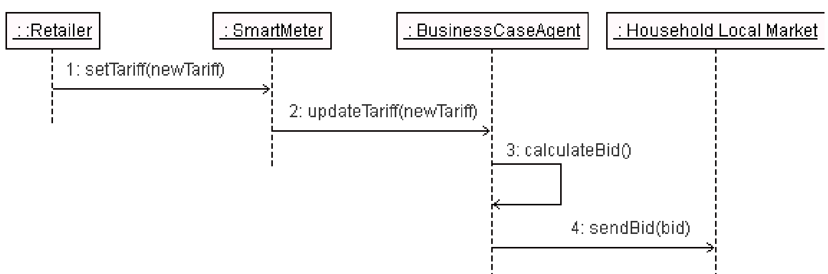



Figure 5-9: Use case 4 - Updating the control strategy based on new information at the smart meter

| Use case : | Updating control strategy based on new information from the smart meter | | |
|---|---|---|---|
| **Goal:** | Take into account new tariff structure and update control strategy accordingly | | |
| **Summary** | The business case agent receives the new information from the smart meter (for example a new tariff). This information is used to update the bid function related to the electricity grid. This will result in a new equilibrium point which will have its effect on the smart control actions which are executed. | | |
| **Main actor** : | Retailer<br>ESP | **Secondary actor(s)** | End user |
| **Scenarios:** | | | |
| **regular** | 1 – The retailer updates the electricity tariff in the smart meter<br>2 – The meter reader polls the smart meter and retrieves the new tariff<br>3 – The meter reader publishes the new tariff information and the business case agent processes this and updates its bid function | | |

| | |
|---|---|
| | 4- A new equilibrium point is calculated at the market and if there are significant changes they will be rippled down to the different local markets on a lower level and eventually will control the individual devices connected to the different local markets |
| **alternative** | - |
| **Conditions** | |
| **pre:** | - Smart meters must be installed at customers<br>- Meter reader must be able to read out the smart meter<br>- Business case agent is subscribed to tariff updates of the meter reader |
| **post:** | - The new tariff has been taken into account by the automatic control system and devices are controlled in relation to this new tariff |
| **Exceptions** | |

Use case 4: Update control strategy based on new tariff in smart meter

### 5.4.4 Information between retailer and end user

The retailer sends invoice information related to electricity and heat consumption/production to the end user.

Table 5-7: Data exchanged between retailer and end user

| Retailer to end user | End user to retailer |
|---|---|
| Consumption/Production data<br>Total price to be paid for electricity/heat | - |

The use case “Sending billing information to the end user” is an example of data exchange between the retailer and an end user and is described in the next section.

#### 5.4.4.1 Use case: sending billing information to the end user

| Use case : | Sending billing information | | |
|---|---|---|---|
| **Goal:** | Retailer sends invoice to customer | | |
| **Summary** | The retailer receives detailed consumption/production data of the DSO about each customer; This information is processed and an invoice is sent to the customer. | | |
| **Main actor** : | Retailer and end user | **Secondary actor(s)** | DSO |
| **Scenarios:** | | | |
| **regular** | 1 – The DSO sends detailed consumption/production data of all customers of the retailer to that retailer<br>2 – Retailer processes this information and creates an invoice for every customer<br>3 – The invoice is sent to the customer | | |
| **alternative** | - | | |
| **Conditions** | | | |
| **pre:** | - The DSO has read out the meter of the customer | | |
| **post:** | - An invoice has been sent to the customer | | |
| **Exceptions** | | | |

Use case 5: Sending invoice information

### 5.4.5 Information between ESP and Retailer

An ESP can deliver different services. Depending on the service the ESP delivers, the information exchange between the ESP and the retailer will also be different. For example, if the ESP delivers a smart DR control system, the retailer will inform the ESP with information on the intended objective of the DR. If the ESP is not granted to read out the smart meter it can also receive this information by the retailer.

Table 5-8: Data exchanged between ESP and retailer

| | ESP to retailer | Retailer to ESP |
|---|---|---|
| **ESP (Smart DR control system)** | - | Information on the intended DR objective (Metering information) |

As an example of the information exchanged between the ESP and the retailer the use case “Changing demand response objective” is described in the next section.

#### 5.4.5.1 Use case: changing demand response objective

The sequence diagram shown below is similar to the one in 5.4.3.1 except the tariff change is replaced by a change in demand response objective.

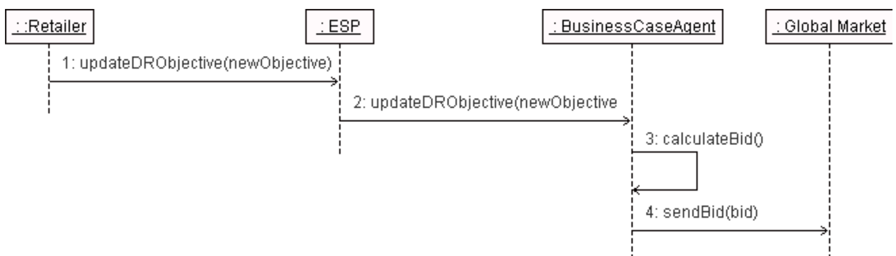



Figure 5-10: Use case 6 - Changing demand response objective

| **Use case :** | **Changing DR objective** | | |
|---|---|---|---|
| **Goal:** | Retailer changes its DR objective | | |
| **Summary** | The retailer informs the ESP with new information regarding the DR objective (e.g. because of a possible overload the DSO will give a new DR objective). The ESP updates its business case in the automatic DR control system which will take these into account immediately. | | |
| **Main actor** : | DSO, ESP | **Secondary actor(s)** | - |
| **Scenarios:** | | | |
| **regular** | | 1 – The retailer sends information on the new DR objective to the ESP<br>2 – The ESP processes this information and changes the bid function of its business case agent according to this newly received information<br>3 – The new bid function is sent to the market by the business case agent<br>4 – A new equilibrium point is calculated at the market and if there are significant changes they will be rippled down to the different | |

| | | |
|---|---|---|
| | local markets on a lower level and eventually will control the individual devices connected to the different local markets | |
| **alternative** | | |
| **Conditions** | | |
| **pre:** | - | All the devices which will participate in the automatic DR control system have to be registered at one of the markets |
| **post:** | - | The new DR objective has been taken into account by the automatic control system and devices are controlled in relation to this new goal |
| **Exceptions** | | |

Use case 6: Changing DR objective

## 5.4.6 Information between ESP and end user

In case the ESP delivers a smart DR control system all the information, configured by the end user to let devices participate, indirectly flows from the end user to the ESP. In return the ESP for example can provide real time information to the end user regarding his take-off or injection behavior and information on the smart DR control actions which are taking place.

Another scenario is that the ESP only does an optimization on a higher level in which it does not provide information on DR actions taking place on a household level because in that case the ESP is not responsible for the actions on the lower level.

Table 5-9: Data exchanged between ESP and end user

| | ESP to end user | End user to ESP |
|---|---|---|
| **ESP (automatic DR control system)** | Real-time information on consumption/production data<br>Real-time information on automatic DR actions taking place etc. | Details of devices configured to participate in the automatic DR control |

As an example of interaction between the ESP and the end user the use case "Displaying real-time information on automatic control actions taking place" is described in the next section.

### 5.4.6.1 Use case: displaying real-time information on automatic control actions taking place

This can be realized by summarizing all control signals on a display which can also show the actual and historic power consumption/production etc.

| **Use case :** | **Display real-time information on automatic control actions taking place** | | |
|---|---|---|---|
| **Goal:** | Inform the end user about the automatic control actions currently on-going | | |
| **Summary** | The ESP shows the end user detailed information on his production/consumption behaviour together with information regarding the currently on-going automatic control actions. | | |
| **Main actor** : | DSO, ESP | **Secondary actor(s)** | - |
| **Scenarios:** | | | |
| **regular** | | 1 – The DSO sends information on the new DR objective to the ESP<br>2 – The ESP processes this information and changes the bid function of its business agent according to this newly received information<br>3 – The new bid function is sent to the market by the business case agent<br>4 – A new equilibrium point is calculated at the market and if there | |

| | |
|---|---|
| | are significant changes they will be rippled down to the different local markets on a lower level and eventually will control the individual devices connected to the different local markets<br>5- The executed control actions are shown on a display which is placed in every apartment. Together with these actions also a real-time representation of the consumption/production data of the end user can be found on the display. |
| **alternative** | |
| **Conditions** | |
| **pre:** | - All the devices which will participate in the automatic DR control system have to be registered at one of the priority managers<br>- The meter reader must be able to read out the smart meter<br>- A display has to be in place and has to be connected to the DSM system in order to show the desired information |
| **post:** | - The display shows the end user detailed information on his production/consumption behaviour together with information regarding the currently on-going automatic control actions. |
| **Exceptions** | |

Use case 7: Display real-time information on automatic control actions taking place

# 6 Information Security Architecture

This chapter describes the information security architecture of the e-hub control platform, the basis of the e-hub Energy Management System. The overall architecture is defined to assure the interoperability of the different components of the district system and to enable implementation of user requirements. The goal of the security architecture is to describe the security controls (security countermeasures), how they are positioned, and how they relate to the overall architecture. The controls serve the purpose to maintain the system's quality attributes such as confidentiality, integrity, availability, accountability and assurance. . This chapter presents a first iteration, not a full fledge it security architecture.

In order to get better understanding of this energy management system and the required security controls, we need to get an understanding of several aspects of it. In the following subsections these aspects are briefly described.

This chapter starts with an analysis of the e-hub Energy Management System, and identifies the most important risks to be mitigated, and concluding with a list of architecture guidelines for the E-hub Energy Management System.

## 6.1 Analysis

### 6.1.1 The Objective

The objective is to define an architecture, implement and test an energy management system to be used to manage energy neutral or low energy districts.

### 6.1.2 Data and Lifespan of the data

The e-hub project, and the energy management itself is to be applied in a demonstration environment 'TweeWaters'. Data about the current or historical energy consumption of individual households can be tagged as sensitive data that should be protected from unauthorized access.

### 6.1.3 Performance requirements

The performance requirements of the energy management system can be described as: near-real-time ability to control devices managed by the system, and near-real-time insight in the operational status of the system.

### 6.1.4 Security goals

The security goal for the architecture of the energy management system is to increase availability of data without compromising a confidentiality baseline. In other words: demonstrations (via internet) of the system and remote access for engineers may be enabled while access to data and control of individual households and devices is restricted.

### Security risks

This paragraph gives a qualitative overview of the most important security risks (described in terms of threats and impacts) of the energy management system. In this case, risk is analysed by qualitatively describing the likelihood of the threat, and the amount of impact. Each of the following tables, describes a specific risk, and discusses the threat, impact, likelihood of occurrence and possible mitigation.

Table 6-1: Lack of scalability

| | |
|---|---|
| **Title** | Lack of scalability |
| **Threat** | Lack of scalability. System performance is dependent on the number of households or devices. The number of households in 'TweeWaters' exceeds 1000. |
| **Likelihood** | A newly developed system is traditionally more vulnerable to scalability |

| | |
|---|---|
| | issues. It is relatively straightforward to test for possible scalability issues in advance. |
| **Impact** | System performance drops below acceptable thresholds. This could result in malfunctioning of heat/electricity control algorithms |
| **Mitigation** | Make use of decentralized (control-loop) architecture. If possible make use of independent operating areas. Include scalability/performance testing phase before deployment in practice. |

Table 6-2: Exposed control interfaces

| | |
|---|---|
| **Title** | Exposed control interfaces |
| **Threat** | Control interfaces of heat/electricity producing/consuming devices could be exposed to 'public' networks, for instance the Internet. Devices could become available for operation by unauthorized parties. |
| **Likelihood** | For systems to be used in the e-hub project (with many stakeholders) it is very practical to have high availability for research, demonstration, piloting purposes. Coupling to public computer networks is therefore very likely. |
| **Impact** | Negative publicity of the project and project members. Malfunctioning of control system. Increased energy/electricity costs. |
| **Mitigation** | Make use of access control mechanisms. Consider if coupling to public networks is really needed. If this is the case use of security systems, such as firewalls and virtual private networks and use different zones for specific purposes (demonstration, remote access, …) |

Table 6-3: Affected privacy

| | |
|---|---|
| **Title** | Affected privacy |
| **Threat** | The log-data of energy management system is available to unauthorized parties. |
| **Likelihood** | For systems to be used in the e-hub project (with many stakeholders) it is very practical to have high availability for research, demonstration, piloting purposes. Coupling to public computer networks is therefore very likely. |
| **Impact** | (log)-data of energy management systems may contain very privacy sensitive information. For instance consumer behaviour could be derived from this data. This can lead to various forms of undesired activities: from unsolicited offers, burglary. The potential threat may give consumers a general feeling of unsafety. Negative publicity of the project and project members |
| **Mitigation** | Don't store data which is not needed. Minimize or avoid coupling to public networks. Use a security infrastructure with zones which can be used for different purposes. Anonymization of data so that it is impossible to link data for individual households/consumers. |

Table 6-4: Unfriendly users

| | |
|---|---|
| **Title** | Unfriendly users |
| **Threat** | (end-)-Users of the energy management system make use of the system for other undesired activities (testing, stressing the system) than originally intended. |
| **Likelihood** | If the population of (end-) users of the energy management system is large enough, the probability increases that some of these end-users will investigate the possibilities, and limits of the system. In a more or less controlled pilot environment with a limited amount of users, this threat is unlikely to occur. |
| **Impact** | System instability. Failing functionality of the energy management system for other users. Increased costs. |
| **Mitigation** | Use physical security on devices (in-house devices or devices, computers in the building). Store computer systems in a separate and locked room. Limit the functionality of in-house devices. Make use of security zones so that an impact of on occurred incident is limited. |

## 6.2 Architecture guidelines

Based on the analysis and the overview of risks in the previous subsection, a number of architecture guidelines can be distilled for the e-hub energy management system. These guidelines are briefly discussed in the sections below.

### 6.2.1 Use a zoned network infrastructure

Make use of a zoned network infrastructure, where each zone provides a network for a specific group of devices. The zones are separated from others by means of network security devices like firewalls. An example of a zoned network infrastructure is depicted in the following graph where a firewall separates four different zones.

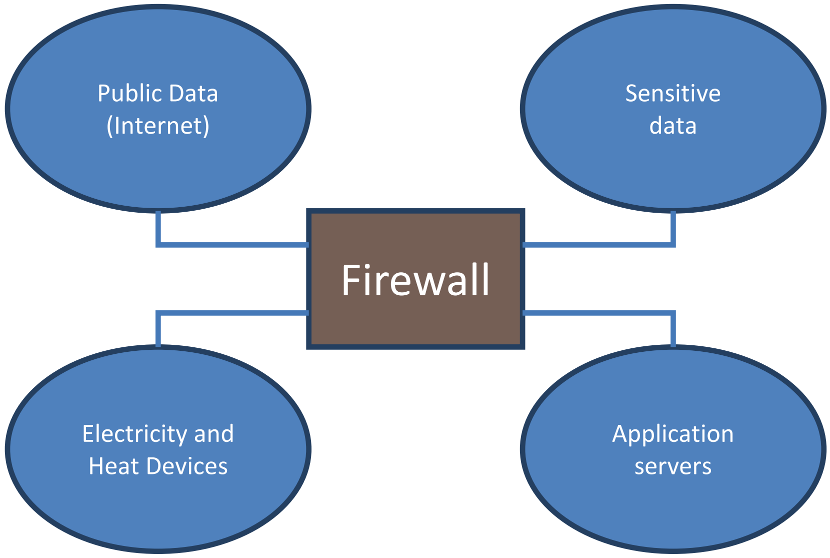



Figure 6-1: Zoned network architecture

### 6.2.2 Use a decentralized architecture

For a system such as the e-hub energy management system it is important to consider a decentralized architecture in order to prevent scalability and performance issues. This means that control-loops should operate in a local area without direct control by a master system.

### 6.2.3 Anonymize data

For the e-hub energy management system it is important to investigate and to consider if the system can operate successfully with anonymized data (that is not linked to a specific user or household).

### 6.2.4 Make use of Physical security

A lot of components in the e-hub energy management system are located at or nearby the location of physical users. Electricity and heat-devices and their control systems must be physically secured from unauthorized access.

# 7 Performance evaluation

## 7.1 e-hub EMS KPIs and initial test plan

In the original task description of task 4.1 it was mentioned that the performance of the overall architecture of the Energy Management System (EMS) would be evaluated for the different grids. But performance of an architecture is not what we can and want to evaluate in this early design phase. We want to evaluate the performance of the EMS itself (see also deliverable 1.4 "Energy Rating System and Evaluation Methodology"), which will be designed in task 4.3 with the necessary algorithms. Therefore we limit ourselves in this chapter to the e-hub EMS KPIs and propose an initial test plan, that will be executed later in WP4 (e.g. task 4.5) but also WP5 (e.g. task 5.5).

## 7.2 e-hub EMS KPIs

Different Key Performance Indicators (KPIs) can be useful to measure, depending on aspects (derived from D1.4) like energy, technical, ecological, economical, operational, implementation and end-users. The KPIs act as an measurement tool to investigate the fulfillment of certain requirements. For instance, the user requirement "reducing energy consumption" could be checked by analyzing the KPI "energy consumption".

Energy related KPIs

- Energy Consumption [kWh Electricity, Gas, Heat, Cold)
- Energy loss by storage [kWh]

Ecological related KPIs

- Renewable energy consumed in E-hub system [% of total Energy]
- CO2 reduction [%]
- Amount of primary energy consumption reduction [%]
- Efficiency of renewable energy systems [%], due to adaptation of the demand to renewable supply energy can be lost in for example heat buffers.

Economical related KPIs

- Energy System Cost [€/year]
- Energy Unit Cost [€/kWh]
- Investment cost [€]
- Payback time (ROI) [y]
- Maintenance cost [€/month]

Operational related KPIs

- Reliability [MTBF]
- Availability [%]
- Service life [year]

Technical and implementation related KPIs

- Peak power, peak heat [W]
- Savings on installations [€]
- Amount of communicated data required [bps]

End-users related KPIs

- Comfort [Predicted Percentage of Dissatisfied (PPD)]
- Temperature deviation from target [°C]
- Flexibility: amount of electricity (energy) shiftable; amount of time shiftable [kWh;h]

## 7.3 e-hub EMS initial test plan

We want to evaluate the performance of the EMS by testing it under different external circumstances with different types and or algorithms of the EMS. This testing of the system will be done in the simulation phase. Different types and or algorithms of the EMS can be (pending the outcome of task 4.3):

- EMS that only reacts on target temperature and electricity demand, so without taking flexibility into account (conventional control)
- EMS that not only reacts on target temperature and electricity demand, but also taking flexibility of the heat (e.g. earlier heating) and electricity (e.g. delayed start of washing machines) into account. This EMS will use basic Supply Demand Matching (SDM) techniques.
- EMS that besides basic demand and system flexibility, also takes energy demand forecasts into account, for example based on weather and day of the week. We could call this also predictive Supply Demand Matching.

Testing the EMS under different external circumstances, we consider here mainly the seasonal periods like:

- Winter: Due to lower temperatures there will be a higher electricity and heat demand therefore heat pumps will run frequently as well as CHPs.
- Spring/Autumn: average electricity demand, and lower heat demand, some solar energy available.
- Summer: low heat demand, probably some cooling demand, solar energy available.

A test period of 9 months covering 3 seasons (winter, spring, summer or summer, autumn, winter) will enable the testing the EMS in different seasons. To exclude effects of a single specific day of the week all tests need to run for at least 1 whole week. This results in 13 weeks for testing the different types and or algorithms of the EMS. One week for testing the conventional control (to set a measuring base line), 4 weeks for testing variations of control including use of flexibility (for different optimization targets like energy or CO2 or economic), 4 weeks of control including use of forecasting and flexibility. This leaves 4 weeks spare for rerun of tests that failed or where conditions were not according to the test specification (e.g. a warm week in winter). Per test we want to measure several KPIs. The most important ones will be: Energy Consumption, CO2 reduction, Energy System Cost, Comfort, Energy Unit Cost, and percentage of renewable energy consumed in E-hub system.

Several other KPIs cannot be measured in tests since they depend on the overall system implementation, which will be specific per test site. These can be evaluated or simulated in an earlier phase (e.g. in task 4.5 Simulation of scenarios) by comparing the KPIs for different implementation alternatives taking as starting point the outcome from WP2 (WP2 suggest possible implementation alternatives for each model district). The KPIs that should be evaluated are: Investment cost, Maintenance cost, Payback time, Service life, Reliability, Availability, Peak power, Peak heat, Savings on installations (due to a better EMS some components can probably be designed with a lower peak power). Of course the KPIs that can be measured should also be simulated and evaluated before making the system implementation choice.

# 8 Communication architecture

Looking at the communication architecture there are many options available today to implement a communication network. And although from architectural and engineering viewpoint we may advocate one homogeneous communications network – and even one data model at information level - in reality it will be a heterogeneous network with different communication protocols. At system level it will be a system of different systems, at network level it will be network of networks. Inherent to communication this means that interoperability at the level of communication and information is one of most important requirements for sharing data.

## 8.1 Interoperability

For communications architecture to be future proof, particularly on the aspect of interoperability, it is of utmost importance that the architecture is designed with the current EMS standards for smart grids in mind. Energy management on district level is part of the overall smart grids and will have some kind of interaction with the major stakeholders of the smart grid. Currently a lot of standardization work on Smart Grids, micro grids included, is going on. Standardization organizations all over the world like IEC, ANSI, NIST, CEN/CENELC/ETSI, IEEE etc. are working on a Smart Grid reference architecture and the associated standards. In accordance with the standardization mandate M/490 on smart grid standardization the European standards organizations will have a first set of results available before the end of 2012. In addition to these standards organizations a lot of industrial alliances and workgroups are working on specifications regarding technologies and solutions they want to promote. Many of these proposals may in the end be integrated in the standards.

Be aware that standards are not mandatory unless mentioned this way in the countries legislation. A different way to come to an open architecture can be by means of open interfaces. These interfaces, be it protocols or application programming interfaces, specify at different levels how two or more elements (programs) interact, making it easy for programs to share functionality or content.

It is not the intention to list all smart grid standards regarding communication in smart or micro grids, or all communication technologies that can be used for constructing such a network. The most important ones relevant to this architecture will be mentioned in the following subchapters. A very well overview of the smart grid standards and even gaps in the current set of standards can be found in the following roadmaps of the standardization organisations:

- JWG report on standards for smart grids [1]
- IEC Smart Grid Standardization Roadmap [2]
- Draft NIST Framework and Roadmap for Smart Grid Interoperability [3]

The EMS ICT architecture must be designed it can handle:

- Different communication technologies. New communication technologies may emerge and it must be possible to integrate these technologies into the architecture with minimal effort. Abstraction layers and adaptors is one of several techniques to tackle this.
- Different information models used throughout the system. If for the control communication one information model isn't possible (due to the fact control systems with different information models may have to be integrated), translation functions have to be foreseen. One can translate between several models or one can translate all models to one common model.

## 8.2 Building management standards

One of the components the district EMS will interact with is the building management system if available. This system can be a small system, for instance a home automation system or energy management box with some limited EMS functionality. Or it can be a complex building system with a highly integrated EMS.

In the EN standards these systems are known as Building Automation and Control System (BACS) and Technical Building Management (TBM). These systems have impact on building energy performance in many aspects. BACS provides effective automation and control of heating, ventilating, cooling, hot water and lighting appliances etc., that leads to increase operational and energy efficiencies. Complex and integrated energy saving functions and routines can be configured on the actual use of a building depending on the real user needs to avoid unnecessary energy use and CO2 emissions. Building Management (BM) especially TBM provides information for operation, maintenance and management of buildings especially for energy management - Trending and alarming capabilities and detection of unnecessary energy use.

The first standard looked at is the EN 15232 standard [11] and is one of a series of European standards that focus on calculating the energy efficiency of the technical installations of a building such as heating, cooling, lighting and ventilation systems. Besides a complex and a simplified method to calculate the impact of a BACS on the energy performance of a building it also specifies a list of building management functions which have an impact on the energy performance of buildings.

Main classifications of BACS refer to architectural topology and infrastructure:

1. centralized, if a control unit supervises the whole system;
2. distributed, if sensed information is locally processed by autonomous controllers, each supervising specific appliances and/or areas;
3. mixed, i.e., peripheral controllers are able to acquire and process information for groups of devices while a central building supervising unit acts as coordinator among local controllers.

The main building management standards are briefly described in the next table and further developed in Annex A.

Table 8-1: Existing building management standards

| Standard | Description |
|---|---|
| **EN 15232:2007: Energy performance of buildings** | The aim of this standard is to support Directive of Energy Performance of Building (EPBD) to enhance energy performance of buildings in the member states of EU. Standard EN15232 specifies methods to assess the impact of BACS and TBM functions on the energy performance of buildings, and a method to define minimum requirements of these functions to be implemented in buildings of different complexities. |
| **ISO/IEC 14543: KNX** | KNX is a standard for applications in home and building system technology and controls the heating, lighting, blinds, ventilation, security technology, audio/video and numerous other functions. |
| **ISO/IEC 14908: LonWorks** | LonWorks control networking technology was formally approved as ISO/IEC 14908, parts 1, 2, 3, and 4 by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). These specifications apply to the communication protocol and associated transport channels for networked control systems in commercial Building Automation, Controls and Building Management. |
| **ISO 16484-5: BACnet** | BACnet is an open multi-vendor data communication protocol that allows various automation and control components in a building to communicate with each other, ensuring interoperability and manufacturer independence. |
| **ZigBee Building Automation & Home Automation profiles** | ZigBee Building Automation provides the commercial building industry with a global standard for interoperable products and enables secure and reliable monitoring and control of a variety of building systems. |

## 8.3 Smart grids standards

This information is primarily based upon [1], [2] and [3]. It is not the intention to repeat the content of these roadmaps in this chapter, but only to give a high level overview. The documents and the standards referred to should be consulted for detailed information.

### 8.3.1 The information model:

From the viewpoint of Smart Grid, highly interoperable communication between all components is the major goal of smart grid communication. This means that the communication shall be based on a common semantic (data model), common syntax (protocol) and a common network concept. Therefore a convergence and a harmonization of subsystem communication should be pursued. Referring to the OSI stack the information model can be viewed as the presentation and the application layer of the stack describing the entities interacting at application level, the representation of these entities and of the exchanged data. The communication layer represents protocols and mechanisms for the exchange of information between components.

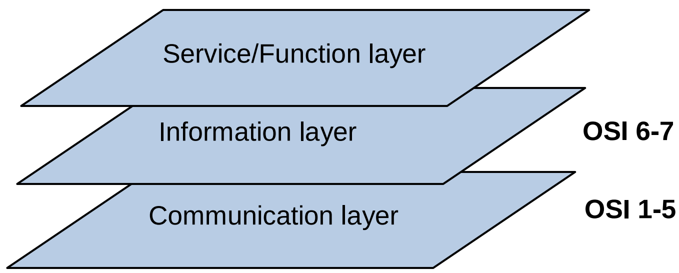



Figure 8-1: Service, Information and communication layer

The representation of the entities that interact within or between subsystems is mandatory for ensuring a required level of interoperability. The role of information models is to ensure this. Several data models for the smart grid have been and are still being defined. Among which:

- General-purpose models such as the IEC 61970, IEC 61968 Common Information Model (CIM)
- Specific models addressing a particular application domain such as:
    - This IEC 61850 model includes object types representing nearly all existing equipment and functions in a substation.
    - ANSI C12, IEC 61850 (partly), DLMS and COSEM for smart metering
    - SAE J1772, J2847-1 work , ISO/IEC 15118 for interaction with electrical vehicles
    - Other models

A critical issue is the coherence of data models and the risk of too specific models leading to silo-ed applications. It is even more complicated when different organizations have defined in parallel similar models for the same range of applications. The Information Architecture must rely on precisely identified standards. The consistency of the Information Model should be guaranteed by an appropriate mechanism for re-aligning separately developed (and possibly diverging) models.

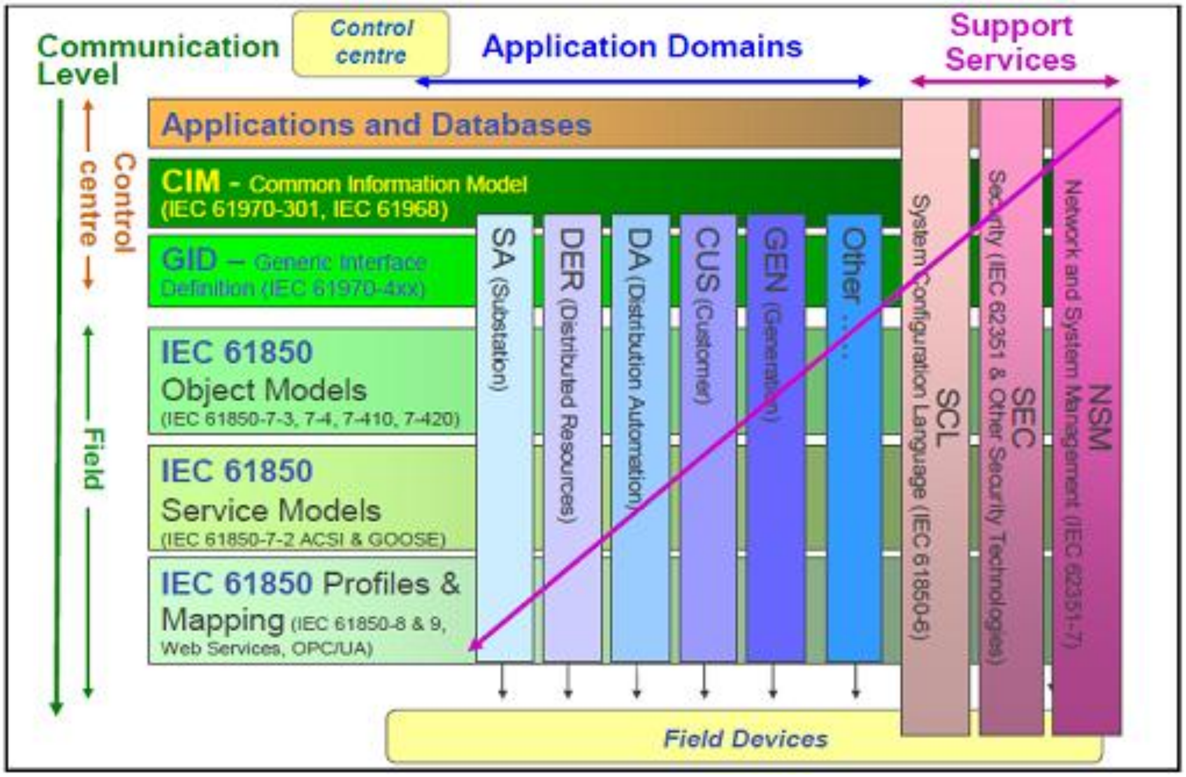


Figure 8-2: IEC 61850 models and the Common Information Model (CIM)

The core standards according [2] include:

- IEC/TR 62357 – Framework of power automation standards and description of the SOA
- (Service Oriented Architecture) concept
- IEC 61850 – Substation automation and beyond.
- IEC 61970 – Energy Management System – CIM and GID definitions
- IEC 61968 – Distribution Management System – CIM and CIS definitions
- IEC 62351 – Security

IEC 61850 is a group of standards originally designed for the use in substation automation. By now the standard has been extended for controlling hydroelectric power plants, wind turbines, and other distributed energy resources. Since January 2009, part 7-420 has been added to IEC 61850 and covers distributed energy sources and storage. It could even be used for V2G (Vehicle to grid) activities. Also of interest is IEC 61400-25, an adaptation of 61850 for wind-turbines. IEC 61850 is a flexible, mature and future proof standard that is most likely to follow through in the utilities sector.

Small DER resources are more likely to be directly connected and controlled by local EMS or BACS.

### 8.3.2 Standards regarding meter reading

To facilitate the implementation process on the technical level, the European Commission issued in 2009 a standardization mandate m/440 concerning smart meters to the standardization organizations CEN, CENELEC and ETSI. The standardization organizations, supported by European FP7 projects like open meter [12], are developing an open system architecture for utility meters involving communication protocols that enable interoperability. This architecture and related standards will be presented in 2012.

Table  lists the most referenced standards regarding communication with (smart) meters.

Table 8-2: Metering standards

| Standard | Description |
|---|---|
| **IEC 61968-9** | For meter reading & control, in which meter reading and control systems are able to exchange messages with other systems. The message include meter reading, meter control, meter events, customer data synchronization and customer switching. |
| **IEC 61334** | Is a standard for low-speed reliable power line communications by electricity meters, water meters and SCADA. It is also known as S-FSK, "spread frequency shift keying". |
| **ANSI C12.18** | Is an ANSI standard that describes a protocol used for two-way communications with an electricity meter, mostly used in North American markets. The C12.18 standard is written specifically for meter communications via an ANSI Type 2 Optical Port, and specifies lower-level protocol details. ANSI C12.19 specifies the actual data tables. ANSI C12.21 is an extension of C12.18 written for modem instead of optical communications, so is better suited to automatic meter reading. |
| **IEC 61107** | Is a communication protocol for smart meters published by the IEC that is widely-used for utility meters in Europe. It is superseded by IEC 62056 (DLMS/COSEM), but remains in wide use because it is simple and well-accepted. It sends ASCII data using a serial port. The physical media are either modulated light, sent with an LED and received with a photodiode, or a pair of wires, usually modulated by EIA-485. The protocol is half-duplex. IEC 61107 is related to, and sometimes wrongly confused with, the FLAG protocol. Ferranti and Landis+Gyr were early proponents of an interface standard that eventually became a sub-set of IEC1107. |
| **DLMS/COSEM** | The Device Language Message Specification (DLMS) and Companion Specification for Energy Metering (COSEM) as defined in IEC 62056-53 and IEC 62056-62 form together the DLMS/COSEM application layer communication protocol and an interface model for metering applications. Using the wrapper layer defined in DLMS/COSEM can be used over TCP/IP and UDP/IP. DLMS/COSEM is based on a strict client-server structure. |
| **Smart Message Language (SML, IEC 62056-58 Draft)** | This application layer communication protocol is widely used in Germany. SML is different from DLMS/COSEM and IEC 61850 in that it defines messages instead of defining an interface object model and services to access it. It is not a client/server model and it allows to push metering data. |
| **IEC 61850** | IEC 61850 is a group of standards originally designed for the use in substation automation, but extended for controlling all kind of distributed energy resources. In [IEC 61850-7-420 ed1.0] the DLMS/COSEM and ANSI C12.19 standards are referred to for revenue metering. IEC 61850 shall only support those metering applications that have no billing requirements. This distinction between revenue metering and other metering seems to be more a political than a technical decision. There is no technical reason why IEC 61850 should not be used for revenue metering.[4] |
| **IEC 62056-21** | This standard specifies the interface and communication protocol for direct local data exchange via local port for electricity meter reading, tariff and load control. |
| **ZigBee Smart Energy Profile 1.x** | This SE 1.0 and 1.1 profiles provide amongst others support for utility meter interaction based upon the existing ZigBee PRO, a protocol stack over the wireless IEEE 802.15.4 standard. It provides support for multiple commodities: electric, gas, water. |
| **ZigBee Smart Energy Profile 2.0** | In this version, the ZigBee Alliance addressed several key features including support of multiple networking technologies based on both wireless and wired standards, multiple MAC/PHY layers (e.g., IEEE |

| | |
|---|---|
| | 802.11, IEEE 802.15.4-2006, IEEE 1901, etc.), multiple security providers and protocols suites. The data model was aligned with IEC 61968 CIM model. With respect to the OSI network model, the Smart Energy Profile 2.0 Application Protocol is primarily an application layer protocol, built on top of an Internet Protocol (IP) stack. The SEP 2.0 profile is expected to be finalized and issued early in 2012. The Smart Energy Profile 2.0 has been identified as a "standard for implementation" in NIST's Framework and Roadmap for Smart Grid Interoperability Standards. [3][5][6] |
| **Open Smart Grid Protocol (OSGP)** | OSGP is a communication protocol used to communicate with smart meters and smart grid devices. It is currently proposed as an International and European open standard. OSGP is built on existing ISO/IEC and IEEE standards, and adds additional security and reliability services necessary to properly network and manage devices in the smart grid. OSGP is a widely used communication and data model specification for smart metering and smart grid applications in Europe and is supported by multiple suppliers and software providers.[8] |

Generally the growing trend is to use the Internet Protocol (IP) as the means to connect and to integrate different networks and communication technologies. This applies also to the Smart Meter infrastructure enabling utilities to use communication systems (technologies) best fitted to the situation and to be vendor independent. Despite that interoperability at network level provides the means to applications to communicate with each other, it doesn't guarantee they can understand each other. So a common information/data model is necessary.

A detailed overview of the smart meter standards, interfaces and communication technologies adequate for reading and controlling the smart meters is described by the Open Meter project [12].

## 8.4 Integrating different communication technologies

Although there are many communication technologies and standards, it is very likely the Internet Protocol IPv4 / IPv6 will be the common basis, resulting in an IP centric architecture. Looking at the OSI stack the IP Network layer and the TCP/UDP Transport layer form the middle segment of the stack. Looking at the layers below there are many alternatives to transport the IP packets, based on wireless and wired technologies. These technologies can be divided in technologies supporting communication over long distances and technologies supporting local communication over short distances. The short distance technologies can be applied for communication within the home or building, while the long distance communication technologies are used for WAN communication with actors like the DSO or the ESP.

Although the IP layer shields an application from the specifics of the underlying communication technology (physical and data link layer), it does not provide a solution for devices using different communication technologies to interact with each other. Two common solutions, which also can be combined, are used to tackle this problem.

The first solution is a gateway/access point capable of handling different communication technologies and converting the protocols. On this topic a lot of research has been done and is still ongoing. Examples of such architectures making use of middleware and communication abstraction layer are Open Gateway Energy Management Alliance (OGEMA) [23], EEBus [24] and openMUC [25]. Also the Home Gateway Initiative (HGI) [26] provides specifications and requirements on this topic. Likewise the IEC standards IEC 15067-3 [19], IEC 15045-1 [20], IEC 15045-2 [21], IEC 18012 [22] belong to a series of standards for the Home Electronic System (HES) gateway that deal with the topic of control and communication networks in homes and other small buildings.

The second solution is based upon a communication module to make the device communication technology agnostic. The Modular Communication Interface (MCI) document [18] is such a specification, evaluated and approved by the NIST-established SGIP Home-to-Grid Domain Expert Working Group (H2G DEWG). It combines elements of the EPRI Demand Response Socket Interface Specification and the USNAP Alliance 2.0 specification, and defines the mechanical, electrical, and logical characteristics of a socket interface that allows communication devices to be decoupled from end-use devices. Although the potential applications of this technology are wide-ranging, it is intended at a minimum to enable residential end-use devices to work with any load management system through user installable plug-in communication modules. Besides defining the physical and data link characteristics, the specification includes certain network and application layer elements to assure interoperability over a broad range of device capabilities. The scope of this specification is limited to the local socket interface and does not define any communication network or protocol. It however provides two DR applications command sets and a tunnelling mechanism:

- a basic DR application command set. Some of these commands are mandatory;
- an optional intermediate DR application command set, to support more advanced functions;
- tunneling/pass-through of higher layer protocol. Standard are message type assignments foreseen for protocols like USNAP, OpenADR, ZigBee Smart Energy Profile 2.0, Generic IPv4/IPv6 pass-through, but also proprietary, vendor specific message types are supported.

Table 8-3: Basic DR command set

| Command | Description | Supported |
|---|---|---|
| Shed | Sent from the Universal Communication Unit (UCM) to the Smart Grid Device (SGD) when a load shed event begins. | √ |
| End Shed/ Run normal | Sent once from the UCM to the SGD when a load shed or other curtailment event ends. | √ |
| Basic Application ACK | Acknowledge successful receipt and support of previous command. | √ |
| Basic Application NAK | Reject previous command. | √ |
| Request for Power Level | Sent from the UCM to the SGD to request that its average power level (relative to the full rating of the device) be reduced to a level between 0 and 100% of full value on a 7bit precision scale. | |
| Present Relative Price | Sent from the UCM to the SGD when a change in relative price occurs to inform of the new relative price. | |
| Next Period Relative Price | Sent from the UCM to the SGD when a change in relative price occurs to inform of the relative price in the next future period. | |
| Time Remaining in Present Price Period | Sent from the UCM to the SGD when a change in price occurs to inform of the duration of the present price period. | |
| Critical Peak Event | Critical Peak Event is in Effect (Critical Peak Events are intended to represent events that occur only a few times per year, on system peak days, for a maximum duration determined by the terms of the program) | |
| Grid Emergency | A Grid Emergency is occurring. | |
| Grid Guidance | Sent from the UCM to the SGD to provide an arbitrary indication of whether energy consumption is preferred or not. | |
| Outside Comm Connection Status | Sent from the UCM to the SGD when outside communication status is gained or lost. | |
| Customer Override | Sent from the SGD to the UCM when a customer chooses to override any load reduction process. | |
| Query: What is your operational state? | Sent from the UCM to the SGD. | |
| State Query Response | Sent from the SGD to the UCM in response to previous mentioned command | |
| Sleep | Sent from the SGD to the UCM to inform it that the SGD is idle, that information from the UCM is not needed, and that the UCM may shift into a low power state, if exists. | |
| Wake /Refresh | Sent from the SGD to the UCM to end a “Sleep” period and to | |

| | | |
|---|---|---|
| **Request** | request that all messages related to currently valid connection status, price, time, and/or load curtailment be sent. | |
| **Simple Time Sync** | When supported, this command is sent from the UCM to the SGD on the hour. | |

Table 8-4: Intermediate DR command set

| Command | Description | Supported |
|---|---|---|
| **Info Request** | Request device information | |
| **Get/Set UTC Time** | Set or request Time | |
| **Get/Set Energy Price** | Set or request the current price of energy | |
| **Get/Set Tier** | Set or request the current tier value | |
| **Get/Set Temperature Offset** | Set or request the current temperature offset value | |
| **Get/Set Set Point** | Set or request the current temperature set point value(s) | |
| **Start Autonomous Cycling** | Start a Demand Reduction cycling event per the parameters passed in the command | |
| **Terminate autonomous Cycling** | Terminate a Demand Reduction cycling Event | |
| **Demand Response Event Schedules** | Send Scheduled Events Request | |
| **Get/Set CommodityRead** | Get or Set(Publish) Energy Consumption Values | |
| **Get/Set Commodity Subscription** | Gets the Commodity Types supported by a metering device/system, and the update frequency. Sets the types that are being subscribed to. | |

In relation to this interface there are 3 locations to embed the Intelligator / PowerMatcher agent:

- When the agent is located in the RTU as shown in Figure 8-3, a standard UCM can be used. The UCM can be chosen depending on the preferred communication technology. It however means that the agent – device protocol has to be mapped to the higher layer protocol used over the RTU – UCM connection. Let it for example be ZigBee SE 2.0, then the agent-SGD commands have to be mapped to the ZigBee SE 2.0 protocol. If the implementation of the UCM provides a mapping to the basic/intermediate command set and the SGD supports this set, the SGD must not be SE 2.0 compliant.

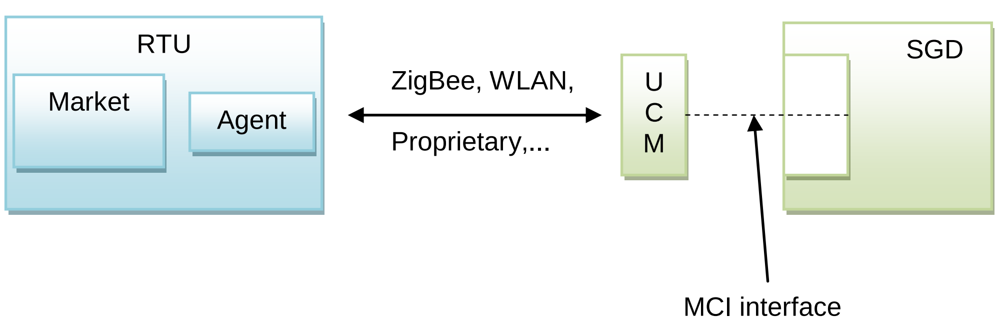



Figure 8-3: Option 1 - standard UCM

- When the agent is located in the UCM as shown in Figure 8-4 the proprietary Intelligator/PowerMatcher (IP based) protocol on top of any communication media can be used between the RTU and UCM. When the Intelligator/PowerMatcher agent matches this protocol onto the basic or intermediate command set, it is likely that no changes to the SGD have to be made, assuming the end-device will map its available capabilities to the basic and intermediate command set.

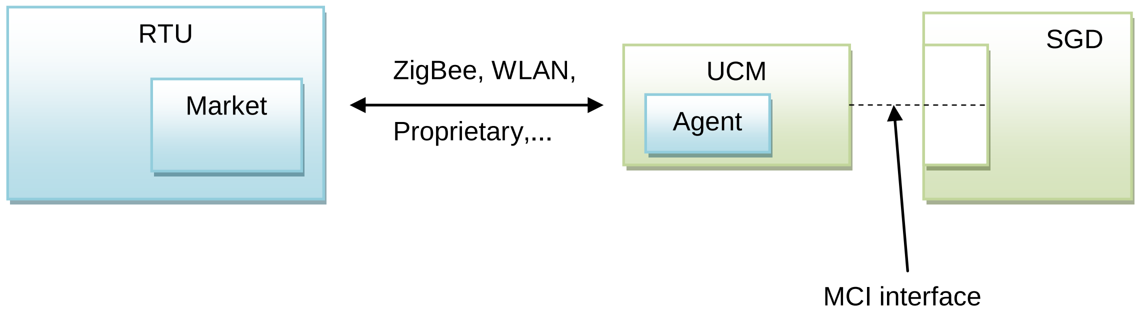



Figure 8-4: Option 2 - agent incorporated in UCM

- When the agent is located in the SGD as shown in Figure 8-5, a standard UCM can be used. The proprietary Intelligator/PowerMatcher (IP based) protocol can be tunneled via the generic IP pass-through mechanism in the MCI.

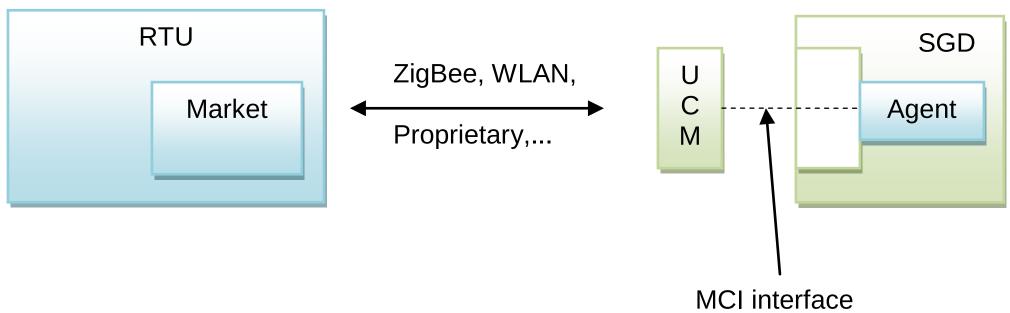



Figure 8-5: Option 3 - agent incorporated in SGD

Research indicates that it is in the public's best interest to have a standard physical interface that allows smart appliances, energy management consoles, and other consumer products to support a variety of user-installable communication modules. Such an interface could provide consumers and manufacturers with reduced risk of end device obsolescence due to evolving communication technologies. It would also provide flexibility for utilities, allowing the communication systems used for load management to be selected and evolved based on individual needs and circumstances. A modular interface can enhance customer choice, stimulate competition and foster innovation.

## 8.5 Conclusions

From communications point of view there are no special requirements for an e-hub communication architecture comparing it with a standard automation/control architecture. However, the wide variety of communication technologies and protocols used in the overall system, certainly when connecting to end users' appliances, stresses the importance of interoperability. IP will most likely be the binding protocol between all these networks, but convergence of the information models (the semantics) has to be solved at a higher layer. "Divide and conquer" strategy by means of gateway's between networks, and hardware and communication technology abstraction layers (adapters) may help to overcome this problem. A multi agent system, as proposed in the previous chapters, fits well on top of this type of architecture due to its hierarchical nature.

# 9 Conclusions

First, the major stakeholders of an e-hub system were defined together with their requirements. They are presented by means of the conceptual architecture, which is a high-level overview of these major stakeholders. Secondly the functional architecture, which describes the functions of the system together with its internal and external interfaces, was discussed. Thereafter the information data architecture was described. A formal representation of the information that is exchanged between the different stakeholders is given together with some applied use cases. It is of high importance that this information is exchanged in a secure way, therefore the information security architecture was discussed. The communication architecture is the last architecture which is addressed. A wide variety of communication standards and protocols is given together with their advantages and disadvantages. Because of the wide variety of communication standards and protocols, a generalized architecture has been discussed throughout the document.

From the viewpoint of the communication architecture two techniques were applied to ensure it is technology agnostic. First an UCM is used to decouple the communication module of a device from the device itself. It is good practice to implement this tactic to increase the extensibility of the system. It enables easy switching of the physical communication media, e.g. one UCM for powerline communication, one for ethernet, etc. Secondly at the device level a generic interface is defined to make it control system independent. An adapter will handle the transformation of the device state and characteristics into the desired format of the control solution. This adapter will be device type and control system dependent. For reusability and extensibility, the adapter will be implemented at the control system and not at the device level.

The multi-agent control architecture, explained in chapter 4 and 5, fits well on top of a complex communications' system and complies with the architecture principles explained in 4.1.

From a technical viewpoint implementing an EMS which is capable of optimizing consumption and production of both heat and electricity is a big challenge in the e-hub project. The focus in this project is on the control architecture, and simulation of the systems' control behavior is of the highest importance. Taking into account the simulation requirement an EMS based on the generic ICT architecture discussed in this document will be developed. This will be accomplished in task 4.3 "Development of the EMS".

The EMS in the field test will apply the architectural principles discussed in this document.

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# Annex A Main building management standards

## 1. EN 15232:2007: Energy performance of buildings – Impact of Building Automation Control and Building Management (EN 15232)

Intelligent control and optimization of the energy related services as well as continuous monitoring of the devices and their consumptions constitute the core of efficient interaction of a building. In order to unify conventions and methods for estimation of the energy saving potential brought by building control systems, this European Standard EN 15232 has been worked out.

The aim of this standard is to support Directive of Energy Performance of Building (EPBD) to enhance energy performance of buildings in the member states of EU. Standard EN15232 specifies methods to assess the impact of BACS and TBM functions on the energy performance of buildings, and a method to define minimum requirements of these functions to be implemented in buildings of different complexities.

The standard divides Building Automation and Controls Systems into four energy efficiency classes:

- **Class D** stands for the buildings with no or inadequate BACS, which is considered as not energy efficient and in a need to be retrofitted. No new buildings shall be built according to this solution.
  - Without networked building automation functions
  - No electronic room automation
  - No energy monitoring
- **Class C** corresponds to standard BACS that have only limited central functionality
  - Networked building automation of primary plants
  - No electronic room automation, thermostatic valves for radiators
  - No energy monitoring
- **Class B** marks advanced controls with room based approach and management functionalities: advanced BACS and dome specific TBM functions.
  - Networked room automation without automatic demand control
  - Energy monitoring
- **Class A** stands for holistic, high energy performance control system with communication between different parts of the system: corresponds to high energy performance BACS and TBM
  - Networked room automation with automatic demand control
  - Scheduled maintenance
  - Energy monitoring
  - Sustainable energy optimization

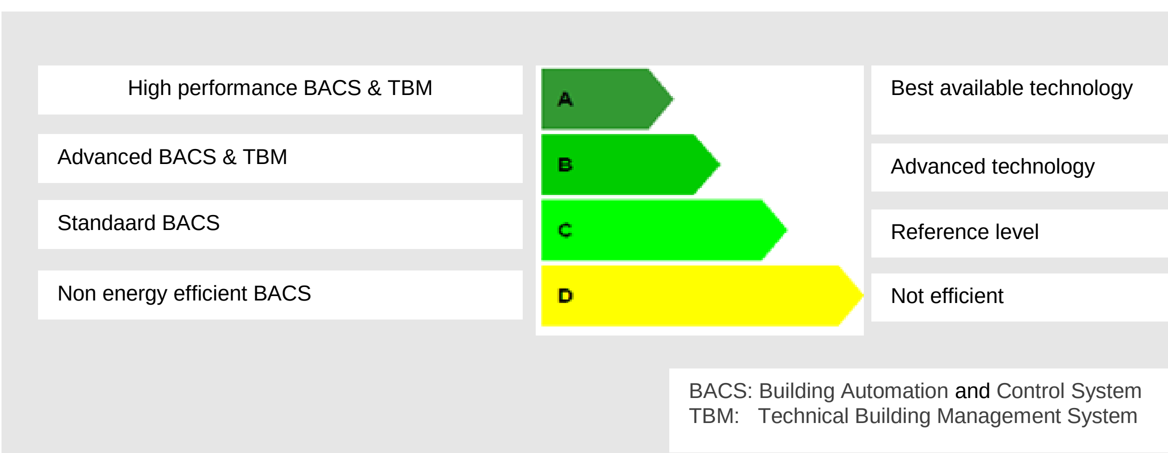


Figure A-1: building automation energy performance classification

This standard specifies:

- a structured list of control, building automation and technical building management functions which have an impact on the energy performance of buildings
- a method to define minimum requirements regarding the control, building automation and technical building management functions to be implemented in buildings of different complexities
- detailed methods to assess the impact of these functions on the energy performance of a given building. These methods enable to introduce the impact of these functions in the calculations of energy performance ratings and indicators calculated by the relevant standards
- a simplified method to get a first estimation of the impact of these functions on the energy performance of typical buildings

Among more specific scopes, the standard helps the building owners, architects and engineers to define the functions to be implemented and to easily get a first estimation of the impact of these functions on typical buildings.

Table A.1, based on the BAC efficiency factors mentioned in the standard [11] gives an idea of the potential energy savings that can be reached when switching from a class D or C system to a class A system.

Table A-1: Energy savings potential

| | Electrical savings potential | | Thermal savings potential | |
|---|---|---|---|---|
| | D→ A | C→ A | D→ A | C→ A |
| **Offices** | 21% | 13% | 54% | 30% |
| **Schools** | 20% | 14% | 33% | 20% |
| **Hotels** | 16% | 10% | 48% | 32% |
| **Restaurants** | 12% | 8% | 45% | 32% |
| **Residential buildings** | 15% | 8% | 26% | 19% |

## 2. ISO/IEC 14543: KNX

KNX is a standard for applications in home and building system technology and controls the heating, lighting, blinds, ventilation, security technology, audio/video and numerous other functions. KNX results from the convergence of three existing protocols for EIB (European Interconnection Bus), EHS (European Home Systems) and BatiBus. KNX was ratified by CENELEC as the European Standard **EN50090** in 2003. In 2006 a large section of this standard was approved for inclusion in the **ISO/IEC 14543** international standard, making KNX a worldwide open standard for home and building control. Open in this context means that devices from different manufacturers can communicate with each other. The standard is widely used in Europe. The KNX Association[1] represents more than 100 manufacturers from the electrical and electronics, HVAC and household appliance industries. The KNX Standard ISO/IEC 14543 was extended to include smart metering and smart grid applications.

KNX supports several physical communication media: twisted pair (KNX.TP), power-line (KNX.PL), radio frequency (KNX.RF) and Ethernet (also known as EIBnet/IP or KNXnet/IP).

[1] www.knx.org

## 3. ISO/IEC 14908: LonWorks

LonWorks is a family of products developed by the Echelon Corporation, in co-operation with Motorola. The communications protocol is referred to as LonTalk. A proprietary communications chip (the Neuron) is required for the implementation.

LonWorks has been published under the ANSI/CEA-709.1 LonWorks networking specification protocol and the ANSI/EIA-852 standard. In December 2008, LonWorks control networking technology was formally approved as ISO/IEC 14908, parts 1, 2, 3, and 4 by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). These specifications apply to the communication protocol and associated transport channels for networked control systems in commercial Building Automation, Controls and Building Management.
LonTalk supports a variety of different communication media (twisted pair, power line, wireless and optical fiber) and different wiring topologies. Also IP tunneling is supported by LonWorks/IP.

- ISO/IEC 14908-1: Open Data Communication in Building Automation, Controls and Building Management – Control Network Protocol – Part 1: Protocol Stack
- ISO/IEC 14908-2: Open Data Communication in Building Automation, Controls and Building Management – Control Network Protocol – Part 2: Twisted Pair Communication
- ISO/IEC 14908-3: Open Data Communication in Building Automation, Controls and Building Management – Control Network Protocol – Part 3: Power Line Channel Specification
- ISO/IEC 14908-4: Open Data Communication in Building Automation, Controls and Building Management – Control Network Protocol – Part 4: IP Communication

## 4. ISO 16484-5: BACnet

BACnet (Building Automation and Control Network) is a standardized data communication protocol developed by the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) for use in building automation to enable devices and systems to exchange information. BACnet is used in numerous building automation systems worldwide and specified in the international ISO 16484-5 standard. BACnet is an open multi-vendor data communication protocol that allows various automation and control components in a building to communicate with each other, ensuring interoperability and manufacturer independence. Compared to the former two protocols BACnet is designed top-down, meaning it was developed to interconnect different control systems.

BACnet can be implemented over different types of networks:

- Master-Slave/Token –Passing (MS/TP). MS/TP is a simple, inexpensive technology suited for smaller control and operation units not needing a high transfer rate. It uses RS-485 (EIA-485 standard) over a shielded twisted pair cable.
- Point-to-point communication over modem or via a direct cable connection based upon RS-232
- ARCNET (ATA/ANSI 878.1), a token bus standard developed for office intranets, but now superseded by the faster Ethernet. Unlike Ethernet however, it is deterministic, which makes it attractive for use in industrial communication networks. It is however not widely used outside the USA.
- Ethernet (ISO 8802.3)
- LonTalk, developed by the company Echelon as part of the family of LonWorks protocols. Being able to send BACnet messages over LonTalk does not imply that BACnet and LonWorks can communicate with each other without the need of gateways. LonTalk is just the transport medium.
- Recently BACnet International announced that it has approved the ZigBee building automation standard as the only wireless mesh network standard for BACnet-based devices. Its integration with BACnet building automation systems and its implementation of low-power mesh networks will make it feasible to meet the needs of just about any type of building automation project.

Table A-2: KNX, BACnet and LonWorks comparison [9][10]

| | KNX | LonWorks | BACnet |
|---|---|---|---|
| **Standard** | EN50090, ISO/IEC 14543 | ANSI/CEA-709,ISO/IEC 14908 | ISO 16484-5 |
| **Control architecture** | Decentralized | Decentralized | Centralized |
| **Network architecture** | "Bottom Up" solution<br>Low speed free topology | "Bottom Up" solution<br>Common communication Protocol<br>Peer-to-Peer | "Top Down" solution<br>Multiple communication protocol<br>Tiered network topology |
| **Device architecture** | Initially used a 68HC05 processor | Neuron Chip<br>Neuron C (Programming language) | Processor independent<br>Programming language independent |
| **Communication** | TP, PL, Wireless, optical fiber | Single protocol: LonTalk<br>TP, PL, Wireless, optical fiber | Multiple protocols supported:<br>Ethernet, ARCNET, MS/TP, LonTalk, PTP, ZigBee HA |
| **Internet support** | KNXnet/IP | LonWorks/ IP i.LON – Web service device series | BACnet/IP<br>BACnet/WS |

Although KNX, BACnet and LonWorks are commercially available products, security issues are still present. An extensive security analysis of BACS falls out of the scope of this document therefore table A.3 gives an overview of the strength and weaknesses of the different standards. This table is discussed in detail in [29].

Table A-3: Security evaluation of available standards [29]

| Functional Requirements (FR) / Domain-Specific Challenges (DC) | BACS | | | |
|---|---|---|---|---|
| | KNX | LonTalk | BACnet | ZigBee |
| **Entity Authentication (FR1)** | - | - | + | + |
| **Authorization (FR2)** | ~ | - | ~ | ~ |
| **Data Integrity (FR3)** | - | ~ | + | + |
| **Data origin authentication (FR4)** | - | - | ~ | + |
| **Data freshness (FR5)** | - | ~ | + | + |
| **Data confidentiality (FR6)** | - | - | + | + |
| **Data availability (FR7)** | - | - | - | - |
| **Embedded Devices (DC1)** | + | + | + | + |
| **Communication Models (DC2)** | - | ~ | - | - |
| **Scalability (DC3)** | - | - | - | - |
| **Non IP networks (DC4)** | + | + | + | + |
| **QoS parameters (DC5)** | - | ~ | - | ~ |

Besides these three standardized automation systems a lot of proprietary building/home automation systems are available on the market. Commonly these systems are characterized by central control architecture and a communication over RS-485 or equivalent communication media.

## 5. ZigBee Building Automation & Home Automation profiles

ZigBee is a wireless communication architecture developed on top of the IEEE 802.15.4 reference stack model. IEEE 802.15.4 is a low-rate wireless personal area network (LR-WPAN) solution. It is designed to be simple for low-power devices and lightweight wireless networks. IEEE 802.15.4 and ZigBee Alliance continue to work closely to ensure an integrated and complete solution for the market especially for sensor networking-based applications. ZigBee provides services such as security, discovery, profiling and so on for the two layers specified by the IEEE group.

In September 2011 the ZigBee Building Automation standard was completed. ZigBee Building Automation provides the commercial building industry with a global standard for interoperable products and enables secure and reliable monitoring and control of a variety of building systems. It’s the only BACnet approved wireless mesh network standard for commercial buildings, letting buildings with BACnet expand their existing systems into new areas that were previously unreachable before.