**SEVENTH FRAMEWORK PROGRAMME**  
*ICT systems for Energy Efficiency*

**Project Title:**  
**Occupant Aware, Intelligent and Adaptive Enterprises**

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### Deliverable

**State of the art on semantic device descriptions for energy-efficient buildings design**

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<td>BIM</td>
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<td>CECED</td>
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<td>DOLCE</td>
<td>Descriptive Ontology for Linguistic and Cognitive Engineering</td>
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<td>EP</td>
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<td>Web Ontology Language (W3C)</td>
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<td>PPP</td>
<td>Public Private Partnerships</td>
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<td>Radio-frequency identification</td>
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<td>Remote Method Invocation</td>
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<td>Semantic Sensor Network</td>
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<td>Semantic Web Rule Language</td>
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<td>Universal Plug and Play</td>
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Executive Summary

The so-called “semantic devices” are children of the IoT (Internet of Things). The last decade showed quite busy research activity on the field of IoT and semantic devices.

This deliverable provides an overview about the current development on the field of semantic devices and their interconnection with energy conservation during the building design phase. It describes existing approaches, methodologies, on-going research and technologies connected to the field. The overview concentrates mostly on research from EU projects like SEEMPubS, eDiana, HESMOS, Hydra, AIM etc.

LinkSmart, the middleware to be used in Adapt4EE, is a descendant of Hydra. Therefore, the Hydra ontology will be especially inspected in regard of possible extensions towards Adapt4EE and handling of energy profiles.

Chapter 2 examines the definition of the “semantic device”.

In Chapter 3 a list of common ontologies used for semantic devices is presented. We focus on FIPA, SEIPF, SESAME, SSN, Hydra and SEEMPubS. This chapter also lists EU financed projects where semantic devices were used. Most of those projects also have background of either energy-efficiency and/or building design.

Section 3.11 exposes some preliminary thoughts about using the Hydra ontology in Adapt4EE. A specification will be part of D3.2 “Adapt4EE Middleware Specification, Ontology and Semantic Components”.

Chapter 4 gives a brief overview about existing, related scientific publications. We focus especially on M2M research and technologies in Chapter 5: M2M: selected scientific publications.

Finally, Chapter 6 presents a summary and and conclusions of this deliverable.
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1. Introduction

The purpose of this deliverable is to gain a detailed insight and a thorough literature review on State of the art and technologies concerning semantic devices, ontologies used to describe semantic devices, management of semantic devices (middleware platforms) and relevant European projects connected with main topic. The document was created in order to be able to decide on which technologies and experience the Adapt4EE semantic device framework can build upon and how these tools must be improved for Adapt4EE to fulfill its main objectives.

1.1 Scope of the Report

This document reports the findings of the literature & project review about State of the art on semantic device descriptions. It is based on partners’ knowledge, literature survey and survey of past and on-going European projects.

The document focuses mainly on existing ontology types, technologies and frameworks used to model and/or manage devices that are of relevance in the energy-efficient buildings domain. The ultimate goal of the detailed analysis of existing frameworks, technologies and EU projects in these fields will establish groundwork for research and development that will be conducted in Adapt4EE. The next section gives an overview of the layout and the structure of this document.

1.2 The Structure of the Deliverable

The structure of the deliverable is as follows:

Chapter 1: Introduction

Chapter 2: Semantic Device Descriptions for Energy-Efficient Buildings

After a short introduction of semantic device definition, following sections outline ontologies and relevant EU projects

Chapter 3: State of the Art: EU projects and ontologies
The chapter gives an overview over existing device ontologies and about related EU projects. Most of the ontologies are related to certain projects due the research done there.

Chapter 4: **State of the Art : Selected scientific publications**
This chapter briefly presents a few selected papers related to the topic of this deliverable.

Chapter 5: **M2M : selected scientific publications**
This chapter presents some selected papers and ontologies related to M2M (Machine-2-Machine) networks.

Chapter 6: **Summary and Conclusions**
This chapter summarizes on the content described in this report.

According to Lassila & Adler [15] a semantic device can be defined as:

“A semantic device is a system that is spontaneously aware of surrounding context information, capable of reasoning and interpreting this information at a semantic level, and finally able to develop a reactive behavior accordingly.

A semantic device should be able to spontaneously discover, exchange and share context information with other fellow semantic devices as well as augmenting this context information via reasoning in order to better understand the situation and perform the appropriate reactive response.”

Another definition of a semantic device can be found here [16]:

“A Semantic device is a structure that is capable of manipulating values and attaching said values to deeper concepts. The most obvious example of such a structure is the human brain. Compare this to a Syntactic device, which is only capable of manipulating values and can never hope to grasp the context of the values.”

The definitions point out the awareness of the surrounding context and the ability to interpret such contexts by a semantic devices.

Modeling such contexts and certain behaviors can be done with the help of ontologies. Ontology is a formal description of concepts and relationships between them. It defines objects, actors, properties and interactions. Ontologies are subject of the next section. A formal definition of a ontology (Struder et. al [47]):

"An ontology is a formal, explicit specification of a shared conceptualization."
Conceptualization refers to an abstract model of some phenomenon in the world by having identified the relevant concepts of that phenomenon. Explicit means that the type of concepts used, and the constraints on their use are explicitly defined. Formal refers to the fact that the ontology should be machine-readable. Shared reflects the notion that an ontology captures consensual knowledge, that is, it is not private of some individual, but accepted by a group.”

Quite a lot of ontologies have been developed in recent years for the description of products including semantic device descriptions. They have been designed and released as a result of institutional scientific research or R&D EU projects. In most cases, the models have very similar information basis, and the differences are, of course, application or domain specific. Due to the large number of existing models and methods, this section will describe only a few of the selected examples, which may be most relevant to Adapt4EE strategy. In Adapt4EE it is also important to focus on the energy-related behavior of devices. Generally, any semantic model can be easily extended with the additional energy-related information depending on the purpose and usage of the device. The examples were chosen to describe the basic modeling approaches, to address also the concrete energy-related information.
3. **State of the Art : EU projects and ontologies**

Following sections describe several relevant EU projects, connected with the scope of the current deliverable. Some sections also depict a few relevant ontologies which are not a result of an EU project. Several EU projects described in current document were already mentioned in T3.1[14]. The T3.1 list of related EU-projects was extended with additional candidates. Every project described in section 3. provides a sub-section called “ADAPT4EE’s perspective”. This section depicts possible overlaps, synergies and also incompatibilities between ADAPT4EE and the described project.

### 3.1 **HESMOS – Virtual Energy Lab**

Main idea behind the HESMOS project (hesmos.eu) has been the optimization of energy performance and CO2 emissions reduction through integrated design and simulation. The objective has been to use the existing building data for a life cycle simulation. Such simulations can be used to design, refurbish and retrofit a building, to see the largest existing energy potentials.

One of the project’s main contribution has been to propose and to develop an Integrated Virtual Laboratory (IVEL) to allow decision makers to design and compare different energy and life cycle alternatives.

This project goal was achieved by:

- Extending existing BIM, energy simulation and cost tools for data exchange purpose
- Integration of simulation tools into design and Facility Management process
- Development of new applications to visualize building performance
- New Cockpit functionality in BIM-CAD to provide feedback of the impact of design parameters on lifecycle energy performance
- Extending BIM-CAD to model and manage buildings and surrounding areas
-Extending BIM-CAD by Web Services to act as Integrated Virtual Energy Laboratory
The project uses the Building Automation System (BAS) component ontology. The ontology is based on work of Dibowski [18].

3.1.1 Motivation behind the HESMOS ontology

HESMOS depicted several phases of the building lifecycle in the Public Private Partnerships (PPP) process:

- Design Phase
- Commissioning Phase
- Operational Phase
- Refurbishment and Retrofitting Phase

The phases of `AS-IS` situation and `TO-BE` process can be seen in Fig. 1
The HESMOS group analyzed those scenarios and derived a few technical scenarios for the IVEL usage.

A technical schema for the design phase was created. This schema allows architects and building engineers to predict energy consumption prior to the operational phase. An approach to integrate device data from BAS with facility management tools was created for the operational phase. Also a standalone scenario was developed in which a public access to the IVEL was granted by owners, tenants or building authorities.

The starting point of the HESMOS ontology were two groups of already existing ontologies, which use different modeling approaches and concentrate on separate aspects. The first group of ontologies was meant to integrate different BAS types. Such ontologies are usually technology-oriented but not aimed to be used by end users of buildings. The second group are ontologies describing smart homes. Such ontologies describe washing machine, TV-sets etc. Smart homes ontologies usually have less focus on technical details of building automation but more emphasis on the semantic meaning of certain devices and their energy-efficiency, and in this sense can be read by end users of this domestic equipment.
HESMOS project didn’t try to mimic either one of the two ontology modeling approaches while creating its own ontology, but instead created a new ontology to close the gap between building information model (BIM) and building automation systems (BAS). Closing the gap between BIM and BAS means a simplification of energy evaluation.

HESMOS ontology is also meant to allow easy integration by building operators and generation by electronic device descriptors.

### 3.1.2 HESMOS ontology

The HESMOS architecture contains three separate parts:

- Building automation system with sensors, actuators and controllers.
- IVEL database for caching purposes
- Components repository database for storing building automation devices

The ontology can be queried by users. It is used to translate rooms into device lists and to enrich these lists with data from the component repository.

The ontology itself describes devices of the BAS with their functionality in an abstract form, which contains the following attributes:

- **Device** – description of physical entities with several functions
- **Functional Profile** - functional profiles combine so-called “inputs” and “outputs” to sets. Examples of such profiles are: light switch, temperature sensor, etc.
- **Input** – An interface allowing to influence a function of a functional profile is called an input. E.g. the profile of a ventilator has a binary input state of on/off
- **Output** – Analogous to the input, an output provides an interface for showing the results of a functional profile. E.g., a ventilator output could show the current state of the device, namely on/off.
- **Operational Mode** – is an extension of a functional profile. Depending on the semantic meanings of a profile, inputs and outputs can change. Imagine two operational modes for the stated ventilator example: “simple” - this one shows the current state of the device in a binary form (on/off).
The second mode called “RPM” shows the current rotations speed of the rotor per minute as an output.

- **Function** – Within HESMOS, the function is an attempt to standardize the semantic meaning of an operational mode according to room control standard/recommendation VDI 3813 [19]

- **Configuration Parameter** – are similar to inputs but cannot be altered by applications or functional profiles

- **Parameters** – represents a set of configuration parameters which may be used by a specific operational mode.

Figure 2 shows an example of a HESMOS ontology with all its parts.

**Figure 2**: Part of the HESMOS Ontology is a subset of the building information model (BIM) based on IFC (Industry Foundation Classes ISO-16739).[20]

Component types and their instances are separated from each other. Component types are stored in the component database repository. This data base is available for all projects. Component instances (i.e. real devices in buildings) are
stored in separate databases bound to the projects that use these specific devices. The device instances have their own operation modes and parameterizations.

### 3.1.3 ADAPT4EE’s perspective

From an ADAPT4ee standpoint, the resulting ontology and the modeling approach of the HESMOS Project are relevant due to the similar objectives shared by the two projects:

- To extend existing BIM, energy simulation and cost tools for data exchange purpose, to provide advanced simulation capabilities to decision makers in the whole building lifecycle, taking into account energy savings, investment and lifecycle costs
- To close the gap between Building Information Modeling (BIM) and Building Automation Systems (BAS) so that decisions can be made economically (energy & cost related) in all lifecycle phases.

In the Adap4EE we are aiming at providing simulation capabilities to decision makers in the design phase for a new building or for reconfiguration of an existing building. This is more specific than HESMOS objectives, who are supporting the whole lifecycle of buildings. The Adapt4EE system will take into account the occupancy and behavioral patterns in the existing (similar) buildings and the business processes for which the building is designed. Based on this information it will be able to evaluate the energy savings of proposed/designed buildings early in the design phase. HESMOS proposal to extend existing BIM (see [24] and [25]) can be used as guiding modeling approach and inspiration source for Adapt4EE, relevant to the first above-mentioned objective.

Adapt4EE project aims to close the gap between Building Information Models (BIM) and Business Process Models (BPM) for enterprise processes performed in the building, so that decisions can be made economically (energy & cost related) in the design phase. Therefore, Adapt4EE project could benefit from the ontology modeling approach and the results of HESMOS project (which is in its final phase, and will be completed at the beginning of 2013). One option is to cooperate with
the HESMOS team on the tasks related to processing of BIM information (e.g. BIM Enhancement Specification [24], [26]), or on integration of information from other sub-systems within the Adapt4EE system (based on HEMOS Ontology specification for model-based ICT system integration - [20], [27]).

3.2 SEEM Pubs (FP7)

SEEMPubs project specifically addresses reduction in energy usage and CO2 footprint in existing public buildings without significant construction works, by an intelligent ICT-based energy consumption monitoring and managing.

Special attention is paid to historical buildings to avoid damage by extensive retrofitting. SEEMPubs aims to create real-time energy-awareness services for all users of the public space and to combine awareness services with a community portal.

SEEMPubs utilizes the LinkSmart middleware to integrate different kinds of sensor/actuator technologies and Building Management Systems into a Building Energy Management System. The LinkSmart device proxy approach\(^1\) is going to be further developed to ease the integration of technology specific to energy efficient building management.

SEEMPubs deliverable D1.2 [33] proposes the following attributes to be used in the energy performance diagnosis of the building:

General context of the environment and the constraints of the building site: geographical location, year of construction, constraints / assets of the site, relief and masks, compactness of the building, orientation of the construction, definition of surfaces and heated volumes.

\(^1\) views every device as an data content provider, and wraps access to this data content through a services-based interface
Characteristics of the envelope of the building: vertical walls, low Floors, roofs, thermal bridges, windows, concealment, solar protections.

Heating systems of the building: present heating system, regulation system, performance of devices.

Installations of production of hot water of the building: hot water production system, distribution system, performance of devices.

Installations of ventilation of the building: type of natural ventilation, performance of the natural ventilation, type of mechanical ventilation, performance of the mechanical ventilation.

In the SEEMPubs deliverable D6.4 [34], several standards are listed, relevant to building energy performance. Lighting performance of building is the main topic of these standards. EN 12464-1 [42] specifies requirements for lighting systems in terms of quantity and quality for most indoor workplaces. EN 15193 [43] standardizes conventions and procedures for the estimation of energy requirements of lighting in buildings, and gives a methodology for a numeric indicator of energy performance of buildings.

These findings can be reused in the Adapt4EE project, when preparing the energy performance calculation formulas and designing the measurement phase of the project.

3.2.1 SEEMPubs Ontology

The SEEMPubs ontology is an ontology to foster semantic interoperability in energy efficient buildings. It uses the basic LinkSmart ontology that models dependencies between devices, LinkSmart proxies, observable properties and events. The SEEMPubs ontology represents the domain model, describing mainly domain entities and locations.
Figure 3: SEEMPubs Ontology

Figure 3 shows the LinkSmart and SEEMPubs Ontologies (T-Box) in the upper part and a possible instantiation (A-Box) in the lower part.

The ontologies in the picture are simplified to give an overview of the concept. The LinkSmart ontology describes how sensors and actuators are modeled by the LinkSmart middleware. Each physical sensor observes a physical world event (observable property) that represents a context property of a domain entity. Each sensor is also represented by a proxy that has an id which is named PID.
(persistence id). Each event generated by a sensor can be identified through an event topic.

An actuator type of device on the other hand offers functions that may influence the context property of the domain entity (e.g.: actuator of an air conditioner influences the temperature of a room).

In the SEEMPubs ontology, the domain entities represent any object that is to be monitored and controlled through an interoperable energy management system, e.g. air conditioner, lighting, heating. Domain entities normally have simple context attributes such as the power state, energy consumption, as well as complex context attributes that may be relative to other entities in the environment e.g.: a heater wastes energy when it is on while the window is open.

The application ontology contains the concrete implementation of the system also known as A-Box or instances of the LinkSmart and Application Domain model.

From the perspective of semantic device descriptions, the LinkSmart and SEEMPubs ontologies focus on describing the dependencies between the real-world objects and the middleware implementation following a keep-it-simple approach. With respect to taxonomy both ontologies try to avoid highly complex taxonomies of e.g. devices and/or device classes. Experience has shown that modeling too much complexity in the taxonomy will lead to a hard to manage ontology. Further it must be noted, that both ontologies are under development at the time of writing this report. Information on further development can be found on the project site of SEEMPubs [21] and on the LinkSmart Sourceforge site [22].

### 3.2.2 ADAPT4EE’s perspective

In contrast to Adapt4EE, SEEMPubs aims at the operational and retrofitting/refurbishment phases of the building lifecycle. Nevertheless, lessons learned from device management approaches in SEEMPubs can be transferred to Adapt4EE and taken further. E.g. methodologies for managing wireless sensor networks with LinkSmart middleware can be applied in Adapt4EE.

Further, SEEMPubs aims at developing ontologies and context awareness components for smart energy efficient buildings, modeling the application domain
and devices (cf. Section 2.1). As Adapt4EE aims for defining a common information model, the modeling efforts of SEEMPubs play an important role in finding models that can be applied during all phases of a building’s lifecycle.

FIT is involved in the SEEMPubs project and will foster technology and knowledge transfer between both projects.

SEEMPubs defines several useful categories for lighting, heating and cooling systems and classifies the public building types along these dimensions:

- Type of building – Historic, Modern
- Type of activity and occupation – Low absence probability, Medium absence probability

Lighting systems are classified based on the following characteristics:

- Daylight availability – Medium, Weak
- Type of shading control system – Manual, Automatic
- Type of lighting strategy – Manual, Daylight harvesting, Presence detection, Personal control

The cooling and heating systems are classified based on the following characteristics:

- Solar gains – Medium-strong, Weak
- Type of heating control strategy – Manual, Automatic, Presence detection, Personal control

### 3.3 FIPA device ontology

The device ontology of FIPA (Foundation for Physical Agents) was introduced in 2001, as one of the first descriptions of compact devices. The FIPA device ontology modeling patterns were developed for addressing multiple device functions. Those are now common in most of the models used. The FIPA ontology was developed to allow the agents to exchange information of the different properties of devices. For example an agent can ask another agent whether the device has enough capabilities to handle certain tasks. The frame-based representation of the ontology is shown in Figure 4.
FIPA ontology provides a framework to describe compact devices (e.g. smartphones, PDA). Such description of devices contains basic information about the device (name, vendor, version, type), hardware description and software description. Hardware and software description are called profile of device. Agent is considered as any software entity capable of reasoning over the FIPA device profile [35]. This means that the agent is able to identify appropriate devices based on the profile description and use the services of the device. FIPA was taken as a base for Hydra ontology and thus also for the SEEMPubs Ontology. Example of a device description is given in Annex A. (see Table 1.)

3.3.1 ADAPT4EE’s perspective

We consider FIPA approach as a general one in case the bindings between agents and devices in the environment are not predefined (i.e. the binding is dynamic and the right device has to be discovered by agent). This is not the case in the Adapt4EE system. In Adapt4EE the bindings between agents and devices are predefined in the BPM module or are coming from the measurement data (occupancy and behavioral patterns). This means that the roles of agent that interacts with devices are predefined. The structure describing how roles are assigned to the agents (people) is also predefined (it is modeled in BPM at least). Another aspect is information about device that is connected with BIM (most likely including also energy profile). Such information is modeled in the common information model of Adapt4EE system. Thus the device profile should contain, amongst others, spatial information from BIM and its energy profile (in general Adapt4EE domain-specific information) and that is missing in FIPA ontology. To conclude, FIPA approach is good in case the bindings between agents and devices in the environment are not predefined. However, the FIPA ontology does not model domain-specific information, thus it is not necessarily a good starting point for our device middleware model.

Annex A — Profile of a Hypothetical Smart Phone

Table 1 : Profile of the hypothetical Smartphone xyz
<table>
<thead>
<tr>
<th>Profile</th>
<th>fipa.profiles.device.smartphonexyz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ontology</td>
<td>Fipa-Device</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>info-description</td>
<td>name</td>
</tr>
<tr>
<td></td>
<td>vendor</td>
</tr>
<tr>
<td></td>
<td>version</td>
</tr>
</tbody>
</table>

**Type**
- Mobile-phone
- PDA
- GPS

**agent-compliancy**
- true

**hw-description**
- name: Bluetooth
- version: x.x
- name: Infrared Data Association
- version: y.y
- name: High Speed Circuit Switched Data
- version: z.z

**ui-description**
- width: 500
- height: 800
- resolution-description
  - width: 1024
  - height: 768
  - unit: pixels
  - bpp: 32
  - graphics: true
- color: true
- audio-input: true
- audio-output: true

**memory-description**
- memory-type-description
  - amount: 8
  - unit: MB
  - usage-type: storage
- memory-type-description
  - amount: 3856
  - unit: KB
  - usage-type: storage

**cpu**
- 64-bit
- ARM9-based
- RISC

**sw-description**
- name: SmartOS abc
- vendor: ABCVendor Corp.
- version: 8.1
### 3.4 SEIPF ontology

The Semantic Energy Information Publishing Framework (SEIPF) [1] was designed to publish the power consumption information and other appliance properties, in a machine understandable format in the smart home environment. The energy-related information is modeled using the energy profiles represented in ontology (so-called E.P. ontology). The SEIPF approach should serve as the framework providing metering and visualization of energy information to realize the statistics and analysis of the energy data.

The core of E.P. ontology contains the device profile representing the device, which has attached several consumption profiles related to the concrete device states (e.g. switched-on/off). The consumption profile represents the power consumed by the device in concrete state. The consumption is described by nominal/real power consumption value, the unit (e.g. Watt) and the associated device state. For accessing the information in the machine understandable semantic format, SEIPF uses the Domotic OSGi Gateway (Dog) [2] that is able to expose different domotic networks as a single, technology neutral automation system. Dog uses the DogOnt ontology [3] to model devices and house environment. Dog provides the ability to control different devices installed in a home environment and to query different device properties ranging from location

<table>
<thead>
<tr>
<th>agent-platform2[13]</th>
<th>name</th>
<th>FIPA-OS v2.1.1</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>dynamic</td>
<td>true</td>
</tr>
<tr>
<td></td>
<td>mobility</td>
<td>true</td>
</tr>
</tbody>
</table>
to current operating state. E.P. ontology was created as an extension of the DogOnt. The example of the device power consumption profile is illustrated in Fig.5.

**Figure 4**: Device ontology introduced by FIPA (Foundation for Intelligent Physical Agent) in 2001.
3.4.1 ADAPT4EE’s perspective

SEIPF ontology is oriented on home devices not on devices used in office/hospital spaces, but the concept of Energy Performance (EP) might be of interest for Adapt4EE system (and some devices are common – e.g. light, computer etc.). The SEIPF system uses EP of devices and DogOnt ontology to be able to expose different domotic networks as a single, technology neutral automation system. There is no intention to operate with building as a single automation system in Adap4EE approach, thus this part might be not reusable. The possibly interesting/reusable part of the SEIPF system is that it provides metering and visualization of energy information to realize the statistics and analysis of the energy data. Thus the integration of results from metering (using EP profiles of devices) is done in the SEIPF system and that might be of interest for Adapt4EE middleware/system (the same task needs to be done in Adap4EE system).
3.5 DEHEMS Project

Digital Environment Home Energy Management System (DEHEMS) project investigated how technology can improve domestic energy efficiency. The aim was to improve monitoring of energy levels being used by households. The project used the domain-independent SUMO ontology [17].

The home appliance ontology was defined by defining all potential concepts and phrases in the domain of interest. Those terms were structured into provisional categories. Later the grouping was refined and semantic cross-references identified between areas. Figure 6 shows an overview of DEHEMS ontologies.

ENERGY STAR and European Efficiency Labels were taken into account during the ontology development. Also different short- and long-term consumption patterns were incorporated. Example: a washing machine may consume less energy per cycle but also more water. Such profile is not energy efficient in the long term.

The appliances in the test environment were connected to a data collector. The data collector also served as gateway between the home network and a data server in a remote location. The ontology was deployed on a remote server. DEMEHS used Web Services to provide the expected functionality.

DEHEMS system is designed to give advice on which device is more efficient while several aspects (not only energy consumption) are taken to account. Thus this ontology models knowledge about the energy efficiency of appliances. In the Adapt4EE system we need to model simple energy profiles of devices. There is no need to infer which device is better to be chosen from many aspects (like in DEHEMS). However, there is a need to have information about the energy consumption in on/off (and possibly others) modes and connection of those to the tasks and/or occupancy of people. Due to its orientation on operational inferences and decision making, the results of DEHEMS project (e.g. ontologies) cannot be directly reused in the design of Adapt4EE Common Information Model.

3.5.1 DEHEMS ontology
DEHEMS (Digital Environment Home Energy Management System project) is an EU-funded initiative [4] to influence energy consumption behavior of households by providing the advice on efficient energy consumption and visibility of their energy consumption data. One of the outcomes of the DEHEMS project is the ontology for home energy management domain. The ontology encodes knowledge of home appliances, their energy efficiency, and knowledge of energy saving strategies/tips. The ontology was developed with focus on the energy efficiency characteristics of the appliances to provide an rich knowledge representation for reasoning tools, to not only reason about short term energy efficiency of an appliance but also to provide a long term operational aspects of the appliance energy consumption (for example a washing machine that consumes less energy per cycle but consumes more water may not be an energy efficient machine in the long term).
Figure 6: Ontology overview used in the DEHEMS European project, including conceptual alignment with SUMO upper level ontology schema [45].

The ontology development takes into account energy efficiency rating/labeling provided by ENERGY STAR [5] and European Energy Efficiency Labels [6]. ENERGY STAR is a US Environmental Protection Agency and US Department of Energy backed program helping businesses and individuals to protect the environment by using more energy efficient appliances, machines and energy saving strategies. ENERGY STAR rating provides a more detailed view of energy efficiency of the appliances. EU label define energy efficiency of washing machine on a scale from A to G, with A most efficient and G least efficient.
3.5.2 Adapt4EE’s perspective

DEHEMS ontology is aligned with SUMO upper level ontology [7] to allow the knowledge sharing and information retrieval in the common form. The illustration example of DEHEMS ontology hierarchy is on Figure 6. As described above this ontology models knowledge about the energy efficiency of appliances. It is designed to give advice which device is more efficient while more aspects (not only energy consumption) are taken to account. The fact is that in Adapt4EE system we need to model simple energy profiles of devices. There is no need to do inference which device is better to be chosen from many aspects. There is need to have information about energy consumption in on/off (and possibly others) modes and connection of those to the tasks and/or occupancy of people. Thanks to this information the Adapt4EE system can evaluate (in the simulation module) possible set-ups of devices in the building (by taking into accounts business processes where devices are used and/or measurements of relevant behavioral patterns). Thus it enables to find (amongst others) the most energy efficient set-up of clearly defined devices (not finding most suitable/energy-efficient device). Based on the above defined arguments, the DEHEMS ontology would be not used as a base for Adapt4EE Common Information Model.

3.6 SESAME ontology

The project SESAME [8] uses semantic modeling and reasoning to support home owners and building managers in saving energy and in optimizing their energy costs while maintaining their preferred quality of living. A semantic layer has been designed as a technical solution that integrates smart metering, building automation and policy-based reasoning in order to offer an energy-optimization capability for the energy consumer and provider.

SESAME uses an ontology-based modeling approach to describe an energy-aware home and the relationships between the objects and actors within the control scenario.

The ontologies provide a hierarchy of concepts to model the automation domain and the energy domain. The ontology includes a number of general concepts such
as resident, location, and concepts in the automation and in the energy domain, such as device, tariff or energy usage profile. The devices can be the appliance, sensor or UI device. Device model contains the set of properties, e.g. consumption per hour, peak power, the switch on/off status but also the required state “to be switched on/off”. The central function-level concept in the SESAME ontology is the configuration class, which has two subclasses: activity (automation activity) and energy policy. A configuration connects appliance, sensor and UI device into a joint task. The configuration can provide regulation of different types, e.g. regulation on time, occupancy of location, threshold value. For this purpose configuration includes properties including thresholds and scheduled times.

The knowledge base contains the system-level rules, which complement the definition of automation activities and energy policies in the ontology. The system-level rules specify how the information from the knowledgebase is used to reason about the changes on the appliances state. Energy management rules are executed after automation rules to verify the automation decision based on energy constraints. The example of the system-level rule working with the ontology information looks as follows:

\[
\text{Activity}(?a), \text{Sensor}(?s), \text{regulatesOnThreshold}(?a, ?s), \text{usesAppliance}(?a, ?d), \text{hasReading}(?s, ?r), \text{isSwitchedOn}(?d, false), \text{hasThresholdSwitchOn}(?a, ?t), \text{lessThanOrEqual}(?r, ?t) \rightarrow \text{IsToBeSwitchedOn}(?d, true)
\]

### 3.6.1 ADAPT4EE’s perspective

The general concepts from SESAME, such as residence and location, the energy domain concepts, such as device, tariff or energy usage profile (defining e.g. consummation of energy per hour) are useful for the Adapt4EE system middleware. In the Adapt4EE system middleware there is a need to describe the energy usage profiles and (most likely) tariff as well as location of the device in the building and (most likely) the residence of building (it is possible to obtain
weather data based on residence). These concepts together with the status of the device (on/off) and thresholds (from SESAME ontology) enable to define solid rules for activities (from Adapt4EE perspective) that are performed with the devices in the building (e.g. define when should be the ventilation or light in a room switched on/off based on the data about occupancy and light condition from sensors). When such capability to model information will be connected with the information about the business process models (tasks characteristics – e.g. user roles, users, frequencies of usages etc.) and measurement data (e.g. data about occupancy and usages of certain devices) it can be used by the Adapt4EE simulation module to evaluate energy-efficiency of building layout proposals (when new building/part of building is designed) or configurations of devices within the existing building/part of building.

3.7 Semantic Sensor Network Ontology (SSN)

The W3C Semantic Sensor Network Incubator Group provides a formal OWL DL ontology for modeling sensor devices (and their capabilities), systems and processes [9]. The ontology is built around concepts of systems, processes, and observations. It supports the description of the physical and processing structure of sensors. Sensors are not limited to physical sensing devices: rather a sensor is anything that can estimate or calculate the value of a phenomenon, so a device or computational process or combination could play the role of a sensor.

In general, the sensors observe the stimuli to derive information about environmental characteristics and construct features of interest. The SSN ontology revolves around the central Stimulus-Sensor-Observation pattern, which acts as the upper core-level of the Semantic Sensor Network ontology. The pattern is developed in accordance to the principle of minimal ontological commitments to make it reusable for a variety of application areas. SSN ontology is tailored to the ultra-light version of the DOLCE foundational ontology [10].

Several conceptual modules based on the pattern to cover key sensor concepts, such as: basic skeleton, devices, measuring capabilities and constraints, energy consumption, data, processes, operating restrictions, platforms, deployment and systems containing the sensors. The ontology does not include a hierarchy of
sensor types; these definitions are left for domain experts, and for example could be a simple hierarchy or a more complex set of definitions based on the workings of the sensors. The modules include the classes and properties that can be used to represent particular aspects of a sensor or its observations: for example, sensors, observations, features of interest, the process of sensing (i.e.: how a sensor operates and observes), how sensors are deployed or attached to platforms, the measuring capabilities of sensors, as well as their environmental, and survival properties of sensors in certain environments.

The SSN ontology can be extended with the energy module that determines the aspects of energy management, such as battery lifetime or operating power range. The illustration of SSN ontology energy extension is shown in Fig.7

![Ontology Figure](image)

**Figure 7**: Overview of ontology defined by W3C Semantic Sensor Network Incubator Group for modeling sensor devices, systems and processes.
SSN ontology is a robust well documented W3C sensor and device ontology that can be extended for energy domain (as described in [13]). The representation of a sensor in the ontology links together what it measures (the domain phenomena), the physical sensor (the device), its functions and processing (the models). This approach is useful in case creating of applications with the ability of real-time management of devices based on the sensor inputs is needed.

### 3.7.1 ADAPT4EE’s perspective

The necessary information for the Adapt4EE system describes domain information and processes. That looks similarly to SSN representation but it is not the same. The domain information is comprised of devices (with energy profiles, and measurement data related to them) and their position in the building, occupancy in the building (from measurement module), occupant profiles defining organizational information such are roles (e.g. check-in administrator in hospital). The processes in Adapt4EE need to be described the following characteristic of tasks: in which case are they performed, before/after task, lasting time of task, frequency, links with Adapt4EE domain information (thus position in the building is determined by this link). It is not intention of the Adapt4EE system to define real application consisting of sensor and devices. The intention is to provide necessary information to the simulation module so it can do the evaluation of the layout proposal (building/devices). Thus for the middleware of Adapt4EE system it is not necessary to model the information that enable SSN ontology. It is “too robust” or “too complex” for Adapt4EE and thus it cannot be the best starting point for the design of Adapt4EE Common information model. The opportunity is the overall philosophy or in other words basic concept as it matches with the Adapt4EE approach (basic profile of sensor/device containing domain phenomena measurement, physical sensor (the device), its functions and some processing elements such as status of device).

### 3.8 AIM (FP7)

AIM’s main objective is to develop technologies for managing energy consumption in domestic environments in real-time. Residential users administer their home
networks while functionalities are exposed as services to the outside network via a gateway offering functions for policy management, device discovery, and proactive configuration. AIM will provide a reconfigurable middleware to allow uploading new functions to gateways, which can then be used by clients.

3.8.1 ADAPT4EE’s perspective

AIM formulates several objectives that are relevant for Adapt4EE project scope:

- Design and implementation of an energy resources virtualization environment and appropriate semantics to be used for building energy management applications
- Design and implementation of a generic method for measuring energy consumption of appliances at home
- Design and implementation of logic for managing the energy consumption of home appliance intelligently, beyond the simple ON/OFF model
- Interfacing to the home network the energy consumption values of three household appliance types
- Designation and implementation of a methodology addressing energy management of active as well as stand-by appliances

The main idea of AIM project [29] is to forge a generalized method for managing the power consumption of devices that are either powered on or in stand-by state. Especially for the second category of devices, the project will define intelligent mechanisms for stand-by state detection, using all-device-fit control interfaces. Such idea together with use cases of AIM projects are out of the scope of Adap4EE project. Therefore the possible inspiration from ontologies/models of the AIM system for the design of Common Information Model in the Adapt4EE system is low. The only option for an overlap between AIM project and Adapt4EE project is 2nd use case (Use-case for power distribution network operators - metering service for energy planning) with their modeling that is behind metering service for energy planning. Unfortunately, the information available at [29] at the time of writing, do not enable us to investigate this model.
3.9 **ebbits project (FP7)**

Ebbits does research in architecture, technologies and processes, which allow businesses to semantically integrate the Internet of Things (IoT) into mainstream enterprise systems and support interoperable end-to-end business applications. It will provide semantic resolution to the Internet of Things and hence present a new bridge between backend enterprise applications, people, services and the physical world. The pilot application domains of **ebbits** are car manufacturing and pork industry chain management. **Ebbits** tries to solve a broad range of large-scale issues related to IoT architecture and enterprise integration.

Ebbits uses the LinkSmart middleware to create the connection between devices and appliances and enterprise applications. Although ebbits does not specifically deal with energy efficiency, the efforts in the field of device management should be considered. Results will be directly integrated into LinkSmart, so LinkSmart device management will become a robust and generic methodology for different application domains.

The Service Layer of ebbits is a place where applications are translated into service components. Every device is accessible as a service, so services and device ontologies allow developers to create new instances for any device type. FIT is coordinator of the ebbits project and will ensure knowledge transfer regarding LinkSmart device management.

Several ontologies related to description of sensors are introduced in the [41] deliverable of the ebbits project. These ontologies include SensorML, OntoSensor, Sensor Data Ontology, Coastal Environmental Sensor Networks Ontology, Agent-based Middleware for MME (A3ME) Ontology, Ontonym, CSIRO Sensor Ontology, Sensei Observation and Measurement Ontology, Semantic Sensor Network (SSN) Ontology.

### 3.9.1 ADAPT4EE’s perspective

The ebbits project focuses on support of eventing for sensors. These ontologies and the ebbits eventing model should be considered, when preparing ontologies within upcoming WP3 tasks of the ADAPT4EE project.
3.10 eDiana (ARTEMIS)

eDiana (Embedded Systems for Energy Efficient Buildings) addresses the need of achieving energy efficiency in buildings through innovative solutions based on embedded systems.

The eDIANA Platform is a reference model-based architecture, implemented through an open middleware including specifications, design methods, tools, standards, and procedures for platform validation and verification. eDIANA Platform enables the interoperability of heterogeneous devices at the Cell and MacroCell levels, and it provide the hook to connect the building as a node in the producer/consumer electrical grid.

Thus, eDIANA provide a Reference Architecture for a network of composable, interoperable and layered embedded systems that will be instantiated to several physical architectures. The eDIANA Platform realizations cope with a variable set of location and building specific constraints, related with parameters such as climate, Cell/MacroCell configuration (one to many, one to one etc.), energy regulations etc.

3.10.1 ADAPT4EE’s perspective

Some of the functionalities of eDiana system are different then the functionalities of Adapt4EE system. Thus the whole eDiana ontology is not needed/cannot be reused within Adapt4EE. For instance it is not in the scope of Adap4EE system to operate with the devices and embedded systems within building in real time. It is also not needed to operate with the whole building as one node (for the sake of electric grid management). Anyways, eDiana ontology (based on [30]) defines some concepts and relations between them that can be reused in the Adap4EE system. Namely, it specifies Comfort_Variable_Information concepts in a way that might be needed for the interpretations of measurement data from the measurement module of Adapt4EE system. Also the Physical_Sensor concept (including Light, Power, Humidity, Airflow etc.) specification and possibly Threshold_Sensor concept specification (including Movement, Smoke) might be useful for Adapt4EE specification of Common Information Model.
3.11 HYDRA project (LinkSmart middleware)

Hydra has pioneered research into service-oriented architectures for networked embedded devices based on a semantic model-driven approach. System developers are provided with development tools for easily and securely integrating heterogeneous physical devices into interoperable distributed systems.

The Hydra project ended successfully on 31 December 2010. The software results of the project have been published under the name LinkSmart middleware and under the well-recognized and respected Lesser GNU Public License (LGPL). The source code is freely available at Sourceforge\(^3\).

The LinkSmart middleware allows developers to incorporate heterogeneous physical devices into their applications by offering web service interfaces for controlling any type of physical device irrespective of its network technology. The middleware incorporates means for Device and Service Discovery, Semantic Model Driven Architecture, P2P communication, and diagnostics. Hydra enabled devices and services can be secure and trustworthy through distributed security and social trust components of the middleware. Figure 8 shows an example of a LinkSmart network consisting of various kinds of devices. Each device is connected to the middleware by a set of software components, either deployed on the device itself or – if the device is not powerful enough – on a gateway. Once “LinkSmart enabled” device talk to each other over an overlay P2P network (indicated by the yellow flashes).

\(^3\) http://sourceforge.net/projects/linksmart/
Partners Chg./FIT and TUK are members of the Hydra project and can freely transfer their knowledge to the Adapt4EE project.

LinkSmart is used and further developed in a number of European Projects from different application domains, reaching from healthcare over large-scale enterprise applications to energy efficient buildings. In the course of these projects LinkSmart itself will become more robust and developer tools will be a great help for application developers.

Various kinds of LinkSmart device proxies are currently under development in the different projects. These efforts are subject to constant assessment and consolidation to foster a high degree of reusability for developers.

Further, semantic modeling is now diverging from generic models to more application specific models, meeting the reoccurring requirements of specific application domains.
LinkSmart is currently applied and further developed in the following European Projects (of which the most relevant with regard to Adapt4EE will be described in more detail below (Table 2.)):

**Table 2:** Past and Ongoing European Projects using LinkSmart Middleware in various application domains

<table>
<thead>
<tr>
<th>Application Domain</th>
<th>HealthCare</th>
<th>Enterprise</th>
<th>Energy Efficiency</th>
<th>Security</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• inCASA (<a href="http://www.incas">http://www.incas</a> a-project.eu)</td>
<td>• BEMO-COFRA (<a href="http://www.be">http://www.be</a> mo-cofra.eu)</td>
<td>• Adapt4EE (<a href="http://www.adapt4ee.eu">http://www.adapt4ee.eu</a>)</td>
<td>• BRIDGE (<a href="http://www.bridgeproject.eu">http://www.bridgeproject.eu</a>)</td>
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<td></td>
<td>• REACTION (<a href="http://www.react">http://www.react</a> ion-project.eu)</td>
<td>• Ebbits (<a href="http://www.ebbits-project.eu">http://www.ebbits-project.eu</a>)</td>
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<td>• SEAM4US (<a href="http://seam4us.eu/">http://seam4us.eu/</a>)</td>
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</tr>
</tbody>
</table>

### 3.11.1 HYDRA ontology

One of the goals of the HYDRA project was to develop a middleware solution for networked embedded systems in ambient environments. The main output of the project is the middleware, which enables to connect various heterogeneous devices providing different services and with different capabilities. It combines the use of ontologies with semantic web services, supporting thus true ambient intelligence for ubiquitous networked devices. The ontologies in HYDRA are mainly focused to model the devices. The models are used for both static information storage and also complex query answering purposes.

The HYDRA device ontology represents the concepts describing device related information, which can be used in both design and runtime. The basic ontology is composed of several partial models representing specific device information. The initial device ontology structure was extended from the FIPA device ontology.
specification [11] and the initial device taxonomy was adopted and extended from AMIGO project vocabularies for device descriptions [12] (within the Amigo project there was also created quite wide set of device ontologies dedicated mostly for the smart home automation). The major ontology concepts used in HYDRA ontologies were the device and the service. The core ontology contains the taxonomy of various device types and the basic device description including model and manufacturer information. Device services are modeled in the terms of operation names, inputs and outputs. The services are also organized into the taxonomy. The services are the basic executable and functionality units in HYDRA. To enrich the device and service description, the models can be annotated several additional information, such as various capabilities, software and hardware features, quality of service or security properties.

The model of device was also extended with the energy profile, which served as the device energy consumption information represented by the energy classification, energy operation, the related energy mode and state. The illustration example of the HYDRA device ontology energy module is in Fig.9

**Figure 9**: Overview of the ontology used in the Hydra project for the device ontology closely related to energy consumption information
In the progress of transferring the results of the HYDRA Project to the open source LinkSmart Middleware, this ontology is subject to change and re-engineering. Section 4.6 explains how the HYDRA ontology is further developed and how results and lessons learned from the HYDRA project are applied in developing a LinkSmart ontology. One example of such ontology is currently under development in the SEEMPubs project, namely the SEEMPubs ontology for energy efficient buildings, which will be described in more detail in the SEEMPubs section (3.2)

**3.11.2 ADAPT4EE’s perspective**

Hydra ontologies are currently not available online in any of ontology repositories. There is a version of ontologies available as a part of LinkSmart open source software in its 1.1 version here [44].

The code is provided under the GNU LESSER GENERAL PUBLIC LICENSE Version 3. There are 13 OWL files in the ...

folder. All the ontology uses a prefix [http://localhost/ontologies/Device.owl#](http://localhost/ontologies/Device.owl#). If we will use the ontology in Adapt4EE, it will be using our own prefix defined in the WP3 later. Energy.owl and Device.owl are of interest for the Adapt4EE project, but other files contain used imports also. The licence on the ontology is a

The Device.owl file contains a taxonomy of hydra devices. These are subclasses of the Device class (see Fig.10),
Figure 10: Device Class of the Hydra Ontology

which is either a PhysicalDevice or a SemanticDevice. The PhysicalDevice taxonomy is depicted on Fig.11

Figure 11: Taxonomy of physical devices in Hydra Ontology
For the need of Adapt4EE project these ontologies would have to be extended in several aspects. In the taxonomy of devices, there are some higher level devices, that could fit Adapt4EE devices used in the measurement phase. These are: LightSensor, FlowMeter, Thermometer, Windmeter. However some other sensor types are missing, like moisture meters, CO2 meters, electric energy meters. Another device type possibly usable in the Adapt4EE use cases are devices used within buildings as equipment within the business processes. There are some devices used as equipment in the Hydra ontologies, like IODevices, StorageDevices.

In the Energy.owl ontology, the EnergyProfile class is defined, which is used to describe the energy properties of a device. The EnergyProfile class is depicted on Figure12. The figure shows, that there is also a Units class, which is only a simple taxonomy of usable units for the Hydra project. This can be possibly also extended and used within Adapt4EE.

![EnergyProfile class in the Hydra Ontology](image)

**Figure 12**: EnergyProfile class in the Hydra Ontology

### 3.12 SOFIA (ARTEMIS)
With the SOFIA project solutions the "embedded information" in the physical world can be made available for smart services - connecting physical world with information world. The project envisions the SOFIA environment, where embedded systems (ES) connect, discover and enjoy personalized and cooperating services operating on interoperable, heterogeneous data. Connection at the lower level occurs through a SOFIA general overlay based on legacy connectivity and communication protocols that can be seen as the basic communication layer of the architecture. At a higher level of abstraction, each ES can participate to one or more smart spaces. ESs participating to the same smart space are connected through a second level overlay. From an application viewpoint, ESs participating to a smart space overlay may provide services/data to another smart space. SOFIA's goals encompass the middleware layer and go up to user-interface layer.

3.12.1 ADAPT4EE's perspective

The public deliverables of Sofia project provides rich materials about the interoperability in Smart Spaces [31]. One of the key models for smart spaces is the appropriate representation of such spaces. Sofia project is addressing this issue ((e.g. here [32]) and Adap4EE have to cope with the spaces representation in the Adap4EE system as well (a simple representation is needed not a complex one like in BIM). This is the potential overlap where we can be inspired by SOFIA when creating our (Adap4EE) Common Information Model.

3.13 ME³GAS (Artemis Program)

The purpose of ME³GAS is to research and develop an energy-aware middleware platform making it possible to network heterogeneous physical devices into a service-oriented architecture. The middleware will hide the complexity of the underlying device and communications technologies for application developers and raise the level of programming abstraction to a web services layer and provide necessary functionality and tools to add energy efficiency features to any
application. The ME³GAS project builds on the architecture developed in the FP6 project Hydra for embedded heterogeneous physical devices.

The project aims at developing an energy-efficiency ontology to model all aspects of devices’ energy use. This ontology will plug-in to and extend existing device ontologies such as the one in the Hydra middleware. This ontology aims to create the ontology models describing several energy features of devices, energy profiles, but also relationships between energy consumption/production of devices and the indoor environments. The ontologies aim to contribute to standards supporting the creation of energy-aware homes and increasing the semantic interoperability between various applications.

At the time of writing this report, ME3Gas is an on-going project and no concrete reports on the ontologies have been published yet. A high level proposal of the ontology structure was proposed as shown in Fig.13.

![ME3Gas ontology proposal](image)

**Figure 13**: ME3Gas ontology proposal [37]

### 3.13.1 ADAPT4EE’s perspective

At the time of writing this report, ME3Gas is an on-going project and no concrete reports on the ontologies have been published yet. As it was mentioned above, the project aims at developing an energy-efficiency ontology to model all aspects
of devices’ energy use. What we know at the time of writing this report, the intention of the ME3gas Ontology is to describe several energy features of devices together with the relationships between energy consumption/production of devices and the indoor environments. How the delivered solutions cope with the relation of energy consumption of devices and the indoor environments might be of interest for Adapt4EE middleware.
4. State of the Art : Selected scientific publications

Research in the EU-project context is not everything done on the field of ontologies and semantic devices. Current section presents a few scientific publications mostly beyond EU based research. The compilation of four publications [38],[39],[40],[46] gives the interested user a good starting point for further examinations.

Meshkova et al. [38] describe their COMANCHE approach. The COMANCHE framework aims to organize and manage the information for software configuration management for the devices at home. With industry partners such as Alcatel-Lucent, Indesit, and Gorenje, the approach is centered on making devices work with each other, and also on successfully managing the process of adding services and new capabilities to a device at a later point in time. The authors provide the example of a washing machine, to which the "Delicate" washing program is to be added. This necessitates verifying dependencies of this program and its hardware needs, installing programs that provide those dependencies, and finally installing the desired program, much like package-management in a Debian Linux system.

Each home in the COMANCHE framework has a gateway device that uses an ontology-based knowledge base to determine what capabilities and services a device offers and what interdependencies are there between those services.
Additional information describes users, software and service providers, and their authentication methods. The ontology classes describe devices in a generic way, but there are also instances of those classes to describe the particular device installed at the user's home. The ontology classes and instances make up the knowledge base of the system. They are divided into three separate ontologies: the service ontology, the home environment and context ontology, and the business domain and user ontology.

The service ontology defines software services -- available locally -- and Internet services, to be accessed via the Internet. The business domain and user ontology describes users, business rules and relationships, and identity and privacy.
preferences. The home environment and context ontology (Fig.14) describes the environment context within which the devices work. Of particular importance is the Device Function class, which describes services a device can offer. Through mappings in the Device Function Installation class, the Device Functions are related to the software and hardware already installed for that function.

Grassi et al. [39] introduces a set of ontologies that aims to solve the "lack of semantics" problem that UPnP and DLNA have. Their vision relies on a centralized Smart Home Manager, some low-cost gateways to enable IP and UPnP in devices that do not support it, and an ontology framework that describes context, energy, users, devices, and services (Fig.15).

![Figure 15: The Grassi et al. [39] ontology framework](image)

Each of the component ontologies in the framework is independent and self-sufficient. Inference capabilities stemming from the semantic descriptions allow for logics and decision making based on the ontologies.

The Service ontology defines services available -- whether communication, security, calculations, and many more other services not foreseen in UPnP. It provides for priority of service, energy consumption, and a host of other data for each service.

The Device ontology and Energy ontology together support energy management applications. They adopt standard descriptors from the FOAF ontology for the
Manufacturer and Owner classes, and incorporate also the standard UPnP definitions for UPnP devices (Fig.16).

The Energy ontology defines the main categories of PowerProducer and PowerConsumer. An important point to note is the PowerAtTime class, which allows to describe the power used or supplied at a certain time, effectively allowing both a log of production/consumption, and a future forecast to be expressed. Several kinds of producer plants are also provided, covering a range of power production technologies and their characteristics.

![Device Ontology](image)

**Figure 16**: Grassi et al. [39] Device Ontology (part)

Using the above mentioned ontologies, it is possible to encode the information needed for the scheduling of, e.g. a washing machine powered by a PV power plant. At 8.30 the power plant is producing very little power, perhaps due to rain.
or a long winter night (Fig.17). But the forecast, coming from the Context or Service ontology, says that it will be sunny in the afternoon and the power generated will be 4kW. The scheduler then has all the information to schedule the washing later, at 3pm instead of right now at 8.30.

![Diagram of energy-efficient scheduling](image)

**Figure 17**: Grassi et al. [39] example of energy-efficient scheduling

The approach taken by Kofler et al. [40] take a similar approach in making an ontology out of self-sufficient smaller ontologies, but they categorize classes and information differently. The main ontologies in their approach represent the building itself, the processes happening in it, resources and their consumption (e.g. devices or energy), factors with an influence on the system (e.g. wind), and user information that influences the rest (comfort level, schedules, user preferences etc.). Where Grassi et al. [39] kept the PowerAtTime class, Kefler et al. [40] offer an EnergyProperty class to describe the demand, supply, and costs of energy. Notable in Kefler et al. [40] is the introduction of concepts of primary and secondary energy, and renewable and non-renewable energy. For example sunlight is primary energy but electricity is secondary, as it has to be generated from some other kind of energy. The renewable vs. non-renewable distinction is important for environmentally-friendly management. A final very important distinction they make is that of FinalEnergy and UsefulEnergy. FinalEnergy is energy that is typically consumed at home but can still be transformed into another kind of energy, e.g. Gas can be transformed to heat or light. UsefulEnergy is energy that cannot be converted to another type within a common home, e.g. Heat. (It can be converted to electricity at a power plant, but...
The reason for this distinction is that the ontology is modeling for both consumers and producers of energy, and a certain energy type may be Final in one of them but only Useful in the other.

The ontology also introduces the concept of states for devices, e.g. an off state or a standby state, and of the "needsPermanentSupply" property. Each state is associated with a certain power consumption, thus enabling the reasoner to find out consumption as function of state, and turn the device off if it is not being actively used and it does not need permanent supply.

Out of all three ontologies discussed, the Kefler ontology is the most complex and developed of all three and might be a good basis to start for the Adapt4EE ontology. Especially interesting is the explicit attention on external factors, building factors, and device states as related to context and processes happening in the environment.

The last selected publication is the “Proceedings of the 2nd Workshop organized by the EEB Data Models Community” [46]. The publication is not a specialized paper like the previous three. The Proceedings are sorted by different themes, and provide a broad overview about groups working in the EU-Project context.

Following sessions are issues of [46]:

- Ontological Engineering State of the Art
- Green Building Information Modeling
- Ontology models and design patterns for building automation
- BEMS Integration Platforms & Ontology's
- Ontology's for Heterogeneous Physical Devices
- Middleware for EupP (Energy using or producing Products), White goods, HVAC, Storage and Micro Renewables
- Prosumers Micro Energy Trade Semantics
- eEB Data Models collaboration space

The first session, namely “Ontological Engineering State of the Art”, is a good introduction to the field of ontologies. It starts with formal definition of the ontology term [48].
Later the key words from the ontology domain are introduced, namely classes, relations, formal axioms and instances. Also methodologies for building ontologies are clarified in the document. Next section depicts the ontology languages like RDF, OWL and SPARQL. A section about the leading ontology tools follows. The final section describes how to publish ontology data.

Some sessions and sections have strong intersections with EU-based projects like HESMOS (session 2.), FIEMSER (section 3.1), IntUBE (sections 4.1, 4.7), eDiana (section 5.1), HYDRA (section 5.2), SmarCoDe (6.2), DEHEMS (6.3), MIRABEL (7.1) and NOBEL (7.2).

Industry sponsored projects are also represented in the proceedings. E.g. Session 4.3 (project HOMES [48]) focuses on autonomous sensors and an energy management system ensuring an adequate level for their counterparts.

Other sessions concentrate on specific topics. E.g. Section 3.2 reviews the current state of research of various aspects of energy and behavioral modeling and simulation. This includes topics like BIM, BPM, occupancy simulation, workplace design and simulation. Section 4.2 presents an open source platforms for the semantic integration of cross-disciplinary data. Section 6.1 presents an OSGi based middleware for energy aware appliances. Section 6.4 proposes a mechanism and system for the iterative identification and self-configuration of home/building appliances through a shared backplane of networked sensors and actuators available in the building.
5. M2M: selected scientific publications

Since the industrial revolution and especially the IT revolution, magnitude of technology around us increases steadily. Not only we communicate with machines and vice versa, also machines are meant and programmed to do so among them. A general expression for communication between machines is called "Machine to machine" (M2M).

The increased focus for this field, can be explained with current, worldwide amount of devices, but also with future studies. Walczak [49] sums the studies about the future hardware amount worldwide: "The WWRF predicts that by 2017 there will be around 7 Trillion devices connected; Market Study estimated in 2009 that there will be 50 Billion devices by 2010; and ABI Research estimated in 2010 that there will be 225 Million objects connected by means of a cellular link by 2014.

Regarding to Min Chen [55] "machine to machine (M2M) communications have surpassed H2H, thus drawing significant interest from industry and the research community recently."

A good example of the increasing numbers of M2M gadgets worldwide is given by Spiegel Online [56]. The article shows people are waiting in front of Via Della Conciliazione for the appointment of the new pope. First image shows the crowd in 2005. You can see a few cell phones inside the gathering along Via Della Conciliazione. The second image shows the crowd in 2013. Almost
everybody holds a smartphone, a tablet PC or a digital camera.

Figure 18 Via Della Conciliazione 2005. Spiegel Online [56]

Figure 19 Via Della Conciliazione 2013. Spiegel Online [56]
5.1 **M2M: Definitions**

Several, strong overlapping definitions of M2M exist. Min Chen [50] describes M2M as: “Typically, machine-to-machine (M2M) refers to the communications between computers, embedded processors, smart sensors, actuators, and mobile devices without or with limited human intervention”

The OECD [51] defines M2M devices as “those that are actively communicating using wired and wireless networks, are not computers in the traditional sense and are using the Internet in some form or another.”

For Grønbæk [52], M2M means: “M2M is emerging, focused on the issues of how machines communicate, how they are managed, how the data and information within them are processed, and perhaps most importantly, how the world (humans, businesses and society) can deal with them. M2M incorporates sensor and actuator networks and will ultimately create the Internet of Things (IoT), resulting from the convergence of machine-to-machine communications, Internet connectivity, enterprise-level data management applications, and web-based smart services.”

A short definition comes from Yen-Kuang Chen(Intel Labs) [53]: “M2M: where smart devices that collect data, relay information to one another, process the information collaboratively, and take action automatically”

For Wikipedia [54] the M2M expression means: “Machine to machine (M2M) refers to technologies that allow both wireless and wired systems to communicate with other devices of the same ability. M2M uses a device (such as a sensor or meter) to capture an event (such as temperature, inventory level, etc.), which is relayed through a network (wireless, wired or hybrid) to an application (software program), that translates the captured event into meaningful information (for example, items need to be restocked). Such communication was originally accomplished by having a remote network of machines relay information back to a central hub for analysis, which would then be rerouted into a system like a personal computer.”
5.2 M2M: selected scientific publications

5.2.1 2nd Workshop of M2M Semantics for Smart eeAppliances

On 5th March 2013 the 2nd Workshop of M2M Semantics for Smart eeAppliances took place in Brussels.

Context of the workshop are the targets of greenhouse gas emissions reduction. Those targets are set up by EU governments. In EU 40% of the energy consumption comes from buildings. They also contribute to 36% of EU's total CO2 emissions. EU wants to empower architects at the design phase to reduce the total emissions. Therefore enhanced CAD systems supporting energy efficient design are the aim. The interoperability between IT tools and objects like sensor clouds and energy meters is still a challenge. Lot of low-level protocols compete with each other. Therefore ICT tries to standardize the area, at least for the high level data models.

The so called “Energy using and producing Products” (EupP), or appliances produce and manage large parts of energy inside buildings. Standardization of the interface to the EupP will help establishing a market for energy efficient systems and services. Examples here are: white goods, HVAC systems, storage systems, micro renewables etc.

Increased number of such appliances is networked. Also they becoming “smart” which means incorporation of limited autonomous behavior. For CECED a smart appliance means: "a smart household appliance is an appliance which plays an active role in energy management, complying with the system policies, respecting the user settings and always assuring its best performance. The smart appliance is thus a part of the energy management system (smart grid and energy sources at home such as photovoltaics). Smart Appliances are part of larger energy management systems. Typical for a smart appliance is that they do not react on commands, but instead get signals that describe the situation (e.g. lack of energy in the grid), and (re-act) autonomously. White goods can be “schedulable appliances”. An example is, appliances knowing their requirements to do a task
(say a washing machine knows it has to wash before tomorrow), are able to negotiate their flexibility with the rest of the system in order to work at a cheaper electricity price time slot. For lightning, consumers demand for scene and mood driven illumination. There is a shift in demand from products that can simply be switched “on/off” to products that can be used for scene and mood setting.”

The publication makes some assumption about the level of intelligence of Smart Appliances. It expects “intelligent” functions in the near future:

Appliances can decide what to do based on information from its environment. Environment level could be the grid level. For the purpose of decision making it will use own functions stored in the firmware. The functions in firmware are very limited, or frankly speaking the appliance is a finite-state machine. Thus speaking of “intelligence” is ambiguous.

Another assumed functions of the future appliances are: decentralized decision capacity, cooperation capacity, two way communication capacity.

The publication states correctly a need for interoperability for the smart appliances. It suggests a basic set of commands for this task. The classification of messages follows:

- Basic control and sensor reading functions
- Appliances product information
- Intelligence behavior messages
- Discovery functions

Basic control and sensor reading functions allows direct connection to sensors and actuators. They also can be used for aggregation of sensor- and actuator data.

The appliance product information allows communication of specific parameters of appliance classes.

The intelligence behavior messages can signal environmental status like cost of energy to the appliance. They also can announce need of energy from appliance to a management system. Emergency management is also part of this message class.

The discovery functions deal with availability of plug architecture like UPnP.
A wide field of competing and overlapping communication standards exists on the field of smart appliances.

The diversity among them is confusing consumers and industries. The workshop publication lists functionality which may fulfill needs for such standardized communication in the future:

- **KNX Application Descriptions** describes the KNX application models grouped per Application Domain: lightning, shutters and blinds, HVAC, access control. The description of the application models is done by functional blocks with datapoints [57]
- **Bac.net BACnet Clause H.5** contains the normative BACnet-EIB/KNX mapping [58]
- **ZigBee SEP 2.0 Commands** for announcing availability of energy to smart appliances [59]
- **uPNP Commands** for announcing availability of services, sensors, appliances. [60]

Aims of the workshop were increased adoption of these technologies, agreeable solutions for interoperability, communication with smart appliances at information level in smart homes and “Plug and Play“ deployment. The use case was energy management with relationship towards eHealth, eInclusion, big brother appliances, and multimedia.

Accordingly to ETSI, smart appliances connectivity should be based on standardized M2M communication approach. For ETSI, M2M is a AP for the Internet of Things. The proposed M2M protocol is REST. The ETSI standardized resource structure builds upon an M2M Service Capability Layer (SCL). The applications and/or M2M SCL exchange information sober reference points. The SCL reside on top of devices and gateways. ETSI hopes, their proposal will allow different participants to develop and provide services independent of the actual connectivity (LAN,WAN etc.)

ETSI further recommends:

- interconnection with non M2M devices (IETF 6LowPan,CORE, 3GPP APPs)
- gateway architectures (OSGI, HGI, BBF)
- abstracted layer with tooling support, languages to address the devices (semantic tools, browsing tools etc.)
- An “universal” data model and tools for vertical applications
The long term view is an idea that every new generation of smart appliances with active behavior at energy efficiency, will be optional conformant to a “plug and play” interoperability capacity giving the manufacturers a competitive advantage.

The idea of a so called “semantic device” is described as:

“..a device is newly registered in a home, it will find his own character and its relationship with its neighbor devices and Things automatically based on semantic information within the M2M system without the interference of human being. For example, the house owner bought a lamp and a switch to the lamp for his house. Both the lamp and switch is enabled with wireless abilities to be able to communicate with the home automation gateway and other devices. The lamp is for the lobby and accordingly the switch is located near the entrance of the lobby. When the house owner has placed the lamp and the switch properly, a simple power-on would make the lamp and the switch work fine”

An important conclusion from previous FP7 workshops is clear: a single, unified ontology can be used to satisfy the needs of all energy efficiency appliances.

The basic version of the ontology is simple, but it can be expanded to cover future requirements.

As far regarding the future, next steps were proposed.

The main recommendation of the workshop was a proposal of a high-level modeling of information. In the first step a common vocabulary for appliances, commands, signals etc. hast to be found. To be able to achieve it, the available semantic resources can be reused. Than the whole range of use cases need a discussion. This will cover all device types (HVAC, white goods, plumbing, security, electrical systems, illumination, sensors, actuators, micro renewables, multimedia, home PCs etc. The step will extend the basic vocabulary from previous step.

Another recommendation was an agreement on an abstract architecture with a perspective for connection with current M2M approaches and standards. The recommendation will create a bridge to the communications layer chaos. A proposal of available architectures is needed to proceed. A set of open repositories of reusable pieces can be created to support the development.
5.2.2 Ontology-based Abstractions for M2M Virtual Nodes and Topologies

In the next paper, Grønbæk et al. [52] proposed a ontology based abstraction of M2M virtual nodes and topologies. In his approach, Grønbæk et al. divides the M2M infrastructure in backbone network, separate device networks, smart devices or connected objects (COs as he calls them), gateways and different types of servers. The device networks may be further divided, because of different transmission range, capacity, power availability, spatial coverage and location. In his paper, Grønbæk et al. defines an API for the management of a Virtual Node Layer. The API itself is defined as an ontology.

The ontology itself consists of so called “service classes” and primitives. The service classes presented in [52] are “Class application component” and “Class internet”.

![Figure 20: Grønbæk et al. [52] Service Ontology](image)

Figure 20 shows the service ontology modeling the M2M Internet. The service classes “Class application component” and “Class internet” are depicted as “AppComp” and “Internet”. The “Class application component” provide a small
set of high level service primitives like: event-subscription, event notification and event-report-send.

Figure 21 shows such primitives for possible event reporting. The primitives are received by the application by calling the MsgReceived function.

<table>
<thead>
<tr>
<th>Primitives (Slots)</th>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event-Subscription-Send</td>
<td>(Registrar-CO-ID, Target-CO-ID, Parameters)</td>
<td>Event subscription at the event server (i.e. the registrar)</td>
</tr>
<tr>
<td>Event-Notification-Send</td>
<td>(Subscriber-CO-ID, Target-CO-ID, Parameters)</td>
<td>Event notification from the event server</td>
</tr>
<tr>
<td>Event-Report-Send</td>
<td>(Registrar-CO-ID, Parameters)</td>
<td>Event report from a CO to the registrar</td>
</tr>
</tbody>
</table>

**Figure 21**: Grønbæk et al. [52] Class application component, Event service primitives

Grønbæk et al. [52] propose a further extension of their ontology by introduction of so called Virtual Node Layer (VNL). The VNL is additional layer which provides a high-level description of a network which later is emulated by low-level network nodes. The authors introduced the VNL to take out uncertainty and dynamic behavior out of low-power, lossy networks. Regarding to Grønbæk et al. it simplify the design of so called command and control applications. Actuator and sensor nodes used to control a factory are an example for command and control applications. In such environments, a failure of a single node is not acceptable.

In a given example, cars involved in a crash autonomously establish M2M communication by building a VN with neighbors of the place. This VN is meant to inform oncoming vehicles of the potential danger of roadblocks and reduced traffic capacity.

The example car-accident-ontology for VNL construction looks like:
1. VN creation for local alerting by cars involved in crash:
Create-region (Priority= override, Accident);
Create-VNL (Accident, Policy= high-reliability, Topology= Geographic, Circular-Area= 2000m, Trajectory= Stationary, Accident-Area);
Send-ID (Accident-Area, “Accident in local area”);

2. Alerting alarm units by cars on each side of point of accident:
Create-region (Priority= override, Accident-allert1);
Create-region (Priority= override, Accident-allert2);
Create-VNL (Accident-allert1, Policy= high-reliability, Trajectory= Move-North, Speed= Full, Alert-North);
Create-VNL (Accident-allert2, Policy= high-reliability, Trajectory= Move-South, Speed= Full, Alert-South);
% The following assumes a gateway to reach 911:
Send-ID (Alert-North, Relevant data for rescue operation, Recipient= 911);
Send-ID (Alert-South, Relevant data for rescue operation, Recipient= 911);

5.2.3 Towards smart city: M2M communications with software agent intelligence

The next paper presents a overall architecture approach for M2M communication. In his approach, Min Chen [55] proposes a four-layer based architecture for M2M communication.
The first layer consists of object sensing and information gathering. This very basic layer is basically build of sensors and data storage. Simple use case, which describes it, could be continuous monitoring of a signal (e.g. ambient light) and saving the data for later processing. According to Min Chen the surrounding information has to been filtered to reduce it the amount of it. The reduction will be done by the first layer. The reduced information pool is called personalized information system and represents only “relevant” information about the surrounding world.

The second layer describes the information delivery. Min Chen [55] favors several wireless techniques (WiFi,Bluetooth,Zigbee,GPRS,GSM,3G etc.) to solve the task. Here Min Chen predicts the overall availability of M2M devices. Min Chen like other authors predicts cheap, low-power and ubiquitous devices. Regarding to him P2P technology can assist users while delivering or processing information.

In the third layer, the information is processed. The author speaks of “autonomic” and “smart” way to provide a pervasive and autonomic services. Generation of more complex events out of basic sensor data is a good example which represents the information processing layer. Here parts of the layer can be outsourced into the cloud due the hardware limits of terminal devices. Actions of users will be determined by decision making techniques. Min Chen also suggest to use this layer to filter meaningless information by using personal profiles. This seems to overlap with the first layer.

In the last layer, Min Chen [55] places applications and services. The focus there lies on network performance, bandwidth utilization, computing capability and energy efficiency. Min Chen requires very fast responses from this layer to acquire symbiotic relationship between real life phenomena and the virtual world: “The IoT implies a symbiotic interaction among the real/physical, the digital/virtual worlds: physical entities have digital counterparts and virtual representation; things become context-aware and they can sense, communicate, interact,
exchange data, information and knowledge. Through the use of intelligent decision-making algorithms in software applications, appropriate rapid responses can be given to physical phenomena, based on the very latest information collected about physical entities and consideration of patterns in the historical data, either for the same entity or for similar entities.”

Figure 22 shows the 4-layer approach.

Figure 22: Four layer architecture of Min Chen [55]

Min Chen [55] further suggests the incorporation of second generation RFID (2G-RFID) technology into the proposed IoT architecture. Regarding to him, the combination will produce a novel intelligent system for M2M communications. As an application example he describes two cases. A video blogging application and a location-aware smart multimedia services for healthcare. For both applications a “smart house” has to be setup. RFID readers are placed in proximity of house entrances. In case the user (“Tom”) enters the house a simple video blogging application starts. A code snippet explains the idea behind it:
if InBuilding(Tom) then
    position = RFID-Locating();
    StartVideoTrack(position, resolution);
    if position = LivingRoom then StartAirConditioning(temperature).
end if

The position is triangulated from different RFID-readers. After "Tom" is located, the video tracking applications starts. A simple scenario starts the air-conditioning if "Tom" enters the living room.

The second application namely the Location-aware smart multimedia services for healthcare also uses the RFID to get the position of "Tom" inside the house. In this system vital signals are extracted by body sensors. The signals are then transmitted via e.g. cell phone to a database. Not life threatening, abnormal signals are subject of database logs. Body signals may trigger increased video surveillance if needed. The additional video information may be used in later, more accurate diagnosis. An example of mixed vital signal, RFID and video tracking can be seen in following code snippet:

if InBuilding(Patient) then
    position = RFID-Locating();
    if Diagnosis( BodySignal()) = NeedCare
        then StartVideoTrack(position,LowResolution);
    if Diagnosis( BodySignal()) = Serious
        then StartVideoTrack(position,HighResolution);
end if

In given example different levels of body signals ("NeedCare", "Serious") trigger video tracking using appropriate resolutions.
6. Summary and Conclusions

This report gives an introduction into semantic devices with special background on energy-efficient building designs. Although the topic is rather specific there is an on-going research on this field, which results in a small, but growing number of scientific publications.

This also can be seen as a problem, because domain definitions and specific nomenclature is still not well defined. On the other hand the domain is a new and dynamic field with lot of scientific opportunities for Adapt4EE.

The report also shows a quite good amount of already existent ontologies connected with semantic devices and energy consumption. This fact documents the above average efforts already done on those fields. A lot of work done on M2M networks was also presented and analyzed.

The survey about related projects shows also existing active research attempts in Europe. The presented ontologies and projects provide beneficial data for the ADAP4ee project. Here a list of overlapping issues/topics:

- Simulation capabilities of whole lifecycle of buildings for decision makers (HESMOS)
- Closing gap between BIM and BAS (HESMOS)
- Energy performance calculations formulas and measurement phase can be reused (SEEMPubs)
- Evaluation of energy-efficiency of building layout proposals and placement of devices within existing building (SESAME)
- Possible reuse of Use-case for power distribution network operators (AIM)
- Possible reuse of ontology- „physical sensor- and threshold sensor-concept. (eDiana)
- Extension of taxonomy of certain high level devices possible (Hydra)
- Representation of spaces (Sofia)
The current report can be used as a good starting point for people interested in the matter. A rather exhaustive reference list provides sufficient information for further research.
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