SWIMING: H2020 - 637162

Semantic Web for Information Modelling in Energy Efficient Buildings

Deliverable number	**D2.2**
Deliverable title	**Guidelines and best practices for BLCEM process and data management - Phase I**
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Grant Agreement number	637162
Project ref. no	H2020 - 637162
Project acronym	SWIMing
Project full name	Semantic Web for Information Modelling in Energy Efficient Buildings
Starting date (dur.)	01/02/2015 (24 months)
Ending date	01/02/2017
Project website	www.swiming-project.eu

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Phone	+353 (0)1 896 8431
Document Identifier	D2.2
Class Deliverable	SWIMing EU-EEB-2015-637162
Version	v1
Document due date	01/01/2016
Submitted	01/01/2016
Responsible	Matthias Weise
Reply to	
Document status	Final
Nature	R(Report)
Dissemination level	PU(Public)
WP/Task responsible(s)	WP2
Contributors	Matthias Weise, Kris McGlinn, Hendro Wicaksono, Nikolaos Kaklanis, Ioanna Petri, Dimitrios Tzovaras, Willie Lawton
Distribution List	Consortium Partners
Reviewers	
Document Location	swiming-project.eu/?page_id=7

Executive Summary

The management of data across Building Life Cycle Energy Management (BLCEM) processes presents a considerable challenge in terms of maintaining interoperability between those processes. Several data domains have been identified in D1.1. to meet the data requirements of BLCEM processes. For each data domain several data models exist, each with their own set of vocabularies and structure. Identifying which data model is the best to meet a particular use case whilst also maintaining interoperability with the wider BLCEM processes can require considerable investment of time and effort. For EU projects where time and resources may be limited, this can lead to projects neglecting the important issue of interoperability, resulting in the development of new models without consideration of the wider BLCEM and BIM communities, available data models and standards.

A methodology is required which supports developers of new use cases in identifying data requirements in a generic way, and providing capabilities to then map those data requirements to existing data models. The outcome of this process will be to:

1. **provide a set of reference use cases** for those developing new use cases, so that existing data models for meeting existing use case data requirements can be quickly identified without a need to understand the entirety of a given data model
2. **provide a methodology for harmonizing similar use cases** between projects, which will help with the identification of potential links between data models, or the need to merge two similar data models.

In this report we present a methodology for developing use cases, and for identifying data requirements on a use case by use case basis. We focus specifically on the data requirements identification stage of this process, making use of a web-based tool with a centralized requirements developed by AEC3 (buildingSMART) for capturing data requirements, the ReqCap tool. The proposed methodology is intended to be used as guidelines for EU projects when identifying use case data requirements and where possible, supporting their alignment with existing standards and ontologies.

In order to make this data open and accessible, the report recommends publishing data as Linked Data. Therefore, the main focus of data models are RDF based. By making BLCEM data open and accessible as Linked Data, the potential for new and novel use cases based on the query of multiple open data sets becomes a possibility.

Document Information

IST Project Number	H2020 - 637162	**Acronym**	SWIMing
Full Title	Guidelines and best practices for BLCEM process and data management - Phase I		
Project URL	www.swiming-project.eu		
Document URL	swiming-project.eu/?page_id=7		
EU Project Officer	Jose Riesgo		

Deliverable	**Number**	D2.2	**Title**	Guidelines and best practices for BLCEM process and data management - Phase I
Workpackage	**Number**	WP2	**Title**	Guidelines and best practices for industry

Date of Delivery	**Contractual**	01/01/2016	**Actual**	01/01/2016
Status	version 1		final ■	
Nature	prototype □ report □ dissemination ■			
Dissemination level	public ■ consortium □			

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Abstract (for dissemination)	This deliverable presents the Guidelines and best practices for BLCEM process and data management - Phase I in the SWIMing project (WP2).
Keywords	SWIMing, Guidelines and Best Practices

Version	**Modification(s)**	**Date**	**Author(s)**
1	First draft	20/10/2015	Matthias Weise, Kris McGlinn, Nikolaos Kaklanis, Ioanna Petri, Hendro Wicaksono, Willie Lawton

2	Revised draft	15/11/2015	Matthias Weise, Kris McGlinn, Nikolaos Kaklanis, Ioanna Petri, Hendro Wicaksono, Willie Lawton
3	Version to be sent for peer-review	29/12/2015	Matthias Weise, Kris McGlinn, Nikolaos Kaklanis, Dimitrios Tzovaras, Hendro Wicaksono, Willie Lawton
4	Submitted version	31/12/2015	Matthias Weise, Kris McGlinn, Nikolaos Kaklanis, Hendro Wicaksono, Willie Lawton

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List of Abbreviations

Abbreviation	Definition
BIM	Building Information Modelling
BIM_LD	Building Information Modelling – Linked (Open) Data
LD	Linked Data
LBD	Linked Building Data
BLC	Building Life Cycle
BLCEM	Building Life Cycle Energy Management
E2B (OR EEB)	Energy Efficient Buildings

1 Introduction

The goal of WP2 is to provide a set of guidelines and best practices that support data management in BLCEM processes. This can be broken down into the following tasks:

- **Identification of best practices in EeB projects, data generation and use (Task 2.1):** This task is concerned with the identification of best practices and models within the EeB cluster. In this task, the aim is to analyze existing project results and identify existing vocabularies for BIM and Linked Data and further analyze their potential extensions to better represent issues such as data modality and data format, with the goal of enabling fully automatic discovery and consumption of resources by BLCEM systems.
- **Development of guidelines and models for BLCEM data generation, publication and exploitation (Task 2.2):** This task concerns three key aspects of BLCEM resources: firstly, to build consensus on how to build linked data vocabularies to represent, search and maintain BLCEM models from existing sources. Second, the publication of these resources on the Web and, finally, the exploitation of these resources in BLCEM process. To this end, we will build on existing models in order to develop guidelines that support the entire lifecycle of these resources, including the modelling, publishing and long-term maintenance of these resources with the goal of enabling querying and interchange of these resources in BLCEM processes. We will take into account characteristics such as: license, intellectual property, sustainability, time, space, and provenance.
- **Development of guidelines for BIM-LD Services (Task 2.3):** This task will focus on the use of BIM-LD in BLCEM, in particular by means of “BIM-LD-aware BLCEM services”. Such services enable novel BLCEM applications by exploiting BIM-LD resources on the Web. In particular, a key goal here is the discovery, delivery and extraction of BIM resources from the Web. Guidelines will thus be developed to enable both existing and new BLCEM processes and to discover BIM-LD resources by means of querying the Web using data repositories. Secondly, the guidelines will describe how such systems can seamlessly download these resources, either as a full resource or only required slices of the resource. Finally, the guidelines will describe how these resources can be quickly converted into a form that can be used in an existing BLCEM process, e.g. an XML BIM format.

This deliverable introduces the methodology for achieving the above results. In particular it focuses on the building of consensus on how to generate linked data vocabularies to represent, search and maintain BLCEM models. It is structured as follows: Chapter 2 reviews work completed in D1.1 [1]. and its relevance to this deliverable, Chapter 3 presents the methodology we have identified based on best practices towards developing interoperable data models, Chapter 4 presents the important step of data harmonization and alignment, e.g. identification of use case data requirements and their mapping to existing standards and ontologies and finally Chapter 5 gives our conclusion and next steps.

2 Requirements and Use Cases

The guidelines and best practices in this report are built upon the use cases and data requirements identified in D1.1 and gathered in WP1. The majority of these (46) are based upon our analysis of the 33 EU projects identified as part of our clustering effort. These have been published on the Linked Building Data (LBD) Community Group wiki [2]. Use cases have also been contributed from members of the Linked Building Data Community Group not associated with any of the project identified. The LBD group has also provided input for the creation of the use cases template, including the classification of the building lifecycle stages, the data domains and stakeholders. These were further refined through the use of a paper, and online, survey. This was also developed with input from the LBD group, and distributed during the different clustering workshops D3.7 [3], D3.8 [4] and D3.9 [5].

The LBD group has also been aligned with the BuildingSMART initiative to create an RDF based version of the Industry Foundation Classes (IFC) standard called ifcOWL, which we view as an important enabler for publishing open and accessible BIM data. BuildingSMART also provides access to an extended community of academic and industrial members, who can provide further validation of the SWIMing project.

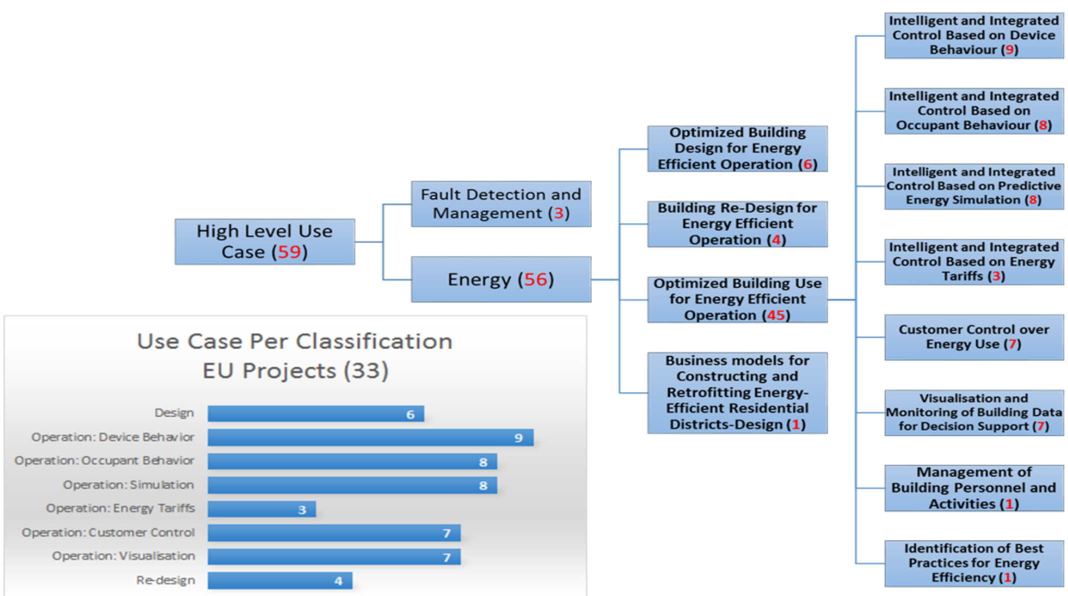


Figure 1: Number of Use Case per classification for 33 EU projects. Some use cases span more than one classification.

2.1 Analysis of Requirements and Use Cases

The use cases have undergone a classification process (Figure 1), presented in D1.1. Here we give a brief overview of three of the major clusters of use cases identified, which we use to structure the exploration of project use cases in this deliverable:

- **Optimized Building Design for Energy Efficient Operation:** This covers use cases which fall under the design stage of the building and which are intended to result in energy savings during the operational phase of the building. This requires simulation of the buildings performance which may take into consideration thermal load, energy consumption and tariffs, ventilation and indoor thermal quality prediction, influences of (and on) occupants and weather data. These use cases make use of product data, device data, behavior, control, weather and geolocation.
- **Optimized Building Use for Energy Efficient Operation:** This covers the largest number of use cases identified, which take place during the operational phase of the building. These use cases are mainly concerned with intelligent control of buildings through analysis of device data, occupancy data and through the use of predictive simulations. It is also concerned with tools which support visual analysis and feedback to stakeholders to inform about energy consumption for decision support and also knowledge of energy usage and energy tariffs to empower customers through modulation of device use. These types of use cases take into account the full spectrum of identified data domains.
- **Building Re-Design for Energy Efficient Operation:** This covers use cases which fall under the retrofitting, refurbishment and reconfiguration of building and which are intended to result in energy savings during the operational phase of the building. Here decision support tools are employed to analyze building materials and devices to provide feedback regarding new facades, devices, etc. to reduce energy consumption. These use cases can also take into account the behavior of occupants. They make use of product data, device data, measured data, behavior data, energy data, and weather and geolocation data.

To date the best practices for generating linked data in these different domains are based on our experiences working with several of the EU projects (e.g. Ambassador, DIMMER, CASCADE, SEAM4US, SEAS, etc.) identified in D3.4 [6] and D1.1 [1], attendees of various SWIMing workshops (document in report D3.7 [3], D3.8 [4], etc.) and awareness of W3C best practices (briefly document in D2.1 [7]). Due to the number of data domains and the variance of data models within those domains, a considerable challenge has been to develop methods for harmonizing data requirements for use cases, so as to provide guidance, when developing new use cases, about which data models may best fit as an enabler for open, accessible and interoperable data. To meet this challenge a set of tasks have been identified for helping in the process of identifying and publishing data to meet a particular use case. In the next section we introduce and explain this process in detail.

3 Identification of best practices in EeB projects, data generation and use

In the previous section an overview of the analysis of project use cases (D1.1 [1]) was given. The process of defining these use cases is based upon an established methodology called the IDM/MVD methodology [8] and also guidelines[1] set down in the Ready4SmartCities project. We have taken and extended this methodology for the purpose of identifying data requirements (and models) within the EeB projects. Figure 2 gives the BPMN [9] process model we have developed for defining use cases (task 1- 3 in swim lane 1) and which have been employed in D1.1. In the following sections of this report we explore Task 4 'Define Data Requirements' and begin to explore Task 5 'Map Data Requirements'. Due to the prevalence of IFC use in a number of projects (i.e EeEmbedded [10], Holisteec [11], Design4Energy [12] and ISES [13]) and its identification in D1.1 as a core model for supporting interoperability across the data domains, we often present alignments within the use case data requirements identified in section 4.2 with reference to terminology from the IFC schema. Before we explore Task 4 and 5 in greater detail, we shall first briefly explain each task next.

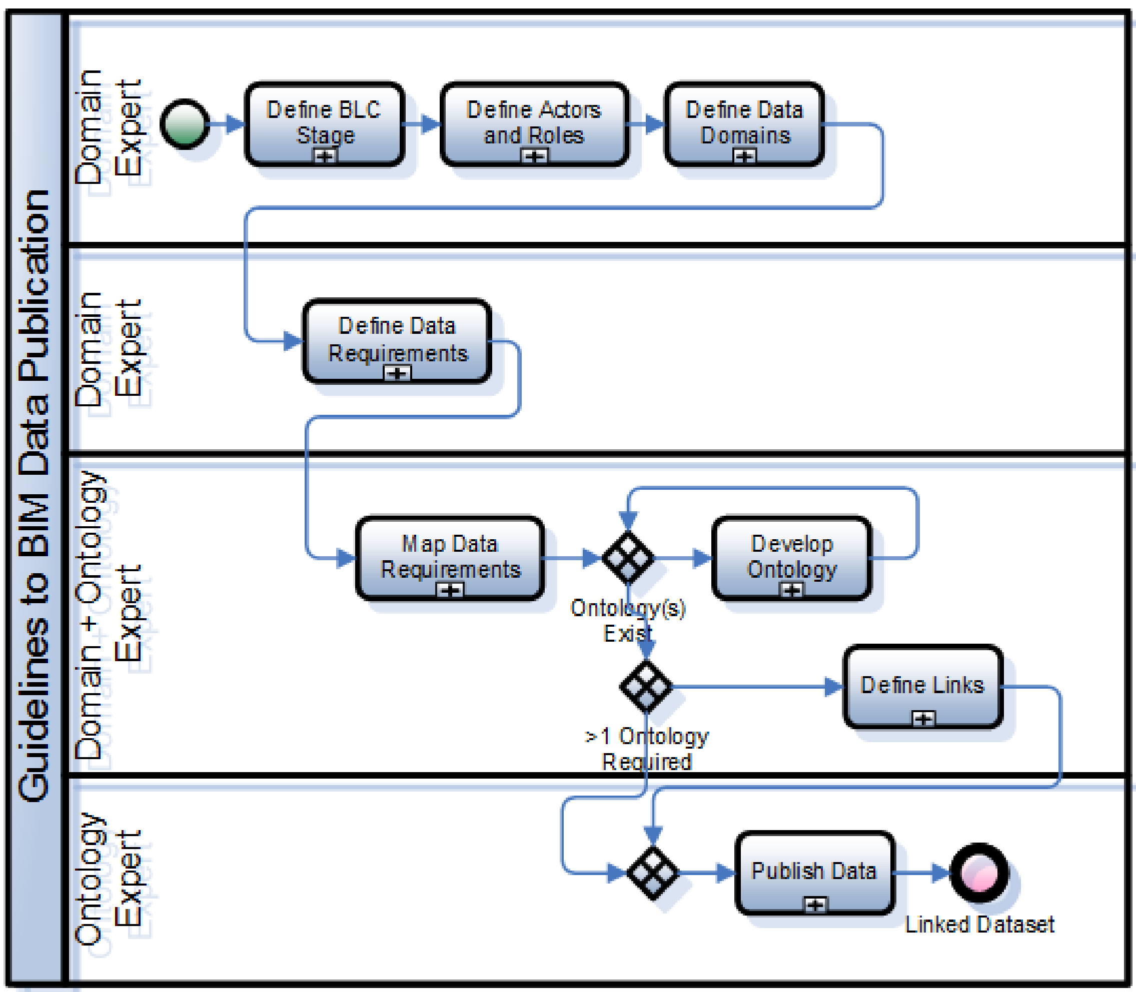


Figure 2: BPMN Model of Guidelines for BIM Data Publication

[1] http://www.ready4smartcities.eu/guidelines

Task 1 'Define BLC Stage'

Task 1 is concerned with identifying the stages of the BLC for a use case. The purpose of this process is to enable the quick identification of where in the BLC data is both generated and processed. The BLC stages have been defined within the context of the Linked Building Data community and consist of: Design, Construction, Commissioning, Operation, Retrofitting/ Refurbishment/ Reconfiguration, Demolition/Recycling. For more information on these life cycle stages please consult D1.1. More fine grained definitions of processes may also be defined during this task. For example, the different processes that must be completed for the use case. Each of these processes can then be aligned with a specific data exchange (more on this in Task 4). It is possible to apply different modelling techniques to capture processes, for example processes may be defined more formally using BPMN (as is done in the IDM methodology), but this is not a mandatory requirement.

Task 2 'Define Actors and Roles'

In Task 2 the different actors involved in the different processes required to complete the use case are identified. The purpose of this process is to enable the quick identification of responsible stakeholders for generating and processing data exchanges. Currently we have identified a number of suggested actors on the LBD wiki based on our exploration of the 33 projects. For each process identified in the use case one actor must be defined who is responsible for generating that data. An actor may include non-human agents which process data and generate new data outputs.

Task 3 'Define Data Domains'

In Task 3 the different data domains that the use case requires are identified at a high level. The purpose of this process is to provide a quick reference of data domains of concern. These data domains are also identified in D1.1 and include the following models: Product, Device, Control, Communications, Data Messages (formally Measures), Energy, Weather and Geolocation. Once these three tasks are complete, the next step is to begin to explore the data requirements in greater detail, assigning each data exchange requirement to its previously identified processes and actors.

Task 4 'Define Data Requirements'

In Task 4 the specific data requirements for each process in the use case are defined in greater detail. The purpose of this task is to understand the exact structure of the data required to meet the use case. Each data value that is required must be captured and described. This involves capturing the data at a conceptual level, and structuring the data as classes/objects and properties. These classes are then aligned with the processes and actors. In section 4 we describe this process in greater detail, which makes use of a web based tool called the ReqCap tool.

Task 5 'Map Data Requirements'

In Task 5 previously defined conceptual data models are mapped with existing ontologies and standards. The purpose of this task is to provide a quick reference point for the identification of alignments within existing domain model classes and properties to meet the data requirements of use cases, thus supporting those who wish to enable similar use cases. The alignment process is based upon expert knowledge of the existing domain models and therefore may need to undergo several review steps to ensure that the data alignments are correct.

Task 6 'Develop Ontology'

Task 6 is concerned with the development of models for meeting the data requirements of use cases which are not currently supported by any existing ontology or standard. The development of these ontologies should be conducted using existing methodologies and tools, for example the Protégé tool [14]. Where these new data structures are extensions of existing schema, they may be used as a pre-cursor to extending the schema for certification purposes. This task will be addressed in greater detail in DR2.3.

Task 7 'Define Links'

Task 7 is concerned with the definition of links between ontologies and data models, where multiple are required to meet the use case. At this stage the mappings and alignments identified in task 5 must be formalized with equivalence statements (e.g. owl:sameAs, or owl:equivalentClass/Property) as well as other types of linked properties. This task will be addressed in greater detail in D2.3.

Task 8 'Publish Data'

In Task 8 the publication of data so as to make it accessible both within the scope of a particular use case, but also to make it available to external use cases, is addressed. It is envisaged that prior to this task all concerns related to licensing, security and privacy, etc. have been addressed. This task will be addressed in greater detail in D2.3.

Now that we have explored the different tasks required for generating and making BIM data accessible to BLCEM processes, the next section will explore the activities within SWIMing towards identifying data requirements to meet a representative set of project use cases.

4 Guidelines and best practices for BLCEM process and data management

In the previous section we presented a set of tasks towards identifying data requirements to meet BLCEM use cases, the alignment of these data requirements to existing ontologies and standards and the publication of the data to make available to BLCEM processes. In this section, we explore task 4 of Figure 2 which is concerned with identifying the specific data requirements to meet a particular use case and then mapping those data requirements to existing models as a precursor to Task 5. In many cases these models are based on existing data structures and ontologies, for example IFC.

In order to build linked data vocabularies to represent, search and maintain BLCEM models from existing sources, it is first necessary to build a consensus between projects and experts on how to best represent the different data models. In the next section we present a process for supporting the identification of data requirements and the linking of these to existing standards using the ReqCap tool, a tool that makes use of the IDM/MVD methodology. This process is intended to support the harmonization of data models through a growing awareness of what models already exist and the different vocabularies used to describe the different classes and properties. In the next section we describe this process in greater detail.

4.1 Define Use Case Data Requirements

In this section we examine the data requirements of representative use cases from each of the use case classification identified in D1.1. The Requirements Capture tool[2] (ReqCap) is a web based tool for enabling the capture of data requirements for use cases. It has the following features which align with steps in the IDM/MVD process and the process model we have developed (Figure 2). These are:

- Set the link to IDM use case definitions (see Figure 3), namely
  - BLC stages and processes: *when* something is needed
  - Actor roles, stakeholders or domains: *who* is responsible to deliver data
- Define the Exchange Requirements by
  - Identifying all concepts relevant for data exchange (typically divided into classes and class properties)
  - Specify the meaning of concepts by providing a description, type information, links to used classification systems or translation to other languages
  - Configuring concepts to requirements (link classes and class properties to a conceptual model)
- Define the Exchange Requirement Model (MVD) by
  - mapping concepts to existing or new ontologies

The ReqCap tool helps to structure requirements that can already be seen as a lightweight ontology representing the knowledge of domain experts (see Figure 3). This knowledge is derived from expert interviews and the review of project deliverables conducted by each of the swimming partners.

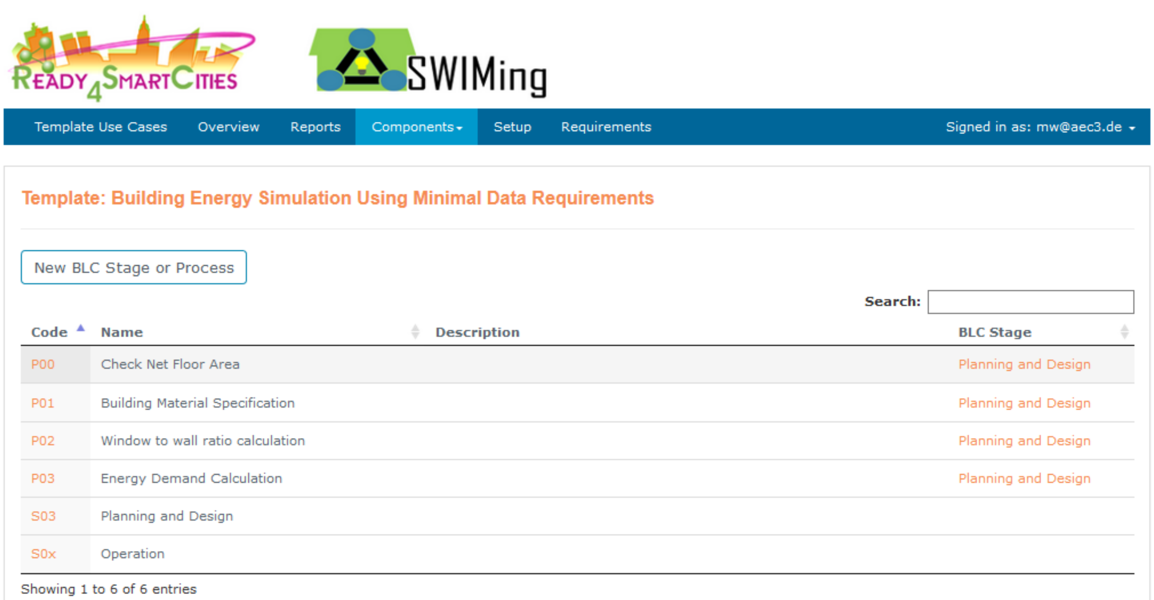
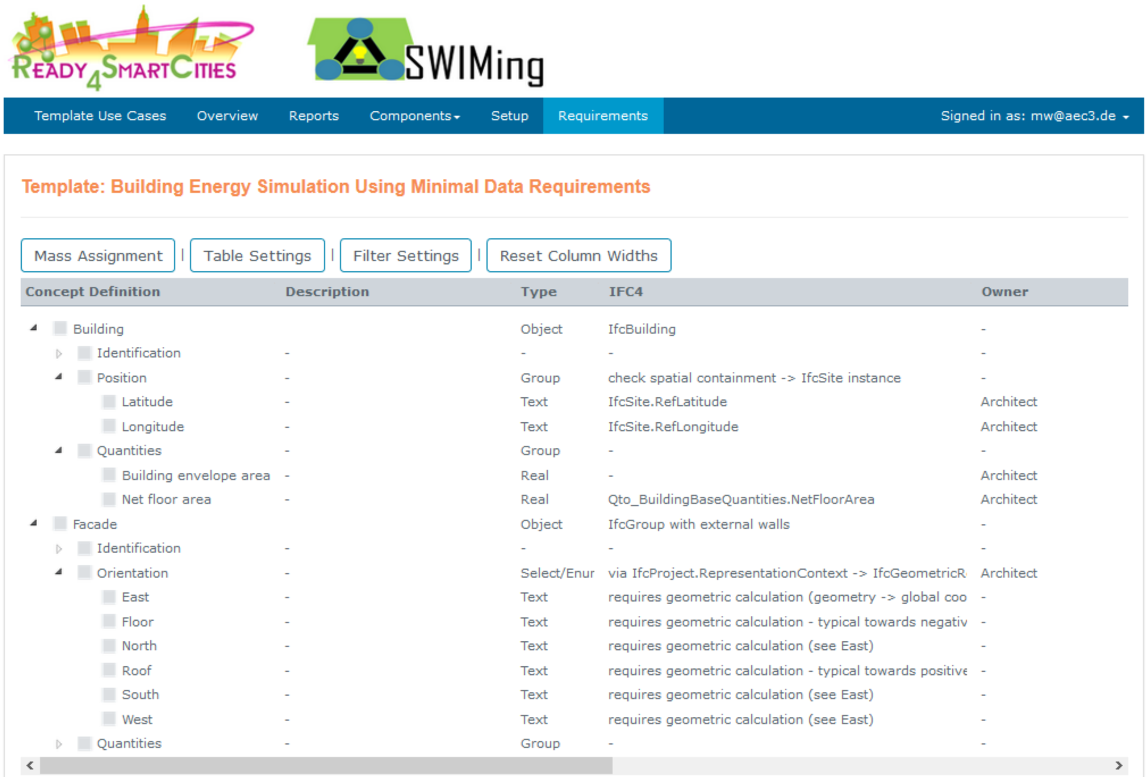


Figure 3: Screenshot that shows the definition of BLC stages and processes.

[2] ReqCap is currently hosted under http://85.10.201.48:4590 and requires a login.



Concept Definition	Description	Type	IFC4	Owner
Building		Object	IfcBuilding	-
Identification	-	-	-	-
Position	-	Group	check spatial containment -> IfcSite instance	-
Latitude	-	Text	IfcSite.RefLatitude	Architect
Longitude	-	Text	IfcSite.RefLongitude	Architect
Quantities	-	Group	-	-
Building envelope area	-	Real	-	Architect
Net floor area	-	Real	Qto_BuildingBaseQuantities.NetFloorArea	Architect
Facade		Object	IfcGroup with external walls	-
Identification	-	-	-	-
Orientation	-	Select/Enur	via IfcProject.RepresentationContext -> IfcGeometricR	Architect
East	-	Text	requires geometric calculation (geometry -> global coo	-
Floor	-	Text	requires geometric calculation - typical towards negativ	-
North	-	Text	requires geometric calculation (see East)	-
Roof	-	Text	requires geometric calculation - typical towards positive	-
South	-	Text	requires geometric calculation (see East)	-
West	-	Text	requires geometric calculation (see East)	-
Quantities	-	Group	-	-

Figure 4: Screenshot that shows structured requirement definitions and further definitions like descriptive text, type information or the mapping to IFC.

It is influenced not only by discussed use cases but also by personal experiences and other constraints such as relevant regulations, used tools and applied methods.Exchange requirements may therefore look different even for similar use cases, for instance because of the use of different terms for same concepts or because of organizing it in a different way. Accordingly, reuse and harmonization of specifications is a general challenge when working on use cases.

The ReqCap tool is very flexible in capturing exchange requirements, which means that the domain knowledge can be managed more or less as specified by the domain experts or reviewed projects. As it will be seen in this deliverable it is challenging to harmonize requirements on domain level, which would also require changing the terms of concepts and its structure so that domain experts may no longer recognize their own requirements. A potential solution to harmonize requirements (and to identify same concepts) is to define a link to a reference structure like for instance a classification system, or a data structure.

ReqCap allows to capture such knowledge because it enables to specify the mapping to other structures like ifcOWL, SAREF, gbXML or any other ontology. Whereas this information first of all is used to see whether a concept can be represented or exchanged by a specific ontology, it also enables to make an analysis of which concepts are linked to a class or property of an ontology. For instance, if a concept called "Building" and a concept called “Gebäude” are linked to the same class “IfcBuilding” then they probably represent the same concept in a different context, or language.

The current version of ReqCap enables the capture of requirements of different use cases and their links to ontologies and standards. It does not yet support harmonization of concept definitions or deduction of new relationships, which for instance would help to give recommendations about ontologies or discover similarities between use cases (see section 4.3 on page 98, “Alignment and Harmonization of Data Requirements across Use Cases”).

4.2 Data Requirements to meet BLCEM Use Cases

In this section we present some indicative, exploratory use cases through the application of the ReqCap tool for defining data requirements and managing mappings. The types of data required from each data domain is highly dependent on the use case which must be met. For each use case we identify data modelling requirements to meet each required domain for that use case as generated through the application of the ReqCap tool outlined previously.

The section is structured as followed: first the use case title and a code for the use case is given. These codes can be used to cross reference the use cases in the following section 4.3 on page 98 “Alignment and Harmonization of Data Requirements across Use Cases”. After the title, a short description is given. Next the processes in the use case are identified, followed by the stakeholders. Finally, a list of class and class properties are provided along with initial mappings to standards and ontologies. The use cases are classified according to the classification detailed in D1.1, which can also be found in Figure 1.

The first use case (UC1) is concerned with the design phase and the final (UC11) the re-design, all the use cases between are in the operational phase (UC11). It may be useful when reading this document to refer to section 4.3 and where concepts or alignments of interest are addressed, refer back to the more detailed use cases description. Here is an overview of each use case and title and where it falls within our classification system.

Optimized Building Design for Energy Efficient Operation, 1 Use Case

- UC1 = Minimum Data Requirements for Building Energy Simulation

Optimized Building Use for Energy Efficient Operation, 4 Use Cases

- Intelligent and Integrated Control Based on Building Behavior (of Devices)
    - UC2 = Minimize Energy Cost
    - UC3 = Reducing energy consumption for energy constrained RF communication between devices for monitoring
    - UC4 = A Generic communication protocol for controlling building devices to manage building energy consumption
    - UC5 = Energy Forecasting

- Intelligent and Integrated Control Based on Building Behavior (Occupancy), 2 Use Cases
  - UC2 = Minimize Energy Cost
  - UC6 = Sustainable Energy management for Underground Stations
- Intelligent and Integrated Control Based on Predictive Energy Simulation, 1 Use Case
  - UC7 = District Key Performance Indicators and Forecasting
- Intelligent and Integrated Control Based on Energy Tariffs, 1 Use Case
  - UC8 = Decision support and energy awareness in a district
- Visualization and Monitoring of Building Data (e.g. Energy Consumption) for Decision Support, 1 Use Case
  - UC9 = Integration of BIM and district level 3D models with real-time data from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors'
- Management of Building Personal and Activities, 1 Use Case
  - UC10 = Energy and maintenance action management

Re-design and Re-commissioning for Energy Efficient Operation, 1 Use Case

- UC11 = Decision support tool for district renovation planning

The information found in each use case description should not be considered to be complete; rather, the descriptions are the beginning of an iterative process of defining and refining data requirements. Also, alignments to existing standards may be provided where they either a: already exist or b: where they could potentially be made. In some cases, these alignments will require further interaction with the appropriate domain expert for the use case to ensure their validity. In other cases, there may be no current suggestions for alignments with existing concepts. In those cases, they are left blank.

The first use case we begin with is in the energy simulation domain and was identified in the LDAC workshop [15]. It is chosen here as an initial example as it is based on a minimal set of data requirements, and as such was seen as a good initial starting point for use cases exploration using the defined methodology. For this use case, we make reference to the methodology for each step.

4.2.1 Optimized Building Design for Energy Efficient Operation

4.2.1.1 Use Case 1 [UC1] 'Minimum Data Requirements for Building Energy Simulation'

This use case is concerned with enabling building energy simulation using a minimal set of data, for example, data on the floor area of the building, ratio of window area, etc. Using this data it is possible to make predictions about kWh energy requirements for different zones in the building, which is then used to inform the responsible party about what building systems (e.g. HVAC) are required for installation and how these devices should be configured.

Referring to Figure 2 page 13 (BPMN Process), after defining the use case (Task 1-3) the next task is to identify data requirements. Here we provide the output of the ReqCap tool. The first step when using the ReqCap tool is to define the different processes in greater detail, based upon Task 1. Table 1 highlights the required processes identified and their stage of the BLC, as defined in the ReqCap tool.

Use Case Processes

Table 1: The different processes within this use case.

Code	Name	Description	BLC Stage
P00	Check Net Floor Area	Determine the net floor size.	Design
P01	Building Material Specification	Determine the building materials.	Design
P02	Window to wall ratio calculation	Calculate window to wall ratio.	Design
P03	Energy Demand Calculation	Calculate energy demand.	Design

Stakeholders

Next, we define the stakeholders, in the tool, who are responsible for generating or processing the data, based upon Task 2. This data can be taken directly from the high level use case description. In this use case the following stakeholders were identified:

- Architect
- Building/Facility Owner
- Energy Manager/Auditor
- Operations Manager.

Data Domains

The following data domains are then defined, based on Task 3:

- Building Product
- Building Behavior
- Geolocation

Class and Class Property Definition

Once Task 1-3 have been entered into the ReqCap tool, the next step is to begin to define the data requirements at a conceptual level. Here we are interested in the Product domain for describing the building Geometry (as a collection of products, e.g. walls, etc. and also spaces), the buildings Geolocation and also Behavior (Occupancy and occupant schedules for spaces). This process begins by dividing the data requirements into Classes and Class Properties. Table 2 gives an overview of the different classes identified for quick reference. Table 3 to Table 6 then give more detailed descriptions of these classes and their class properties, along with an initial alignment with existing standards, in this case IFC and gbXML.

Table 2: An overview of classes required for this use case.

Classes	Description
Building	A description of the building which includes information for identification, positioning and quantities (building envelope, net floor area)
Building Envelope	A container for the different building facades.
Facade	The external building walls.
Identification	Data to uniquely identify a class.
Orientation	The orientation of the different walls which make up the building facade.
Position	The longitude and latitude of the building.
Quantities	All the quantities to enable the energy simulation, which include; the building envelope area, net floor area and the window area ratio.
Occupancy	A description of occupancy patterns on a zone/space by zone/space basis.
Zone/Space	A geometric zone/space which has associated with it an occupancy schedule.

Table 3: The class Building, its properties and their details and mappings

Class	Building		
Details	A description of the building which includes information for identification, positioning and quantities (building envelope, net floor area)		
Class Mappings	**IFC4**	**gbXML**	
	IfcBuilding	Building	
Properties	**Details**	**Properties Mappings**	
		IFC4	**gbXML**

Identification: ID, Name	An identifier for the building.	IfcRoot.GlobalId, IfcRoot.Name	GUID
Position: Latitude, Longitude	The global coordinates of the building.	IfcSite.RefLatitude, IfcSite.RefLongitude	Location:Latitude, Location:Longitude
Quantities: Envelop Area, Net Floor Area	The surface area of the building envelope and the net floor area.	Qto_BuildingBaseQuantities.NetFloorArea, Window area / (Envelop + Roof)	surfaceTypeEnum

Table 4: The class properties of class Facade

Class	Facade		
Details	A description of the building which includes information for identification, positioning and quantities (building envelope, net floor area)		
Class Mappings	**IFC4**	**gbXML**	
	IfcGroup with external walls		
Properties	**Details**	**Properties Mappings**	
		IFC4	**gbXML**
Identification: ID, Name	An identifier for the Facade.	IfcRoot.GlobalId, IfcRoot.Name	GUID
Orientation: East, West, North, South, Roof, Floor	The orientation of the different walls which make up the building façade. Requires a geometric calculation (e.g. geometry -> global coordinate	Via IfcProject.RepresentationContext -> IfcGeometricRepresentationContext.TrueNorth	?

	system -> true north definition)	, Not explicitly defined, requires geometric calculation	
Quantities: Window area ratio	The window area/(Envelope+Roof)	Qto_BuildingBaseQuantities.NetFloorArea, Window area / (Envelop + Roof)	surfaceTypeEnum

Table 5: The class properties of class Occupancy

Class	Occupancy		
Details	A description of the building which includes information for identification, positioning and quantities (building envelope, net floor area)		
Class Mappings	**IFC4**	**gbXML**	
	IfcOccupant		
Properties	**Details**	**Properties Mappings**	
		IFC4	**gbXML**
Identification: ID, Name	An identifier for the Occupancy Model.	IfcRoot.GlobalId, IfcRoot.Name	GUID
NumberOfOccupants	The current number of occupants in a zone or space.	May be calculated from IfcOccupant	PeopleNumber
Zone/Space	A zone or space which has a unique occupancy schedule associated with it.	IfcZone/IfcSpace	Zone
Schedule	A time series indicating occupancy for different time periods.	Collection of IfcTasks	Schedule

Table 6: The class properties of class Zone/Space

Class	Zone/Space		
Details	A description of the building which includes information for identification, positioning and quantities (building envelope, net floor area)		
Class Mappings	**IFC4**	**gbXML**	
	IfcZone	Zone	
Properties	**Details**	**Properties Mappings**	
		IFC4	**gbXML**
Identification: ID, Name	An identifier for the Zone Model.	IfcRoot.GlobalId, IfcRoot.Name	GUID
Representation	A geometric representation of the zone.	IfcRepresentation	CADObjectID

Concept Definition	IFC4	P00	P01	P02	P03
Building	IfcBuilding	-	-	-	-
Identification	-	-	-	-	-
ID	IfcRoot.GlobalId	OPT	MAN	MAN	MAN
Name	IfcRoot.Name	OPT	MAN	MAN	MAN
Position	check spatial containment -> IfcSite instance	-	-	-	-
Latitude	IfcSite.RefLatitude	OPT	MAN	MAN	MAN
Longitude	IfcSite.RefLongitude	OPT	MAN	MAN	MAN
Quantities	-	-	-	-	-
Building envelope area	-	-	MAN	MAN	MAN
Net floor area	Qto_BuildingBaseQuantities.NetFloorArea	-	MAN	MAN	MAN
Facade	IfcGroup with external walls	-	-	-	-
Identification	-	-	-	-	-
ID	IfcRoot.GlobalId	-	MAN	MAN	MAN
Name	IfcRoot.Name	-	MAN	MAN	MAN
Orientation	via IfcProject.RepresentationContext -> IfcGeometricRepresentationContext.TrueNorth	-	MAN	MAN	MAN
East	requires geometric calculation (geometry -> global coordinate system -> true north definition)	-	-	-	-
Floor	requires geometric calculation - typical towards negative z-Axis	-	-	-	-
North	requires geometric calculation (see East)	-	-	-	-
Roof	requires geometric calculation - typical towards positive z-Axis	-	-	-	-
South	requires geometric calculation (see East)	-	-	-	-
West	requires geometric calculation (see East)	-	-	-	-
Quantities	-	-	-	-	-
Window area ratio	Window area / (Envelop + Roof)	-	MAN	MAN	MAN

Figure 5: The ReqCap data requirements for this use case along with mappings to IFC4 and the different processes and whether the data is Mandatory or Optional.

Once the collection of Classes and Class Properties are defined, the next step is to select the class properties for the required classes and then associate these with each required process. Figure 5 is a snapshot of the ReqCap tool and how this process is managed. We continue this process now for each of the other use cases we have identified and give an overview of our findings in section 4.3 on page 98.

4.2.2 Optimized Building Use for Energy Efficient Operation, • Intelligent and Integrated Control Based on Building Behavior (of Devices):

4.2.2.1 Use Case 2 [UC2] Minimize Energy Cost

This use case is concerned with optimized energy use through knowledge of the usage schedules of systems, devices and appliances, HVAC-L (lighting) management systems, HVAC systems, building heating/cooling systems, building ventilation, rolling shutters and sun visors, domestic hot water systems)) and knowledge of occupancy patterns and use of local renewable and stored energy.

Use Case Processes

Table 7: The different processes within this use case.

Code	Name	Description	BLC Stage
P1	Minimize energy cost	Measurement is the first step in understanding the energy consumption of the technical systems, devices, and appliances within a building. This allows the building operator to know the usage of the technical systems, devices, and appliances within the building and forecast their usage depending on building schedules, day of the week/month/year, or weather. If the loads within a building are smart, then those loads can be controlled to match the needs of the building occupants in order to minimize energy consumption when they are not being utilized. Thus, control is the second step in minimizing energy costs. The use of local renewable energy production and stored energy is the third step. When these three steps are available to the building operator and exercised, then it is possible to minimize energy costs.	Op-eration
P2	Optimize Building for Occupa nt Comfort	One of the primary missions of a building operator is to ensure that its occupants are comfortable in the building. This includes the management of the lighting and HVAC systems of the building to suit the needs of the occupants. The thermal envelope of the building and the efficiency of its technical systems will impact the buildings ability to change its performance over a	Op-eration

		period of time. Understanding the flexibility of the building's technical systems and forecasting of the buildings usage will allow the building to be maximized for the comfort of its occupants.	
P3	Identify priorities during periods of limited energy availabili ty	During periods where energy capacity is limited / constrained, customers will want to shed loads in order to reduce peak energy charges. By understanding the building loads and identifying their priorities, customers will be able to shed the least critical loads in order to minimize their energy consumption.	Op- eration
P4	Impleme nt Thermal Energy Manage ment	Knowledge of a building's thermal envelope and its ability to change due to weather, temperature, and/or climate condition will allow a building operator to manage the energy consumption under varying thermal conditions and in anticipation of forecast events.	Op- eration
P5	Get prepare d to participa te in district level manage ment	As district priorities and energy costs change, the building should be prepared to participate and change its performance in response. The building operator should have knowledge of the flexibility of the building performance as well as a forecast of the buildings energy consumption, production, and storage capacity in order to prepare for a change in district energy strategies and pricing policies in order to minimize its energy costs.	Op- eration

Stakeholders

This use cases require coordination between the Building Operation Manager and the District Energy Manager. Here we only address those use cases which involve the former:

- Building Operation Manager

The Building Operation Manager may have a number of priorities that they wish to implement. Some of these priorities may be mutually exclusive while others are not.

Data Domains

The following data domains were defined which include:

- Building Devices
- Building Data

- Building Behavior
- Energy

Class and Class Property Definition

Due to the large number of data requirements to meet this use case, we focus on one of the processes identified in Table 7, P1. In P1 we identify the following data domains within this process, which are devices as well as their usage schedules and also measured data. Devices are a subdomain of Products, so we therefore include here the superclass of Product. A large number of types of devices have been identified for this use case (Ambassador D1.1). Here we begin by first classifying the different types of devices within the device domain. We do not explore these specific classes individually, rather, we explore a generic device model (Table 10) for capturing the majority of required properties.

Table 8: the high level classes required for this use case.

Class	Details
Building	Describes the building
MeasuredData	A distinct piece of measured data
Device	A device is a more specific type of product which is usually electronic or mechanical.
Appliance	A more specific type of device, for example, a computer, fridge, lamp, portable heater, etc.
CoolingDevice	Any device for cooling the building, and is generally part of a large building cooling system.
DataStorageDevice	A device for storing data.
EnergyProducingDevice	Any device which generates energy
EnergyStorageDevice	Any device which stores energy
HeatingDevice	[Air/Water] Any device for heating the building, and is generally part of a large building heating system.
VentilationDevice	Any device for lighting the building, and is generally part of a large building lighting system.
LightingDevice	Any device for lighting the building, and is generally part of a large building lighting system.

Sensor	A device for observing phenomena and returning a measurement.

Table 9: The class properties of class Building

Class	Building		
Details	Describes the building		
Class Mappings	**IFC4**	**Saref**	
	IfcBuilding	saref:BuildingSpace	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
hasGUID	All classes have a unique ID	ifcRoot.GlobalId	Rdfs:Resource
hasType	All classes have a type which is specific to that class	ifcRoot.Name	rdfs:Label
hasPlacement	The global coordinates of the building.	IfcObjectPlacement	saref:isLocatedIn
hasRepresentation	A Geometric Representation of the building.	IfcProductRepresentation	
isContainedInSpace	The building is contained within a space.	IfcSpace	saref:isLocatedIn

Table 10: The class properties of class Device

Class	Device		
Details	A device is a more specific type of product which is usually electronic or mechanical.		
Class Mappings	**IFC4**	**Saref**	
	IfcDistributionControlElement	saref:Device	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**

hasGUID	All classes have a unique ID	ifcRoot.GlobalId	Rdfs:Resource
hasType	All classes have a type which is specific to that class	ifcRoot.Name	Rdfs:Label
hasPlacement	The position of the device relative to some coordinate system.	IfcObjectPlacement	saref:isLocatedIn
hasRepresentation	A Geometric Representation of the device.	IfcProductRepresentation	
isContainedInSpace	The device is contained within a space.	IfcSpace	saref:isLocatedIn
hasUsageSchedule	A time series describing the device operation, e.g. duration of time at different settings.	IfcTask?	saref:hasProfile

Table 11: The class properties of class MeasuredData

Class	MeasuredData		
Details	A distinct piece of measured data		
Class Mappings	**IFC4**	**SSN**	
	?	ssn:SensorOutput	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
hasDataTime	A date time. Together with a unique description of the measuring device, this can be used to uniquely identify a measurement.	IfcDateTimeResource	ssn:observationResultTime
hasValue	The measured value of the observed phenomena.	IfcValue	ssn:ObservationValue
hasSource	A link to the model that describes the source of the measurement, e.g. a sensor.	IfcSensor	ssn:SensingDevice

Data Requirements Linked to Processes

As measured data is required in all the processes identified (P1-P5), so we include these as Mandatory for each:

Concept Definition	Semantic Sensor Network Ontology	P1	P2	P3	P4	P5
MeasurementData	ssn:SensorOutput	MAN	MAN	MAN	MAN	MAN
hasDateTime	ssn:observationResultTime	MAN	MAN	MAN	MAN	MAN
hasSource	ssn:SensingDevice	MAN	MAN	MAN	MAN	MAN
hasValue	ssn:ObservationValue	MAN	MAN	MAN	MAN	MAN

Figure 6: Measurement Data Linked to Processes

4.2.2.2 Use Case 3 [UC3] 'Reducing energy consumption for energy constrained RF communication between devices for monitoring'

This use case is concerned with reducing the energy consumption required for RF communication between devices through the use of a lightweight message format. Here we focus on data for monitoring, although potentially this should be extended for command data for device configuration and control (see use case **UC4**). Additional benefits of this use case are:

- Reduce amount of storage space required for storing sensor measurements and other messages.
- Reduce time for processing messages, thus reducing risk of bottlenecks in communications infrastructure.
- Reduce bandwidth allowing more data to be transmitted for a given time period.

Use Case Processes

Table 12: The different processes within this use case.

Code	Name	Description	BLC Stage
P1	Query Device Models	A service queries all available device models as a precursor to beginning communication.	Operation
P2	Transmit Message	A device transmits a message.	Operation

Stakeholders

This use cases require the following stakeholders:

- Building Energy Manager
- Facility Manager (anyone interested in building device data)

Data Domains

The following data domains were defined which include:

- Building Devices
- Building Communication
- Building Data

Class and Class Property Definition

Table 13: The high level classes required for this use case.

Class Properties	Description
SensorMeasureMessage	A sensor can have at most one phenomenon it measures.
SensorModel	A description of a sensor for recording a single measurement of a phenomenon.
SensorNodeMeasureMessage	A sensor node message encodes multiple measurements from multiple sensors.
SensorNodeModel	A model of a sensor node, which aggregates multiple sensors.

Table 14: The class properties of class SensorMeasureMessage

Class	SensorMeasureMessage		
Details	A sensor can have at most one phenomena it measures		
Class Mappings	IFC4	SSN	
		ssn:SensorOutput	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
hasSensor	An identifier for the sensor model which describes the sensor.	IfcSensor	ssn:Sensor
hasTimeStamp	Date of acquisition; e.g. format YYYY-MM-DD; HH:MM:SS	IfcDateTime Resource	ssn: startTime
hasValue	A single value that represents a measurement, which can be	IfcValue	ssn:ObservationValue

	a string, an integer, a double, etc. In some cases a sensor may transmit multiple readings at once to conserve power, in which case, these are transmitted as an array and the sensor model describes how these messages should be interpreted, units, etc.		

Table 15: The class properties of class SensorNodeMeasureMessage

Class	SensorNodeMeasureMessage		
Details	A sensor can have at most one phenomena it measures		
Class Mappings	IFC4		
		ssn:SensorOutput	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
hasSensorNode	An identifier for the sensor node model which describes the sensor.	IfcSensor	ssn:Sensor
hasTimeStamp	Date of acquisition; e.g. format YYYY-MM-DD; HH:MM:SS	IfcDateTime Resource	ssn: startTime
hasValue&Unit	An array of values, one for each sensor measure. Where time series is transmitted, a 2D array is required. Where access to a device model is limited, information regarding the unit of measure may be encoded along with the value.	IfcValue	ssn:ObservationValue

Table 16: The class properties of class SensorModel

Class	SensorModel
Details	A description of a sensor for recording a single measurement

	of a phenomena.		
Class Mappings	IFC4	SSN	
	IfcSensor	ssn:Sensor	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	A unique global identifier	IfcGlobalUniqueId	
hasPlacement	For example, a geolocation, a 3D point related to a building model, or a topological placement (on a wall, or in a zone).	IfcPlacement	ssn:hasLocation
hasRepresentation	A way to visually recognize a device, can be a JPEG, a 3D model, etc.	IfcProductRepresentation	
hasDevice Description	Meta-data about the device. For example, manufacture, manufacture date, model number.		
MeasuredPhenomena	The natural phenomena being measured		ssn:observes
UnitOfMeasure	The unit of measure, i.e. lux, temperature, humidity, CO2, etc.		ssn:SensorOutput
MeasurementRange	The set of values that the sensor can return as the result of an observation under the defined conditions with the defined measurement properties.		ssn:MeasurementRange
PowerConsumption	The power consumption of a device. This may relate to its operational state under certain conditions.		ssn:OperatingPowerRange

SamplingPeriod /FrequencyofMeasure	The expected time period between measurements.		ssn:Frequency
Latency	The variance between sensing and 'reporting' a measured value. May have a relation to the communication medium.		ssn:Latency
Accuracy	The closeness of agreement between a measured quantity value and a true quantity value		ssn:Accuracy
Precision	The closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions		ssn:Precision

Table 17: The class properties of class SensorNodeModel

Class	SensorNodeModel		
Details	A description of a sensor for recording a single measurement of a phenomena.		
Class Mappings	IFC4	Saref	
		ssn:System	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	A unique global identifier	IfcGlobalUniqueId	
hasPlacement	For example, a geolocation, a 3D point related to a building model, or a topological placement (on a wall, or in a zone).	IfcPlacement	ssn:hasLocation

hasRepresentation	A way to visually recognize a device, can be a JPEG, a 3D model, etc.	IfcProductRepresentation	
NumberOfSensors	The number of sensors on the node.		Calculated from ssn:hasSubsystem
hasSensorModels	A sensor node will usually have multiple sensors.	IfcSensor	ssn:Sensor

4.2.2.3 Use Case 4 [UC4] 'A Generic communication protocol for controlling building devices to manage building energy consumption'

This use case is concerned with controlling devices in buildings through generic message structures. All message are related to command and control and as such only messages communicated by the device back to the 'controller' in response to received messages are considered.

Table 18: The different processes within this use case.

Code	Name	Description	BLC Stage
P1	Query Device Models	A service queries all available device models as a precursor to beginning communication.	Operation
P2	Transmit Control Message	A controller transmits a control message to a device.	Operation
P3	Transmit Acknowledgment Message	A device transmits an acknowledgment message in response to a command message.	Operation

Stakeholders

This use cases require the following stakeholders:

- Building Energy Manager
- Facility Manager (anyone interested in controlling building devices for energy management)

Data Domains

The following data domains were defined which include:

- Building Devices
- Building Communication

- Building Data

Class and Class Property Definition

Table 19: The high level classes required for this use case.

Class Properties	Description
DeviceCommandMessage	A message sent to a device in order to change its set point or reconfigure its behavior.
Device(Registration)Model	A model of a device which is queried before communication can begin. It describes all the properties of the device required to enable communication and control.
DeviceResponseMessage	A response message sent by a device after it has received a command.
DeviceStateModel	A model of the state of the device and stored on the device. This is necessary if the device responds to the receipt of a command with information on its current state.

Table 20: The class properties of class DeviceReponseMessage

Class	DeviceCommandMessage		
Details	A message sent to a device in order to change its set point or reconfigure its behavior.		
Class Mappings	IFC4	Saref	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
hasSource	An identifier for the transmitter of the message.	IfcDistributionControlElement	saref:Device
hasTimeStamp	Date of acquisition; e.g. format YYYY-MM-DD; HH:MM:SS	IfcDateTimeResource	

Control Command	An array of commands, which can include: setting r/g/b values of lights, on/off, progressive/continuous setting, step/discrete setting, rotation		
Configuration Command	A List which is a kind of schedule for configuring device behavior, which describes durations of time at certain settings. Used for devices which may not be accessible for communication at all times.		
Priority	High, low, etc. Some devices may be involved in critical activity, and therefore should be capable of ignoring certain commands.		

Table 21: The class properties of class DeviceResponseMessage

Class	DeviceResponseMessage		
Details	A response message sent by a device after it has received a command.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
hasSource	An identifier for the transmitter of the message.	IfcDistributionControlElement	saref:Device
hasTimeStamp	Date of acquisition; e.g. format YYYY-MM-DD; HH:MM:SS	IfcDateTimeResource	
Acknowledgment	Command Message ID, [Error Code, Successful, etc.] This		

	message informs the controller that a: it received the message and b: whether it was able to act upon the message		
CurrentState	The response message may also include information about the current state of the device.		

Table 22: The class properties of class Device(Registration)Model

Class	Device(Registration)Model		
Details	A model of a device which is queried before communication can begin. It describes all the properties of the device required to enable communication and control.		
Class Mappings	**IFC4**	**Saref**	
	IfcDistributionControlElement	saref:Device	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	A unique global identifier	IfcGlobalUniqueId	
hasPlacement	For example, a geolocation, a 3D point related to a building model, or a topological placement (on a wall, or in a zone).	IfcPlacement	ssn:hasLocation
hasRepresentation	A way to visually recognize a device, can be a JPEG, a 3D model, etc.	IfcProductRepresentation	
hasDevice Description	Meta-data about the device. For example, manufacture, manufacture date, model number.		
hasPowerProfile	Power consumption depending on settings.		ssn:OperatingPowerRange

Communication Window	A schedule for when the device is available for communication [timeStamp, duration]		
CommunicationType	Bi-directional or only accepts commands.		
MessageStructure	The expected structure of command and response messages		

Table 23: The class properties of class DeviceStateModel

Class	DeviceStateModel		
Details	A model of the state of the device and stored on the device. This is necessary if the device responds to the receipt of a command with information on its current state.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	A unique global identifier		
currentState	Stores the current state of the device.		

4.2.2.4 Use Case 5 [UC5] 'Energy Forecasting'

This use case is concerned with sufficient prediction of the energy demand of the building. The use case was defined after the analysis of the NRG4Cast – Energy Forecasting (ref) project, which focuses on the development of real-time management, analytics and forecasting services for energy distribution networks in urban/rural communities. The use case mainly refers to the operation stage of the BLC but it also includes functionalities concerning the planning and design phase.

Use Case Processes

Table 24: Stages and Processes involved in Energy Forecasting use case

Code	Name	Description	BLC Stage

S01	Operation	Includes all day to day activity of the in use building.	
S02	Planning & Design	Refers to the architectural, engineering and technical design of buildings.	
P03	Energy forecasting	Automatic prediction of the energy demand of the building	Operation

Stakeholders

The following stakeholders were identified:

- Building/Facility Owners
- Energy Manager/Auditors

Data Domains

In addition, the data domains referring in this use case were defined and they include the following domains:

- Building Devices
- Building Control
- Energy

Class and Class Property Definition

Once these steps have been taken, the next step was to define the data requirements at a conceptual level. As briefly described before, within SWIMing the ReqCap tool was employed, so as to capture data requirements. In order facilitate the conceptual modelling the data requirements were divided into Classes and Class Properties as demonstrated in Table 43 to 61.

Table 25: The class Campus energy consumption, its properties and their details and mappings

Class	Campus energy consumption		
Details	Existing monitoring data of a campus/area		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Electricity consumption	Data format: .xls, unit of measurement: kW, time step: each month. Existing monitoring data of a campus/area		saref:Energy
Natural gas consumption	Data format: .xls, unit of measurement: GJ, time step: each month.		Saref:Gas

	Existing monitoring data of a campus/area		

Table 26: The class Local Energy Consumption, its properties and their details and mappings

Class	Local Electricity Consumption		
Details	Electricity consumption of a particular building of the campus/area		
Class Mappings	**IFC4**	**Saref**	
	IfcSensor	saref:Sensor	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Electricity consumption	Data format: .xls, unit of measurement: kW, time step: each 15 minutes. Electricity consumption of a particular building of the campus/area		saref:Energy
Natural gas consumption	Data format: .xls, unit of measurement: GJ, time step: each 15 minutes. Natural gas consumption of a particular building of the campus/area		Saref:Gas

Table 27: The class Total energy consumption, its properties and their details and mappings

Class	Total energy consumption		
Details	New input on electricity consumption of all buildings in the campus/area		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Electricity consumption	Data format: .xls, unit of measurement: kW, time step: each 15 minutes. New input on electricity consumption of all buildings in the campus/area.		saref:Energy
Natural gas consumption	Data format: .xls, unit of measurement: GJ, time step: each 15 minutes.		Saref:Gas

	New input on natural gas consumption of all buildings in the campus/area.		

Table 28: The class In-door thermal comfort level, its properties and their details and mappings

Class	In-door thermal comfort level		
Details	New input on thermal comfort level in one established office.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Temperature	Data format: .xls, unit of measurement: deg C, time step: each 15 minutes. New input on thermal comfort level in one established office.		saref:Temperature
Humidity	Data format: .xls, unit of measurement: %, time step: each 15 minutes. New input on thermal comfort level in one established office.		saref:Humidity
Illuminance	Data format: .xls, unit of measurement: W/m^2, time step: each 15 minutes. New input on thermal comfort level in one established office.		saref:Light

Table 29: The class Electricity prices, its properties and their details and mappings

Class	Electricity prices		
Details	Electricity prices for households and industrial end-users.		
Class Mappings	**IFC4**	**Saref**	
		saref:Price	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**

Old methodology of price calculation	Data format: .xls, unit of measurement: Euro/kWh, time step: The price is taken at 1st January of each calendar year. Yearly electricity prices for households and industrial end-users. http://appsso.eurostat.ec.europa.eu/nui/show.do		

Table 30: The class Natural gas prices, its properties and their details and mappings

Class	Natural gas prices		
Details	Natural gas prices for households and industrial end-users.		
Class Mappings	**IFC4**	**Saref**	
		saref:Price	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Old methodology of price calculation	Data format: .xls, unit of measurement: Euro/GJ, time step: The price is taken at 1st January of each calendar year. Yearly natural gas prices for households and industrial end-users. http://appsso.eurostat.ec.europa.eu/nui/show.do		
New methodology of price calculation	Data format: .xls, unit of measurement: Euro/GJ, time step: The price is taken for the first semester of each calendar year Average half-yearly natural gas prices for households and industrial end-users.		

	http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_203&lang=en		

Table 31: The class Energy trend 2030, its properties and their details and mappings

Class	Energy trend 2030		
Details	Scenarios and reports on energy balances and oil and gas prices for future years		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Scenarios on energy balances for future years under current trends and policies	Data format: .pdf, report http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf		
Scenarios on high oil and gas prices under the evolution of the world energy system and possible implication on energy price	Data format: .pdf, report http://ec.europa.eu/energy/observatory/trends_2030/doc/high_oil_and_gas_prices_scenarios.pdf		

Table 32: The class Meteorological data, its properties and their details and mappings

Class	Meteorological data		
Details	Data are provided by a meteorological station installed in the campus/area or by existing data sources		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Temperature	Data format: .hts, unit of measurement: deg C, time step: each 10 minutes.		saref:Temperature
Relative Humidity	Data format: .hts, unit of measurement: %, time step: each 10 minutes.		saref:Humidity

Precipitation	Data format: .hts, unit of measurement: mm, time step: each 10 minutes.		
Wind speed	Data format: .hts, unit of measurement: m/sec, time step: each 10 minutes.		
Wind direction	Data format: .xts, unit of measurement: deg, time step: each 10 minutes.		

Table 33: The class Traffic, its properties and their details and mappings

Class	Traffic		
Details	Information about location and period of road works and traffic jams from existing data sources		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Location and Period of Road works	Data format: .xls, unit of measurement: Coordinates and dates, time step: Given period. From existing data sources. http://www.mdm-portal.de/		
Traffic jams	Data format: .xls, unit of measurement: Coordinates, lengths (m) and descriptions, time step: Fast-changing (every 10 to 60 minutes). From existing data sources. http://www.mdm-portal.de/		

Table 34: The class Car user profile, its properties and their details and mappings

Class	Car user profile

Details	Information about location and period of road works and traffic jams from existing data sources		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Efficiency coefficient for each car user depending on his road behavior	Data format: .xls, unit of measurement: %, time step: triggered by car-login/usage. New input http://www.osc4car.de/		saref:has value

Table 35: The class Route profile, its properties and their details and mappings

Class	Route profile		
Details	New input about the route profile generated by typical itineraries of vehicles, typical consumption on this route and current traffic information.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
The route profile generated by typical itineraries of vehicles, typical consumption on this route and current traffic information.	Data format: .xml, unit of measurement: Map, time step: Given period from historical data. New input http://www.osc4car.de/		

Table 36: The class Vehicle profile, its properties and their details and mappings

Class	Vehicle profile		
Details	New input about velocity, battery and energy consumption.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Velocity	Data format: .xls, unit of measurement: Km/h, time step: each minute. New input		

	http://www.osc4car.de/		
Battery data	Data format: .xls, unit of measurement: %, time step: each minute. New input http://www.osc4car.de/		
Energy consumption of Vehicles	Data format: .xls, unit of measurement: kW/h, time step: each minute. New input http://www.osc4car.de/		

Table 37: The class Charging station (usage profile), its properties and their details and mappings

Class	Charging station (usage profile)		
Details	New input about position availability status and amount of energy taken/needed by charging car.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Position	Data format: .xls, unit of measurement: Coordinates, time step: Triggered by usage. New input http://www.osc4car.de/		
Status	Data format: .xls, unit of measurement: Occupied/available, time step: Triggered by usage. New input http://www.osc4car.de/		saref:State
Amount of energy taken/needed by charging car	Data format: .xls, unit of measurement: kW, time step: Triggered by usage. New input		saref:Power

	http://www.osc4car.de/		
Energy price	Data format: .xls, unit of measurement: Euro, time step: Triggered by usage. New input http://www.osc4car.de/		saref:Price

Table 38: The class Data on trips and charging cycles from trial, its properties and their details and mappings

Class	Data on trips and charging cycles from trial		
Details	New input about car position, date time, distance, mean velocity and energy consumption.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Car Position	Data format: .xls, unit of measurement: Coordinates, time step: Triggered by usage. New input http://www.osc4car.de/		
Start date/time	Data format: .xls, unit of measurement: yy-mm-dd; hh:mm, time step: Triggered by usage. New input http://www.osc4car.de/		
End date/time	Data format: .xls, unit of measurement: yy-mm-dd; hh:mm, time step: Triggered by usage. New input http://www.osc4car.de/		
Distance	Data format: .xls, unit of measurement: Km,		

	time step: Triggered by usage. New input http://www.osc4car.de/		
Mean velocity	Data format: .xls, unit of measurement: Km/h, time step: Triggered by usage. New input http://www.osc4car.de/		
Energy consumption	Data format: .xls, unit of measurement: kW/h, time step: Triggered by usage. New input http://www.osc4car.de/		saref:Property

Table 39: The class Power consumption for street light, its properties and their details and mappings

Class	Power consumption for street light		
Details	New input about the route profile generated by typical itineraries of vehicles, typical consumption on this route and current traffic information.		
Class Mappings	**IFC4**	**Saref**	
	IfcSensor	Saref:Sensor	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Power Consumption	Data format: .CSV, unit of measurement: kW/h, time step: Each second- reported by 15 minutes granularity. New data recorded by a control device integrated into the light armature.		saref:Property

Table 40: The class Power quality for the power inlet and the user, its properties and their details and mappings

Class	Power quality for the power inlet and the user
Details	New input on power quality KPI’s (approx. 300 counters) describing the quality parameters of the power inlet and the user.

Class Mappings	IFC4	Saref	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Voltage	Data format: .CSV, unit of measurement: V, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		saref:Property
Current	Data format: .CSV, unit of measurement: mA, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		saref:Property
Real Power	Data format: .CSV, unit of measurement: W, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		saref:Power
Reactive power	Data format: .CSV, unit of measurement: var, time step: Each second-		saref:Property

	reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		
Apparent Power	Data format: .CSV, unit of measurement: VA, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		saref:Property
Power Factor	Data format: .CSV, unit of measurement: 1.00, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		saref:Property
CAP/IND Power factor	Data format: .CSV, unit of measurement: deg, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the		

	power inlet and the user.		
Power Angle	Data format: .CSV, unit of measurement: deg, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		
THD-Up	Data format: .CSV, unit of measurement: %, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		
THD-1	Data format: .CSV, unit of measurement: %, time step: Each second-reported by 15 minutes granularity. New input on power quality KPI's (approx. 300 counters) describing the quality parameters of the power inlet and the user.		

Table 41: The class Specification of building location within the urban area, its properties and their details and mappings

Class	Specification of building location within the urban area	
Details	Existing data collected for ENERCAD3D concerning building properties	
Class Mappings	**IFC4**	**Saref**

Properties	Details	Properties Mappings	
		IFC4	Saref
Building heating demand	Data format: .shp, unit of measurement: kWh / m^2, time step: Information are taken at the end of each year. Existing data collected for ENERCAD3D http://www.csipiemonte.it/web/it/		
Building typology	Data format: .shp, unit of measurement: Typology, time step: Information are taken at the end of each year. Existing data collected for ENERCAD3D http://www.csipiemonte.it/web/it/		
Building volume	Data format: .shp, unit of measurement: m^3, time step: Information are taken at the end of each year. Existing data collected for ENERCAD3D http://www.csipiemonte.it/web/it/	IfcGrossVolume	
Building age	Data format: .shp, unit of measurement: yy, time step: Information are taken at the end of each year. Existing data collected for ENERCAD3D http://www.csipiemonte.it/web/it/		

Table 42: The class Energy Performance Certificate of a Building, its properties and their details and mappings

Class	Energy Performance Certificate of a Building		
Details	Existing data collected for SICEE concerning energy performance of a building		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Building position	Data format: .xls, unit of measurement: Coordinates, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		saref:Property
Building typology	Data format: .xls, unit of measurement: Alphanumeric, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Building year	Data format: .xls, unit of measurement: yy, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Building characteristics	Data format: .xls, unit of measurement: Alphanumeric, time step: Information are taken at the end of each year		saref:Property

	Existing data collected for SICEE http://www.regione.piemonte.it/		
Energy class	Data format: .xls, unit of measurement: From A+ to G, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Heat requirements	Data format: .xls, unit of measurement: Alphanumeric, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Energy performance index	Data format: .xls, unit of measurement: kWh/m^2, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Renewable energy	Data format: .xls, unit of measurement: Alphanumeric, time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		
Greenhouse gas emissions	Data format: .xls, unit of measurement: kg/m^2,		

	time step: Information are taken at the end of each year Existing data collected for SICEE http://www.regione.piemonte.it/		

4.2.3 Optimized Building Use for Energy Efficient Operation, Intelligent and Integrated Control Based on Building Behavior (Occupancy)

4.2.3.1 Use Case 6 [UC6] 'Sustainable Energy Management for Underground Stations'

In this use case, sustainable energy management is achieved through the development of an advanced energy management system for metro stations, involving model based control of forced ventilation, lighting and passenger transfer systems. This use case was defined after the analysis of the SEAM4US project, which focuses on the development of a sustainable energy management system for underground stations. The use case mainly refers to the operation stage of the BLC but it also includes functionalities concerning the retrofitting/refurbishment/reconfiguration phase.

Use Case Processes

Table 43:BLC Stages and Processes involved in sustainable energy management for underground stations use case

Code	Name	Description	BLC Stage
S01	Operation	Includes all day to day activity of the in use building.	
S02	Retrofitting/Refurbishment/Reconfiguration	Covers all changes to the operational building.	
P03	Control of the energy management in public spaces.	Implementation of optimal control of ventilation, lighting and passenger transfer systems in public spaces.	Operation

Stakeholders

The following stakeholders were identified:

- Project Engineers
- Local Employees
- Line/Station Operators/Managers

Data Domains

In addition, the data domains referring in this use case were defined and they include the following domains:

- Building Devices
- Building Control
- Building Behavior
- Building Communication
- Building Data
- Energy
- Geolocation
- Weather

Class and Class Property Definition

Raw data

Raw data for monitoring

Table 44: The class Measured Data, its properties and their details and mappings

Class	Measured data		
Details	A variety from measured data mainly collected from sensors		
Class Mappings	**IFC4**	**Saref**	
		saref:Sensor	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
category	depends on the measured quantity		saref:has category
name	name of the sensor		saref:has name
value	absolutePressure, windSpeed, numberOfPeople, concentration (CO2), pressureDrop (differential pressure), relativeHumidity, numOfParticles (indoor PM10), PM10 (outdoor PM10), Power (apparent power), solarRadiation, temperature, speed, frequency (for fan control)		Saref:Property

date	date of acquisition; format yyyy-mm-dd	IfcDate	
time	time of acquisition; Format hh:mm:ss		Saref:Time
location	there are different events for every location	IfcSite	

Post processed data

Table 45: The class Measured post processed data, its properties and their details and mappings

Class	Measured post processed data		
Details	A variety of post processed measured data		
Class Mappings	**IFC4**	**Saref**	
		saref:Sensor	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
category	Absolute Pressure		saref:has category
name	corresponding real sensor at which the postprocessed data refers to (if existing)		saref:has name
value	absolutePressure, airChangeRate (expressed in m^3/s), airFlowRate (expressed in m^3/s), windSpeed, CO2, frequency (number of the trains arrived in the last 10 minutes), relativeHumidity, PM10 (particles concentration), numberOfPeople, consumption (active power), temperature, status (for the post processed data for control concerning the status of the fan, True or False), frequency (fan frequency in Hz)		Saref:Property
date	date of acquisition; format yyyy-mm-dd	IfcDate	

time	time of acquisition; Format hh:mm:ss		Saref:Time
location	there are different events for every location	IfcSite	
confidence	level of confidence[0,1]		

Table 46: The class Weather Forecast, its properties and their details and mappings

Class	Weather forecast		
Details	for the post processed data concerning the weather forecast		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
category	"Weather Forecast"		saref:has category
name	Name of the weather station		saref:has name
temperature	expressed in ºC, it can be empty ("NaN")		saref:Temperature
pressure	expressed in Pa, it can be empty ("NaN")		saref:Property
relativeHumidity	expressed in %, it can be empty ("NaN")		Saref:Humidity
windSpeed	expressed in m/s, it can be empty ("NaN")		Saref:Property
windDirection	expressed in degrees, it can be empty ("NaN")		Saref:Property
windDirectionString	e.g., "north-east", it can be empty ("NaN")		
skyCondition	e.g., "partly cloudy", it can be empty ("NaN")		
date	date of acquisition; format yyyy-mm-dd	IfcDate	
time	time of acquisition; Format hh:mm:ss		Saref:Time
forecastDate	format yyyy-mm-dd		
forecastTime	format hh:mm:ss		
location	There are different events for every location.	IfcSite	
confidence	level of confidence[0,1]		

Table 47: The class Weather Station, its properties and their details and mappings

Class	Weather station		
Details	for the post processed data concerning the weather at the station		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
category	"WeatherStation"		saref:has category
name	Name of the weather station		saref:has name
temperature	expressed in ºC, it can be empty ("NaN")		saref:Temperature
pressure	expressed in Pa, it can be empty ("NaN")		saref:Property
relativeHumidity	expressed in %, it can be empty ("NaN")		Saref:Humidity
windSpeed	expressed in m/s, it can be empty ("NaN")		Saref:Property
windDirection	expressed in degrees, it can be empty ("NaN")		Saref:Property
rainAmount	expressed in mm, it can be empty ("NaN")		
date	date of acquisition; format yyyy-mm-dd	IfcDate	
time	time of acquisition; Format hh:mm:ss		Saref:Time
location	There are different events for every location.	IfcSite	
confidence	level of confidence[0,1]		

DB access events

Table 48: The class DB request, its properties and their details and mappings

Class	DB request	
Details		
Class Mappings	**IFC4**	**Saref**
Properties	**Details**	**Properties Mappings**

		IFC4	Saref
category	CSV string		saref:has category
location	CSV string	IfcSite	
name	CSV string (optional)		saref:has name
dateStart	Start date of acquisition; format yyyy-mm-dd	IfcDate	
timeStart	Start time of acquisition; Format hh:mm:ss		saref:Time
dateEnd	End date of acquisition; format yyyy-mm-dd		
timeEnd	End time of acquisition; Format hh:mm:ss		time:hasEnd

Table 49: The class DB Response, its properties and their details and mappings

Class	DB response		
Details			
Class Mappings	IFC4	Saref	
Properties	Details	Properties Mappings	
		IFC4	Saref
category	CSV string		saref:has category
location	CSV string	IfcSite	
name	CSV string (optional)		saref:has name
value	CSV string		saref:hasValue
date	date of acquisition; format yyyy-mm-dd	IfcDate	
time	time of acquisition; Format hh:mm:ss		Saref:Time
confidence	CSV string		

4.2.4 Optimized Building Use for Energy Efficient Operation, Intelligent and Integrated Control Based on Predictive Energy Simulation

4.2.4.1 Use Case 7 [UC7] District Key Performance Indicators and Forecasting

This use case allows the user to view a set of key performance indicators (KPI) related to energy consumption and environment, for example total consumed kWh, consumption per m2, emission per inhabitant, etc., during a user defined time interval. Key performance indicators for district energy consumption are provided to be used by other services or consulted by platform users. The first step is to identify the different processes. Table 50 illustrates the required processes.

Use Case Processes

Table 50: The different processes within this use case

Code	Name	Description	BLC Stage
P00	Define the district area	The user defines an area to be considered a district. The chosen area is the observation space for calculation	All
P01	Measure energy consumption	Sensors are installed in each building to measure energy consumption. The measurement is categorized based on energy consumption types, e.g. heating, cooling, lighting, etc.	Operation
P02	Get aggregated energy consumption	The energy consumption of all buildings in district are summed and aggregated based on their categories.	Operation
P03	Get supporting data	Retrieve supporting data for KPU calculation, for instance district area (m2), number of inhabitants in the district, costs, etc.	Operation
P04	Calculate KPI	Define calculation formulas and calculate different KPIs	Operation

Stakeholders

For this use cases, we identify the following stakeholders, who generate the data:

- Policy maker who defines the district
- Citizen or building owner who provide the energy consumption data
- Policy maker/ statistic office and utility company who provide supporting data

Data Domains

In addition, the data domains referring in this use case were defined and they include the following domains:

- District
- Building Products
- Building Devices
- Measurement Data

Data requirements

Table 51: The class District, its properties and their details and mappings

Class	District			
Details	This class represents districts. A district can be a whole city, a city quarter, a region, a state, etc.			
Class Mappings	**Geonames**		**IFC4**	
	gn:GeonamesFeature		IfcSite	
Properties	**Details**	**Mappings**		
		Geonames	**IFC4**	
locationMap	link to geodata, for example http://www.geonames.org/ It refers by name.	gn:map		
nearbyDistricts	the adjacent or neighbor districts	gn:nearbyFeatures		
parentCountry	link to country	gn:parentFeature	LandTitleNumber	
name	Self explanatory	gn:name	IfcLabel	
postalCode	the postal code of the district if it is available	gn:postalCode		
numberOfInhabitant	number of people living in the district	gn:population		
hasDistrictCharacter	link to a district character object			

Table 52: The class District Character, its properties and their details and mappings

Class	DistrictCharacter	
Details	The class representing character of a district, consisting dynamic information such as weather, energy consumption, etc.	
Class	**Geonames**	**IFC4**

Mappings			
Properties	**Details**	**Mappings**	
		Geonames	**Weather**
hasWeatherForecast	Weather forecast of the corresponding district		http://www.yr.no/
hasMeasurementData	list of (aggregated) measurement data, e.g. energy consumption, CO_2 emission, temperature, etc.		
hasDistrict	associated district	gn:GeonamesFeature	

Table 53: The class Building, its properties and their details and mappings

Class	Building		
Details	This class represents buildings		
Class Mappings	**IFC4**	**Saref**	
	IfcBuilding	Saref: BuildingSpace	
Properties	**Details**	**Mappings**	
		IFC4	**Saref**
buildingType	type of building, for example office building, private house, etc.		
long	longitude coordinate	IfcSite.RefLongitude	wgs84_pos:long
lat	latitude coordinate	IfcSite.RefLatitude	wgs84_pos:lat

label	displayed name	IfcLabel	rdf_schema:label
locatedinDistrict	links to parent district	IfcPlacement	saref:isLocatedIn
owner	refers to building owner		

Table 54: The class BuildingPartCategory, its properties and their details and mappings

Class	BuildingPartCategory		
Details	This class represents categories of building part, which are used to classify KPIs, for example cooling, heating, lighting, etc.		
Class Mappings	**IFC4**	**saref**	
	IfcBuildingElementType	saref:Device_category	
Properties	**Details**	**Mappings**	
		IFC4	**saref**
name	for example heating, cooling, lighting, etc.	IfcLabel	saref:hasName
description	Self explanatory	IfcText	saref:hasDescription

Table 55: The class Sensor, its properties and their details and mappings

Class	Sensor		
Details	The class represents sensors that measure physical phenomenon, for example energy sensor, temperature sensors, CO2 sensors, etc.		
Class	**IFC4**	**SSN**	**saref**

Mappings	IfcSensor	ssn:Sensor	saref:sensor

Properties	Details	Mappings		
		IFC4	SSN	Saref
hasOutputs	list of outputs referring to measurement data		ssn:SensorOutput	Saref:hasMeterReadingValue
type	type of the sensor	IfcSensorType	ssn:Device or ssn:System	saref:DeviceCategory
label	displayed name	IfcLabel		rdfs:label
placement	placement in the building	IfcPlacement		saref:isLocatedIn

Table 56: The class MeasurementData, its properties and their details and mappings

Class	MeasurementData	
Details	This class represents an information unit that is outputted by a sensor or device	
Class Mappings	SSN	saref
	ssn:ObservationValue	

Properties	Details	Mappings	
		SSN	saref
starttime	start time of the measurement	ssn:startTime	saref:hasBeginning
endtime	end time of the measurement	ssn:endTime	saref:hasEnd
value	measurement value	ssn:hasValue	saref:hasValue

unit	measurement unit		saref:UnitOfMeasure

Generated Data

Table 57: The class KPI, its properties and their details and mappings

Class	KPI		
Details	The class representation of an energy related KPI that has certain time range		
Class Mappings	**SSN**	**saref**	
Properties	**Details**	**Mappings**	
		SSN	**saref**
name	Self explanatory		saref:hasName
hasOwner	Owner of KPI, it could be district, building or part of building		saref:isOfferedBy
value	KPI value		saref:hasValue
unit	unit		saref:UnitOfMeasure
starttime	starting time range, where the KPI is valid	ssn:startTime	saref:hasBeginning
endtime	end of time range, where the KPI is valid	ssn:endTime	saref:hasEnd

Table 58: The class Forecast, its properties and their details and mappings

Class	Forecast

<table>
<tr><th>Details</th><th colspan="4">The class representation of energy related forecast that has certain time range</th></tr>
<tr><td rowspan="2">Class Mappings</td><td colspan="2">SSN</td><td colspan="2">saref</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Properties</td><td rowspan="2">Details</td><td colspan="3">Mappings</td></tr>
<tr><td>SSN</td><td colspan="2">saref</td></tr>
<tr><td>name</td><td>name of the forecast, for example power peak load</td><td></td><td colspan="2">saref:hasName</td></tr>
<tr><td>hasOwner</td><td>Owner of forecast, it could be district, building or part of building</td><td></td><td colspan="2">saref:isOfferedBy</td></tr>
<tr><td>KPIs</td><td>a list of KPIs, sorted by time</td><td></td><td colspan="2"></td></tr>
<tr><td>starttime</td><td>starting time range of the forecast</td><td>ssn:startTime</td><td colspan="2">saref:hasBeginning</td></tr>
<tr><td>endtime</td><td>end of time range of the forecast</td><td>ssn:endTime</td><td colspan="2">saref:hasEnd</td></tr>
</table>

4.2.5 Optimized Building Use for Energy Efficient Operation, Intelligent and Integrated Control Based on Energy Tariffs

4.2.5.1 Use Case 8 [UC8] Decision support and energy awareness in a district

This use case deals with the support the planning activities of energy providers (e.g. definition of new tariffs, planning advertising campaigns.). It makes use of combinatorial optimization technology to support the decision-making activities of Policy Makers, Energy Providers, Building Owners, and Citizens. Table 59 illustrates the required processes.

Use Case Processes

Table 59: The different processes within this use case

Code	Name	Description	BLC Stage
P01	Definition of a	The user defines an area to be	

	district	considered a district. The chosen area is the observation space for calculation	
P02	Obtain price suggestion of a district	The system gives a suggestion to the user about the optimal tariff for the chosen district.	Operation
P03	Definition of a group of buildings	The user chooses an area containing a group of buildings. The chosen area is the observation space for calculation	All
P04	Suggest tailored tariffs for a group of buildings having the same owner	The system gives a suggestion to the user about the optimal tariff for their buildings.	Operation

Stakeholders
For this use cases, we identify the following stakeholders, who generate the data:energy providers

- building owners
- citizens

Data Domains
In addition, the data domains referring in this use case were defined and they include the following domains:

- District
- Measurement Data

Required Data

Table 60: The class District, its properties and their details and mappings

Class	District		
Details	This class represents districts. A district can be a whole city, a city quarter, a region, a state, etc.		
Class Mappings	**Geonames**	**IFC4**	
	gn:GeonamesFeature	IfcSite	
Properties	**Details**	**Mappings**	
		Geonames	**IFC4**

locationMap	link to geodata, for example http://www.geonames.org/ It refers by name.	gn:map	
nearbyDistricts	the adjacent or neighbor districts	gn:nearbyFeatures	
parentCountry	link to country	gn:parentFeature	LandTitleNumber
name	Self explanatory	gn:name	IfcLabel
postalCode	the postal code of the district if it is available	gn:postalCode	
numberOfInhabitant	number of people living in the district	gn:population	
hasDistrictCharacter	link to a district character object		

Table 61: The class DistrictCharacter, its properties and their details and mappings

Class	DistrictCharacter		
Details	The class representing character of a district, consisting dynamic information such as weather, energy consumption, etc.		
Class Mappings	**Geonames**	**IFC4**	
Properties	**Details**	**Mappings**	
		Geonames	**Weather**
hasWeatherForecast	Weather forecast of the corresponding district		http://www.yr.no/
hasMeasurementData	list of (aggregated) measurement data, e.g. energy consumption, CO2 emission, temperature, etc.		

hasDistrict	associated district	gn:GeonamesFeature	

Table 62: The class MeasurementData, its properties and their details and mappings

Class	MeasurementData		
Details	This class represents an information unit that is outputted by a sensor or device		
Class Mappings	**SSN**	**saref**	
	ssn:ObservationValue		
Properties	**Details**	**Mappings**	
		SSN	**saref**
starttime	start time of the measurement	ssn:startTime	saref:hasBeginning
endtime	end time of the measurement	ssn:endTime	saref:hasEnd
value	measurement value	ssn:hasValue	saref:hasValue
unit	measurement unit		saref:UnitOfMeasure

Generated Data

Table 63: The class Tariff, its properties and their details and mappings

Class	Tariff	
Details	This class represents a specific energy tariff	
Class Mappings	**IFC4**	**saref**

Properties	Details	Mappings	
		IFC4	saref
starttime	start time of tariff validity		saref:has Beginning
endtime	end time of tariff validity		saref:has End
hasOwners	list of entities associated to the tariff, e.g. district, building. The multiple owners correspond to a tailored tariff that can be assigned to several buildings.		saref:isOff eredBy
hasTariffCl ass	associated tariff class		

Table 64: The class TariffClass, its properties and their details and mappings

Class	TariffClass		
Details			
Class Mappings	**IFC4**	**saref**	
		saref:class	
Propertie s	**Details**	**Mappings**	
		IFC4	**saref**
value	value of the tariff		saref:hasValue
currency	currency of the tariff		saref: Currency
energyTy pe	type of energy source, e.g. gas, electricity, heat, etc.		saref:Commodit y

4.2.6 Optimized Building Use for Energy Efficient Opeation, Visualisation and Monitoring of Building Data (e.g. Energy Consumption) for Decision Support

4.2.6.1 Use Case 9 [UC9] 'Integration of BIM and district level 3D models with real-time data from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors'

This use case is concerned with the Integration of BIM and district level 3D models with real-time data from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors. The data is derived from Deliverable D1.3.2 of the DIMMER project. This deliverable introduces several data domain which require modelling. Unfortunately it does not include any information regarding processes, although the solution is applied during the operational stage of buildings.

Stakeholders

Stakeholders:

- Grid manager
- District heating manager
- Building manager
- Energy manager
- System manager
- Users
- Equipment installers

Data Domains

The following data domains were defined which include:

- Building Product
- Building Devices
- Building Data
- Building Behavior
- Energy
- Weather and Geolocation

Class and Class Property Definition

Table 65: The high level class properties required for this use case

Class Properties	Description
DataMeasurement	A data measure.
MeasurementQuantityBuilding	A list of all quantities this use case measures in buildings.

MeasurementQuantityDistrict	A list of all quantities this use case measures in districts.
DataStorage	Indicates how the data measurements are stored
District	A data model describing aspects of the district, including a visual representation
Building	A data model describing aspects of the building, including a visual representation
DistrictNetworkTopology	The topology and the characteristics of the three network types: heat, gas and electricity
Node	Each node in the network has an energy profile

Table 66: The class properties of class MeasuredData

Class	DataMeasurement		
Details	A data measure.		
Class Mappings	**IFC4**	**SSN**	
		ssn:SensorOutput	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	Unique Identifier	ifcRoot.GlobalId	
hasDateTime	date of acquisition; format YYYY-MM-DD; HH:MM:SS	IfcDateTimeResource	ssn:observationResultTime
Value	Either Temperature or Humidity, depending on type	IfcValue	ssn:ObservationValue
Type	Temperature or Humidity		

Table 67: The class properties of class MeasurementQuantityBuilding

Class	MeasurementQuantityBuilding	
Details	A list of all quantities this use case measures in buildings.	
Class Mappings	**IFC4**	**SSN**

		ssn:SensorOutput	
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
ExternalTemperature	The temperature outside the building	IfcValue	ssn:ObservationValue
IndoorTempAndRelativeHumidityInSelectedRoomsRepresentativeOfBuildingType	Indoor temperature and humidity	IfcValue	ssn:ObservationValue
InternalTempInBuildingRoomsOnTopFloor	Top floor internal building temperature	IfcValue	ssn:ObservationValue
PumpRunningStatus	Current status of pump	IfcValue	ssn:ObservationValue
SelectedClimateCurve	Expected climate curve	IfcValue	ssn:ObservationValue
WaterMassFlowRate	Water mass flow rate in pipe	IfcValue	ssn:ObservationValue
WaterTempEnteringHeatExchanger(UserNetwork)	Water temperature entering heat exchanger of users network	IfcValue	ssn:ObservationValue
WaterTempEnteringHeatExchanger(SecondaryNetwork)	Water temperature entering heat exchanger of secondary network	IfcValue	ssn:ObservationValue
WaterTempExitingHeatExchanger(SecondaryNetwork)	Water temperature exiting heat exchanger of users network	IfcValue	ssn:ObservationValue

Table 68: The class properties of class MeasurementQuantityDistrict

Class	MeasurementQuantityDistrict	
Details	A list of all quantities this use case measures in buildings.	
Class Mappings	**IFC4**	**SSN**
		ssn:SensorOutput

Properties	Details	Properties Mappings	
		IFC4	SSN
MassFlowEnteringEachPumping/BoosterPumpingStation	Self explanatory	IfcValue	ssn:ObservationValue
MassFlowExitingEachPumping/BoosterPumpingStation	Self explanatory	IfcValue	ssn:ObservationValue
MassFlowRateEnteringHeatExchanger(EachThermalPlantAndStorageTank)	Self explanatory	IfcValue	ssn:ObservationValue
TempWaterEnteringHeatExchanger(EachThermalPlantAndStorageTank)	Self explanatory	IfcValue	ssn:ObservationValue
TempWaterExitingHeatExchanger(EachThermalPlantAndStorageTank)	Self explanatory	IfcValue	ssn:ObservationValue
WaterPressureEnteringEachPumping/BoosterPumpingStation	Self explanatory	IfcValue	ssn:ObservationValue
WaterPressureExitingEachPumping/BoosterPumpingStation	Self explanatory	IfcValue	ssn:ObservationValue

Table 69: The class properties of class DataStorage

Class	DataStorage	
Details	Indicates how the data measurements are stored	
Class Mappings	IFC4	SSN
		ssn:SensorOutput
Properties	Details	Properties Mappings

		IFC4	SSN
GUID	Unique Identifier	ifcRoot.GlobalId	
hasDataSchema	The data schema will dictate the structure of the data base schema	IfcDateTime Resource	ssn:observationResultTime
Type	E.g. relational database		

Table 70: The class properties of class District

Class	District		
Details	A data model describing aspects of the district, including a visual representation		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
GUID	Unique Identifier	ifcRoot.GlobalId	
hasPlacement	Geolocation		
hasRepresentation	A 3D surface model		

Table 71: The class properties of class Building

Class	Building		
Details	A data model describing aspects of the building, including a visual representation		
Class Mappings	**IFC4**	**gbXML**	
	IfcBuilding	Building	
Properties	**Details**	**Properties Mappings**	
		IFC4	**gbXML**

GUID	Unique Identifier	ifcRoot.GlobalId	GUID
Type	E.g. Home, hospital, etc.		
hasPlacement	It geoloction		
hasRepresentation	A 3D surface model		

Table 72: The class properties of class DistrictNetworkTopology

Class	DistrictNetworkTopology		
Details	The topology and the characteristics of the three network types: heat, gas and electricity		
Class Mappings	IFC4		
Properties	**Details**	**Properties Mappings**	
		IFC4	**SSN**
GUID	Unique Identifier	ifcRoot.GlobalId	
Type	Heat, gas, electricity		
electricalImpendances	For electrical cables		
sizeOfGasPipes	Assumed to be radius		
sizeOfHeatPipes	Assumed to be radius		
lengthOfTransportMedium	E.g. length of cables or pipes (depending on type)		

Table 73: The class properties of class DistrictNetworkTopology

Class	Node	
Details	Each node in the network has an energy profile.	
Class Mappings	**IFC4**	**SSN**
		ssn:SensorOutput

Properties	Details	Properties Mappings	
		IFC4	SSN
GUID	Unique Identifier	ifcRoot.GlobalId	
hasConversionTechnologyCharacteristics	Information about the conversion technology characteristics that may be present at different nodes (for instance, connection to the upstream electrical network, treated as the slack node in the electrical model; or the presence of a gas boiler in another building)		
hasEnergyProfile	Information about the multi-energy consumption at each node of the networks, also corresponding to buildings connections (for example, electricity and gas or electricity and heat, depending on specific node and building)		

4.2.7 Optimized Building Use for Energy Efficient Operation, Management of Building Personal and Activities

4.2.7.1 Use Case 10 [UC10] Energy and Maintenance Action Management

This use case is focused on a systematic way to plan maintenance related actions including basic finicalities like tasks and responsibilities assignation to people and time planning but also advanced functionalities like considerations on actions related energy savings, implementation costs and payback period calculation. Its objective is to automate and systemize the energy and maintenance action management. Table 74 describes the required processes. In this use case the following stakeholders were identified: Building owner, engineer

Use Case Processes

Table 74: The different processes within this use case

Code	Name	Description	BLC Stage

P01	Improvement Opportunities/Suggestions	Recognised ways of correcting/fixing inefficiencies, failures, leaks, pressure drops, damaged components, etc.	Operation
P02	Pre-populated Energy Audit Items	cost-effective methods for ensuring reliability, safety, and energy efficiency	Operation
P03	Fault detection diagnosis alarms (FDD)	processes the message FDD signal from FDD software	Operation
P04	BMS alarms	processes filtered alarms in BMS/SCADA	Operation

Table 75: The class Area, its properties and their details and mappings

Class	Area		
Details	This is the base class for all types of areas. An area is a region in the real world. An area can be part of, or can be adjacent to another area. An area can contain devices. Inherited from SUMO ontology (entity: geographicalArea). Also Inherited from CIM standard (Core/geographicalRegion).		
Class Mappings	**IFC4**	**saref**	
	IfcBuilding	saref:BuildingSpace	
Properties	**Details**	**Mappings**	
		IFC4	**saref**
partOf	This property gives the information about the area (room, zone and sector) that the specific area entity is part of.		saref:BuildingSpace

connectedTo	This property indicates physically connected areas (for instance by doors).		
locatedAt	An area or aggregated area can contain several devices/components (piece of equipment).	IfcLocalPlacement	saref:locatedIn
id	Unique identifier	IfcGlobalUniqueId	
name	Self explanatory	IfcLabel	saref:hasName
description	Description of an area (as topological unit) and its usage.	IfcText	saref:hasDescription
area_m2	Area surface (in squared meters).	IfcAreaMeasure	

Table 76: The class Device, its properties and their details and mappings

Class	Device		
Details	It represents the technical equipment (such as AHU fan, filter). Inherited from CIM standard (Core/equipment). Devices include Sensors and Actuators.		
Class Mappings	**IFC**	**saref**	
	IfcSensor	saref:Device saref:Sensor	
Properties	**Details**	**Mappings**	
		IFC	**saref**
partOf	provides the information of the device/system that the corresponding device/component entity is part of.		
belonging_signal	the signal which is controllable or readable and belongs to the domain device entity.		

connected To	the devices which are closely coupled (physically connected or functionally integrated).	IfcRelConnects Elements	
locatedAt	the information about area in which a specific entity device is located at.	IfcObjectPlace ment	saref:isLocatedI n
name	device name	IfcLabel	saref:hasName

Table 77: The class Reading, its properties and their details and mappings

Class	Reading		
Details	Signals that represent sensor readings (measurements coming from the sensors).		
Class Mappings	**ssn**	**saref**	
	ssn:ObservationValue	saref:Property	
Propertie s	**Details**	**Mappings**	
		IFC	**saref**
belongsTo	This property indicates the device to which domain signal entity (controllable or readable signal) belongs.		
data_type	This property provides the description of the data type related to a specific signal entity (for instance type of the measurement).	IfcUnit	saref:unitType
medium	This property provides the information about the medium (air, water, gas and etc.) that the specific device entity is located in.		
id	This property represents the original identifier of each signal entity (from BAS/BMS).about area in which a specific entity device is located at.	IfcGlobalUniqu eId	
descriptio	This property provides the	IfcText	saref:hasDescri

n	descriptions about the corresponding signal entity.		ption
source	Source of the signal (such as BMS system, dataloggers etc).	SOURCE	

Table 78: The class DataType, its properties and their details and mappings

Class	DataType		
Details	It represents the types of data communicated within the integrated system. Inherited from CIM standard (Domain). It is also inherited from SUMO ontology (physicalQuantity/unitsOfMeasurements).		
Class Mappings	**IFC4**	**saref**	
	IfcValue		
Properties	**Details**	**Mappings**	
		IFC4	**saref**
name	This property indicates the name of the data type entity (temperature, frequency etc).	IfcLabel	saref:hasName
mes_max	Upper limit of the corresponding measurement. Inherited from CIM standard (Meas/limit).		saref:hasSensingRange
meas_min	Lower limit of the corresponding measurement. Inherited from CIM standard (Meas/limit).		saref:hasSensingRange
sampling	Sampling method of the acquired data (such as average, difference etc).		
unit	Unit of the acquired data. Inherited from CIM standard (Core/unit).	IfcUnit	saref:unitType

Table 79: The class Operation, its properties and their details and mappings

Class	Operation

Details	This class models operational cycles and management related parameters.			
Class Mappings	**IFC4**		**saref**	
	IfcTask		saref:Task	
Properties	**Details**	**Mappings**		
		IFC4	**saref**	
workingHours	Time period of certain operation cycle/schedule (starting time-ending time).	IfcTaskTime		

Table 80: The class Maintenance, its properties and their details and mappings

Class	Maintenance		
Details	It represents maintenance related procedures and reports.		
Class Mappings	**IFC4**	**saref**	
	IfcTask	saref:Task	
Properties	**Details**	**Mappings**	
			saref
interval	This property provides the information about the maintenance interval.	IfcTaskTime	saref:Interval

4.2.8 Re-design and Re-Commissioning for Energy Efficient Operation

4.2.8.1 Use Case 11 [UC11] 'Decision support tool for district renovation planning'

This use case is concerned with developing decision support tools to assist district renovation planning and integrating the needs of different stakeholders: inhabitants, local authorities and business investors. These tools offer the opportunity to select stakeholders' highest priorities and report building renovation scenarios. The tools will specifically assess related costs & benefits, as well as environmental & social impacts at a district level. This use case was defined after the analysis of the ECODIST-ICT (ref) project. The use case mainly refers to the retrofitting/refurbishment/reconfiguration stage of the BLC but it also includes functionalities concerning the operation phase.

Use Case Processes

Table 81: Stages and Processes involved in Decision support tool for district renovation planning

Code	Name	Description	BLC Stage
S01	Operation	Includes all day to day activity of the in use building.	
S02	Retrofitting/Refurbishment/Reconfiguration	Covers all changes to the operational building.	
P03	Decision Support System for sustainable retrofitting	Enables analysis of different scales and different time frames	Retrofitting/Refurbishment/Reconfiguration

Stakeholders

The following stakeholders were identified:

- Building/Facility Owners
- Engineering Companies
- Financial/Cost Managers
- Housing Corporations
- Operations Managers
- Urban Planners

Data Domains

In addition, the data domains referring in this use case were defined and they include the following domains:

- Building Products
- Building Devices
- Building Control

Class and Class Property Definition

In order facilitate the conceptual modelling the data requirements were divided into Classes and Class Properties as demonstrated in Table 36 to 41 and the data requirements were mapped, wherever possible, with already existing ontologies.

Table 82: The class Building geometry, its properties and their details and mappings

Class	Building geometry	
Details	Describes the shape of the buildings and provides a geometric model of a building stock	
Class Mappings	**IFC4**	**Saref**
		Geo:SpatialThing
Properties	**Details**	**Properties Mappings**

		IFC4	Saref
Building 2D footprint	Georeferenced description of the building footprint geometry as a polygon, possibly with holes. Source: ·National Mapping Agencies ·Local authorities ·Open data (e.g. OpenStreetMap)		
Building 2D roof shape	Georeferenced description of the building roof shape geometry as a polygon, possibly with holes. Source: Idem If not available, could be the same as building footprint for a LoD1 model.		
Building gross floor area	Description of the gross floor area attached to a single building. Deduced from *building 2D footprint* and *number of complete storeys*	IfcGrossFloorArea	
Height	Gutter or mean roof height of the building. Usually contained as a GIS attribute associated with *building 2D footprint*	IfcNorminalHeight	Saref:Propert y

Building 3D geometry	Georeferenced 3D geometry of a building. Source: ·Local authorities ·Automatic reconstruction from aerial images ·Manual modeling		

Table 83: The class Building semantic, its properties and their details and mappings

Class	Building semantic		
Details	Enriches the geometric model of the building stock with semantic data.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
ID	Unique identifier of a building Usually contained as a GIS attribute associated with *building 2D footprint*	IfcRoot.GlobalId	
Name	Convenient name of a building (*optional*) Source: ·Cadastre ·Local authorithies ·Owner or administrator	IfcRoot.Name	saref:has name
Address	Address of a building specifying names of the road and number,	IfcPostalAddress	

	city, country (*optional*) Source: ·Building attribute ·Reverse geocoding		
Construction date	Date when the building construction ended Source: ·Cadastre ·Owner or administrator	IfcNorminalHeight	
Last renewal	Last renewal date of the building Source: ·Cadastre ·Owner or administrator		
Renewal type	Last renewal type Source: ·Cadastre ·Owner or administrator		
Heritage protection	Flag to indicate if the building is protected and need special care for renovation Source: Cadastre		
Number of complete storeys	Number of complete storeys of the building Source: ·Automatic image interpretation ·Manual image interpretation		saref:hasValu e

	·Cadastre ·Owner or administrator		
Windows positions	Position of each window on each facade of the considered building Source: ·Automatic image interpretation ·Manual image interpretation ·From LoD3 model if available		
Windows sizes	Sizes of each window on each facade of the considered building Source: ·Automatic image interpretation ·Manual image interpretation ·From LoD3 model if available	IfcWindow	
Windows percentage	Percentage of glazing for each facade of the considered building Source: ·Automatic image interpretation ·Manual image interpretation ·From LoD3 model if available		

Table 84: The class Building quantities and related statistics, its properties and their details and mappings

Class	Building quantities and related statistics		
Details	Adds more specific data concerning buildings, in order to implement energy simulations.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Type of housing	Whether the building is collective or an individual house Source: ·Cadastre ·Owner or administrator		
Type of building	Refers to the main building activity Source: ·GIS data ·Cadastre ·Owner or administrator		
Component and quantity	Component can be one of the following: ·Roof ·Wall ·Bottom floor ·Ceiling Quantity can be one of the following: ·Materials (which describes each layer in detail: thickness, material type etc)		saref:Buildingrelated

	·U-value For quantities attached to a given component, if the U-value is available, or other values are not mandatory, and vice-versa Source: ·Manual interpretation from images ·Experts' knowledges ·Based on building typologies ·Crowd-sourcing		
Green roof	Flag to indicate if the building has a green roof Source: ·Owner or administrator ·Manual (aerial) image interpretation	IfcNorminalHeight	
Roof shape	Description of the roof shape Deduced from building geometry		
Facade heritage protection	Flag to indicate if a specific façade is protected Source: Cadastre		
PV systems technology	Technology used by the PV panels Source: Owner or		

	administrator		
Number of PV panels	Total number of PV panels Source: ·Owner or administrator ·Manual (aerial) image interpretation		saref:hasValue
PV systems area	Total area of PV panels Source: ·Owner or administrator ·Manual (aerial) image interpretation		
PV systems slope	Slope of PV panels Source: ·Owner or administrator ·Manual (aerial) image interpretation	IfcWindow	
PV systems orientation	Orientation of PV panels Source: ·Owner or administrator ·Manual (aerial) image interpretation		
Opening component and quantity	Opening component can be one of the following: ·Window ·Door Quantity can be one of the following:		

	·Glazing type ·Glass G-value ·Frame U-value ·Window U-value Source: ·Manual interpretation from images ·Experts' knowledges ·Based on building typologies ·Crowd-sourcing		
Glazing ratio	Window percentage of glazing Source: ·Automatic image interpretation ·Manual image interpretation		

Table 85: The class Socio-economic and demographic, its properties and their details and mappings

Class	Socio-economic and demographic		
Details	Provides information on a population and its characteristics		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Number of inhabitants	Source: ·Data should be gathered as accurately as possible, in adequation with the required accuracy (it		
Ownership type			
Occupancy status (are the inhabitants owners or tenants)			
Unemployment			

Education level	will then be possible to aggregate them to any level of detail) ·Data should be collected as representative samples ·From city censuses ·From city statistical offices		
Mean income			Saref:Property
Mean age			Saref:Property
Family type			
Working hours			

Table 86: The class Buildings usages, its properties and their details and mappings

Class	Buildings usages		
Details	It concerns buildings' equipments (collective and individual), how they are used, but also the building' composition, i.e. its division in spaces and their specializations (living rooms, bathrooms, etc)		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
Number of elevators	Source: ·Cadaster ·Owner or administrator ·Infered from building typology		saref:hasValue
Number of apartments			saref:hasValue
Number of rooms			saref:hasValue
Number of bathrooms			saref:hasValue
Heating system			
Heating system energy			
Heating system type			

Heating system efficiency			
Water heating system			
Water system efficiency			
Cooling system			
Cooling system efficiency			
Ventilation system			
Conditioned space area			
Air-conditioning system			
Energy demand for lighting and domestic appliances	Source: ·Based on in-situmeasures or observations ·Computed from other parameters (systems, socio-economic and demographic data, building's usage etc) ·Suppliers data (might be subject to privacy concerns when available)		saref:Lighting energy
Energy demand for heating			saref:Energy
Energy demand for cooling			saref:Energy
Energy demand for hot water			saref:hot water energy
Water consumption			saref:Water
Produced renewable energy			
Energy cost (electricity)	Mean electricity price per kWh For European countries, yearly updated data are available: http://www.vaasaett.com/wp-content/uploads/2013/05/European-Residential-Energy-		saref:Price

	Price-Report-2013_Final.pdf		
Energy cost (gas)	Mean gas price per kWh For European countries, yearly updated data are available: http://www.vaasaett.com/wp-content/uploads/2013/05/European-Residential-Energy-Price-Report-2013_Final.pdf		saref:Price
Energy cost (fuel)	Mean fuel price per kWh For European countries, yearly updated data are available: http://www.vaasaett.com/wp-content/uploads/2013/05/European-Residential-Energy-Price-Report-2013_Final.pdf		saref:Price
Indoor air setpoint temperature (heating)	Source: ·Inferred from building typologies ·Inferred from socio-economic and demographic data and heating / cooling systems		saref:Multi level state
Indoor air setpoint temperature (cooling)			saref:Multi level state

Table 87: The class Climatic data, its properties and their details and mappings

Class	Climatic data		
Details	It defines for a given geographic area the climatic conditions.		
Class Mappings	**IFC4**	**Saref**	
Properties	**Details**	**Properties Mappings**	
		IFC4	**Saref**
General data	Source: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm		
Air temperature	Refer to ISO 15927-1 standard Source: ·http://www.ncdc.noaa.gov/cdo-web/http://www.ncdc.noaa.gov/cdo-web/ ·http://www.climatedata.eu/http://www.climatedata.eu/		saref:Temperature
Relative humidity			saref:Humidity
Total rainfall			
Diffuse solar irradiance	Refer to ISO 15927-1 standard Source: ·http://www.soda-is.com/eng/services/services_radiation_free_eng.phphttp://www.soda-is.com/eng/services/services_radiation_free_eng.php		
Direct solar irradiance			
Global solar irradiance			
Solar declination			
Solar irradiance			
Solar irradiation			

	·http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.govhttp://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov		
Wind speed	Source: http://power.larc.nasa.gov/cgi-bin/cgiwrap/solar/agro.cgi?email=agroclim@larc.nasa.gov		Saref:Property
Wind direction			

4.3 Alignment and Harmonization of Data Requirements across Use Cases

Once the process of defining the different data requirements for the different use cases is complete, the next step within the SWIMing project is to begin to identify similar data requirements across projects. In this section we analyze the data requirements across the use cases we presented in the previous sections and identify where use cases are making use of similar data structures. The purpose of this process is to begin to harmonize these data requirements and data structures.

First we present a quick overview of each of the use cases according to their classification. The use cases are numbered UC1-11 and we use this numbering in the following tables for reference. The majority of use cases are in the operational stage of the BLC. We include also one from the design and one from the re-design stages (retrofitting, refurbishment, and reconfiguration) stages. Use case 2 (UC2) is included under two sub-classifications. The use cases are:

Optimized Building Design for Energy Efficient Operation, 1 Use Case

- UC1 = Minimum Data Requirements for Building Energy Simulation

Optimized Building Use for Energy Efficient Operation, 4 Use Cases

- Intelligent and Integrated Control Based on Building Behaviour (of Devices)
    - UC2 = Minimize Energy Cost
    - UC3 = Reducing energy consumption for energy constrained RF communication between devices for monitoring

- UC4 = A Generic communication protocol for controlling building devices to manage building energy consumption
- UC5 = Energy Forecasting

- Intelligent and Integrated Control Based on Building Behaviour (Occupancy), 2 Use Cases
  - UC2 = Minimize Energy Cost
  - UC6 = Sustainable Energy management for Undeground Stations
- Intelligent and Integrated Control Based on Predictive Energy Simulation, 1 Use Case
  - UC7 = District Key Performance Indicators and Forecasting
- Intelligent and Integrated Control Based on Energy Tariffs, 1 Use Case
  - UC8 = Decision support and energy awareness in a district
- Visualization and Monitoring of Building Data (e.g. Energy Consumption) for Decision Support, 1 Use Case
  - UC9 = Integration of BIM and district level 3D models with real-time data from sensors and user feedback to analyze and correlate buildings utilization and provide real-time feedback about energy-related behaviors'
- Management of Building Personal and Activities, 1 Use Case
  - UC10 = Energy and maintenance action management

Re-design and Re-commissioning for Energy Efficient Operation, 1 Use Case

- UC11 = Decision support tool for district renovation planning

4.3.1 Data Requirements across Use Cases by Data Domains

Table 88 gives an overview of all the use cases and the different data domains we have uncovered during our exploration of the data requirements using the ReqCap tool. In this section, for each data domain, we examine some of the classes and their properties that are shared across the use cases. We then begin to harmonise the classes and properties using a shared terminology. Once this is done, the following section will explore some initial mappings for the shared terminology to existing standards and ontologies.

Table 88: Overview of Use Cases and all Data Domains

	Design	Operation Devices				Operation Occupancy	Operation Simulation	Operation Tariffs	Operation Visualisation	Operation Personal	Re-Design
	UC1	UC2	UC3	UC4	UC5	UC6	UC7	UC8	UC9	UC10	UC11
Product	X	X			X		X		X	X	X
Behavior	X	X		X						X	
Device		X	X	X			X	X		X	X

MeasuredDataMessage and DataStorage		X	X		X	X	X	X	X	X	X
Communications and Data Messages			X	X		X					
District							X	X	X		X
Energy					X						
Weather					X	X					

4.3.1.1 Product Domain Data Requirements across Use Cases

Table 89 provides an example of a class shared across multiple use cases. Here we are looking specifically at use cases which make use of a model of the building. Within our classification system, outlined in D1.1, a building model falls under the product domain. A building can be considered as a more specific example of a product. A building is also comprised of multiple products (walls, windows, etc.). Here we take the properties of building for those use cases which require a building model, and begin the process of identifying concepts which are shared. We then begin to define a shared terminology with the goal of mapping these to existing standards and ontologies. To adhere to this process may require that projects adjust the way they represent their properties to align better with the terminology we have identified. This is necessary to ensure that interoperability be maintained beyond the requirements for the specific use case.

The most common shared terms identified across use cases for ‘Building’ are GUID (required to identify the building) and Placement. Placement is mostly given as a longitude and latitude, although in some cases an address is used (UC11). Also common are the use of type (i.e. an enumeration of building types, office, hospital etc.) and Space/Zone/Area concepts which are used to organise and label the different spaces in the building. It may also be the case that the type of building is encoded in the space/zone model along with the types of rooms (for example in UC1). A way to encode the building envelop/volume is also required for both energy and performance simulations. Building representation is required where tools which make use of a visual representation of the building are required (e.g. UC2 and UC9).

Less common terms are related to its orientation and quantaties (again for energy simulation during design), age and energy class (related to energy performance during operation).

Table 89: Overview of Use Cases by Product Data Domain and Data Requirements (example, Building Model)

	Design	Operation -						Re-Design
Shared Termin-ology	UC1	UC2	UC5	UC6	UC7	UC9	UC10	UC11

GUID	Identification (ID, Name)	GUID			Label	GUID	GUID	ID, Name
Type		Type	Typology		Type			
Placement (geolocation)	Position	Placement	Position		Long, lat	Placement	located At	Address
Orientation	Orientation (e.g. east)							
Quantaties	Quantities (e.g. window area)							
Space/Zone	Space/ Zone	isContained InSpace					Area	
Representation		Representation				Representation		
Heating Demand/ Requirements			Heating Demand					
Year/Age			Year/Age					
Energy Class			Energy Class					
Facade	Facade							
Building Envelope	Building Envelope		Volume					

4.3.1.2 Device (and Sensor) Domain Data Requirements across Use Cases

Table 90 gives an example of a class for the Device domainthat can be used to describe both devices and more specifically, sensors. Sensor falls under the device domain outlined in D1.1. Once again the most common properties for devices are GUID and Placement as it is important to be able to locate any device or sensor for monitoring and control. Type and power profile are also common properties. Once again, type gives added semantics to the device model. Power profile is used in four use cases as a means to understand the energy consumption of the device. These profiles themselves may be dependent on other factors, e.g. the device setting.

Other less commons properties are representation, which is used for identifying physical devices, for example for an FM who wishes to locate a device in the building. Meta data regarding devices is also required in two use cases in the form of device description. This would include data such as the manufacturer, when it was created and installed, etc. Other properties, only represented once, include device schedules, and information on communication about when a device can be communicated with (communicationWindow), the type of communication (e.g. bi-directional) and the structure of any communication message (MessageStrcutre).

For sensors some common requirements are the sampling period (how often a measurement is taken), unit of measurements (what unit the returned value is), measurement range (the range beyond which the sensor cannot record a reading, used to identify errors) and measured phenomena (the phenomena being observed by the sensor). Less common properties are accuracy, latency and precision.

Table 90: Overview of Use Cases by Device (Includes Sensor properties) Data Domain and Data Requirements

Device	Operation					
	UC2	UC3	UC4	UC5	UC6	UC7	UC10
GUID	GUID	GUID	GUID		GUID	label	
Type	Type			status	category	type	
Placement	Placement	Placement	Placement	position		Placement	locatedAt
Representation	Representation	Representation	Representation				
DeviceDescription		DeviceDescription	DeviceDescription				
MesuaredPhenomena		MeasuredPhenomena					belonging_signal
UnitOfMeasure		UnitOfMeasure				hasOutputs	unit
MeasurementRange		MeasurementRange					meas_max, meas_min
PowerConsumption		PowerConsumption	PowerProfile	Total energy consumption	Power Consumption		
Sampling		Sampling Period			Date, time, location		sampling
Latency		Latency					
Accuracy		Accuracy					
Precision		Precision					

CommunicationWindow			Communication Window				
CommunicationType			Communication Type				
MessageStructure			MessageStructure				
isContainedInSpace	isContainedInSpace						
partOf							partOf
hasUsageSchedule	hasUsageSchedule						

4.3.1.3 Data Measurements Domain Data Requirements across Use Cases

Table 91 gives an example of a class for the Data Measurements. This domain requires a relatively simple data structure, compared to the previous, and as such this is where the highest level of similarity exists between use cases. The main distinction across use cases when encoding measurement data messages is whether the message refers directly to the id of the model of the sensor that generates it (Source). For those that do not, it is necessary to generate a unique id for each message (a GUID). Alternatively, the sensor model id and the time stamp are used. As a consequence, the most common properties are a DateTime time stamp, a Value and possibly a Unit, where message size is not restricted or where there is no sensor model available.

Other data structures related to this and found in a number of use cases (e.g. UC4 and UC6) which we do not include are those of command messages and response messages and also data storage (UC9). Command and response are data structures for transmitting communications to and from devices, for example to change settings or configure systems. We may therefore consider the possibility of integrating our Data Measurements domain with the communication domain, and begin to look at all monitored data from sensors as a part of the communications domain. We do not explore these here in any futher detail though.

Table 91: Overview of Use Cases by Data Measurements Domain and Data Requirements

Measured Data	Operation								Re-Desgn
	UC2	UC3	UC5	UC6	UC7	UC8	UC9	UC10	UCi11
DateTime	Date-Time	hasTime-Stamp	Start date/time, End date/time	Date, time	starttime, endtime	starttime, endtime	hasDate-Time		

Value(&Unit)	Value	Value/-Value-&Unit	value	value	value & unit	value & unit	Value	unit	value
Source	Source	Has-Sensor			owner	owner		belongsTo	
Type				category			Type	data_type	
GUID				name			GUID	id	ID, name

4.3.1.4 Behavior (and State) Domain Data Requirements across Use Cases

Table 92 gives an example of a class for the behaviour domain. These include models for occupant and device behaviour. In some cases these models are simply referred to in other classes to describe the usage schedule of a device, i.e. when it is operational and at what settings (UC2, UC10). It can also be as simple as a state model, which captures the current state of a device (UC4). Finally, it looks at modelling occupancy, which can include the number of occupants in a location or zone/space, and also the schedule of occupants, which is related to the type of zone/space/room (UC4).

Table 92: Overview of Use Cases by Behavior Domain and Data Requirements

Behavior (and State)	Design	Operation			
	UC1	UC2	UC4	UC6	UC10
NumberOfOccupant	NumberOfOccupants			numberOfPeople	
Location	Zone/Space			location	
Schedule	Schedule	UsageSchedule			Operation, Maintenance
GUID	Identification		GUID		
CurrentState			currentState		

4.3.1.5 Geolocation (District) Domain Data Requirements across Use Cases

Table 93 gives an example of a class for the geolocation domain. Due to its high level of representation in the project use cases, we include here a model of the district. The most common properties for this class are Placement and the locationMap. The locationMap describes a visual representation of the district for locating districts and/or cities. They may include 2D or 3D models of the buildings. This can be used to select the different buildings for energy related queries. The district model may also include more information, for example regarding the network topology which includes description of nodes, energy consumption of nodes, inputs and outputs, etc (see UC9).

Table 93: Overview of Use Cases by Geolocation (District) Domain and Data Requirements

District	Operation			
	UC7	UC8	UC9	UC11

GUID			GUID	
Placement	Location	Location+Address	Placement	Address
locationMap	locationMap	locationMap	Representation	Building 2D footprint, Building 2D roof shape, Building 3D geometry
Network-Topology			NetworkTopology	

4.3.2 Initial Alignment of Data Requirements with Existing Standards and Ontologies

In the previous section we began to identify some shared vocabularies between use case data requirements. In this section, we look at the alignments identified and begin to identify potential links to shared concepts in existing standards and ontologies. We begin with the building class in the Product domain (Table 94), next the device and sensor model alignment (Table 95), followed by data measurement (Table 96) and behavior (Table 97). These alignments will require further review with the use case developers to ensure that the mappins are accurate and valid; nonetheless we present our initial findings. Further refinements of these alignments will be presented in D2.3.

Table 94: Overview of Use Case Product Data Domain alignment with standards and ontologies(example, Building Model)

Shared Terminology	IFC4/ifcOWL	gbXML	SAREF
Class	IfcBuilding	gbXML:Building	Saref:BuildingSpace
GUID	IfcRoot.GlobalId	GUID	
Type	IfcObject.ObjectType-> IfcLabel	buildingTypeEnum	
Placement (geolocation)	IfcSite.RefLatitude, IfcSite.RefLongitude	Location:Latitude, Location:Longitude	Geo:lat, Geo:long
Orientation	Via IfcProjectRepresentationContext	CADModelAzimuth	
Quantaties	Qto_BuildingBaseQuantaties	surfaceTypeEnum	
Space/Zone	IfcSpace, IfcZone	Zone	BuidingSpace
Representation	IfcProductRepresentation		
Heating Demand/Requirements		Results:EnergyCost?	
Year/Age	IfcRoot.OwnerHistory	Age	
Energy Class			
Facade	IfcGroup with external walls	Surface	

Table 95: Overview of Use Cases by Device (Includes Sensor properties) Data Domain and Data Requirements

	IFC4/ifcOWL	Saref	SSN
Class	ifcDistributionControl Element, IfcSensor	saref:Device	ssn:Sensor
GUID	IfcRoot.GlobalId		
Type	IfcObject.ObjectType -> IfcLabel	Saref:hasCategory	
Placement	IfcPlacement	geo:Point	ssn:hasLocation
Representation	IfcProductRepresent ation		
DeviceDescription	IfcRoot. IfcDescription	saref:hasDescription	
MeasuredPhenomena			ssn:observed-Property
UnitOfMeasure			
MeasurementRange			ssn:Measurement-Range
PowerConsumption		saref:hasTypical-Consumption	ssn:Operating-PowerRange
Sampling			ssn:Frequency
Latency			ssn:Latency
Accuracy			ssn:Accuracy
Precision			ssn:Precision
CommunicationWindow			
CommunicationType			
MessageStructure		saref:Command?	
isContainedInSpace	IfcSpace	saref:isLocatedIn	
hasUsageSchedule	IfcTask?		

Table 96: Overview of Use Cases by Data Measurements

	SSN	IFC4/ifcOWL
Class	ssn:SensorOutput	?
DateTime	ssn:observationResultTime	IfcDateTimeResource
Value(&Unit)	ssn:ObservationValue	IfcValue?
Source	ssn:SensingDevice	IfcSensor
Type		IfcObject.ObjectType-> IfcLabel
GUID		IfcRoot.GlobalId

Table 97: Overview of Use Cases by Behavior Domain and Data Requirements

	IFC4/ifcOWL	gbXML	Saref
NumberOfOccupant	May be calculated from IfcOccupant	PeopleNumber	
Location	IfcZone/IfcSpace	Zone	saref:isLocatedIn
Schedule	Collection of IfcTasks	Schedule	saref:accomplishes
GUID	IfcRoot.GlobalId	GUID	
CurrentState			saref:State

5 Conclusion and Next Steps

In this deliverable we have presented a set of guidelines for projects making use of building data for building life cycle energy management (BLCEM) processes. Special focus was given on the challenge of harmonizing data requirements across use cases and the alignment of those data requirements with existing standards and ontologies.

The BLC encorporates several data domains and within each domain new models are being developed to meet the particular requirements of use cases as they arise. This makes the process of harmomisation a considerable challenge due to the heterogeneity of data models being employed across projects. The purpose of this deliverable therefore is to present a part of the overall methodology (Figure 2, page 13) which can be employed by projects early in the project life cycle and continued through the course of the project and which will support the identification of similar use cases, the identification of similar data requirements and the identification and alignment of those data requirements with existing standards and ontologies. By undertaking this process the potential of re-use of existing data models should improve interoperability beyond the scope of a project.

The methodology is based upon the Information Delivery Manual approach and also guidelines[3] generated in a project working on similar issues in the area of SmartCities (i.e. Ready4SmartCitites). As such, it has a strong basis in the current practices both within industry (through IDM) and also within the EeB research community. The core work within the deliverable is based upon the use of a freely available tool (ReqCap), developed by AEC3, for managing the collection and harmonization of use cases and their data requirements. This tool has the additional benefit of providing centralized storage of use cases which will be maintained beyond the duration of SWIMing.

Our initial findings are presented in this deliverable using several core use cases developed through discussion with different project partners and also through the analysis of their corresponding deliverables. As a basis for harmonization, the core data model for reference and definition of terminology has been the IFC schema, due to its non-proprietary status, its wide support amongst existing tools and the fact that ifcOWL is soon to become a working and accepted serialization of the schema. Several EU projects also already support its use. Other models we have examined are gbXML (for energy simulation), Saref (for device modelling), SSN (for sensor and senor output modelling). The potential to include further models (e.g. CityGML for modelling aspects of the district) was considered, but for this deliverable we choose to keep the scope around models for buildings and building data.

Through the harmonization process, we have identified some terminology which can be used as a basis for harmonization. We also have begun the process of alignment of this terminology with existing standards, and identified some potential existing models for managing these data requirements. This process will be ongoing for the duration of the

[3] http://www.ready4smartcities.eu/guidelines

SWIMing project. Ultimately, we intend to have such terminologies for each of the domains we have identified as being relevant to BLCEM along with mappings.

The next steps therefore will be to continue with the development of use cases, incorporating the findings from a greater range of project use cases, and to begin to formalize more carefully the terminology and alignments as a precursor to providing guidelines to publishing open and accessible BLCEM data as Linked Data, supporting greater interoperability amongst existing BLCEM processes and also supporting new and novel use cases based on the query of multiple open data sets.

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