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SEMANCO Semantic Tools for Carbon Reduction in Urban Planning

SEMANCO

Deliverable 4.2
Semantic Energy Model

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Dissemination level		
PU	Public	X
PP	Restricted to other program participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Deliverable Administration & Summary					
No & name	**D4.2 Semantic Energy Model**				
Status	Final	**Due**	m18	**Date**	2013-02-28
Author(s)	German Nemirovskij (HAS), Álvaro Sicilia (FUNITEC)				
Editor	Álvaro Sicilia (FUNITEC)				
DoW	Evaluation of the alignments between different domains by experts. These alignments can be automatically generated by the ontology mapping techniques or manually through collaborations among experts. Design of an ontology which links the data sets modelled in WP3 according to the specifications of the environment created in T. 4.1. The semantic energy model developed in this task will be published in ICT4e2b Forum repository of data models.				
Comments					

Document history

V	Date	Author	Description
1	2013-02-26	Alvaro Sicilia (FUNITEC), German Nemirovskij (HAS)	First draft
2	2013-03-14	Pamela Hadida (FUNITEC)	Proofreading
3	2013-03-15	Leandro Madrazo (FUNITEC)	Review and editing; comments to authors
4	2013-03-18	Alvaro Sicilia (FUNITEC), German Nemirovskij (HAS)	Answers to comments, general review.
5	2013-03-19	Leandro Madrazo (FUNITEC)	General review and editing. This version has been sent to internal reviewers: Ilaria Ballarini (POLITO), Martin Carpenter (UoT)
6	2013-03-20	Alvaro Sicilia (FUNITEC)	Answers to reviewers' comments
7	2013-03-20	Martin Carpenter (FUNITEC)	Proofreading

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EXECUTIVE SUMMARY

Deliverable 4.2 *Semantic Energy Model*, developed within Work Package 4 *Semantic energy information framework*, summarises the work done and the results achieved in Task 4.2, *Design of a semantic energy model*, whose goal is the development of the semantic energy model which is at the core of the SEMANCO energy information system.

Deliverable 4.2 contributes to the project with:

- An ontology design methodology devised specifically for the project which focuses on the integration of data sources and on facilitating the processing of federated queries. This methodology is aligned with the use case methodology described in Deliverable 1.8 *Project Methodology* insofar as the ontology requirements are captured in the use cases and the activities have been processed to implement the semantic energy model.
- A semantic energy model described as a formal ontology using Web Ontology Language 2 (OWL 2). This model comprises concepts gathered from the use cases and the data sources provided by the three case studies.

This deliverable is the result of the collaborative work done in Task 4.2 by FUNITEC –Task leader, HAS and POLITO . This document has been elaborated by HAS and FUNITEC.

The report is structured in the following sections:

1. **Introduction**: Purpose of the deliverable, contributions of partners, and relationships between the work done in this task with other work packages. Particularly, this section highlights the relation between the ontology design methodology devised in this task and other lines of work of the project such as the use case methodology and the semantic integration process.
2. **Ontology design methodology**: Purposes of ontology design, evaluation of existing methodologies including the most relevant precedents of methodologies for ontological design. Since no methodological approach takes into account the integration of data sources and their querying using federated access, SEMANCO's design methodology has been devised. It is composed of three phases –vocabulary building, implementation and evaluation– which are described in this section, as well as their sub tasks: Vocabulary capture, Building of an initial vocabulary, Data sources' vocabularies mappings, TBox coding, Data sources integration, and Evaluation. Finally, how this methodology has been applied and integrated in the overall project development is described.
3. **Properties of SEMANCO's ontology**: Description of the base structure which has been built upon modules of the Suggested Upper Merged Ontology (SUMO). The details of the two hierarchies, based on subsumption and aggregation properties, are described. The application of the *DL-Lite*$_A$ formalism is presented. Further the main features that must be taken into account in the SEMANCO context are described: data properties have to be functional, the explicit definition of domains and ranges should only allow data properties, and the domains and ranges of object properties must be specified by means of axioms. The definition of the units of measure is also included in this section. The values of the data sources are related to a specific class of unit of measure which is based on the SUMO ontology. Finally, the annotation

properties are illustrated – labels, comments, references, and authors. These have been implemented in the ontology and are fully supported by the ontology editor.

4. **Conclusions**: Contributions of the semantic energy model to the project development particularly as a mediator schema for individual data sources. The most important features – the use of the upper-level modules of the SUMO ontology, the application of *DL-Lite*$_A$ formalism to optimize data access, and the specification of units of measure based on SUMO modules – are outlined. The semantic energy model developed in this task is one of the first implemented ontologies using the *DL-Lite*$_A$ formalism.

5. **Appendices:** A representative sample of the ontology code can be found in the Appendix. It includes the definition of the object property, data properties, classes and the *DL-Lite*$_A$ axioms.

1 INTRODUCTION

1.1 Purpose and target group

The purpose of this deliverable is to report about the work done in Task 4.2 *Design of a semantic energy model.*

The semantic energy model is a formal ontology – specified using Web Ontology Language 2 (OWL 2) – comprising concepts developed within the SEMANCO project that have been captured from diverse documents concerning standards, use cases and activity descriptions and data sources containing data related to the three case studies. It provides the language to understand and interpret the complexity of different data sources and their interrelations; a language which enables semantic tools and users to use the data stemming from different domains and applications. Specifically, the language consists of the terms and attributes necessary to describe regions, cities, neighbourhoods and buildings, as well as to relate this to energy related data including climate and socio-economic factors.

Ontologies are a central component of the SEIF. Their purpose is twofold i) helping to integrate data distributed in heterogeneously structured data sources, ii) facilitating data access and interoperability of tools used to evaluate energy performance in urban planning.

Ontology designers and technicians are the main target groups of this document. However the structure of the vocabulary of the semantic energy model is also of interest for domain experts such as urban planners and energy advisors.

1.2 Contribution of partners

The work carried out in Task 4.2 was led by FUNITEC and HAS. POLITO has collaborated with the work done in Tasks 3.2 and 3.3, whose outputs are instrumental for this task.

The ontology has been coded by HAS and FUNITEC using an ontology editor developed in Task 4.3 by HAS.

The report has been jointly written by HAS and FUNITEC. The internal review has been carried out by Ilaria Ballarini (POLITO) and Martin Carpenter (UoT) who has also done the final proofreading.

1.3 Relations to other activities in the project

The semantic energy model is the core component of the Semantic Energy Information Framework (SEIF), which in turn is the central component of the entire environment developed in the project.

The implementation of the semantic energy model is the logical consequence of the work done in Work Package 3 which provided the specification of the informal vocabulary, the identification of data sources and their informal mapping onto a vocabulary. Therefore, the semantic energy model is used as the mediating schema for the representation of the semantics of the data sources. The single data source schemas are mapped onto semantic energy model and by this means, interlinked with each other. The terminology of the semantic energy model, formally specified as an ontology TBox[1], is referred via SPARQL

[1] A TBox is the part of an ontology comprising concepts, roles and axioms, which is contraposed to an ABox consisting of facts or objects represented by labels (URIs) and values.

queries triggered by tools that have been developed in Work Package 5. The relevant parts of the queries are evaluated against single data sources. The results of the queries are transformed into the vocabulary of the semantic energy model and delivered to the tools that have launched the query.

An ontology design process has been devised and it is aligned with (Figure 1):

- The use cases methodology described in Deliverable 1.8 *Project Methodology*. Use cases bring together information about actors, policies and activities to fulfil a goal at a particular scale. This information is the first input of the ontology design methodology.
- The semantic integration process described in Deliverable 4.1 *Environments for collaborative ontology mapping*. This process relies on the existence of a global ontology which acts as a reference for the data sources. Furthermore, the semantic integration process covers the mapping coding stage of the ontology design methodology.

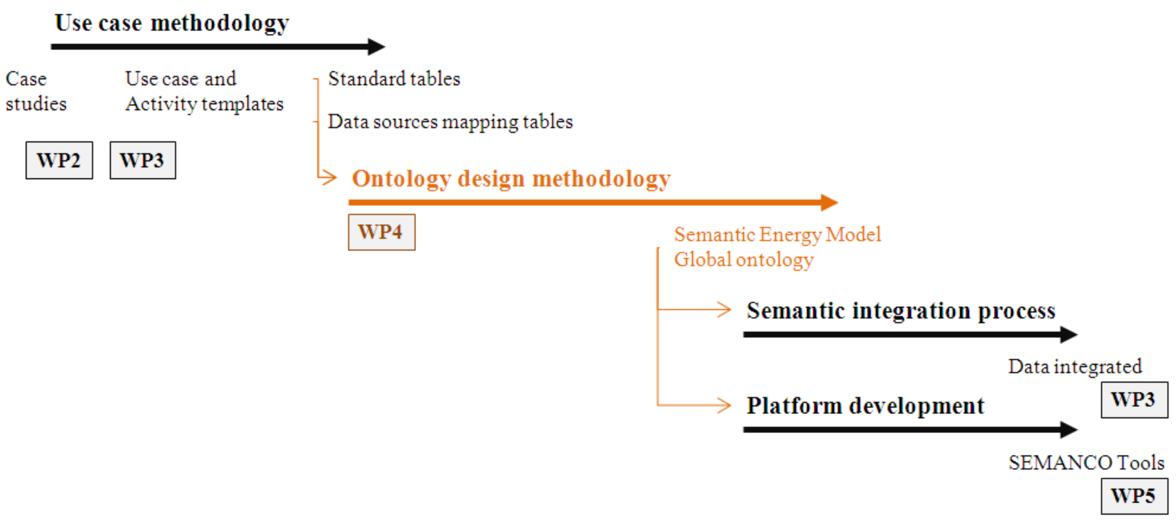

Figure 1. Relations of the ontology design process with other lines of work

Coding of the semantic energy model has been performed using the Ontology Editor developed in Task 4.3 *User interfaces for knowledge representation*.

The application of the semantic energy model as a mediator schema among individual data sources is the purpose of Task 4.5 *Semantic energy information framework integration.*

2 ONTOLOGY DESIGN METHODOLOGY

Methodologies to build ontologies are needed to avoid the unnecessary duplication of work and to reduce the rate of design errors. The relevant work on ontology design was started by Gruber (1995) and Uschold & King (1995) who proposed an ontology design process based on four phases: identifying the purpose of the ontology, building the ontology, evaluating and documenting the ontology. The ontology building phase is subdivided into three steps: 1) ontology capture, 2) ontology coding and 3) integration of existing ontologies. This approach has been further elaborated, for instance in Fernandes, Guizzardi & Guizzardi (2011). A survey of methodologies for ontological design can be found in Fernández-López (1999). However, they are mostly focused on modelling the conceptualization of a specific domain rather than on the integration of data sources in a manner supporting their querying using federated access. Furthermore, a methodology per se is not enough. It should be supported by design patterns, document templates, tools or platforms, which guide developers along the process.

A methodology for the design of the semantic energy model has been devised to take into account the integration of multiple data sources with the purpose to facilitate integrated access to these sources. This methodology supports ontology design decisions with reference to the semantic integration process described in Deliverable 4.1. On the one hand, it helps to analyse and effectively reflect structures and terms used in the data sources and in the resulting ontology code. On the other hand, this methodology determines the design of data source mappings described in D4.1 as well as the design of the queries carried out by the tool that are being developed in the Work Package 5.

SEMANCO's ontology design has been carried out according to the process model described in Nemirovskij, Nolle, Sicilia, Ballarini & Corrado (2013) which is illustrated in Figure 2. It encompasses three phases:

- A ***vocabulary building*** phase which comprises the specification of use cases, building of an initial vocabulary and the assembling of informal mapping tables, revealing relations between terms of vocabularies used in individual data sources and terms forming the initial vocabulary.
- An ***implementation*** phase which embraces formal TBox coding and integration of data sources into the Semantic Energy Information Framework with the purpose of enabling federated query processing on the basis of the distributed data sources.
- An ***evaluation*** phase aimed at the assessment of the Semantic Energy Model, coded on OWL and at the data source mappings coded in D2RQ language (Bizer & Cyganiak, 2007) with reference to the informal specification of the final vocabulary and use cases that have been generated in the vocabulary building phase. At this phase, three different evaluation strategies are applied: **TBox intelligibility check**, **mapping compliance check** and **the assessment of computational efficiency**.

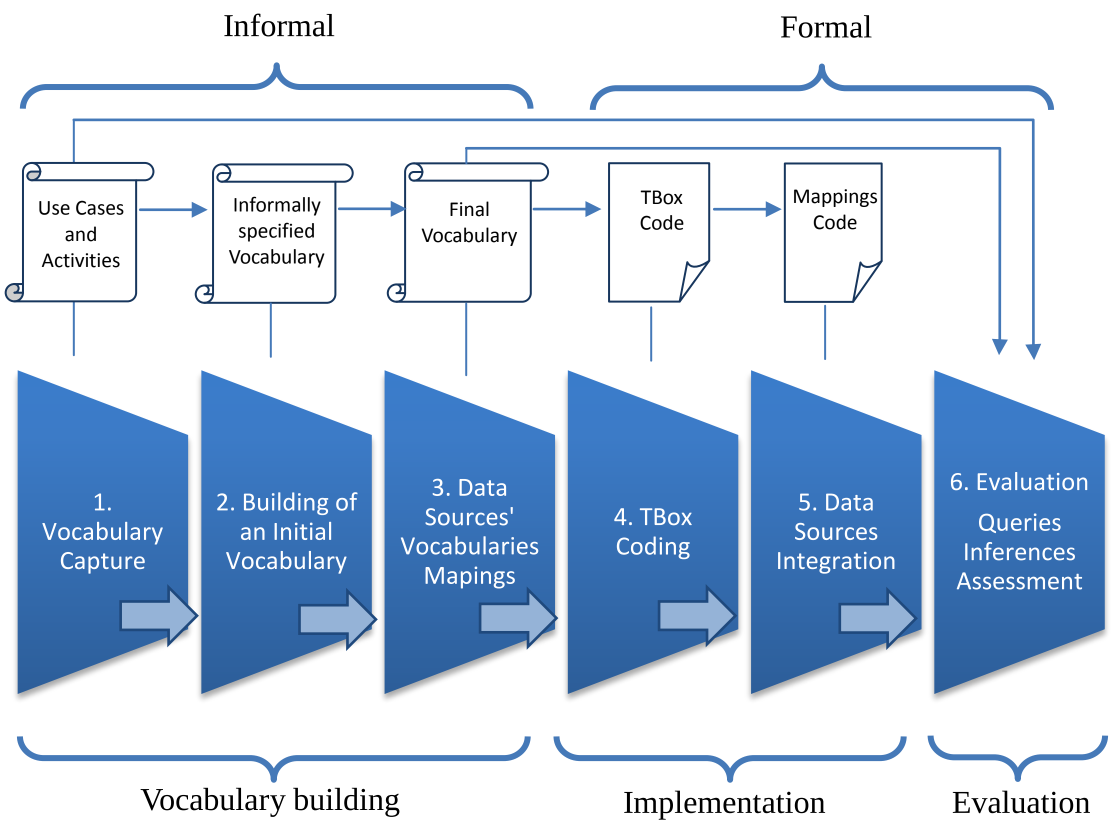

Figure 2. Process model (Nemirovskij et al. 2013)

Each of the phases of the process model is composed of tasks. The vocabulary building phase starts with the vocabulary capture taking the uses cases and activities as inputs. Then, in the second task, an initial vocabulary is built based on existing standards. Finally, in the third task the mapping between the data sources and the vocabulary is carried out. In the implementation phase two tasks are performed: TBox coding in which an ontology editor is used to create the ontology, and Mapping data sources by which D2RQ mapping files are generated for each data source according to the ontology. Finally, the evaluation phase deals with the assessment of the ontology.

2.1 Vocabulary building

2.1.1 Vocabulary capture

The first step of the ontology design process relies on the capture of the base terminology for the ontology. To perform high quality conceptualisation and to give appropriate names to the ontology concepts it is important to take into consideration the users' perspective. In the SEMANCO project, this was achieved through the use case specifications that were created at the beginning of the ontology design process. As has been described in Deliverable 1.8, use case specifications are based on a specification template consisting of a set of attributes, i.e. goal, urban scale, process scale, authors, related policy framework and a list of activities (Table 1).

Table 1. A use case specification generated using use case specification template

Acronym	UC10
Goal	To calculate the energy consumption, CO2 emissions, costs and /or socio-economic benefits of an urban plan for a new or existing development.
Super-use case	None
Sub-use case	UC9
Work process	Planning
Users	▪ Municipal technical planners ▪ Public companies providing social housing providers ▪ Policy Makers
Actors	▪ Neighbour's association or individual neighbours: this goal is important for them to know the environmental and socio-economic implications of the different possibilities in the district or environment, mainly in refurbishment projects. They use to ask these questions to the municipality ▪ Mayor and municipal councillors: In order to evaluate CO2 emissions impact of different local regulations or taxes
Related national/local policy framework	▪ Sustainable energy action plan (Covenant of Mayors) ▪ Local urban regulations (PGOUM, PERI, PE in Spain) ▪ Technical code of edification and national energy code (CTE, Calener in Spain)
Activities	▪ A1.- Define different alternatives for urban planning and local regulations ▪ A2.- Define systems and occupation (socio-economic) parameters for each alternative ▪ A3. Determine the characteristics of the urban environment ▪ A4. Determine the architectural characteristics of the buildings in the urban plans ▪ A5. Model or measure the energy performance of the neighbourhood ▪ A6. Calculate CO2 emissions and energy savings for each proposed intervention ▪ A7. Calculate investment and maintenance costs for each proposed intervention

Furthermore, a use case specification is made of interconnected activities. An activity can occur in multiple use cases, so that a network of activities emerges as shown below (Figure 3).

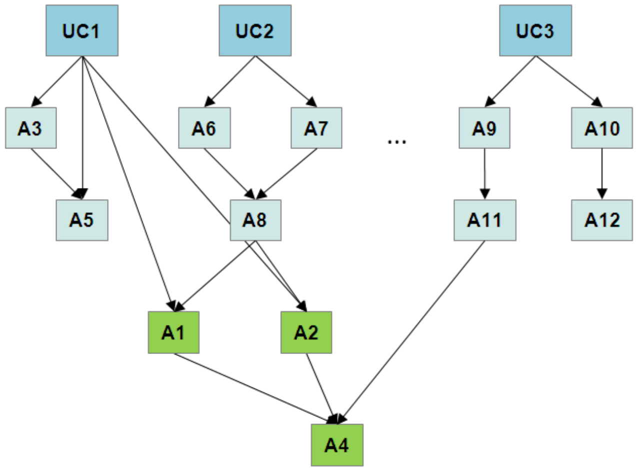

Figure 3. Relationships between activities and use cases

In turn, each activity is specified using a template that is similar to the one used for the specification of use cases. The activity specification template (Table 2) contains the fields used in the use case template (goal, urban scale, process scale, actors, related policy and framework) and the input and output data specifications which are considered candidates to become concepts of the semantic energy model.

Table 2. An activity specification generated using activity specification template

Acronym	A9		
Goal	Determination of characteristics of urban environment		
Urban Scale	Meso –Macro (urban area)		
Process scale	Operational		
Actors	• The municipality (councilors of urban planning, housing, environment and countryside, …) (stakeholder) • Urban Planners, from public authorities or from private companies • Public company of social housing • Owner/promoter of the building • Neighbors association (stakeholder)		
Related national/local policy framework	• National energy code and national technical building construction code (CTE, and RITE) • Nation , regional and local urban planning regulations		
Issues to be addressed	▪ Volumetric information of the buildings conforming the urban area (to obtain profile of shadows) ▪ Geography of the Area ▪ Location and volume of other urban elements ○ Climatic information (Horizontal radiation, wind speed, relative humidity, external temperature)		
Input Data			
Name	**Description**	**Domain**	**Format**
Vector Maps from Manresa GIS	Polygon map showing 3D geometry (buildings footprint, perimeter and height) of the buildings of the urban area	Geography, Manresa GIS	Rdf
GIS maps with topographic information	Topographic information of the urban area and surroundings	Geography, Manresa GIS	Rdf
Horizontal radiation	Amount of W·h/m^2	Climatic	
Wind speed	Speed of the wind in m/s at the nearest weather station	Climatic	
Relative humidity	Relative humidity at the nearest weather station	Climatic	
Air temperature	Outside Temperature at the nearest weather station	Climatic	

The graphic representation of use cases and the detailed specification of activities help to understand the users' requirements, to identify the data they need, to set the semantics of the data, and to determine the desired level of value aggregation. Yet, the activity specifications not only serve for the vocabulary capturing. Also, they are an ideal instrument for query design that becomes essential in the context of data integration. As stated above, in the SEMANCO project the query design serves as a connection between the ontology development (Work Package 4) and the development of end-users' tools (Work Package 5). The use case driven approach for ontology capturing is similar to the goal modelling approach presented in Fernandes et al. (2011). However, the goal of modelling is basically applied to formulate the so-called "competency questions" (Suárez-Figueroa, Gómez-Pérez, Motta & Gangemi, 2012) which are less appropriate for query design.

2.1.2 Building the initial vocabulary

The second step of the ontology design process takes use case and activity specifications as an input and has the goal of defining an initial vocabulary, that is, a categorized set of terms connected with each other by simple relations. At the same time, the terms of the vocabulary are selected taking into account standardization systems, for instance; the ISO/IEC CD 13273-1[2], ISO/IEC CD 13273-2[3], EN 15603[4] and the EN ISO 15927-1[5], and the domain related to scientific publications. The initial vocabulary is specified in the form of a Standard Table using the corresponding template (Table 3). The vocabulary is composed of 24 categories including building use, climate and building geometry. Each of these categories contains numerous terms identified in the various activities. Apart from the terms, the initial vocabulary describes the relations between terms and becoming, in this way, similar to the formal ontology specification.

Table 3. Initial vocabulary (Nemirovskij et al. 2013)

Name/Acronym						*Description*	*Reference*	*Type of data*	*U*
Climate						climatic data	-	-	-
has	**Climatic_Parameter**					climatic parameter	-	-	-
	is	**Air_Temperature**				**the temperature of external air**	**EN ISO 15927-1**	**real**	**°C**
	Is	**Solar_Irradiance**				radiation power per area generated by the reception of solar radiation on a plane	EN ISO 15927-1*	real	W
		has	**Solar_Irradiance_Type**			type of solar irradiance	-	string	-
			Is	**Direct_Solar_Irradiance**		irradiance generated by the reception of solar radiation on a plane from a conical angle which surrounds concentrically the apparent solar disk	EN ISO 15927-1*	string	-
			Is	**Diffuse_Solar_Irradiance**		irradiance generated by the reception of scattered solar radiation from the full sky hemisphere on a plane, with the exception of that solid angle which is used to measure the direct solar irradiance	EN ISO 15927-1*	string	-
			Is	**Global_Solar_Irradiance**		irradiance generated by reception of solar radiation from the full hemisphere on a plane	EN ISO 15927-1*	String	-
						…			
Stationary_Artefact							-	-	-

In this table, the terms can be related with two types of relation: subsumption (is) and aggregation (has). For instance in Table 3 *Air Temperature* is connected to the term *Climatic_Parameter* by means of their relationship. This means that the corresponding concept *Air_Temperature* subsumes the concept *Climatic_Parameter*.

Building an initial vocabulary is an important intermediate step towards the design of the semantic energy model. It simplifies formal ontology coding significantly by using a formal language like OWL.

2.1.3 Mappings of data sources' vocabularies

In this third and last step of the vocabulary building phase, the names of the data entities from sources that have been integrated are mapped to the initial vocabulary. If a target data source is a relational data base, then the fields of their tables are mapped to the terms of the initial vocabulary. Such mapping is specified with a table as the one shown in Table 4.

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[2]ISO/IEC CD 13273-1:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 1: Energy Efficiency.

[3]ISO/IEC CD 13273-2:2012. Energy efficiency and renewable energy sources. Common international terminology. Part 2: Renewable Energy Sources.

[4]EN 15603:2008. Energy performance of buildings - Overall energy use and definition of energy ratings..

[5]EN ISO 15927-1:2002. Hygrothermal performance of buildings. Calculation and presentation of climatic data. Part 1: Monthly and annual means of single meteorological elements.

Table 4. An activity description

Data source	**Data name (in the Data source)**	**Data name (in the vocabulary)**	**Data category (in the vocabulary)**
Cataluña Building Data BuildingParametersNONDomestic	Average set point temperature	Air_Temperature	Building
Cataluña Building Data BuildingParametersNONDomestic	USE	Building_Use	Building
Cataluña Building Data BuildingParametersNONDomestic	DATE	Year_Of_Construction	Building
Cataluña Building Data BuildingParametersNONDomestic	Orientation main façade	Main_Orientation	Building
Cataluña Building Data BuildingParametersNONDomestic	Orientation main façade: East	**MISSING**	Building
Cataluña Building Data BuildingParametersNONDomestic	Orientation main façade: West	**MISSING**	Building

According to the table above, the term *Air Temperature* contained in the initial vocabulary is mapped on the term *Average set point temperature* from the targeted data source. This information serves as a direct instruction for the coding of the mapping implemented using D2RQ language. Unfortunately, not all of the terms used in the individual the data sources can be univocally mapped in terms of the initial vocabulary, (see rows 5 and 6 in Table 4). If this is the case, ontology designers face three alternatives: to modify/extend the initial vocabulary (which is the most often selected alternative); to implement non-trivial mapping preferences or to specify complex queries.

2.2 Implementation

The implementation phase of the process model encompasses two tasks: TBox coding and mapping data sources.

2.2.1 TBox coding

The semantic energy model has its basis on the *DL-Lite$_A$* formalism which outperforms most of the other description logic formalisms in the context of managing data distributed in heterogeneously structured sources. The coding of the Semantic Energy Model's is carried out by SEMANCO's ontology editor described in Deliverable 4.3 *User interfaces for knowledge representation* (Figure 4). The reasons for the development of our own editor instead of using an existing one (e.g. Protégé[6]) are basically two, the participation of domain experts which require a non-technical interface and the coding support of *DL-Lite$_A$* axioms to represent domains and ranges of object properties which requires processing of reasoning (for more detailed illustration of *DL-Lite$_A$* properties see Section 3.2). Ideally, such reasoning should be carried out each time after the ontology has been edited. To our knowledge, on the fly inference is not available in editors such as Protégé. Furthermore, the specification/management of axioms required by the *DL-Lite$_A$* formalism which are needed to determine domains and ranges of roles is a complex and error prone process. Instead,

[6] http://protege.stanford.edu

SEMANCO's ontology editor only requires a mouse click in the context menu to trigger the automated generation of such axioms.

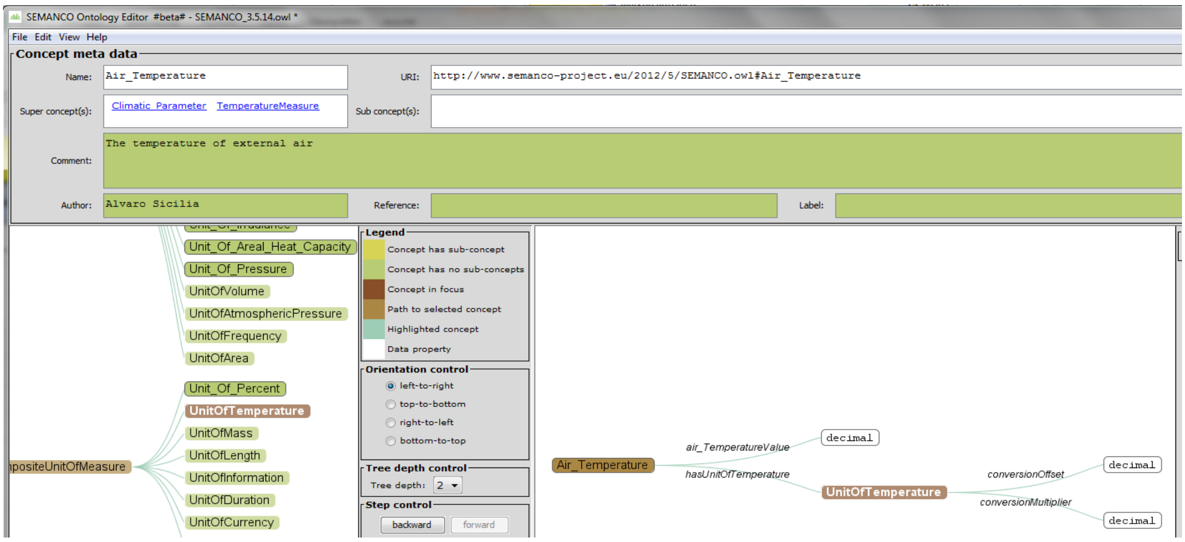

Figure 4. SEMANCO's ontology editor facilitates simultaneous graphic presentations of selected ontology parts

At the core of the coding process lies the ontology TBox. Most of the individuals and data values are naturally specified in the data sources to be integrated. Exceptionally there might be a set of individuals related to management and the calculation of units of measure that belong to the core of the semantic energy model and hence, they are specified in the implementation phase. This part of the ontology is described in Section 3.3.

2.2.2 Mapping data sources

In this step, the informal mappings of data sources vocabularies – such as those shown in Table 4 - and the ontology TBox are used to transform the contents of the data sources into RDF resources. After coding the mappings using a formal language of a dedicated middleware, the data stored in relational data bases becomes available for SPARQL querying in terms of the target TBox. These mappings are implemented with declarative mapping languages which offer rich expressive features to bring the rigid relational schemas to real cases. In SEMANCO we have opted for D2RQ which is supported by the D2R server, a mature and stable lightweight middleware. However, the option for application of other software products, as Quest (Rodriguez-Muro & Calvanese, 2012) and RDB to RDF Mapping Languages such as R2RML[7] in SEMANCO remains open.

The creation of these mappings is a complex process which involves experts from different domains having different skills. Furthermore, the mappings should be aligned with the TBox ontology created in step 4. This requires an understanding of both the structure of the ontology and the data sources. To support this process, two environments were developed in Deliverable 4.1 *Environments for collaborative ontology mapping*, using D2RQ language: a) the OWL mapping extractor to extract an OWL ontology file and a D2RQ mapping file from the structure of a relational database; b) the ontology mapping collaborative web environment that provides a graphical interface to assist non- ontology experts to implement the mappings.

[7] http://www.w3.org/TR/r2rml/

2.3 Evaluation

With regard to the data integration goal, the following three properties of the Semantic Energy Model are evaluated:

- TBox Intelligibility: the ability of actors that use the ontology to understand the ontology structure.
- Mappings compliance: correspondence of mappings with the TBox.
- Computational efficiency: the ability of the ontology to support conjunctive querying on high efficiency level, for example, with a comparatively short response time.

TBox Intelligibility: especially as a consequence of vocabulary mappings in step 3, the initial structure and semantics of the vocabulary designed in step 2 of the development process (Figure 1) can get unintentionally altered. The intelligibility test is carried out by independent testers, who are asked to find ontology concepts by navigating along its TBox graph. The navigation is done using SEMANCO's ontology editor. In the test completed at the early stages of the ontology development two independent groups of users were involved: a group of computer science students, and another formed by experts in the field of building energy. The average score of each group is measured with reference to the shortest navigation path. Our experiments have shown surprisingly, average scores of 97.30% for computer science students and 91.20% for domain experts.

Mappings compliance: The purpose of this evaluation strategy is to reveal mappings that do not correspond to the TBox of the Semantic Energy model. As shown in Rodriguez (2012) a set of mappings defines an "implicit" TBox. Such TBox contains the concepts referred in the mappings. From the logic of the integration procedure, these concepts should belong to the Semantic Energy Model. The idea of the mapping compliance test is to make such TBox explicit and verify if it builds a subset/sub-graph of the Semantic Energy Model TBox.

Computational efficiency: in the focus of this methodology is the evaluation of the query processing. Queries used for the evaluation are generated on the basis of the use cases and activity description specified in step 1 (Figure 2). Results and the time required for query processing is subject to evaluation. In addition, alternative designs of ontology parts can be compares with each other.

2.4 Ontology development process

The ontology design methodology is a transversal process which is carried out in different tasks of the project. Figure 5 shows the ontology design process with the different tasks that have been carried out. Blue circles are the step number, green boxes indicate the deliverables and tasks where the step is carried out, and the arrows define the relations between steps. The text in bold like "Standard Tables" or "Semantic Energy Model" are outputs of a step and the regular text such as "Ontology Editor" represent tools that have been used to carry out a certain step. For example, the description of how the "Building of an initial vocabulary" step has been carried out can be found in Deliverables 3.2 and 3.3. Their output, the Standard Tables, has been coded by ontology engineers and domains experts using the ontology editor in the TBox coding step of the methodology.

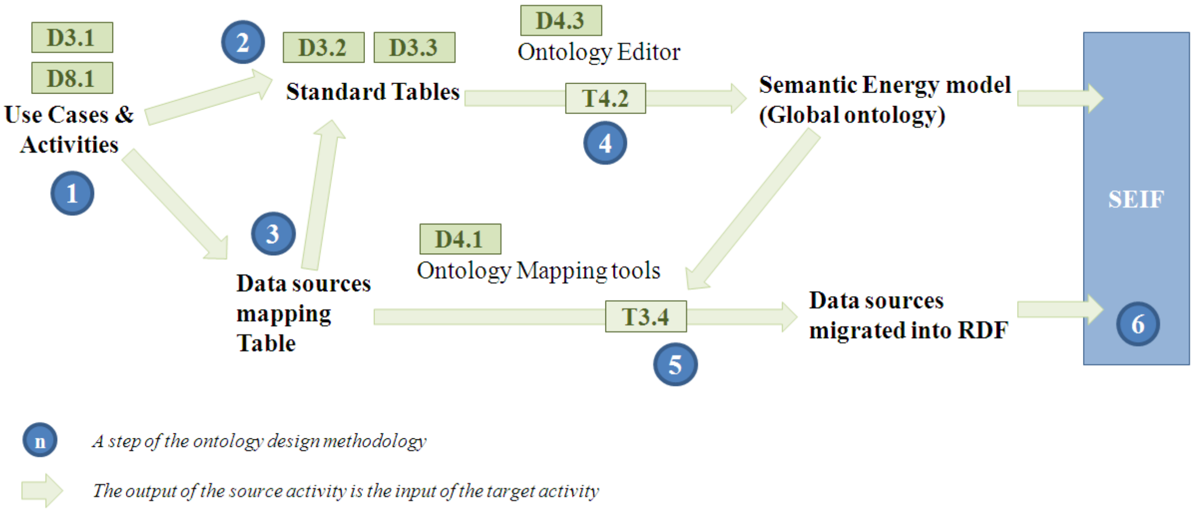

Figure 5. Ontology development implementation in the context of the project

3 PROPERTIES OF SEMANCO'S ONTOLOGY

3.1 Base structure

Following a modular approach to ontological design, the semantic energy model has been built on with modules of the Suggested Upper Merged Ontology (SUMO). In this way, each concept of the semantic energy model is subsumed at least by one concept of SUMO. The foundational relationships and axioms from SUMO remain valid in the semantic energy model. The solutions to the philosophical, engineering and linguistic issues addressed by the SUMO ontology are inherited by the semantic energy model.

The selection of SUMO as upper-level ontology was made following a comparative analysis with four other foundational ontologies; DOLCE, PROTON, General Formal Ontology (GFO) and Basic Formal Ontology (BFO). SUMO scored well in terms of simplicity of understanding, applicability for reasoning and inference purposes – especially from the time performance perspective – and number of concepts related to the domain of interest, in particular urban planning. For example, the concept *Building* of the semantic energy model is subsumed by SUMO's concept of *StationaryArtifact* and SUMO's *Attribute* subsumes *Geometry*, which, in turn subsumes *BuildingGeometry*, both are defined in the Semantic Energy Model:

$$\text{BuildingGeometry} \sqsubseteq \text{BuildingProperty} \sqsubseteq \text{Attribute}$$

The resulting semantic energy model consists of two hierarchies: one is the taxonomy based on the concept of subsumption (Figure 6), the other hierarchy comprises the aggregation properties (Figure 7). The upper level of this taxonomy is built of SUMO concepts. The building elements of this second hierarchy (Figure 7) are non-subsumption properties, basically of aggregative nature. The property names begin with "*has*" prefix, for example, *hasGeometry* or *hasAir_Temperature*.

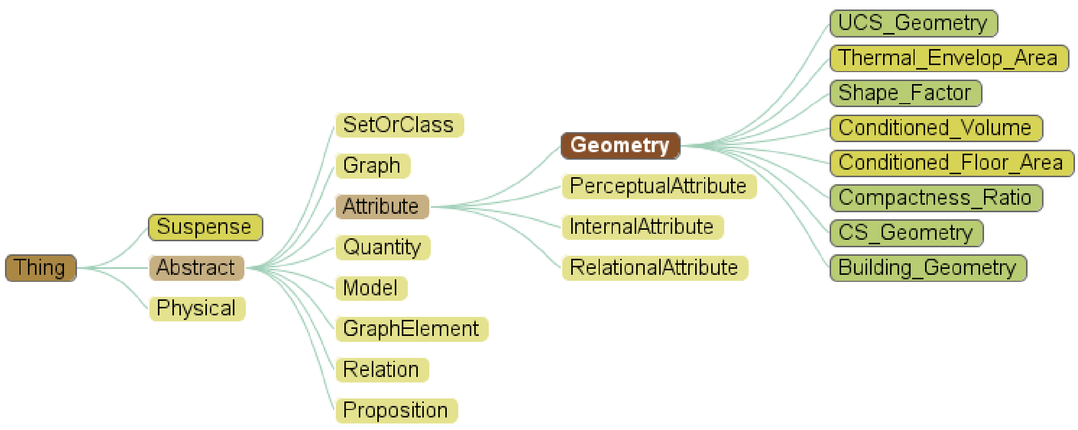

Figure 6. An extraction form the concepts taxonomy of semantic energy model, generated by SEMANCO's ontology editor

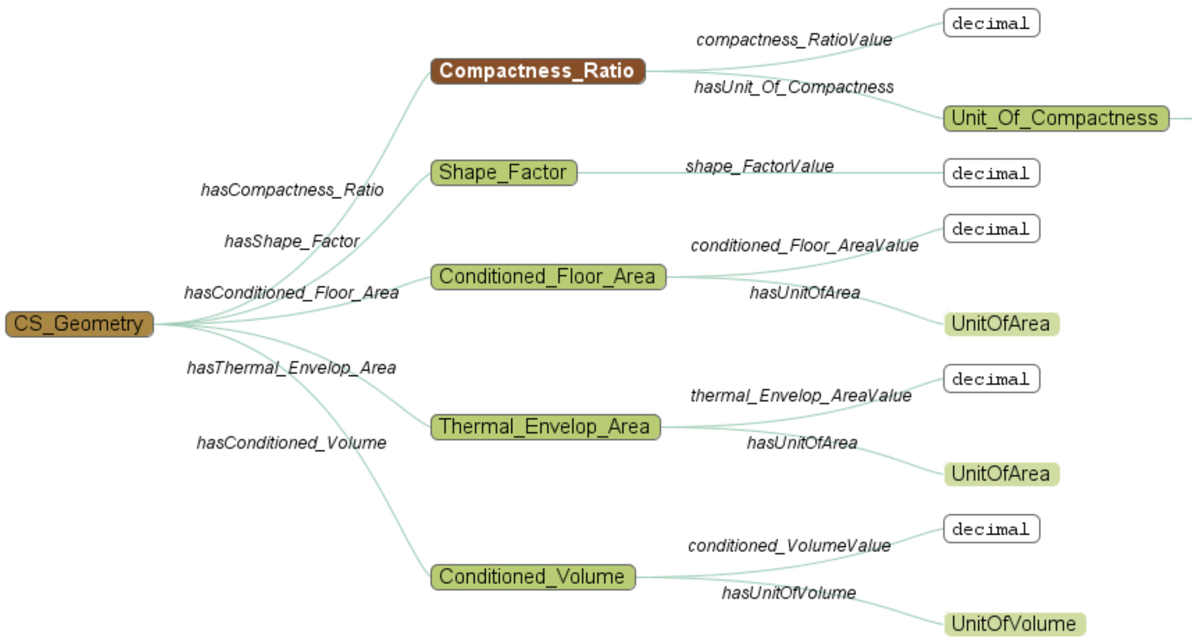

Figure 7. An extraction form the non-subsumption hierarchy of semantic energy model concepts, generated by SEMANCO's ontology editor

The SEMANCO ontology editor offers to the user two simultaneous views of an ontology: one for editing the taxonomy of concepts, and another one for editing the graph of non-subsumption relations. A user can generate new concepts by editing both views. However, because of some foundations of description logics, when a concept is integrated into the network of non-subsumption relations it has to be integrated also into the taxonomy. To avoid continuously switching between views, concepts generated in the non-subsumption view are all initially subsumed by the aggregative concept *Suspense* which is used as a temporary container for new concepts and has any particular semantics. Later on, for each concept subsumed by *Suspense* other parent concepts might be selected from the structure of the informal vocabulary (Table 3) and the semantics of the domain of discourse.

3.2 DL-Lite$_A$ formalism

For the coding of the semantic energy model, we have selected the *DL-Lite$_A$* formalism. The *DL-Lite$_A$* was designed taking into account the requirements of data integration (Poggi et al., 2008). Furthermore *DL-Lite$_A$* is one of the members of the DL-Lite family of description logics. Another member of this family, *DL-Lite$_R$* that has lots of features in common with *DL-Lite$_A$*, serves as a basis for the OWL QL profile of OWL 2, designed for the purpose of data access/management[8].

The most important features of *DL-Lite$_A$* are the following: 1) the restriction requiring that all data properties have to be functional; 2) the rule determining that explicit specification of domains and ranges of roles is allowed only for data properties; for instance, roles connecting individuals of a concept with a domain of values, real or integer, and its prohibition for object properties, for example, roles connecting individuals of two concepts; and 3) the requirement to specify domains and ranges of object properties by means of axioms. For example, the following axioms in DL notation use subsumption ($\sqsubseteq$), existence

[8] http://www.w3.org/TR/owl2-profiles/

quantification (∃) and inversion ( ) to express that the individuals of the concept *Air_Temperature* relate to the individuals of the concept *Building* via the property *has Air_Temperature*:

$$\exists hasAir\_Temperature \sqsubseteq Building$$
$$\exists hasAir\_Temperature \ \sqsubseteq Air\_Temperature$$

3.3 Units of measure

The data sources to be integrated by means of the Semantic Energy Information Framework (SEIF) contain a lot of values. Most of them are measures specifying physical quantities, such as area, volume, energy consumption or CO_2 emission. These data are often defined by different standardization systems, for example data specifying one physical quantity can use different units of measure (meter and feet, kilogram and pounds, litre and gallons). There are many reasons for this constellation, for instance in different European countries, different standardisation systems are adopted. Furthermore, some data sources emerged in an ad-hoc process wherein standardisation was not really a consideration.

Therefore, to facilitate the interoperability of SEMANCO's tools that use integrated data, a conversion of measures between different systems of units is required. The calculation mechanism for such conversion is a part of the query. Yet, the values for calculation as well as the vocabulary specifying units of measure are parts of the ontology.

After analysing existing ontologies, two ontology modules for units of measure management were preselected. One of these ontologies was the QUDT[9], and the other was the SUMO. The QUDT ontology has shown bad time performance when different reasoning tests were processed. Therefore, it was decided to use the corresponding SUMO module as the basis for implementation of the units of the system of measure of the semantic energy model. In this system all concepts whose individuals are measures of physical quantities have a data property. The domain of this property can be decimal or integer (Figure 8). Furthermore, such concepts have object properties which domains are the corresponding unit of measure. For instance, the concept of *Energy_Generator_Power* is associated with the concept *Unit_Of_Power*. Each individual of *Energy_Generator_Power* will be associated with an individual of *Unit_Of_Power*, e.g. *watt* or *joul per second.* In turn each unit of measures is associated with two values: *conversionOffset* and the *conversionMultipler*. For the standard units of measure the former one is 0 and the latter one is 1.

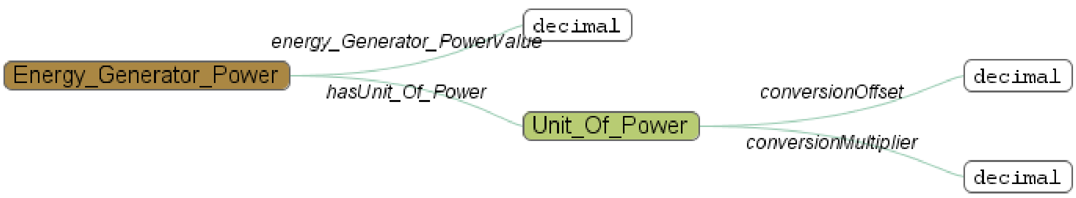

Figure 8. An example illustrating the units of measure system

[9] http://www.qudt.org/ (Accessed 14/03/2013)

Initially, units of measure are associated with generic measures, such as *Power_Measure* or *Energy_Measure*. The generic measures, in turn, subsume concrete more specific measures such as *Energy_Generator_Power* or *Primary_Energy (Figure 9)* which inherit the relations from the generic measures. This architecture reduces the number of relations which must be explicitly specified by the user by inferring them on the fly.

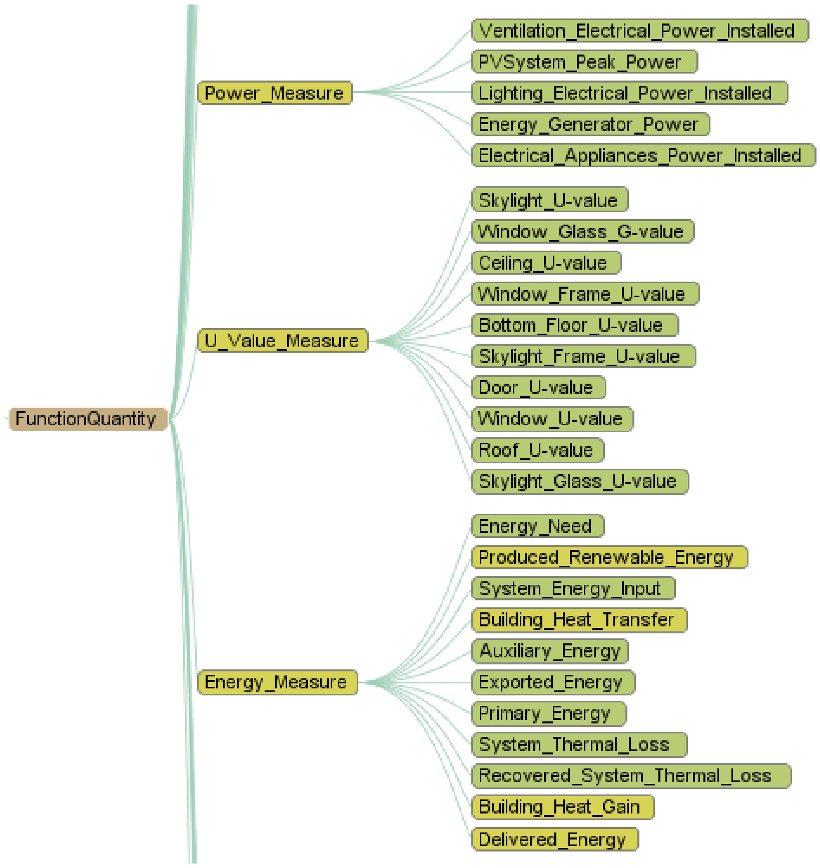

Figure 9. The hierarchy of measure concepts

3.4 Annotations

Annotations are key components of an ontology which enable users to understand its structure and ideas underlying the conceptualisation. Furthermore, these properties (e.g. name, description, references) are relevant to the technological development of the semantic energy model and to the tools developed in Work Package 5. Four annotation properties have been defined for each concept using the ontology editor:

- **Label**. It is the formal name of the concept which will be used in the tools interface. For example, the concept of *Electrical_Appliances_Power_Installed* has the label of *Power installed of the electrical appliances*. Currently, the label is in English but more than one label can be provided using language tags such as @en, @es or @dk.

- **Comment**. This annotation property contains the description of the concept. The description is provided by the domain expert in the second step (Building of an initial vocabulary) of the ontology design methodology (see Section 3.1.2). This description primarily comes from the existing standardization systems and related domain publications. However it can be written ad-hoc if it is not covered by the standards.

- **Reference**. This property is used to state the standardization systems have been used to name and describe the concept.
- **Author**. The name of the person who has created the concept. In this way, it is possible to track who has done what. Since the coding step of the methodology has been carried out by different people, this annotation property may be useful.

4 CONCLUSIONS

4.1 Contribution to overall picture

In this document we have described the most important features of the semantic energy model –a formal ontology developed in the project of SEMANCO to support the management of buildings energy and CO_2 emission related data– and the process to model it. Both the ontology and the methodology are based on current research in the fields of knowledge representation and ontology design.

The most relevant contribution of the semantic energy model is that it combines ontology design with the integration of data sources into one single process model. Thus, the applied methodology explicitly requires formal and informal mappings of data sources vocabularies and an evaluation of the ontology by means of querying data sources managed by this ontology.

In sum, the most important features of the semantic energy model – embracing 592 concepts and 468 relations implemented with 3459 axioms in $DL\text{-}Lite_A$ style – can be summarized as the following:

- The use of selected upper-level modules of the SUMO ontology;
- The application of $DL\text{-}Lite_A$ aiming at optimization of data access; and
- The system for specification of units of measure that extends those provided by the SUMO module while keeping a balance between high expressivity and time performance of reasoning.

4.2 Impact on other WPs and Tasks

The semantic energy model developed in this task is a core piece of the SEIF. It relies on the work done in Work Package 3 since the Standard Tables developed in Task 3.2 and Task 3.3 were used to build the ontology.

The ontology has been coded using an ontology editor developed in Task 4.3.

The purpose of the Task 4.5 *Semantic energy information framework integration* is to develop a federation engine which gives access to the SEMANCO tools, which are being developed in Work Package 5.

4.3 Contribution to demonstration

The semantic energy model developed in this task contributes in the demonstration since it is a central component of the SEIF which will enable users of the SEMANCO platform to query data stored in distributed sources.

4.4 Other conclusions and lessons learned

To our knowledge, the semantic energy model is one of the first implemented ontologies using the $DL\text{-}Lite_A$ formalism. The experience of its application must be of high value for the group of researchers working on data integration using semantic technologies.

Moreover, the concepts underlying the applied methodology for ontology design go beyond the state of the art. To our knowledge, a methodology combining ontology design with data integration techniques, such as formal an informal mapping of data sources vocabularies and query design has not been applied before.

The ontology as well as the process modeling will be further developed as the project continues, especially in connection to the addition of more data sources.

Initially, it was planned to publish the semantic energy model in the repository supported by the ICT4e2B project (http://www.ict4e2b.eu/). After this project was completed, the European Commission migrated the repository to a new technological service platform in order to ensure its access to the research community continuity. The new site is called eeSemantics space Library (https://webgate.ec.europa.eu/fpfis/wikis/display/eeSemantics). The semantic energy model presented in this document will be shared with the research community in the eeSemantics space Library.

5 REFERENCES

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Rodríguez-Muro, M. & Calvanese, D. (2012). High Performance Query Answering over DL-Lite Ontologies. *In Proceedings of 13th International Conference on Principles of Knowledge Representation and Reasoning (KR 2012).* 308-318.

Suárez-Figueroa, M.C., Gómez-Pérez, A., Motta, E. & Gangemi., A. (2012) Ontology Engineering in a Networked World. Berlin: Springer.

Uschold, M. & King, M. (1995) Towards methodology for building ontologies. *Workshop on Basic Ontological Issues in Knowledge Sharing, held in conjunction with IJCAI-95*, Cambridge.

6 GLOSSARY

TBox

The TBox contains the terminology of an ontology also known by intensional knowledge which usually does not change. It comprises the conceptualization statements of an ontology including concepts and relation.

ABox

The ABox is the assertion component of an ontology which contains the facts. It is also called extensional knowledge and includes the data modelled according to the TBox concepts.

RDF

The Resource Description Framework (RDF) is a directed, labelled graph specification for representing information in the Web. It is based upon the idea of making statements about resources. A resource is represented with a set of triples which are subject-predicate-object expressions.

OWL

The Web Ontology Language is a knowledge representation language for coding ontologies. OWL can be used to explicitly represent the meaning of terms in vocabularies and the relationships between those terms. OWL is built on top of RDF. This representation of terms and their interrelationships is called TBox. See further information in the SEMANCO wiki: http://arc.housing.salle.url.edu/semanco/kms/index.php/OWL

OWL formalism

OWL provides different sublanguages that offer advantages in terms of expressiveness. OWL Lite, OWL DL, and OWL Full. Each of these sublanguages has dialects determined to be used in particular scenarios. This project is focused on the $\mathit{OWL\ DL\ Lite}_A$ dialect due to its good performance in reasoning tasks which require conjunctive queries of large data volumes.

SPARQL

SPARQL is a computer language used to make queries into databases stored in RDF format. SPARQL can be used to express queries across diverse data sources, whether the data is stored natively as RDF or viewed as RDF via middleware based on mappings.

Mappings

In the context of data integration, mappings are the explicit relations between a relational schema and an ontology. In the semantic web context, a mapping define how it is transformed the contents of a relational database into RDF.

Subsumption

A hierarchical relation between two concepts of an ontology. It can be used in concept specialization. When a concept is subsumed by another is called subconcept. For example, *ResidentialBuilding* is subsumed by *Building*, therefore the first concept is a sub type of the second one.

7 APPENDICES

7.1 APPENDIX A. Ontology code

The following code is a representative part of the ontology code. It includes the definition of the object property, data properties, classes and the *DL-Lite*$_A$ axioms.

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.semanco-project.eu/2012/5/SEMANCO.owl#"
   xml:base="http://www.semanco-project.eu/2012/5/SEMANCO.owl"
   xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
   xmlns:owl="http://www.w3.org/2002/07/owl#"
   xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
   xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
   xmlns:SUMO="http://www.ontologyportal.org/SUMO.owl#">
  <owl:Ontology rdf:about="http://www.semanco-project.eu/2012/5/SEMANCO.owl">
    <owl:imports rdf:resource="http://www.ontologyportal.org/SUMO.owl"/>
  </owl:Ontology>

<!--
///////////////////////////////////////////////////////////////////////////////////
////
//
// Object Properties
//
///////////////////////////////////////////////////////////////////////////////////
////
-->

<!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasAddress -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasAddress" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasAge -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasAge" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasAllocation -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasAllocation" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasAzimut_Angle -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasAzimut_Angle" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBasement -->
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project.eu/2012/5/SEMANCO.owl#hasBasement" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBasement_Area -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBasement_Area" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBasement_Height -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBasement_Height" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor" />
 <!-- http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Adjacent_Space -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Adjacent_Space" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Area -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Area" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Dimension --
>
```

```
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Dimension" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation -
->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation" />
 <!-- http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation_Thickness -->
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project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation_Thickness" />
 <!-- http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation_Type -->
 <owl:ObjectProperty rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Insulation_Type" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Lenght -->
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project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Lenght" />
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#hasBottom_Floor_Thickness --
>

…

<!--
///////////////////////////////////////////////////////////////////////////////////
////
//
// Data properties
//
///////////////////////////////////////////////////////////////////////////////////
////
-->
<!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#addressValue -->
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  <rdfs:domain rdf:resource="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#Address" />
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string" />
 </owl:DatatypeProperty>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#air_TemperatureValue -->
 <owl:DatatypeProperty rdf:about="http://www.semanco-
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project.eu/2012/5/SEMANCO.owl#Air_Temperature" />
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#decimal" />
 </owl:DatatypeProperty>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#allocationValue -->
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project.eu/2012/5/SEMANCO.owl#allocationValue">
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#FunctionalProperty" />
  <rdfs:domain rdf:resource="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#Allocation" />
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string" />
 </owl:DatatypeProperty>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#auxiliary_EnergyValue -->
 <owl:DatatypeProperty rdf:about="http://www.semanco-
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  <rdfs:domain rdf:resource="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#Auxiliary_Energy" />
  <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#decimal" />
 </owl:DatatypeProperty>

…
```

```
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//////////////////////////////////////////////////////////////////////////////////
////
//
// Classes
//
//////////////////////////////////////////////////////////////////////////////////
////
-->
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#Standard_Unit -->
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project.eu/2012/5/SEMANCO.owl#Standard_Unit">
  <rdfs:subClassOf
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  <author>Andy Nolle</author>
  <rdfs:comment>represents the standard unit of a unit of measure, only one
individual per unit of measure</rdfs:comment>
 </owl:Class>
 <!-- http://www.ontologyportal.org/SUMO.owl#City -->
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project.eu/2012/5/SEMANCO.owl#Scale" />
  <author>Alvaro Sicilia</author>
 </rdf:Description>
 <!-- http://www.ontologyportal.org/SUMO.owl#Neighbourhood -->
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  <author>Alvaro Sicilia</author>
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 </rdf:Description>
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project.eu/2012/5/SEMANCO.owl#Suspense" />
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 </owl:Class>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#Adjacent_Building -->
 <owl:Class rdf:about="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#Adjacent_Building">
  <rdfs:subClassOf rdf:resource="http://www.semanco-
project.eu/2012/5/SEMANCO.owl#Wall_Adjacent_Space" />
  <author>Alvaro Sicilia</author>
 </owl:Class>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#Age -->
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project.eu/2012/5/SEMANCO.owl#Suspense" />
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  <author>German</author>
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project.eu/2012/5/SEMANCO.owl#Age" />
  <author>German</author>
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  <author>Alvaro Sicilia</author>
```

```
 </owl:Class>
 <!-- http://www.semanco-project.eu/2012/5/SEMANCO.owl#Air_Exchange_Measure -->
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  <author>Alvaro Sicilia</author>
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…

<!--
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////
//
// General axioms
//
///////////////////////////////////////////////////////////////////////////////////
////
-->
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project.eu/2012/5/SEMANCO.owl#hasPVSystem_Peak_Power" />
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project.eu/2012/5/SEMANCO.owl#Percent_Measure" />
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project.eu/2012/5/SEMANCO.owl#hasUnit_Of_Percent" />
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/>
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  <owl:someValuesFrom rdf:resource="http://www.w3.org/2002/07/owl#Thing" />
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project.eu/2012/5/SEMANCO.owl#hasInternal_Wall_Areal_Heat_Capacity" />
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project.eu/2012/5/SEMANCO.owl#hasSkylight_Frame_U-value" />
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project.eu/2012/5/SEMANCO.owl#hasElectrical_Appliances" />
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  <owl:someValuesFrom rdf:resource="http://www.w3.org/2002/07/owl#Thing" />
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<!-- Generated by the OWL API (version 3.2.3.1824) http://owlapi.sourceforge.net --
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