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ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Smart Machine-to-Machine communications (SmartM2M).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Introduction

The present document was drafted by ETSI Technical Committee SmartM2M to provide insight into the management of SAREF and its extensions. SAREF was created in 2014/2015 by TNO in a study requested by the European Commission. After finishing the study, SAREF was transformed into a Technical Specification by ETSI SmartM2M and published in November 2015. Since this period, a number of request for updates of SAREF were made, and a first extension of SAREF for the Energy Demand and Response domain was also created. To elaborate a strategy on the management of SAREF and identify possible extensions of SAREF in new domains, ETSI SmartM2M requested a Specialist Task Force (STF) to provide input on these topics.

A number of possible areas for extensions have been identified: energy demand and response, environment, buildings, agriculture and e-health/ageing well. The present document provides insight into the requirements from these domains, and provides the guidelines for the maintenance, extension and publication of SAREF and its extensions.

1 Scope

The present document presents the requirements gathered from the main smart appliances industrial actors to be exploited and implemented in the companion ETSI TS 103 410-1 [i.13], ETSI TS 103 410-2 [i.14] and ETSI TS 103 410-3 [i.15]. Next to that, the present document also provides input on the extension and maintenance of the SAREF ontology. The aforementioned technical specifications define extensions to the Smart Appliances reference ontology (SAREF) and the mapping to oneM2M as defined in ETSI TS 103 264 [i.3]. The objective is to include input from the industrial actors from the appliances domain including non-energy related aspects.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] European Commission and TNO: "Smart Appliances REFerence ontology (SAREF)", April 2015.

NOTE: Available at http://ontology.tno.nl/saref.

[i.2] European Commission and TNO: "D-S4 - SMART 2013-0077 - Smart Appliances - Mapping SAREF to short list assets.xlsx ", February 2015.

NOTE: Available at https://sites.google.com/site/smartappliancesproject/documents.

[i.3] ETSI TS 103 264 (V1.1.1) (11-2015): "SmartM2M; Smart Appliances; Reference Ontology and oneM2M Mapping".

[i.4] ETSI TS 118 112: "oneM2M; Base Ontology (oneM2M TS-0012)".

[i.5] Gruber, T.: "Toward principles for the design of ontologies used for knowledge sharing", International Journal of Human-Computer Studies, Volume 43, Issues 5-6, November 1995, Pages 907-928.

NOTE: Available at http://www.sciencedirect.com/science/article/pii/S1071581985710816.

[i.6] IEC TR 62746-2: "Systems interface between customer energy management system and the power management system - Part 2: Use cases and requirements", 2015.

[i.7] EEBus, SPINE.

NOTE: Available at https://www.eebus.org/en/specifications/.

[i.8] Corcho, O., González, E. Deliverable D1.1. Kick-off meeting report. STARS4ALL project. March 2nd, 2016.

[i.9] Zamorano, J., García, C., González, R, Gallego, J., Pascual, S., Tapia, C., Nievas, M., Sánchez, A., Cardiel, N. Deliverable D4.1. Photometer sensor (prototype). STARS4ALL project. March 30th, 2016.

[i.10] "Variación espacial, temporal y espectral de la contaminación lumínica y sus fuentes: Metodología y resultados". Ph.D. thesis. Universidad Complutense de Madrid. February, 2015.

NOTE: Available at http://eprints.ucm.es/31436/.

[i.11] ISO 16739:2013: "Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries".

NOTE: Available at http://www.iso.org/iso/catalogue_detail.htm?csnumber=51622.

[i.12] Industry Foundation Classes (IFC) - Version 4 - Addendum 1. buildingSMART.

NOTE: Available at http://www.buildingsmart-tech.org/ifc/IFC4/Add1/html/.

[i.13] ETSI TS 103 410-1: "SmartM2M; Smart Appliances Extension to SAREF; Part 1: Energy Domain".

[i.14] ETSI TS 103 410-2: "SmartM2M; Smart Appliances Extension to SAREF; Part 2: Environment Domain".

[i.15] ETSI TS 103 410-3: "SmartM2M; Smart Appliances Extension to SAREF; Part 3: Building Domain".

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

ontology: formal specification of a conceptualization, used to explicit capture the semantics of a certain reality

smart appliances: devices, which are used in the household, e.g. for performing domestic work, and which have the ability to communicate with each other and which can be controlled via Internet

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AEC	Architecture Engineering and Construction
AEF	Agricultural Industry Electronics Foundation
AIOTI	Alliance for the Internet of Things Innovation
API	Application programming interface
CEM	Customer Energy Manager
CRUD	Create Read Update and Delete
DOI	Digital Object Identifier
E@H	Energy@Home association
EEBus	EEBus initiative
FM	Facilities Management
HFC	Hydrofluorocarbon
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
HVAC	Heating, Ventilation, and Air Conditioning
IFC	Industry Foundation Classes
IoT	Internet of Things
ISO	International Organization for Standardization
LOV	Linked Open Vocabularies
MQTT	MQ Telemetry Transport
OM	Ontology of units of Measure
ORSD	Ontology Requirements Specification Document
OWL	Web Ontology Language

PURL	Persistent Uniform Resource Locator
RPC	Remote Procedure Call
SAREF	Smart Appliances REFerence ontology
SAREF4BLDG	SAREF extension for the Building domain
SAREF4ENER	SAREF extension for the Energy domain
SAREF4ENVI	SAREF extension for the Environment domain
SQM	Sky Quality Meter
TESS	Telescope Encoder and Sky Sensor
TNO	Netherlands Organization for Applied Scientific Research
TR	Technical Report
TS	Technical Specification
UML	Unified Modeling Language
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
W3C	World Wide Web Consortium
WGS84	World Geodetic System 1984
XML	Extensible Markup Language

4 SAREF extension and maintenance

4.1 Extensions

SAREF is the core semantic model for smart appliances (see ETSI TS 103 264 [i.3]), which contains the data elements that are used in more than one domain. SAREF has a close relation with the oneM2M base ontology, for which mappings are defined. Since smart appliances can be used in and come from several domains, it is possible that specific data elements for a certain domain are not defined in SAREF. To be able to handle these additional data elements and provide a specific domain with a semantic model that fits all the needs of that domain, there is the possibility to create extensions to SAREF. This is depicted in Figure 1, in which SAREF is represented as the upper model and the extensions for different domains as triangles that generate from the upper model, specializing core concepts from SAREF. Each domain can have one or more extensions, depending on the complexity of the domain. Existing extensions of SAREF are highlighted in the left part of Figure 1 (i.e. for the Energy, Environment and Building domains), while other possible domains of interest are depicted in the right part. Figure 1 further depicts the equivalence of some concepts between SAREF and the oneM2M base ontology [i.4].

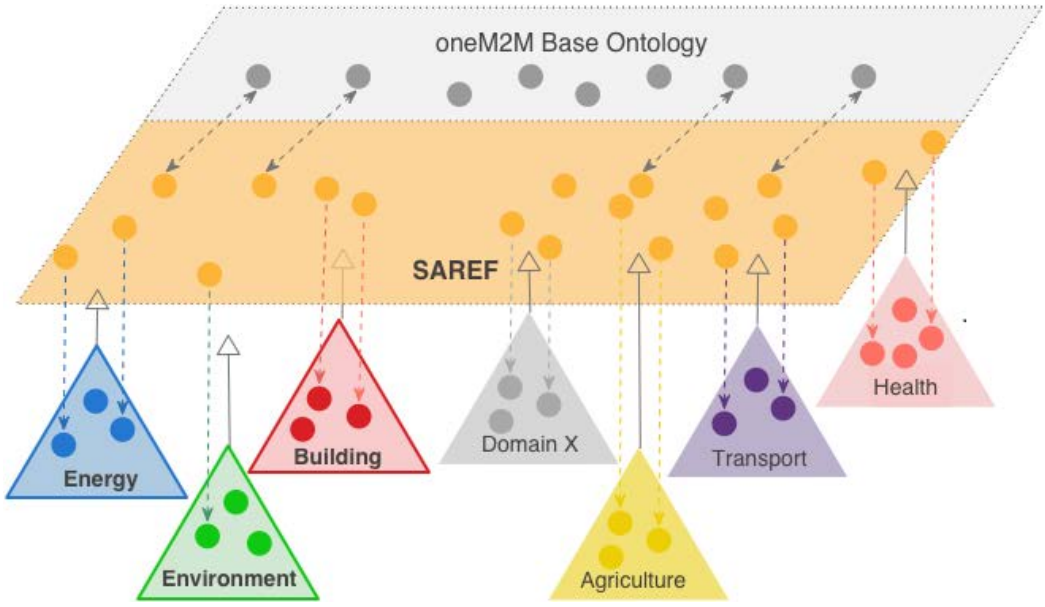


Figure 1: SAREF and extensions

As SAREF is the core semantic model for smart appliances, it functions as the connecting factor between the extensions in the different domains, and the domain specific extensions should reuse the parts of SAREF that are relevant for their domain. A domain specific extension should add new concepts that are not defined in SAREF. Furthermore, domain specific extension can also reuse concepts from other extensions.

Each domain specific extension should be specified as a separate TS in order to ensure that domain specific extensions can be maintained independently of each other and also independently of SAREF. Numbering of SAREF extensions will be based on the following schema: ETSI TS 103 410-X (where X is a positive integer. Naming of SAREF extensions will be based on the following schema: SAREF4XXXX (where XXXX are letters). For example, the extension of SAREF for the energy domain is specified in ETSI TS 103 410-1 [i.13] and is named SAREF4ENER. The extension of SAREF for the environment domain is specified in ETSI TS 103 410-2 [i.14] and is named SAREF4ENVI. The extension of SAREF for the building domain is specified in ETSI TS 103 410-3 [i.15] and is named SAREF4BLDG. Future extensions will follow the same numbering and naming schema.

Extensions can be created within an ETSI committee or outside of ETSI, but for standardization, they have always to pass through the ETSI SmartM2M committee.

Once a year, a check should be performed by ETSI SmartM2M on all extensions to identify concepts and properties that are used in more than one extension, as it could be desirable to move them to SAREF (to keep its role as a reference ontology with core concepts common to several domains).

4.2 Maintenance

SAREF and all the extensions created within the ETSI community are maintained using an approach as open as possible. This means that it is possible for every stakeholder (for SAREF and the domain specific extensions) to provide input on the maintenance of the models and participate in discussions on the improvement of the models.

Furthermore, it is also expected that extensions of SAREF will not only be created within the ETSI community, but also outside. ETSI should play an important role in the standardization of extensions of SAREF by allowing the models created outside of ETSI to be fed as input into the SmartM2M group and stimulating external stakeholders to provide their continuous input over time.

The formal standardization activities of SAREF and turning the drafts into Technical Specifications should be handled by the SmartM2M technical body within ETSI. Furthermore, the SmartM2M group should also be in charge of the vision on the development of SAREF and ensuring that the extensions created are in line with this vision.

As soon as any group or association has created an extension to SAREF and provided it as a contribution to ETSI SmartM2M as candidate to become a Technical Specification, the ETSI SmartM2M technical body will perform a set of predetermined checks to decide whether the proposed extension is accepted. Checks to be performed are:

- Is the extension a proper ontology according to the criteria specified in clauses 4.4 and 4.5?
- Were all relevant stakeholders in the domain involved in the creation process of the extension?
- Is the group that created the extension willing to work on the maintenance of the extension?
- Is SAREF properly used, and is the extension not adding concepts that are already present in SAREF?
- Is the extension properly documented?
- Is the extension in line with the vision of ETSI SmartM2M?

While working on the maintenance, it is important that SAREF and the domain specific extension are kept aligned: as soon as there is a number of domain specific extensions and concepts that occur in several domains are identified, these concepts should be moved as upper concepts in SAREF as a reference for all domains. Furthermore, every domain specific extension should have a maintenance strategy/schedule to ensure consistency and allow input from relevant stakeholders.

4.3 Specification

This clause describes a possible specification process for creating extensions of SAREF. The goal of the ontological requirements specification process is to extract the set of requirements that will guide the implementation and validation of the ontology. This process will allow identifying the purpose and scope of the ontology in the different use cases and to generate a list of requirements (in form of Competency Questions) that will guide the posterior development (and that will be updated along such development).

Figure 2 provides an overview of the ontology requirements specification process followed and its relation with the rest of the ontology development process. In this figure, the following information is included:

- **Actors.** The different roles involved in each activity. These roles can be:
  - Users. The potential end users of the ontology. This group includes software developers that will make use of the ontology within their applications.
  - Experts. Experts in the domains covered by the ontology. This role does not need to be knowledgeable about ontology development.
  - Ontology development team. This role represents ontological engineers and ontology developers with high knowledge on ontology implementation languages, techniques, tools, etc.
- **Activities.** The activities to be carried out in the process.
- **Outputs.** The products derived from each activity and that will serve as input to the posterior activities.

Figure 2 also provides the workflow of activities indicating the order in which they are carried out. In this sense it can be observed that after an implementation cycle the workflow goes back to the ontological requirements specification phase in which new requirements to be implemented will be chosen.

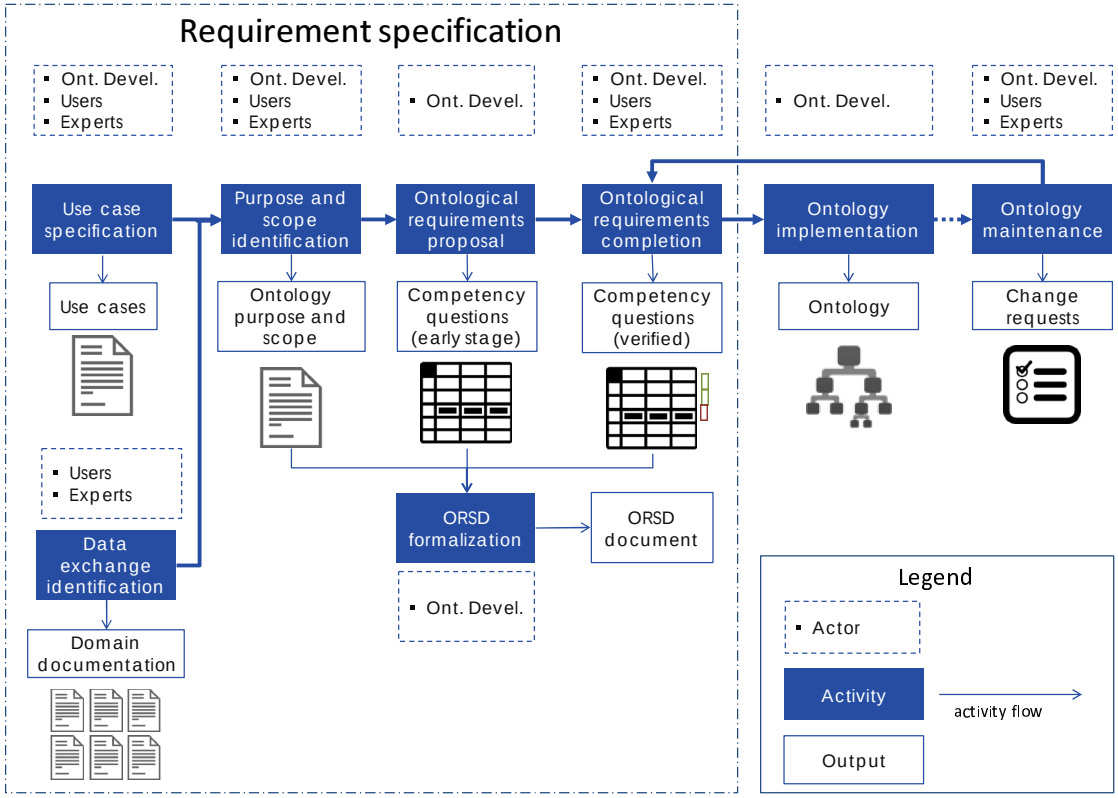


Figure 2: Ontology development process

The activities to be carried out during the ontology requirements specification process are the following:

- **Data exchange identification.** The goal of this activity is to provide the ontology development team with the necessary documentation about the domain to be modelled. In this case such documentation might origin from domain experts and/or users. The documentation to be shared might correspond to: manuals, datasets, standards, API specifications, data formats, etc.

- **Use case specification.** The goal of this activity is to collect a general description of the applications or processes in which the ontology to be developed may be used. These descriptions are written in natural language by domain experts and software developers who could be assisted by the ontology development team if required.

- **Purpose and scope identification.** The goal of this activity is to define the purpose and scope of the ontology for each of the use cases identified. During this activity, the ontology development team works in collaboration with users and domain experts to define the purpose and scope of each ontology or ontology module to be developed.

- **Ontological requirements proposal.** Taking as input the documentation and data provided by domain experts and users, the ontology development team generates a first proposal of the ontological requirements written in the form of Competency Questions [i.5]. The means used for gathering requirements follows a tabular approach in which the following fields are included: Requirement identifier, Competency question (question and answer or a statement in natural language), Provenance information (origin of the requirement), Comments, Relation with other requirements, Priority, and Status (proposed, accepted, rejected).

- **Ontological requirements completion.** During this activity, domain experts and users in collaboration with the ontology development team validate whether the ontology requirements defined in the previous step are correct and complete.

- **Ontological Requirement Specification Document (ORSD) formalization.** During this activity, the ORSD document is compiled by ontology developers. Such compilation of requirements would be taken as a first backlog that will trigger the ontology implementation phase.

4.4 Implementation

SAREF and its extensions should be high-quality ontology standards that provide additional value (e.g. break new ground, fill in an important gap, provide additional value compared to similar efforts, etc.), with high potential of being adopted by others, persistently accessible and available for reuse, and characterized by an exemplary design and technical quality. Concerning the design and technical quality, the most widely adapted, objective criteria for the design of ontologies for knowledge sharing are the principles proposed by Gruber [i.5]. SAREF and its extensions should therefore be implemented according to these criteria. Gruber's criteria can be summarized as follows:

- **Clarity.** For achieving clarity in ontological definitions, Gruber emphasizes the importance of:

    1) independence from social and computational contexts by using formalism;

    2) the use of logical axioms that provide a complete definition, i.e. a predicate defined by necessary and sufficient conditions;

    3) documentation supported by natural language.

- **Coherence.** Gruber states that definitions in an ontology should be logically consistent with the inferences that can be derived from these definitions. Further there should also be consistency between the logical axioms and their natural language documentation to maintain coherence. Extensions should be therefore checked using popular reasoners for logical consistency.

- **Extendibility.** The design of the ontology should enable monotonic extensions of the ontology, i.e. one should be able to define new terms for special use based on the existing vocabulary in a way that a revision of the existing definitions is not necessary.

- **Minimal encoding bias.** To encourage wider adoption of the ontology, Gruber proposes the use of a conceptualization mechanism that minimizes the dependencies on encoding formats (i.e. design choices should not be made purely for the convenience of notation or implementation). SAREF has been formalized in OWL-DL, which is a W3C standard for representing ontologies on the Web and has its foundations in Description Logics. Multiple serialization formats are available for the ontology (Turtle, RDF/XML). The axiomatization in SAREF is therefore accessible to all tools and frameworks that support these serializations. It is recommendable that SAREF extensions to follow the same formalization and serializations.

- **Minimum ontological commitment.** An ontology should make assertions that require only the minimum commitment sufficient to support the knowledge sharing activities, providing the parties that use the ontology with the flexibility to extend and specialize the ontology as needed.

4.5 Publication

The first SAREF technical specification ETSI TS 103 264 (V1.1.1) [i.3] was published as a collection of two documents, which could be downloaded together as a zip-file:

- Technical specification document in PDF format.

- Ontology file in Turtle format.

While this may be the normal method for publishing standards in ETSI, this is not the most suitable method for publishing ontologies. The main reason is that ontologies such as SAREF and its extensions should become part of the Semantic Web to ensure that the community will start adopting them. Publishing ontologies as Technical Specifications in zip-files hinders the possibility for the Semantic Web community to find and access the ontology, and therefore should be discouraged in ETSI.

In contrast, SAREF and its extensions should be made available according to the following best practices for publishing ontologies in the Semantic Web as defined by the W3C (https://www.w3.org/TR/swbp-vocab-pub/):

- Make the ontology available at a persistent URI, such as PURL, DOI or w3id, which redirects the HTTP requests against this persistent URI to another URL of choice (for example on an ETSI server) in which the ontology is actually located. This guarantees that the ontology will always be accessible at the same URI, even if its actual location changes.

- Enable content negotiation to make it possible to access SAREF on one URI, and depending on the request of the user give back machine-processable content (.rdf, .owl, .ttl) or human-readable content (HTML). The HTML documentation will be given as multiple hyperlinked HTML documents plus an overview document.

- Specify an appropriate license for the ontology, such as the creativecommons.org or opensources.org licenses.

- Make the ontology findable by registering it into community registries, such as the Linked Open Vocabularies (LOV, see http://lov.okfn.org/).

4.6 Extension domains

A number of domains have been identified as possible domains for extending SAREF. For three of them extensions have been defined (Energy, Environment and Building); for the other ones, extensions could be created in the near future.

Energy demand response

In the energy domain the associations Energy@Home and EEBus are working on interconnecting smart appliances to be able to perform demand and response use cases on the electricity grid. For this domain an extension has been defined, and the use cases presented are defined in clause 5.1.1.

Environment

Due to the positive connotations about security, wealth and modernity, people tend to illuminate the environment intensively. However, such exceed of artificial illumination, in addition to the waste of energy it represents, also interferes with astronomical observatories, disrupts ecosystems and has adverse health effects. In this context, light pollution is defined as excessive, misdirected or obtrusive artificial light. Based on input from the STARS4ALL project, an extension has been defined based on the use cases defined in clause 5.1.2.

Buildings

A more efficient interaction and integration of actors, methods and tools during the different phases of the building life cycle is being demanded in the Architecture, Engineering and Construction (AEC) and Facilities Management (FM) fields. Along its life cycle, multiple tools interact with building models to extract information for different purposes (e.g. energy demand, appliance characteristics, etc.). Therefore, mechanisms to facilitate the exchange of data between actors along the different stages of the building life cycle and to provide the required interoperability between tools are needed. As the ISO standard data model Industry Foundation Classes (IFC) [i.11] supports interoperability between data and tools, it was decided to extend the SAREF ontology with the subset of the ISO IFC standard related to devices and appliances. An extension has been defined based on the IFC standard [i.11] and the use cases defined in clause 5.1.3.

Health/Ageing well

Another possible extension of SAREF is an extension for the health domain. A number of parties are looking into connecting smart appliances in the home to allow citizens to live longer in their own home, or to be able to better support them remotely. The AIOTI Working Group 5 and the European Commission are interested in creating an ontology for Healthy Ageing, it is worthwhile to discuss this ontology and to see whether there is a link with SAREF. Furthermore, it is important to take into account the activities of the Continua Alliance (http://www.continuaalliance.org/) to ensure alignment with their activities when working on an extension of SAREF. Continua is publishing design guidelines that indicate how existing standards from different standardization bodies should be combined to ensure interoperability between personal health devices. The standards used also facilitate the exchange of data. For an extension of SAREF, it would be interesting to ensure that all data exchanged based on the Continua design guidelines is defined in the SAREF extension so that full mappings are possible.

Agriculture

An additional potential extension of SAREF is an extension for the agriculture domain, which is seen as one of the domains where the implementation of IoT could have a big impact. The Agricultural Industry Electronics Foundation (AEF) establishes and continues the international development and expansion of electronic and electrical technology as well as the implementation of electronic standards and coordinates the international cooperation in agricultural electronics technology. As the AEF is highly involved with the electronic and electrical technology for the agricultural domain, it is very interesting to ensure that an extension of SAREF includes all the data elements that are defined by the AEF to ensure that the SAREF extension could be fully mapped to the AEF standards.

5 Use cases and requirements

5.1 Use cases

5.1.1 Use cases from Energy@Home and EEBus

The Energy@Home and EEBus use cases require an extension of SAREF for Energy@Home (http://www.energy-home.it) - abbreviated in the rest of the document as E@H - and EEBus (http://www.eebus.org/en) to enable the interconnection of their different data models. Its purpose is to facilitate the interoperability between EEBus and E@H devices in demand response scenarios. By using this extension, smart appliances from manufacturers that support the EEBus or E@H data models will be able to communicate with one another using any energy management system at home or in the cloud, abstracting from the specifics of the underlying communication protocols.

In the E@H and EEBus demand response scenarios, customers can offer flexibility to the Smart Grid to manage their smart home devices by means of a Customer Energy Manager (CEM). The CEM is a logical function for optimizing energy consumption and/or production that can reside either in the home gateway or in the cloud. These scenarios involve the following use cases:

Use case 1: configuration of devices that want to connect to each other in the home network, for example, to register a new dishwasher to the list of devices managed by the CEM;

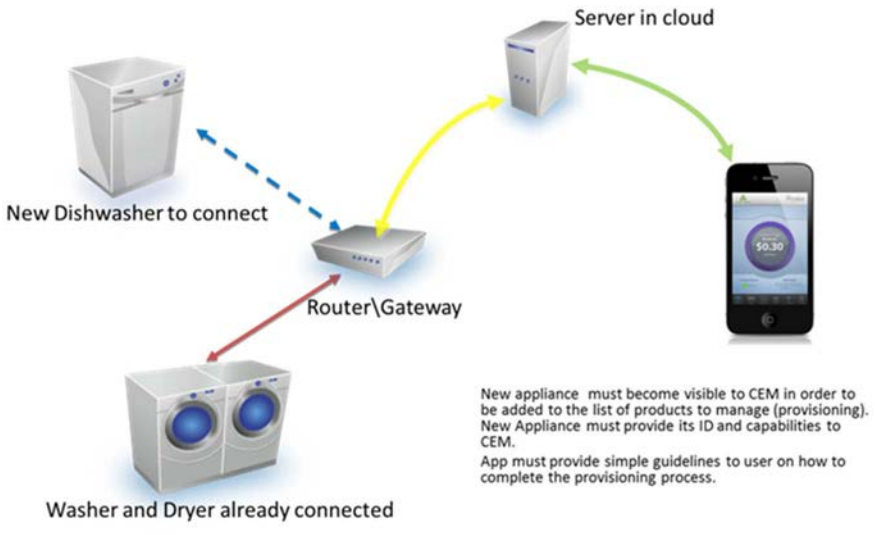


Figure 3

Use case 2: (re-)scheduling of appliances in certain modes and preferred times using power profiles to optimize energy efficiency and accommodate the customer's preferences;

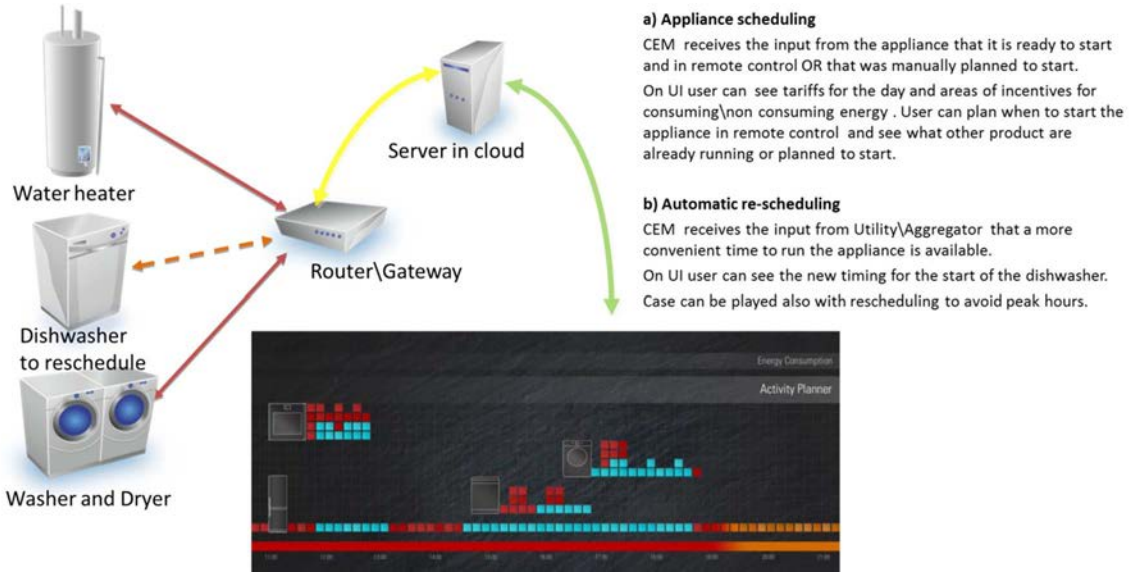


Figure 4

Use case 3: monitoring and control of the start and status of the appliances;

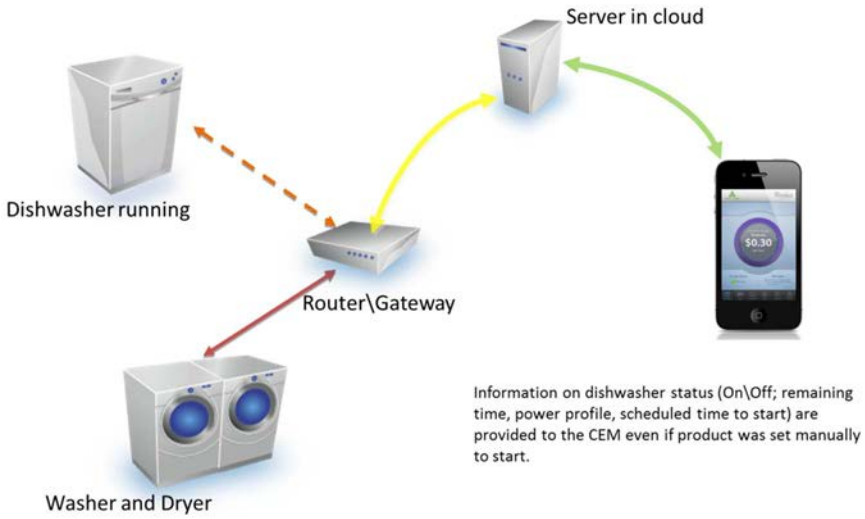


Figure 5

Use case 4: reaction to special requests from the Smart Grid, e.g. incentives to consume more or less depending on current energy availability, or emergency situations that require temporary reduction of power consumption.

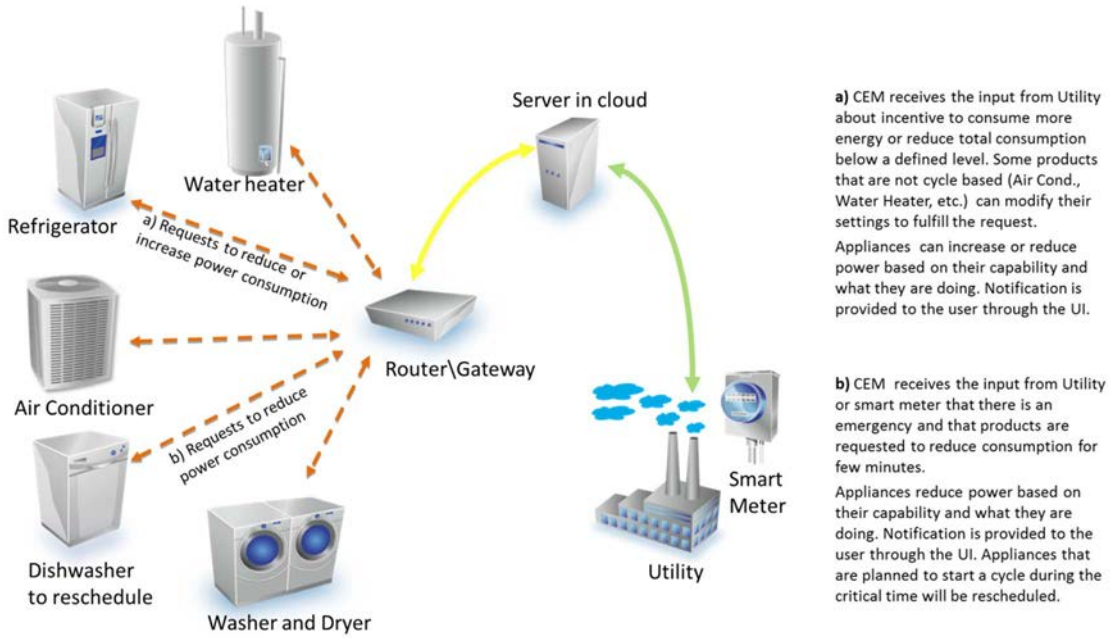


Figure 6

These use cases are associated with the user stories described in IEC TR 62746-2 [i.6], which include, among others, the following examples:

- User wants to do basic settings of his/her devices.
- User wants to know when the washing machine has finished working.
- User wants their washing done by 5:00 p.m. with the lowest electrical power cost.

- User likes to limit his own energy consumption up to a defined limit.
- User allows the CEM to reduce the energy consumption of the freezer in a defined range for a specific time, if the grid recognizes (severe) stability issues.
- Grid related emergency situations (e.g. blackout prevention).

5.1.2 Use cases from STARS4ALL

Due to the positive connotations about security, wealth and modernity, people tend to illuminate the environment intensively. However, such exceed of artificial illumination, in addition to the waste of energy it represents, also interferes with astronomical observatories, disrupts ecosystems and has adverse health effects. In this context, light pollution is defined as excessive, misdirected or obtrusive artificial light.

Due to its importance, a number of light pollution initiatives have arisen such as the STARS4ALL European H2020 project (http://www.stars4all.eu/index.php/lpi/), the international Dark-Sky association (http://darksky.org/), or the Spanish network about light pollution (https://guaix.fis.ucm.es/splpr/SQM-REECL). Indeed, based on this latter initiative, researchers in the field are working towards a broader initiative entitled the European Photometer Network.

In order to extract requirements for extending the SAREF ontology for the environment domain, more precisely, for the case of light pollution, the process presented in clause 4.2 has been followed. The rest of the clause details the roles involved in the process, the documents provided by the domain experts and software developers, the purpose and scope of the ontology, and the use cases extracted.

Roles involved. The requirements gathering process involved three ontological engineers, one end user, and one software developer. The end user and the software developer are members of the STARS4ALL project.

Documents exchanged. Different documentation was provided after the data exchange identification activity that helped in extracting an initial set of requirements: project deliverables [i.8], [i.9], a Ph.D. thesis [i.10], the technical specification of a web API, and sample data.

Ontology purpose. The purpose of extending the SAREF ontology for photometers is to solve the lack of interoperability between sensors that can measure and share information about light pollution.

Ontology scope. The ontology has to focus on the photometers used to measure light pollution. The level of granularity is directly related to the competency questions and terms identified.

The following use cases have been extracted by means of interviewing domain experts.

Use case 1: Monitor light pollution in a city

Photometers are used to collect data about the magnitude of the light emitted in a given area and to analyse such data. These data are used to rank areas according to their light pollution and to visualize such pollution information in maps. The information shown in the maps is used by local authorities in order to identify the lampposts that are emitting excessive or incorrect light and to adapt them accordingly. The ontology representing photometer and lamppost characteristics would allow the integration of data from different types of sensors (for example TESS, SQM and human sensors) since currently there are different photometer networks whose data should be harmonised. The ontology would also allow the description of lampposts in order to identify which ones do not comply with the recommendations for lower pollution.

Use case 2: Adjust lampposts light intensity due to high pollution

Local authorities gather data from sensor networks about light pollution in order to identify the most contaminating lampposts and therefore the areas where more energy is being thrown away. Once the polluting lampposts are identified, operators adjust their intensity using the devices as actuators. The ontology would be used in this case to integrate the information about the lamppost descriptions and their actuator interfaces in order to tune their configuration. In this case, the lamppost characteristics such as whether they have shade or the type of lamp used can also be retrieved to facilitate the decision making.

Use case 3: Register a photometer

A new collection of photometers is incorporated into an existing sensor network. This new type of sensors should be described according to the ontology in order to integrate the data that is going to be collected with the data already gathered by the sensor network. By describing and identifying the new sensors, the discoverability of data sources is increased. In this case, the ontology is also used to describe the sensors characteristics and communication interfaces.

5.1.3 Use cases from IFC

A more efficient interaction and integration of actors, methods and tools during the different phases of the building life cycle is being demanded in the Architecture, Engineering and Construction (AEC) and Facilities Management (FM) fields. Along its life cycle, multiple tools interact with building models to extract information for different purposes (e.g. energy demand, appliance characteristics, etc.). Therefore, mechanisms to facilitate the exchange of data between actors along the different stages of the building life cycle and to provide the required interoperability between tools are needed. As the ISO standard data model Industry Foundation Classes (IFC) [i.11] supports interoperability between data and tools, it was decided to extend the SAREF ontology with the subset of the ISO IFC standard related to devices and appliances. It is worth noting that the IFC specification is developed and maintained by building SMART International as its "Data standard" and, since its version IFC4 [i.12], it is accepted as ISO 16739:2013 [i.11].

In order to extract requirements for extending the SAREF ontology for the building domain, the process presented in clause 4.2 has been partially followed. The reason for this is that, in this case, there have been no domain experts available providing use cases or software developers building real applications in the given domain. Therefore, the requirements have been extracted taking the IFC specification as a starting point.

In order to select the subset of IFC that is relevant in the context of a SAREF extension, the boundaries of the concepts that have been included are delimited by the term "device", that is, every entity that can be classified as a device has been taken into account. In some cases, the concepts are easily recognized because the term "device" is included in its identifier, for example "shading device". However, in many other cases, the description of the entities had to be reviewed in order to elucidate whether the given concept actually represents a device. For example, the description of the term "actuator" reads as "an actuator is a mechanical device, etc.".

In addition, some concept definitions do not contain the term "device" as part of their description but a hypernym of it. That is, they are a more specific type of device. In these cases, WordNet® (http://wordnet.princeton.edu/) was used in order to identify whether such terms are devices, including them therefore in the requirements for the building extension of SAREF. For example, the definition of "lamp" in IFC reads "A lamp is an artificial light source such as a light bulb or tube" giving no evidence of whether a lamp is a device.

In this case a search was made for "lamp" in WordNet® and looked for its list of inherited hypernyms (http://wordnetweb.princeton.edu/perl/webwn?o2=&o0=1&o8=1&o1=1&o7=&o5=&o9=&o6=&o3=&o4=&r=1&s=lamp&i=2&h=10100#c) observing that "device" is listed as part of the inherited hypernyms; therefore, lamp was included within the requirements.

NOTE: WordNet® is the trade name of a product supplied by Princeton University. This information is given for the convenience of users of the present document and does not constitute an endorsement by ETSI of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Roles involved. The requirements gathering process involved three ontological engineers.

Documents exchanged. The document used for extracting requirements is the IFC specification available online [i.12]; as already mentioned, there have been no experts involved to exchange documents.

Ontology purpose. The purpose of extending the SAREF ontology for covering the IFC subset of concepts that describes devices and appliances is to adapt the well-known IFC model to the semantic web technologies used in the SAREF ontology, making both models interoperable.

Ontology scope. The ontology has to focus on the devices, including appliances, described in IFC and on their attributes. The level of granularity is directly related to the competency questions and terms extracted from the IFC HTML documentation.

As already mentioned, for this extension no collaboration with domain experts providing real uses cases has been possible. However, many use cases in the field of using semantics with building data have been defined in the W3C "Linked Building Data Community Group" (https://www.w3.org/community/lbd/) which are publicly accessible in the Community Group Wiki (https://www.w3.org/community/lbd/wiki/Seed_Use_Cases).

5.2 General feedback on SAREF

After the publication of the outcomes of the European Commission study that resulted in SAREF and the publication of ETSI TS 103 264 (V1.1.1) [i.3], a number of stakeholders and organizations provided feedback on SAREF. Furthermore, more requirements emerged when creating the extensions for the energy, environment and building domains considered in the present document and described in ETSI TS 103 410-1 [i.13] (SAREF4ENER), ETSI TS 103 410-2 [i.14] (SAREF4ENVI) and ETSI TS 103 410-3 [i.15] (SAREF4BLDG). This clause lists the requirements that were received, processed and consequently translated into changes to ETSI TS 103 264 [i.3] to create a new version of SAREF:

- Units of Measure. At the moment SAREF refers to the OM ontology for unit of measures (http://www.wurvoc.org/vocabularies/om-1.6/), but this is not the only solution. It should be clarified that the OM ontology is an example, but other ontologies can be used.

- Individuals vs. classes. At the moment, SAREF contains some individuals under the `saref:Device` class to show how to create different types of devices, and how they can be composed by other devices. These individuals need revision.

- Too restrictive constraints. Some changes on existing axioms in SAREF are desirable because of requirements that became relevant in a later stage. For example, SAREF currently restricts the usage of the `saref:hasConsumption` property to energy and power profiles. This was a logical choice at the time SAREF was created, as these were the only types of profile of interest. However, it was realized that it would be desirable to use the same property also for other types of profile, such as water or gas profiles. Therefore it should be considered to revise this restriction in order to allow the usage of the `saref:hasConsumption` property also with other classes, such as `saref:Water` and `saref:Gas`.

- Too restrictive cardinalities. SAREF right now includes several cardinality restrictions that are too strong and hinder reuse and interoperability. Some cardinalities may need revision, especially when it is realized that there is the risk that they are too restrictive. For example, forcing that every device description includes the manufacturer name is too strict; not every device description may have this information. The proposal is to remove all the cardinality restrictions except those that are fundamental for the correct working of the model. For example, a `saref:Profile` currently has a `saref:hasTask exactly 1 xsd:string` constraint that makes the `saref:hasTask` property mandatory, which may be too restrictive. Since SAREF is a reference ontology - and consequently contains core concepts that can be rather abstract - it could be better to leave this property (and other properties, if applicable) as optional instead, restricting its cardinality only in specific models that extend/specialize SAREF for a specific purpose.

- Focus on energy. SAREF was developed with the goal of making houses and buildings more energy efficient. SAREF therefore includes a number of concepts for this specific domain. To make SAREF more a core model, and to properly distinguish between the core model and domain models, the energy specific concepts could be moved into the energy domain extension.

- The Energy class, subclass of the Property class, is specialized in a number of subclasses, i.e. Average Energy, Maximum Energy, Minimum Energy, Total Energy, HVAC Energy, Hot Water Energy and Lighting Energy. This was used originally to provide industrial stakeholders with examples of what type of Energy can be defined using SAREF, but this should be reconsidered for an updated version. Moreover, these subclasses are not defined consistently for the other type of properties, such as Power, Humidity, Light and so forth.

- The energy and power profiles in SAREF at the moment are specific for the SAREF4ENER extension, therefore the Profile class in SAREF needs to be redefined to accommodate properties that are general enough for any type of profile, not only for Energy and Power. For example:

  - remove `hasConsumption` and `hasProduction` and replace it with new property called `isAbout`;

  - remove `hasTask`, `isFlexible` and `isInterruptionPossible` to add them into the Power Profile in SAREF4ENER;

  - change the `rdfs:comment` to accommodate the new (more general) Profile.

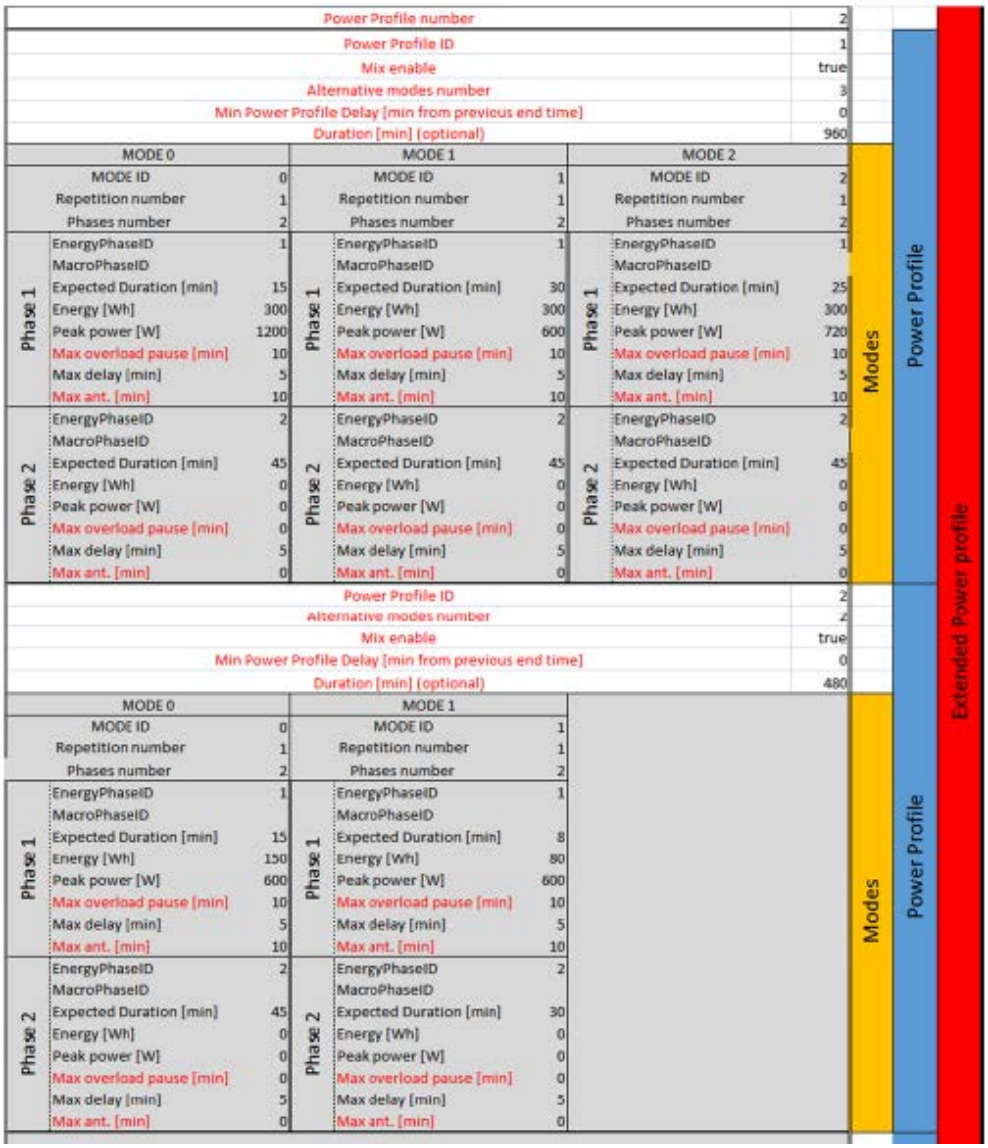
- At the moment, SAREF object properties include global restrictions (`rdfs:domain` and `rdfs:range`) that do not contribute to the definition of the classes defined in the ontology and hinder reuse and interoperability. The proposal is to remove all the global restrictions in object properties.

- The term "task" is used in two different places in the ontology. In the Device description to say that a device accomplishes some task, and in the Profile description to say that a profile has some task. It seems that the meaning of task in both places is different. This ambiguity should be resolved.
- Transform Task subclasses in individuals.
- The reading type of a measurement right now contains strings as values. Besides, the possible values are defined using an enumeration that includes a value of "other". The proposal is to implement measurement reading types, if not through a hierarchy, using an object property with individuals as values; to avoid using an enumeration in the definition; and to remove the type "other".
- SAREF covers some classes and properties related to how to represent devices in building spaces. The proposal is to move them the SAREF4BLDG extension related to buildings.
  - Classes related to buildings that were removed from SAREF:
    - saref:BuildingSpace;
    - saref: BuildingObject with its subclasses saref:Door and saref:Window.
  - Properties related to buildings that were removed from SAREF:
    - saref:Device saref:isLocated in only saref:BuildingSpace;
    - saref:Device saref:isUsedFor in only (saref:Commodity or saref:Property or saref:BuildingObject);
    - saref:BuildingSpace saref:hasSpaceType xsd:string;
    - saref:BuildingSpace saref:contains only (saref:Device or saref:BuildingObject).
- SAREF implements the device hierarchy through the `saref:DeviceCategory` class. The OWL language already includes features to represent hierarchies from different points of view without the need for such a class and to take advantage of reasoning based on those hierarchies. For example, Sensor is classified under Device in a one-level hierarchy, similarly as Temperature Sensor or Smoke Sensor, which are in the same level. However, Temperature Sensor and Smoke Sensor should be subclasses of Sensor. The proposal is to convert the `saref:DeviceCategory` class into a separate hierarchy of devices, the OWL language allows having multiple inheritance, so there is no problem in having multiple hierarchies for a class.
- The definitions of units of measurement using an enumeration (`owl:oneOf`) are too restrictive because they do not allow using other units than those enumerated. The proposal is to keep the individuals of each class but to remove the enumeration.
- Right now the `saref:Property` class is conflating two different concepts: the concept of property (an observable quality of something) and the concept of measurement (a concrete value observed for a property). There are some requirements that forced us to change how this is represented:
  - To differentiate between properties and the measurements made for such properties.
  - To represent measurements for a concrete property in different units of measurement.

  The proposal is to split the current `saref:Property` class into two classes (`saref:Property` and `saref:Measurement`) as it is done in the SAREF4ENVI extension.

5.3 Requirements for the energy domain

The starting point for the extension of SAREF in the energy domain for the demand response use cases from E@H and EEbus is given by the two existing data models of E@H (an UML class diagram, http://www.energy-home.it/Documents/Technical%20Specifications) and EEBus (an XSDs specification, see [i.7]), and their documentation. A representation of the power profile concept in the E@H and EEBus data models is shown in Figure 7 and Figure 8, respectively.



Power Profile number							2	
Power Profile ID							1	
Mix enable							true	
Alternative modes number							3	
Min Power Profile Delay [min from previous end time]							0	
Duration [min] (optional)							960	
MODE 0			MODE 1			MODE 2		
MODE ID		0	MODE ID		1	MODE ID		2
Repetition number		1	Repetition number		1	Repetition number		1
Phases number		2	Phases number		2	Phases number		2
Phase 1	EnergyPhaseID	1	Phase 1	EnergyPhaseID	1	Phase 1	EnergyPhaseID	1
	MacroPhaseID			MacroPhaseID			MacroPhaseID	
	Expected Duration [min]	15		Expected Duration [min]	30		Expected Duration [min]	25
	Energy [Wh]	300		Energy [Wh]	300		Energy [Wh]	300
	Peak power [W]	1200		Peak power [W]	600		Peak power [W]	720
	Max overload pause [min]	10		Max overload pause [min]	10		Max overload pause [min]	10
	Max delay [min]	5		Max delay [min]	5		Max delay [min]	5
	Max ant. [min]	10		Max ant. [min]	10		Max ant. [min]	10
Phase 2	EnergyPhaseID	2	Phase 2	EnergyPhaseID	2	Phase 2	EnergyPhaseID	2
	MacroPhaseID			MacroPhaseID			MacroPhaseID	
	Expected Duration [min]	45		Expected Duration [min]	45		Expected Duration [min]	45
	Energy [Wh]	0		Energy [Wh]	0		Energy [Wh]	0
	Peak power [W]	0		Peak power [W]	0		Peak power [W]	0
	Max overload pause [min]	0		Max overload pause [min]	0		Max overload pause [min]	0
	Max delay [min]	5		Max delay [min]	5		Max delay [min]	5
	Max ant. [min]	0		Max ant. [min]	0		Max ant. [min]	0
Power Profile ID							2	
Alternative modes number							2	
Mix enable							true	
Min Power Profile Delay [min from previous end time]							0	
Duration [min] (optional)							480	
MODE 0			MODE 1					
MODE ID		0	MODE ID		1			
Repetition number		1	Repetition number		1			
Phases number		2	Phases number		2			
Phase 1	EnergyPhaseID	1	Phase 1	EnergyPhaseID	1			
	MacroPhaseID			MacroPhaseID				
	Expected Duration [min]	15		Expected Duration [min]	8			
	Energy [Wh]	150		Energy [Wh]	80			
	Peak power [W]	600		Peak power [W]	600			
	Max overload pause [min]	10		Max overload pause [min]	10			
	Max delay [min]	5		Max delay [min]	5			
	Max ant. [min]	10		Max ant. [min]	10			
Phase 2	EnergyPhaseID	2	Phase 2	EnergyPhaseID	2			
	MacroPhaseID			MacroPhaseID				
	Expected Duration [min]	45		Expected Duration [min]	30			
	Energy [Wh]	0		Energy [Wh]	0			
	Peak power [W]	0		Peak power [W]	0			
	Max overload pause [min]	0		Max overload pause [min]	0			
	Max delay [min]	5		Max delay [min]	5			
	Max ant. [min]	0		Max ant. [min]	0			

Figure 7: E@H representation of power profile and related concepts

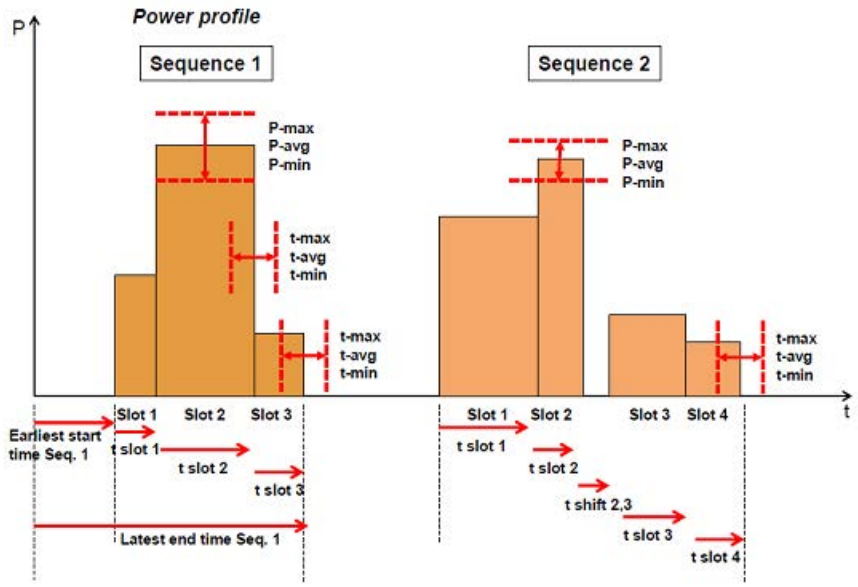


Figure 8: EEBus representation of power profile and related concepts

These two data models of E@H and EEBus focus on similar concepts, such as the concept of "power profile", but they use different terminologies. For example, Figure 7 shows that E@H defines "power profiles", "modes" and "phases", while EEBus refers to these concepts as "power sequences", "alternatives" and "slots", as shown in Figure 8.

The main requirement was therefore to establish a common terminology that could be shared by E@H and EEBus to identify the concept of power profile and its related concepts. The main competency questions are: What is a power profile? What is an alternatives group? What is a power sequence? What is a slot? These questions are supported by the following statements:

- A power profile is a way to model curves of power and energy over time, which also provides definitions for the modelling of power scheduling including alternative plans. With a power profile, a device (or power sequences server) exposes the power sequences that are potentially relevant for the CEM (or power sequences client).
- An alternatives group is a collection of power sequences for a certain power profile.
- A power sequence is the specification of a task, such as wash or tumble dry, according to user preferences and/or manufacturer's settings for a certain device. It is the most 'coarse' view; a power sequence can represent all single steps of a whole task, where the single steps are represented by slots.
- A slot is a single step of a power sequence. A slot is associated with a slot number (while a power sequence is associated with a power sequence identifier). The slot numbers of two power sequences should be considered independent from each other, i.e. slot number 7 of sequence 1 describes a different slot than slot number 7 of sequence 2. Therefore, a slot is only uniquely identified in combination with a sequence ID.

To create the final extension of SAREF for the energy domain it was beneficial to consider some requirements such as:

1) avoid redundancy of data types coming from the EEBus and E@H data models, introducing instead new classes and relationships that allow to reason on the power profile related concepts that are relevant for the energy domain;
2) introduce axioms to constrain the intended meaning of concepts in a more accurate way; and
3) reuse classes and properties of SAREF, creating new classes and properties for the extension only when reuse was not possible.

5.5 Requirements for the environment domain

The ontology requirements presented in Table 1 have been extracted for the environment domain for the use cases described above. These requirements are a snapshot of the requirements in its current state; once they have been validated by end users and experts together with ontological engineers.

Table 1: Requirements for the environment domain

Identifier	Category	Competency question/Statement
Env-1	sensor	What is a TESS? TESS is a Telescope Encoder and Sky Sensor
Env-2	sensor	Which type of sensor is a TESS? TESS is a photometer
Env-3	sensor	What is a photometer? A photometer, generally, is an instrument that measures light intensity or optical properties of solutions or surfaces
Env-4	sensor	What is the main component of TESS? The main component of TESS is a custom-based electronic board
Env-5	sensor	Which are the communication interfaces available in TESS? RS232, Bluetooth, and Wi-Fi
Env-6	sensor	Which components of TESS are sensors? The light detector, nIR temperature sensor
Env-7	sensor	Which properties can be measured by a photometer? Illuminance, irradiance, light absorption, scattering of light, reflection of light, fluorescence, phosphorescence, and luminescence
Env-8	sensor	Each reading in a TESS has a timestamp
Env-9	sensor	Which are the properties observed by a TESS? Ambient temperature, sky temperature, frequency and magnitude
Env-10	sensor	Physical objects can contain devices
Env-11	sensor	A sensor could be a person
Env-12	device	Devices might have different versions and revision numbers

Identifier	Category	Competency question/Statement
Env-13	device	Which type(s) of RS232 is supported by TESS? V.24
Env-14	device	Which type(s) of Bluetooth is supported by TESS? V2.1
Env-15	device	Which type(s) of WiFi is supported by TESS? 802.11ah
Env-16	device	Which are the components of TESS? Printed circuit board, light detector, infrared thermometer module, remote serial port Wi-Fi transceiver module, power supply, light collector, nIR filter, clear glass window, enclosure box
Env-17	device	Which hardware elements is a TESS connected to? To a Wi-Fi router
Env-18	device	Which is the communication protocol used by TESS? MQTT Broker (RabbitMQ + MQTT Adapter)
Env-19	device	What is the transmission period of the TESS? 5 minutes (configurable)
Env-20	device	A device is located in a given geographical point defined by a latitude and a longitude
Env-21	device	A device position is defined using the azimuth and altitude horizontal coordinates
Env-22	device	A sensing device takes measures following a frequency
Env-23	device	A device can be actionable or not
Env-24	device	A device is part of a system
Env-25	device	An actuator is a type of device
Env-26	device	A device has energy consumption
Env-27	lamppost	A lamppost uses a given light generation method
Env-28	lamppost	A lamppost has energy consumption
Env-29	lamppost	A lamppost might have a light shield
Env-30	lamppost	What is a lamppost? A lamppost is a physical object that lights an outdoor area
Env-31	light	A light has a geometry
Env-32	light	A light is projected in a given direction
Env-33	light	A light is projected in a given angle
Env-34	light	A light is projected from a given height
Env-35	light	A light has a colour
Env-36	light	A light can have flash
Env-37	object	What can be considered as physical objects? An Arduino board, a garage door, a bottle of soda, a building, a TV, etc.
Env-38	object	A digital representation of an object has a name
Env-39	object	A digital representation of an object has a description
Env-40	object	A physical object has a description
Env-41	object	A digital representation of an object has a unique identifier
Env-42	object	A digital representation of an object can have zero or more tags
Env-43	object	A digital representation of an object has exactly one creation date
Env-44	object	A digital representation of an object includes the date in which some characteristic of object was last modified (e.g. its geolocation)
Env-45	observation	A sensing device produces a log of property observations
Env-46	observation	A log indicates which is its last value
Env-47	observation	Values in a log are related to the time in which they were observed
Env-48	observation	A physical representation of an object includes an observation log for each property to be observed
Env-49	observation	An observation value is measured in a given unit
Env-50	service	What is a service? A service is a software system to support interaction over a network
Env-51	service	Physical objects can have digital representations that are accessible through services
Env-52	service	A service can expose either none or multiple digital representations of an object
Env-53	service	A digital representation of an object is exposed at maximum by one service
Env-54	service	A digital representation of an object performs actions
Env-55	service	An action manages an actuator
Env-56	service	An action of a digital representation of an object can keep an action log
Env-57	service	A property of a digital representation of an object can keep an observation log
Env-58	service	A digital representation of an object encapsulates a system

5.5 Requirements for the building domain

The ontology requirements presented in Table 2 have been extracted for the building domain according to the use cases described above. These requirements are a snapshot of the requirements in its current state.

Table 2: Requirements for the building domain

Identifier	Category	Competency question/Statement
Bldg-1	building	What is a building? A building represents a structure that provides shelter for its occupants or contents and stands in one place. The building is also used to provide a basic element within the spatial structure hierarchy for the components of a building project (together with site, storey, and space).
Bldg-2	device	A building can contain devices.
Bldg-3	building element	What is a shading device? Shading devices are purpose built devices to protect from the sunlight, from natural light, or screening them from view. Shading devices can form part of the facade or can be mounted inside the building, they can be fixed or operable.
Bldg-4	building element	Which properties has a shading device? Shading device type, whether the element is external, whether the element is operated mechanically, thermal transmittance, solar transmittance, visible light transmittance, solar reflectance, visible light reflectance, and roughness.
Bldg-5	building control	What is an actuator? An actuator is a mechanical device for moving or controlling a mechanism or system. An actuator takes energy, usually created by air, electricity, or liquid, and converts that into some kind of motion.
Bldg-6	building control	What is an alarm? An alarm is a device that signals the existence of a condition or situation that is outside the boundaries of normal expectation or that activates such a device. Alarms include the provision of break glass buttons and manual pull boxes that are used to activate alarms.
Bldg-7	building control	What is a controller? A controller is a device that monitors inputs and controls outputs within a building automation system. A controller may be physical (having placement within a spatial structure) or logical (a software interface or aggregated within a programmable physical controller).
Bldg-8	building control	What is a flow instrument? A flow instrument reads and displays the value of a particular property of a system at a point, or displays the difference in the value of a property between two points. Instrumentation is typically for the purpose of determining the value of the property at a point in time. It is not the purpose of an instrument to record or integrate the values over time (although they may be connected to recording devices that do perform such a function). This entity provides for all forms of mechanical flow instrument (thermometers, pressure gauges etc.) and electrical flow instruments (ammeters, voltmeters etc.).
Bldg-9	building control	What is a sensor? A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument.
Bldg-10	building control	What is a unitary control element? A unitary control element combines a number of control components into a single product, such as a thermostat or humidistat. A unitary control element provides a housing for an aggregation of control or electrical distribution elements that, in combination, perform a singular (unitary) purpose. Each item in the aggregation may have its own geometric representation and location.
Bldg-11	building control	Which properties has an actuator? Fail position and manual override.
Bldg-12	electrical	What is a protective device tripping unit? A protective device tripping unit breaks an electrical circuit at a separate breaking unit when a stated electric current that passes through the unit is exceeded.
Bldg-13	electrical	What is an audio visual appliance? An audio-visual appliance is a device that displays, captures, transmits, or receives audio or video. Audio-visual appliances may be fixed in place or may be able to be moved from one space to another. They may require an electrical supply that may be supplied either by an electrical circuit or provided from a local battery source. Audio-visual appliances may be connected to data circuits including specialist circuits for audio visual purposes only.
Bldg-14	electrical	What is a communication appliance? A communications appliance transmits and receives electronic or digital information as data or sound. Communication appliances may be fixed in place or may be able to be moved from one space to another. Communication appliances require an electrical supply that may be supplied either by an electrical circuit or provided from a local battery source.
Bldg-15	electrical	What is an electric appliance? An electric appliance is a device intended for consumer usage that is powered by electricity. Electric appliances may be fixed in place or may be able to be moved from one space to another. Electric appliances require an electrical supply that may be supplied either by an electrical circuit or provided from a local battery source.

Identifier	Category	Competency question/Statement
Bldg-16	electrical	What is an electric flow storage device? An electric flow storage device is a device in which electrical energy is stored and from which energy may be progressively released.
Bldg-17	electrical	What is an electric generator? An electric generator is an engine that is a machine for converting mechanical energy into electrical energy.
Bldg-18	electrical	What is an electric motor? An electric motor is an engine that is a machine for converting electrical energy into mechanical energy.
Bldg-19	electrical	What is an electric time control? An electric time control is a device that applies control to the provision or flow of electrical energy over time.
Bldg-20	electrical	What is a lamp? A lamp is an artificial light source such as a light bulb or tube.
Bldg-21	electrical	What is an outlet? An outlet is a device installed at a point to receive one or more inserted plugs for electrical power or communications. Power outlets are commonly connected within a junction box; data outlets may be directly connected to a wall. For power outlets sharing the same circuit within a junction box, the ports should indicate the logical wiring relationship to the enclosing junction box, even though they may be physically connected to a cable going to another outlet, switch, or fixture.
Bldg-22	electrical	What is a protective device? A protective device breaks an electrical circuit when a stated electric current that passes through it is exceeded. A protective device provides protection against electrical current only (not as a general protective device). It may be used to represent the complete set of elements including both the tripping unit and the breaking unit that provide the protection. This may be particularly useful at earlier stages of design where the approach to breaking the electrical supply may be determined but the method of tripping may not. Alternatively, this entity may be used to specifically represent the breaking unit alone (in which case the tripping unit will also be specifically identified). This entity is specific to dedicated protective devices and excludes electrical outlets that may have circuit protection.
Bldg-23	electrical	What is a solar device? A solar device converts solar radiation into other energy such as electric current or thermal energy.
Bldg-24	electrical	What is a switching device? A switch is used in a cable distribution system (electrical circuit) to control or modulate the flow of electricity. Switches include those used for electrical power, communications, audio-visual, or other distribution system types as determined by the available ports.
Bldg-25	electrical	What is a transformer? A transformer is an inductive stationary device that transfers electrical energy from one circuit to another. A transformer is used to transform electric power; conversion of electric signals for other purposes is handled at other entities: a controller converts arbitrary signals, an audio visual appliance converts signals for audio or video streams, and a communications appliance converts signals for data or other communications usage.
Bldg-26	electrical	Which properties has a protective device tripping unit? Standard and limiting terminal size.
Bldg-27	electrical	Which properties has an audio visual appliance? Media source and audio volume.
Bldg-28	electrical	Which properties has an electric flow storage device? Nominal supply voltage, nominal supply voltage offset, and nominal frequency.
Bldg-29	electrical	Which properties has an electric generator? Electric generator efficiency, start current factor, and maximum power output.
Bldg-30	electrical	Which properties has an electric motor? Maximum power output, electric motor efficiency, start current factor, starting time, TE time, locked rotor current, motor enclosure type, frame size, whether the motor enclosure is guarded, and whether the motor has part winding.
Bldg-31	electrical	Which properties has a lamp? Contributed luminous flux, light emitter nominal power, lamp maintenance factor, lamp ballast type, lamp compensation type, colour appearance, spectrum, colour temperature, and colour rendering index.
Bldg-32	electrical	Which properties has an outlet? Whether the outlet accepts a loose plug connection and the number of sockets.
Bldg-33	electrical	Which properties has a switching device? Number of gangs, switch function, whether it has a key operated lock, whether there is an illuminated indicator to show that the switch is on, legend, and set point.
Bldg-34	electrical	Which properties has a transformer? Primary voltage, secondary voltage, primary current, secondary current, primary frequency, secondary frequency, primary apparent power, secondary apparent power, maximum apparent power, secondary current type, short circuit voltage, real impedance ratio, imaginary impedance ratio, transformer vector group, whether the neutral point of the primary winding is available as a terminal, and whether the neutral point of the secondary winding is available as a terminal.

Identifier	Category	Competency question/Statement
Bldg-35	hvac	What is an air to air heat recovery? An air-to-air heat recovery device employs a counter-flow heat exchanger between inbound and outbound air flow. It is typically used to transfer heat from warmer air in one chamber to cooler air in the second chamber (i.e. typically used to recover heat from the conditioned air being exhausted and the outside air being supplied to a building), resulting in energy savings from reduced heating (or cooling) requirements.
Bldg-36	hvac	What is a burner? A burner is a device that converts fuel into heat through combustion. It includes gas, oil, and wood burners.
Bldg-37	hvac	What is a chiller? A chiller is a device used to remove heat from a liquid via a vapor-compression or absorption refrigeration cycle to cool a fluid, typically water or a mixture of water and glycol. The chilled fluid is then used to cool and dehumidify air in a building.
Bldg-38	hvac	What is a boiler? A boiler is a closed, pressure-rated vessel in which water or other fluid is heated using an energy source such as natural gas, heating oil, or electricity. The fluid in the vessel is then circulated out of the boiler for use in various processes or heating applications. A boiler is a vessel solely used for heating of water or other fluids. Storage vessels, such as for drinking water storage are considered as tanks.
Bldg-39	hvac	What is a coil? A coil is a device used to provide heat transfer between non-mixing media. A common example is a cooling coil, which utilizes a finned coil in which circulates chilled water, antifreeze, or refrigerant that is used to remove heat from air moving across the surface of the coil. A coil may be used either for heating or cooling purposes by placing a series of tubes (the coil) carrying a heating or cooling fluid into an airstream. The coil may be constructed from tubes bundled in a serpentine form or from finned tubes that give an extended heat transfer surface. Coils may also be used for non-airflow cases such as embedded in a floor slab.
Bldg-40	hvac	What is a compressor? A compressor is a device that compresses a fluid typically used in a refrigeration circuit.
Bldg-41	hvac	What is a condenser? A condenser is a device that is used to dissipate heat, typically by condensing a substance such as a refrigerant from its gaseous to its liquid state.
Bldg-42	hvac	What is a cooled beam? A cooled beam (or chilled beam) is a device typically used to cool air by circulating a fluid such as chilled water through exposed finned tubes above a space. Typically mounted overhead near or within a ceiling, the cooled beam uses convection to cool the space below it by acting as a heat sink for the naturally rising warm air of the space. Once cooled, the air naturally drops back to the floor where the cycle begins again.
Bldg-43	hvac	What is a cooling tower? A cooling tower is a device which rejects heat to ambient air by circulating a fluid such as water through it to reduce its temperature by partial evaporation.
Bldg-44	hvac	What is a damper? A damper typically participates in an HVAC duct distribution system and is used to control or modulate the flow of air.
Bldg-45	hvac	What is a duct silencer? A duct silencer is a device that is typically installed inside a duct distribution system for the purpose of reducing the noise levels from air movement, fan noise, etc. in the adjacent space or downstream of the duct silencer device.
Bldg-46	hvac	What is an engine? An engine is a device that converts fuel into mechanical energy through combustion.
Bldg-47	hvac	What is an evaporative cooler? An evaporative cooler is a device that cools air by saturating it with water vapour.
Bldg-48	hvac	What is an evaporator? An evaporator is a device in which a liquid refrigerant is vaporized and absorbs heat from the surrounding fluid.
Bldg-49	hvac	What is a fan? A fan is a device which imparts mechanical work on a gas. A typical usage of a fan is to induce airflow in a building services air distribution system.
Bldg-50	hvac	What is a filter? A filter is an apparatus used to remove particulate or gaseous matter from fluids and gases.
Bldg-51	hvac	What is a flow meter? A flow meter is a device that is used to measure the flow rate in a system.
Bldg-52	hvac	What is a heat exchanger? A heat exchanger is a device used to provide heat transfer between non-mixing media such as plate and shell and tube heat exchangers. A heat exchanger is commonly used on water-side distribution systems to recover energy from a liquid to another liquid (typically water-based), whereas an air-to-air heat recovery is commonly used on air-side distribution systems to recover energy from a gas to a gas (usually air).
Bldg-53	hvac	What is a humidifier? A humidifier is a device that adds moisture into the air.
Bldg-54	hvac	What is a medical device? A medical device is attached to a medical piping system and operates upon medical gases to perform a specific function. Medical gases include medical air, medical vacuum, oxygen, carbon dioxide, nitrogen, and nitrous oxide.

Identifier	Category	Competency question/Statement
Bldg-55	hvac	What is a pump? A pump is a device which imparts mechanical work on fluids or slurries to move them through a channel or pipeline. A typical use of a pump is to circulate chilled water or heating hot water in a building services distribution system.
Bldg-56	hvac	What is a space heater? Space heaters utilize a combination of radiation and/or natural convection using a heating source such as electricity, steam or hot water to heat a limited space or area.
Bldg-57	hvac	What is a tank? A tank is a vessel or container in which a fluid or gas is stored for later use.
Bldg-58	hvac	What is a tube bundle? A tube bundle is a device consisting of tubes and bundles of tubes used for heat transfer and contained typically within other energy conversion devices, such as a chiller or coil.
Bldg-59	hvac	What is a unitary equipment? Unitary equipment typically combine a number of components into a single product, such as air handlers, pre-packaged rooftop air-conditioning units, heat pumps, and split systems.
Bldg-60	hvac	What is a valve? A valve is used in a building services piping distribution system to control or modulate the flow of the fluid.
Bldg-61	hvac	What is a vibration isolator? A vibration isolator is a device used to minimize the effects of vibration transmissibility in a building.
Bldg-62	hvac	Which properties has an air to air heat recovery? Heat transfer type, whether it has defrost function or not, operational temperature range, primary air flow rate range, and secondary air flow rate range.
Bldg-63	hvac	Which properties has a burner? Energy source.
Bldg-64	hvac	Which properties has a chiller? Nominal capacity, nominal efficiency, nominal condensing temperature, nominal evaporating temperature, nominal heat rejection rate, nominal power consumption.
Bldg-65	hvac	Which properties has a boiler? Pressure rating, operating mode, heat transfer surface area, nominal part load ratio, water inlet temperature range, water storage capacity, whether it is a water storage heater, outlet temperature range, nominal energy consumption, and energy source.
Bldg-66	hvac	Which properties has a coil? Operational temperature range, air flow rate range, nominal sensible capacity, nominal latent capacity, nominal UA, and placement type.
Bldg-67	hvac	Which properties has a compressor? Power source, refrigerant class, minimum part load ratio, maximum part load ratio, compressor speed, nominal capacity, ideal capacity, ideal shaft power, whether it has hot gas bypass, and impeller diameter.
Bldg-68	hvac	Which properties has a condenser? Refrigerant class, external surface area, internal surface area, internal refrigerant volume, internal water volume, nominal heat transfer area, nominal heat transfer coefficient.
Bldg-69	hvac	Which properties has a cooled beam? Whether it is free hanging, water flow control system type, water pressure range, nominal cooling capacity, nominal surrounding temperature cooling, nominal surrounding humidity cooling, nominal supply water temperature cooling, nominal return water temperature cooling, nominal water flow cooling, nominal heating capacity, nominal surrounding temperature heating, nominal supply water temperature heating, nominal return water temperature heating, nominal water flow heating, integrated lighting type, pipe connection, finish colour, coil length, and coil width.
Bldg-70	hvac	Which properties has a cooling tower? Nominal capacity, circuit type, flow arrangement, spray type, capacity control, control strategy, number of cells, basin reserve volume, lift elevation difference, water requirement, operation temperature range, ambient design dry bulb temperature, ambient design wet bulb temperature.
Bldg-71	hvac	Which properties has a damper? Operation, orientation, blade thickness, blade action, blade shape, blade edge, number of blades, face area, maximum air flow rate, temperature range, maximum working pressure, temperature rating, nominal air flow rate, open pressure drop, leakage fully closed, frame type, frame depth, frame thickness, and close off rating.
Bldg-72	hvac	Which properties has a duct silencer? Hydraulic diameter, length, weight, air flow rate range, working pressure range, temperature range, and has exterior insulation.
Bldg-73	hvac	Which properties has an engine? Energy source.
Bldg-74	hvac	Which properties has an evaporative cooler? Flow arrangement, heat exchange area, operational temperature range, and water requirement.
Bldg-75	hvac	Which properties has an evaporator? Evaporation medium type, evaporation coolant, refrigerant class, external surface area, internal surface area, internal refrigerant volume, internal water volume, nominal heat transfer area, and nominal heat transfer coefficient.
Bldg-76	hvac	Which properties has a fan? Motor drive type, capacity control type, operation temperature range, nominal air flow rate, nominal total pressure, nominal static pressure, nominal rotation speed, nominal power rate, operational criteria.

Identifier	Category	Competency question/Statement
Bldg-77	hvac	Which properties has a filter? Weight, initial resistance, final resistance, operation temperature range, flow rate range, nominal filter face velocity, nominal media surface velocity, nominal pressure drop, nominal flow rate, nominal particle geometric mean diameter, and nominal particle geometric standard deviation.
Bldg-78	hvac	Which properties has a flow meter? Read out type and remote reading.
Bldg-79	hvac	Which properties has a heat exchanger? Arrangement.
Bldg-80	hvac	Which properties has a humidifier? Application, weight, nominal moisture gain, nominal air flow rate, internal control, and water requirement.
Bldg-81	hvac	Which properties has a pump? Flow rate range, flow resistance range, connection size, temperature range, net positive suction head, and nominal rotation speed.
Bldg-82	hvac	Which properties has a space heater? Placement type, temperature classification, heat transfer dimension, heat transfer medium, energy source, body mass, thermal mass heat capacity, output capacity, thermal efficiency, number of panels, number of sections.
Bldg-83	hvac	Which properties has a tank? Access type, storage type, nominal length or diameter, nominal width or diameter, nominal depth, nominal capacity, effective capacity, operating weight, pattern type, end shape type, first curvature radius, second curvature radius, number of sections.
Bldg-84	hvac	Which properties has a tube bundle? Number of rows, staggered row spacing, in line row spacing, number of circuits, fouling factor, thermal conductivity, length, volume, nominal diameter, outside diameter, inside diameter, horizontal spacing, vertical spacing, has turbulator.
Bldg-85	hvac	Which properties has a valve? Valve pattern, valve operation, valve mechanism, size, test pressure, working pressure, flow coefficient, and close off rating.
Bldg-86	hvac	Which properties has a vibration isolator? Vibration transmissibility, isolator static deflection, isolator compressibility, height, and maximum supported weight.
Bldg-87	plumbing fire protection	What is a fire suppression terminal? A fire suppression terminal has the purpose of delivering a fluid (gas or liquid) that will suppress a fire. A fire suppression terminal provides for all forms of sprinkler, spreader and other form of terminal that is connected to a pipework system and intended to act in the role of suppressing a fire.
Bldg-88	plumbing fire protection	What is an interceptor? An interceptor is a device designed and installed in order to separate and retain deleterious, hazardous or undesirable matter while permitting normal sewage or liquids to discharge into a collection system by gravity.
Bldg-89	plumbing fire protection	What is a sanitary terminal? A sanitary terminal is a fixed appliance or terminal usually supplied with water and used for drinking, cleaning or foul water disposal or that is an item of equipment directly used with such an appliance or terminal.
Bldg-90	plumbing fire protection	Which properties has an interceptor? Nominal body length, nominal body width, nominal body depth, inlet connection size, outlet connection size, cover length, cover width, ventilating pipe size.
Bldg-91	structural analysis	What is an energy conversion device? The distribution flow element energy conversion device defines the occurrence of a device used to perform energy conversion or heat transfer and typically participates in a flow distribution system.
Bldg-92	structural analysis	What is a flow controller? The distribution flow element flow controller defines the occurrence of elements of a distribution system that are used to regulate flow through a distribution system.
Bldg-93	structural analysis	What is a flow moving device? The distribution flow element flow moving device defines the occurrence of an apparatus used to distribute, circulate or perform conveyance of fluids, including liquids and gases (such as a pump or fan), and typically participates in a flow distribution system.
Bldg-94	structural analysis	What is a flow storage device? The distribution flow element flow storage device defines the occurrence of a device that participates in a distribution system and is used for temporary storage (such as a tank).
Bldg-95	structural analysis	What is a flow terminal? The distribution flow element flow terminal defines the occurrence of a permanently attached element that acts as a terminus or beginning of a distribution system (such as an air outlet, drain, water closet, or sink). A terminal is typically a point at which a system interfaces with an external environment.
Bldg-96	structural analysis	What is a flow treatment device? The distribution flow element flow treatment device defines the occurrence of a device typically used to remove unwanted matter from a fluid, either liquid or gas, and typically participates in a flow distribution system.
Bldg-97	product	What is a transport element? A transport element is a generalization of all transport related objects that move people, animals or goods within a building or building complex.
Bldg-98	product	Which properties has a transport element? Capacity people, capacity weight, and fire exit.

5.6 Requirements from the oneM2M base ontology

oneM2M provides a cross-domain service platform for IoT interoperability in terms of communication and data. It offers an abstraction layer that enables high level applications to communicate, exchange data, and manage heterogeneous devices in a seamless way and independently from the underlying network in different vertical domains such as smart cities, automotive, health, etc.

According to oneM2M, to solve the semantic gap in IoT, a high level application should be able to understand the device characteristics and its relationships with other entities, to understand the meaning of the function offered by the device without ambiguity, and also to understand how to use the different functions exposed by the device in order to collect data or to trigger actions.

oneM2M supports semantics for two main objectives:

- **Semantic interoperability:** Provide a common vocabulary to enable applications and devices to communicate in a seamless way without the need for a beforehand agreement on the data structure to exchange.
- **Generic interworking:** Provide a rich information model that enables describing vendor-specific and non-oneM2M device technologies in a single way, that can be translated automatically into oneM2M resources and therefore simplify and ensure interworking.

oneM2M should support semantics for both powerful and constrained environments. Semantics could be deployed in the service, gateway, and device domains.

With oneM2M, one should be able to describe:

- Device characteristics; they can include basic properties such as device serial number, manufacturer, type, etc. or more complex such as the device operating environment, condition, processing, etc.
- Device relationships with others entities in the environment such as device location, deployment, etc.
- Sub devices: A device can be complex: composed of several sub devices in their turn composed of other sub devices. The meaning of a device may vary from a simple temperature sensor to a complex washing machine.
- Functions provided by the device including measuring, actuating, and configuration capabilities such as switch on/off, measure temperature, open/close the window, etc. Each function can be linked to a particular aspect and may have specific restrictions to survive/operate such as minimum and maximum environment conditions. Functions related to a device should be described in a high level and comprehensive way to make it easy for any interested entity to understand what the device offers without going into technical details.
- Services provided by the device; technical information about how to use the device. A device exposes its functions through a set of services. Each service may contain a set of operations. Each operation can be described with a method, input, output and target end point. Other properties such as minimum and maximum range for device operation or survival could be supported. The service description contains technical details useful to understand how to use the device. Thus, a service description may vary from an API to another. In oneM2M, the service is exposed through a RESTful architectural style based on resources. In addition, the interworking with non-RESTful APIs such as RPC architectural styles should be possible through generic interworking. For this reason, the service description should be generic enough to support different architectural styles and technologies.
- Data generated by the device such as device measurements, observations, states, triggering results, etc. A measurement data can have a specific unit of measure, timestamp, etc. Data consumed by the device should be also represented such as actions, actuations, configuration, etc.

In order to have an abstract view of the oneM2M ontology, the oneM2M ontology was reverse engineered in order to extract from the ontology implementation and its technical specification the set of requirements satisfied by the oneM2M ontology. These requirements are presented in Table 3.

Table 3: Requirements from the oneM2M base ontology

Identifier	Category	Competency question/Statement
oneM2M-1	thing	A thing is an entity that can be identified in the oneM2M System.
oneM2M-2	thing	A thing may have properties.
oneM2M-3	thing	A thing can have relations to other things.
oneM2M-4	thing property	A thing property is a variable.
oneM2M-5	aspect	An aspect could be a (physical or non-physical) entity or it could be a quality.
oneM2M-6	aspect	An aspect can have metadata.
oneM2M-7	metadata	Metadata contain data (like units, precision-ranges, etc.) about a variable or about an aspect.
oneM2M-8	device	A device is a thing that is able to interact electronically with its environment via a network.
oneM2M-9	device	A device may be a physical or non-physical entity.
oneM2M-10	device	A device performs one or more functionalities in order to accomplish a particular task.
oneM2M-11	device	A device has one or more services that expose in the network its functionalities.
oneM2M-12	device	A device can be composed of several (sub-)devices.
oneM2M-13	interworked device	An interworked device is a device that does not support oneM2M interfaces and can only be accessed from the oneM2M System by communicating with a "proxied" (virtual) device that has been created by an interworking proxy entity.
oneM2M-14	interworked device	An interworked device is part of an area network.
oneM2M-15	area network	An area network is a network that provides data transport services between an interworked device and the oneM2M System.
oneM2M-16	area network	An area network follows an standard that defines its physical properties.
oneM2M-17	area network	An area network follows a communication protocol.
oneM2M-18	area network	An area network follows a profile.
oneM2M-19	service	A service is an electronic representation of a functionality in a network.
oneM2M-20	service	A service can expose one or more functionalities.
oneM2M-21	service	A service can be composed of independent (sub-)services.
oneM2M-22	service	A service has an operation.
oneM2M-23	service	A service has an input data point.
oneM2M-24	service	A service has an output data point.
oneM2M-25	functionality	A functionality represents the functionality necessary to accomplish the task for which a device is designed.
oneM2M-26	functionality	A functionality refers to (e.g. observes or influences) some real-world aspect(s).
oneM2M-27	functionality	A functionality has commands that allow human users to influence/observe such functionality.
oneM2M-28	functionality	A controlling functionality represents a functionality that has impacts on the real world, but does not gather data.
oneM2M-29	functionality	A measuring functionality represents a functionality that has no impacts on the real world, but only gathers data.
oneM2M-30	operation	An operation is the means of a service to communicate in a procedure-type manner over the network (i.e. transmit data to/from other devices).
oneM2M-31	operation	An operation is the -machine interpretable- exposure of a -human understandable- command to a network.
oneM2M-32	operation	An operation may receive input data from input data points (persistent entities).
oneM2M-33	operation	An operation may receive data from operation inputs (transient entities that are deleted when the operation finishes).
oneM2M-34	operation	An operation may produce output data into output data points (persistent entities).
oneM2M-35	operation	An operation may produce data into operation outputs (transient entities that are deleted when the operation finishes).
oneM2M-36	operation	An operation has an operation state that allows a oneM2M entity to get informed on the progress of that operation.
oneM2M-37	operation	An operation has a method.
oneM2M-38	operation	An operation has a target URI.
oneM2M-39	operation	A GET input data point is an operation that may be offered by a device to trigger the device to retrieve the data of an input data point (e.g. outside of the schedule when the device normally updates that data point).
oneM2M-40	operation	A SET output data point is an operation that may be offered by a device to trigger the device to update the data of an output data point (e.g. outside of the schedule when the device normally updates that data point).
oneM2M-41	command	A command represents an action that can be performed to support a functionality.
oneM2M-42	command	A command has as input one or more operation inputs.
oneM2M-43	command	A command has as output one or more operation outputs.

Identifier	Category	Competency question/Statement
oneM2M-44	operation input	An operation input describes an input of an operation and also describes the input of a command.
oneM2M-45	operation output	An operation output describes an output of an operation and also describes the output of a command.
oneM2M-46	operation state	An operation state describes the current state of an operation.
oneM2M-47	operation state	An operation state is a simple type variable.
oneM2M-48	operation state	An operation state has exactly one data restriction pattern.
oneM2M-49	input data point	An input data point is a variable of a service that is accessed by a RESTful device in its environment and that the device reads out autonomously (e.g. at periodic times).
oneM2M-50	output data point	An output data point is a variable of a service that is set by a RESTful device in its environment and that the device updates autonomously (e.g. at periodic times).
oneM2M-51	variable	A variable describes an entity that stores some data (e.g. integers, text, etc., or structured data) that can change over time.
oneM2M-52	variable	A variable describes a real-world aspect.
oneM2M-53	variable	A variable can have metadata.
oneM2M-54	variable	A variable can be structured using other variables.
oneM2M-55	variable	A variable may have a value (useful for values that are relatively static).
oneM2M-56	variable	A variable has a CRUD method through which the instantiation of the variable value can be manipulated.
oneM2M-57	variable	A variable has a URI of a resource through which the instantiation of the value of the variable can be manipulated.
oneM2M-58	simple type variable	A simple type variable is a variable that only consists of variables of simple XML types like xsd:integer, xsd:string, etc., potentially including restrictions.
oneM2M-59	simple type variable	A simple type variable contains the name of the attribute of the resource that is referenced with the target URI and that stores the value of the simple type variable.
oneM2M-60	simple type variable	A simple type variable has exactly one datatype.
oneM2M-61	simple type variable	A simple type variable has a data restriction.

6 Instantiating SAREF and its extensions

6.1 SAREF example

Six examples of how to create SAREF devices are available at:

```
http://ontology.tno.nl/examples/saref/lightswitch.ttl
http://ontology.tno.nl/examples/saref/doorswitch.ttl
http://ontology.tno.nl/examples/saref/energymeter.ttl
http://ontology.tno.nl/examples/saref/smokesensor.ttl
http://ontology.tno.nl/examples/saref/temperaturesensor.ttl
http://ontology.tno.nl/examples/saref/washingmachine.ttl
```

This clause shows an example of how to instantiate a light switch using SAREF (see `http://ontology.tno.nl/examples/saref/lightswitch.ttl`), which is depicted in in Figure 9. The corresponding Turtle code is provided in annex A, in which this instantiation is referred to using the `saref-ls:` prefix. This prefix is different from the `saref:` prefix, which indicates the SAREF ontology on which the `saref-ls` instantiation is built upon.

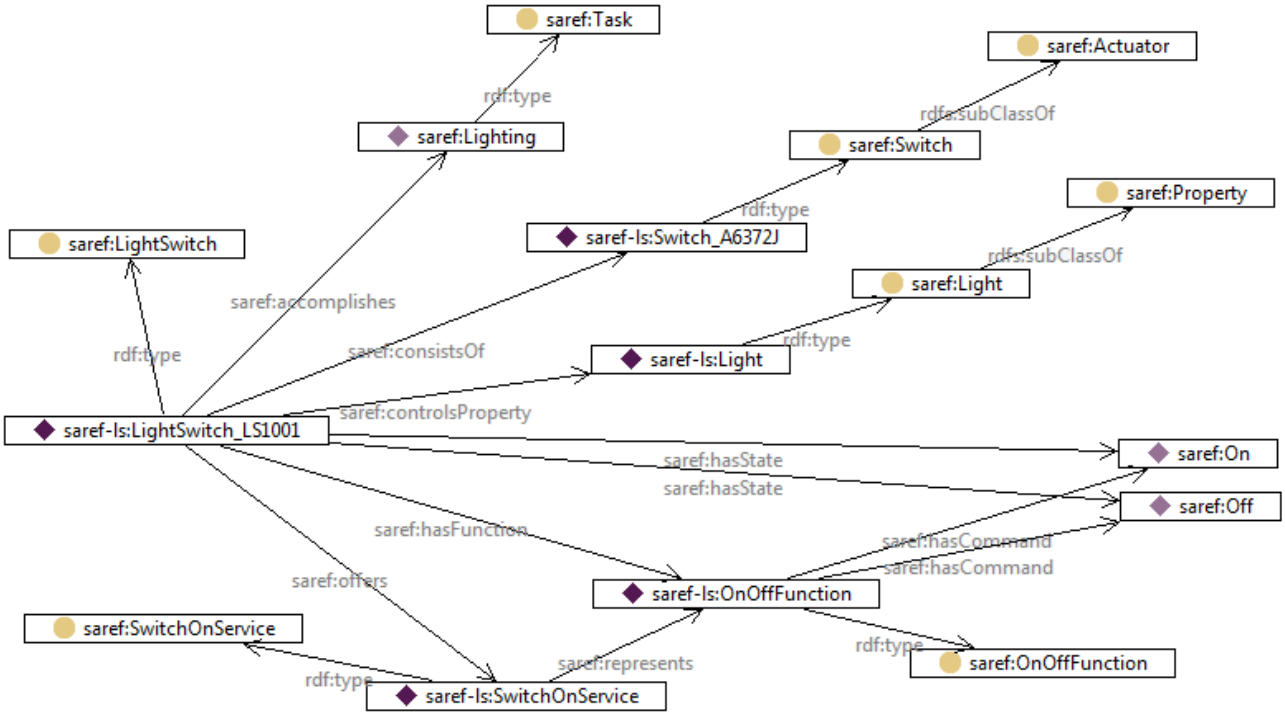


Figure 9: Light Switch example

The light switch instance in Figure 9 is called `saref-ls:LightSwitch_LS1001` and represents a device of type `saref:LightSwitch`, which is in turn subclass of `saref:Actuator`. The light switch instance also has a human readable label `"Light switch LS1001"` and some properties that uniquely characterize it, namely its model, manufacturer and a human-readable description. The light switch is further defined as follows:

- is designed to accomplish the task of `saref:Lighting`, which is of type `saref:Task`;
- consists of a `saref-ls:Switch_A6372J`, which is of type `saref:Switch` and is used for the purpose of controlling a property of type `saref:Light`;
- can be found in the states `saref:On` or `saref:Off`;
- performs a `saref:OnOffFunction`, which has the commands `saref:On` and `saref:Off` (note that the `saref:On` command acts upon a `saref:Off` state, while vice-versa the `saref:Off` command acts upon a `saref:On` state);
- offers a `saref-ls:SwitchOnService`, which in turn is of type `saref:SwitchOnService`. The `saref:SwitchOnService` is a representation of the `saref-ls:OnOffFunction` to allow the remote switch on of the lights through mobile phone devices that are connected to the local network.

6.2 SAREF4ENER example

This clause shows an example of how to instantiate a power profile using the SAREF4ENER extension of SAREF. This power profile is used by an heating system with hot water tank to communicate its energy flexibility to the CEM according to the consumer's preferences and needs. This instantiation is shown in Figure 10. The corresponding Turtle code is provided in annex B. A distinction between SAREF and SAREF4EE is made using the prefixes `saref:` and `s4ener:`, respectively.

A `s4ener:PowerProfile` inherits the properties of the more general `saref:Profile`, extending it with additional properties that are specific for SAREF4ENER. The `s4ener:PowerProfile` is used by a `s4ener:Device` to expose the power sequences that are potentially relevant for the CEM, for example, a heating system with hot water tank that wants to communicate its expected energy consumption for a certain day (`s4ener:HeatingSystem` instance). The `s4ener:HeatingSystem` exposes a `s4ener:PowerProfile` (`s4ener:PowerProfile-1-HS0001` instance), which consists of two groups with alternative plans (each group is modelled as a `s4ener:AlternativesGroup` class). These groups do not overlap in time and allow to model consecutive (and also rather independent) periods of action. For example, the `s4ener:PowerProfile-1-HS0001` contains one group of alternatives for a task in the morning, and another group of alternatives for another (additional) task in the afternoon. Within one group, there can be one or more plans represented by `s4ener:PowerSequence` classes (i.e. `s4ener:AlternativesGroup-1-HS0001` and `s4ener:AlternativesGroup-2-HS0001`) which are alternatives to each other (i.e. at most one of these plans can be finally executed). For example, to charge the hot water tank, the heating system mentioned above can offer within the "afternoon alternative group" two alternative plans, represented as power sequences: (a) a "cheapest" plan in which the CEM should try to minimize the user's energy bill, and (b) a "greenest" plan in which the CEM should try to optimize the configuration towards the maximum availability of renewable energy.

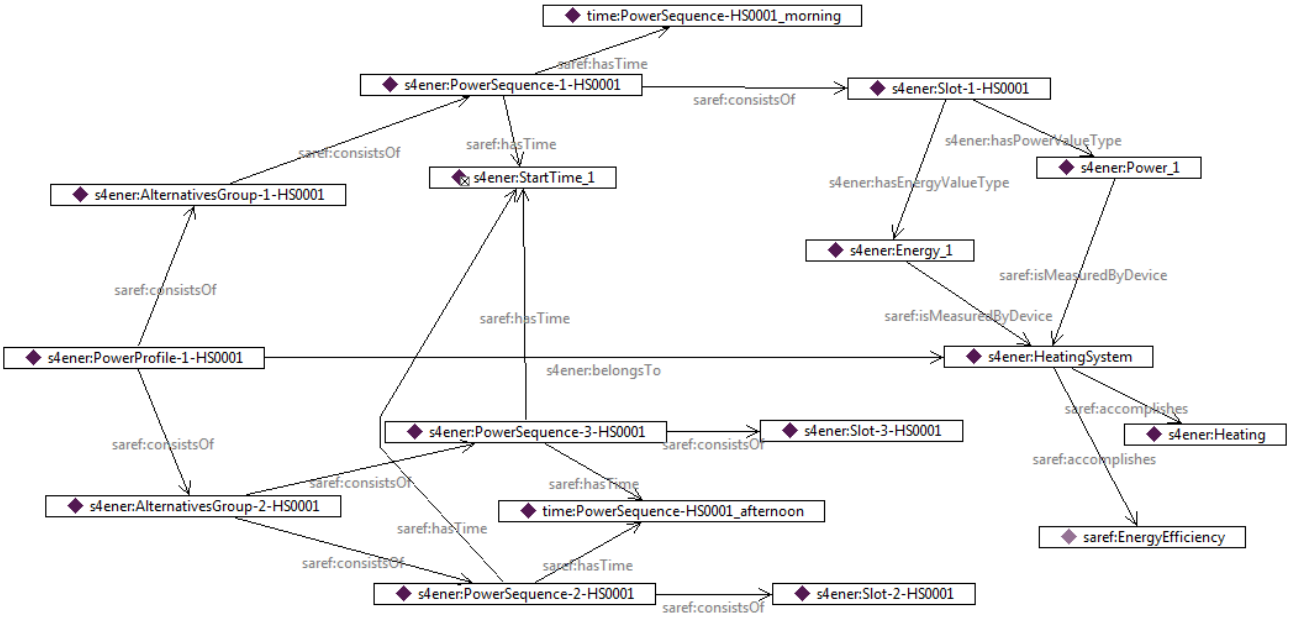


Figure 10: Power Profile for heating system example

Therefore, in the afternoon group (`s4ener:AlternativesGroup-2-HS0001`) the heating system offers two different power sequences: (a) `s4ener:PowerSequence-3-HS0001` that aims to run "as cheap as possible" and permits the CEM to shift the start between 8:45 and 12:00, and (b) `s4ener:PowerSequence-2-HS0001` that aims to reduce energy (it can even announce the user's preference for "green energy"). This means for the afternoon the CEM can take a choice for the "cheap" or the "green" plan. The plans may have further options with regards to their flexibility. For example one of the plans may offer that the CEM can pause a sequence (as long as the sequence completes before the latest time set by the user). Finally, a `s4ener:PowerSequence` consists of one or more slots (`s4ener:Slot` class) that represent different phases of consumption (or production) and their values. The power sequences of the heating system example have a single slot each. However, for other devices such as washing machines, a power sequence may have various slots for the different phases of washing, such as heating the water, washing and rinsing.

6.3 SAREF4ENVI example

This clause shows an example of an instantiation of the SAREF4ENVI ontology. Such example aims to illustrate how to describe a given sensor, in this case a photometer, using the SAREF4ENVI ontology. In addition, the example is complemented with energy consumption information for which the SAREF4ENER ontology is used. The example is graphically represented in Figure 11 and Figure 12 and the corresponding Turtle code is provided in annex C.

The core part of the example, the information annotated by the SAREF4ENVI ontology, is depicted in Figure 11. In such figure a photometer named "stars5" is depicted by a purple box. This purple box represents the instance `ex:TESS005-UC` that belongs to the class `s4envi:Tess`. This photometer is named "stars5", is manufactured by "Universidad Complutense de Madrid" and has version "1", as indicated by the values of the datatype properties `saref:hasName, saref:hasManufacturer` and `s4envi:hasVersion`, respectively.

Figure 11 also shows that the photometer is located in a given point, represented by the instance `ex:LocationTESS005-UCM`, which has specific values for the geographical coordinates indicated by the properties `geo:longitude` and `geo:latitude`.

The communication protocol that the photometer uses is indicated by the object property `s4envi:usesCommunicationProtocol` which links the instance representing the photometer with an instance of the class `s4envi:CommunicationProtocol` named `ex:MQTT-Broker` that represents the protocol "MQTT Broker". In addition, the photometer is able to use three different communication interfaces, namely RS232 v24, Bluetooth v2.1 and Wi-Fi v802.11ah. The photometer is linked to three different individuals that belong to the class `s4envi:CommunicationInterface`, each one representing one interface, by means of the property `s4envi:usesCommunicationInterface`. Each of these individuals has instantiated the datatype property `s4envi:hasVersion` in order to indicate the version of the communication interface.

The TESS photometer is able to measure light magnitude. It is indicated by the link between the photometer and the individual `s4envi:LightMagnitude`, which belongs to the class `s4envi:LightProperty`, using the property `saref:measuresProperty`.

The photometer has a frequency for taking one measurement every 10 seconds. This is represented by the property `s4envi:hasFrequencyMeasurement` that links the photometer with the instance `ex:FrequencyMeasurementTESS005-UC` which belongs to the class `s4envi: FrequencyMeasurement`. Such instance represents the value of the frequency by instantiating the datatype property `saref:hasValue` with the float value "10.0" and indicates the unit of measurement in which such value is measured by means of the object property `saref:isMeasduredIn` and the instance `wurvoc:recriprocal_second-time` reused from the OM ontology.

The photometer has a period for transmitting measurements of 30 seconds. This is represented by the property `s4envi:hasTransmissionPeriod` that links the photometer with the instance `ex:PeriodTransmissionTESS005-UC`, which belongs to the class `s4envi:PeriodMeasurement`. Such instance represents the value of the frequency by instantiating the datatype property `saref:hasValue` with the float value "30.0" and indicates the unit of measurement in which such value is measured by means of the object property `saref:isMeasduredIn` and the instance `time:unitSecond` reused from the time ontology.

The example also shows two measurements of light magnitude taken by the photometer. These measurements are represented by the instances `ex:Measurement2016-10-05T08:15:30TESS005-UCM` and `ex:Measurement2016-10-05T08:15:40TESS005-UCM` that belong to the class `saref:Measurement`. Such instances indicate which property the measurement is about by using the object property `saref:relatesToProperty` to link to the instance `s4envi:LightMagnitude`. The value of each measurement, "0.1" for the first one and "0.8" for the second one, is represented by the float value attached to the datatype property `saref:hasValue`. The unit of measurement in which the values are expressed is indicated by the instance `ex:mgPerArcsec2`. This instance is linked from the instance representing the measurement by the object property `saref:isMeasuredIn`. Finally, the time stamps when the measurements were taken are represented by the values linked from the datatype property `saref:hasTimeStamp`.

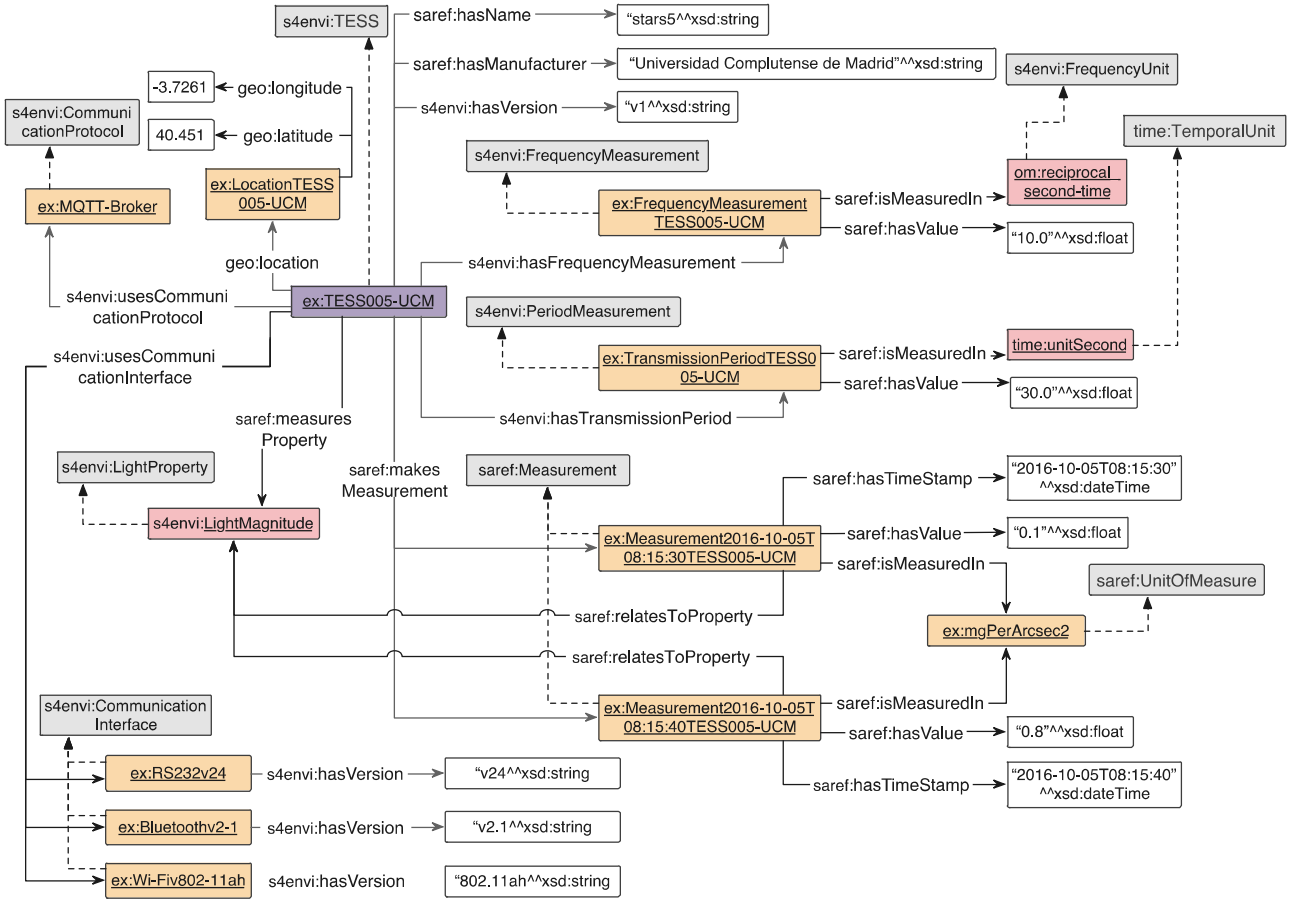


Figure 11: Photometer TESS description example

Figure 12 shows an example about combining ontological elements from the SAREF4ENVI ontology with the SAREF4ENER one. More precisely, it indicates the power consumption of the TESS photometer described above. For doing so, the instance representing the photometer, namely `ex:TESS005-UCM`, is linked to an instance named `ex:PowerProfileTESS005-UCM` that belongs to the class `s4ee:PowerProfile` which represents the power profile of the photometer. This latter instance indicates the photometer power consumption by linking, using the object property `saref:hasConsumption`, to an instance named `ex:PowerTESS005-UCM` that belongs to the class `s4ener:Power`. Finally, this instance indicates the power consumption value "20.0" by means of the datatype property `saref:hasValue` and the unit in which such value is measured by means of the object property `saref:isMeasuredIn` that points to the instance `wurvoc:watt`.

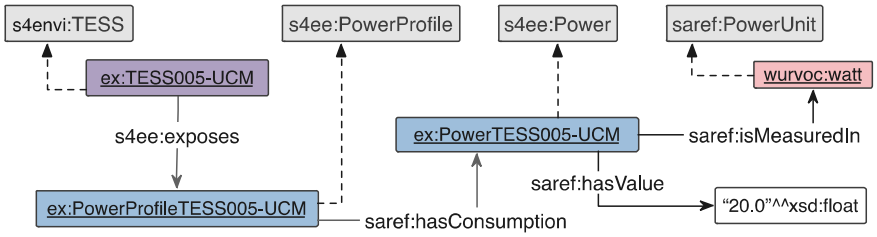


Figure 12: Photometer TESS related to the energy extension example

6.4 SAREF4BLDG example

This clause shows an example of instantiation of the SAREF4BLDG ontology. Such example aims to illustrate how to describe a given device that can be found in a building, in this case a compressor, using the SAREF4BLDG ontology. In addition, the example is complemented with energy consumption information for which the SAREF4ENER ontology is used. The example is graphically represented in Figure 13, Figure 14 and Figure 15 and the corresponding Turtle code is provided in annex D.

Figure 13 represents the core part of the example. In such figure a compressor of type SIERRA 02-0434C3 is depicted by a purple box. This purple box represents the instance `ex:Compressor001SIERRA02-0434C3` that belongs to the class `s4bldg:Compressor`. This compressor is named "Compressor 001 SIERRA 02-0434C3" and is manufactured by "SIEMENS" as indicated by the values of the datatype properties `saref:hasName` and `saref:hasManufacturer`.

The refrigerant used by the compressor is R407C which is a hydrofluorocarbon. This information is represented by the datatype property `s4bldg:refrigerantClass` and the value expressed "HFC" that refers to hydrofluorocarbon according to IFC.

The fact that the compressor is motor driven is indicated by the datatype property `s4bldg:powerSource` and the associated literal value. Besides, since the compressor has no hot gas by pass, the value for the datatype property `s4bldg:hasHotGasByPass` is set to the Boolean "False".

So far values that are represented directly by a datatype property were shown, and values in which only one triple is involved. Next descriptions are presented about the compressor that need to instantiate an n-ary pattern in order to relate the value for a given property with the unit of measurement in which such value is provided.

In order to indicate the compressor speed, it is necessary to have an instance linking the value "3.0" with the unit of measurement of such value, in this case cycles per second. For doing so the instance `ex:CompressorSpeedCompressor001SIERRA02-0434C3` was created that belongs to the class `saref:Measurement`. The compressor is linked to such instance by means of the property `s4bldg:compressorSpeed`. Finally, this new instance represents the value of the compressor speed by means of the datatype property `saref:hasValue` and the unit of measurement by the object property `saref:isMeasuredIn`. The specific unit of measurement is represented by the instance `ex:cyclesPerSecond` that belongs to the class `saref:UnitOfMeasure`.

The same pattern is used to represent the ideal capacity of the compressor, the nominal capacity and the impeller diameter using the object properties `s4bldg:idealCapacity`, `s4bldg:nominalCapacity` and `s4bldg:impellerDiameter`, respectively, between the compressor and the new instance created in each case. It is worth noting that in each case the unit of measurement used has been adapted according to the needs, for example using watts (represented by the instance `wurvoc:watt`) for the measurements about capacity and using inches (represented by the instance `wurvoc:inch-international`) for the measurement about the diameter.

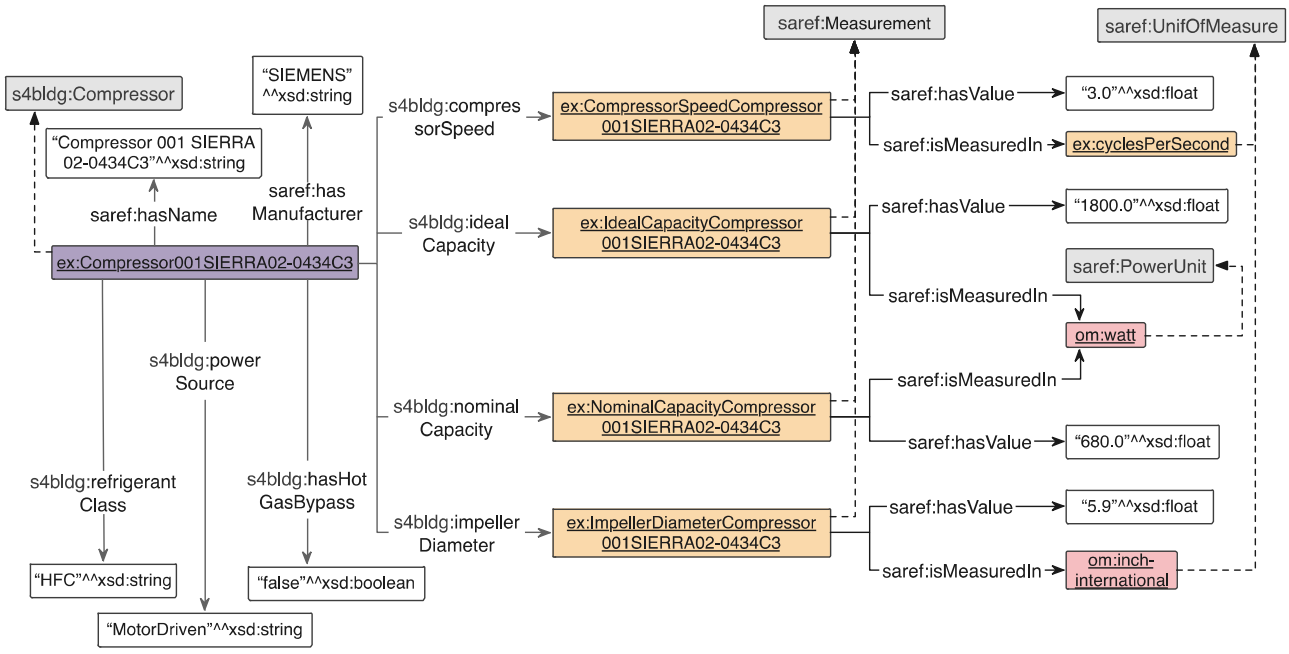


Figure 13: Compressor description example

Figure 14 complements the compressor description including location information also provided by the SAREF4BLDG ontology. In this case the geographical coordinates of the compressor (40.405155, -3.839203) are represented by the instance of the class `geo:SpatialThing` named `ex:LocationCompressor001SIERRA02-0434C3`. Such instance indicates the value of the coordinates by means of the properties `geo:latitude` and `geo:longitude`. The compressor is linked to such instance by means of the object property `geo:location`.

It is also shown that the compressor is located in the refrigeration store of the building 1 in a Computer Science faculty.

The refrigeration store is represented by the instance `ex:RefrigerationStoreComputerScienceBuilding1` that belongs to the class `s4bldg:BuildingSpace`. And the computer science building is represented by the instance `ex:ComputerScienceBuilding1` that belongs to the class `s4bldg:Building`.

It is indicated that the compressor is located in the refrigeration store by means of the object property `s4bldg:isContainedIn` established between the instance representing the compressor and the instance representing the refrigeration store.

The fact that the refrigeration store belongs to the building 1 is represented by means of the object property `s4bldg:isSpaceOf` established between the instance representing the refrigeration store and the instance representing the building.

The geographical coordinates of the refrigeration store and the building are indicated following the same pattern as for the compressor by means of the object property `geo:location` and the creation of an instance from which the values of the latitude and longitude are linked.

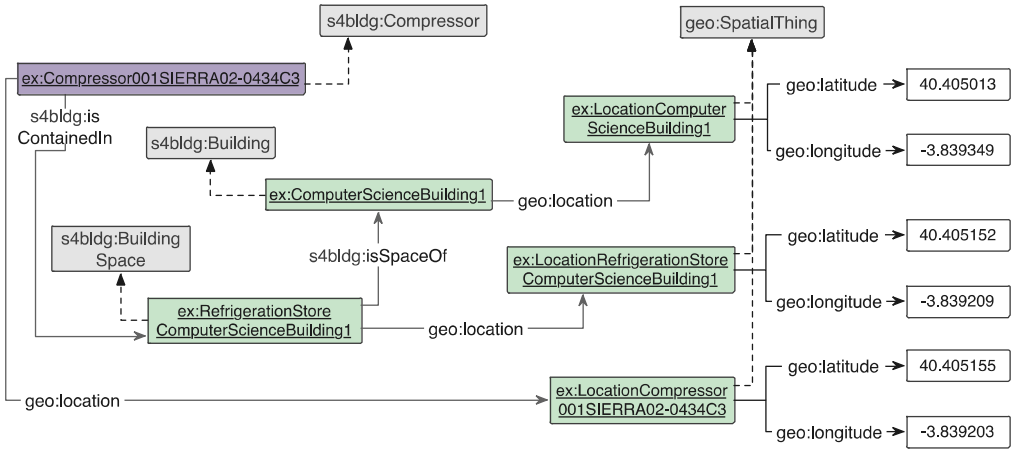


Figure 14: Compressor location example

Figure 15 shows an example that combines ontological elements from the SAREF4BLDG ontology with the SAREF4ENER one. More precisely, it indicates the power consumption of the compressor described above. For doing so, the instance representing the compressor, namely `ex:Compressor001SIERRA02-0434C3`, is linked to an instance named `ex:PowerProfileCompressor001SIERRA02-0434C3` that belongs to the class `s4ee:PowerProfile`, which represents the power profile of the compressor. This later instance indicates the compressor power consumption by linking, using the object property `saref:hasConsumption`, to an instance named `ex:PowerCompressor001SIERRA02-0434C3` that belongs to the class `s4ener:Power`. Finally, this instance indicates the power consumption value "902.0" by means of the datatype property `saref:hasValue` and the unit in which such value is measured by means of the object property `saref:isMeasuredIn` that points to the instance `wurvoc:watt`.

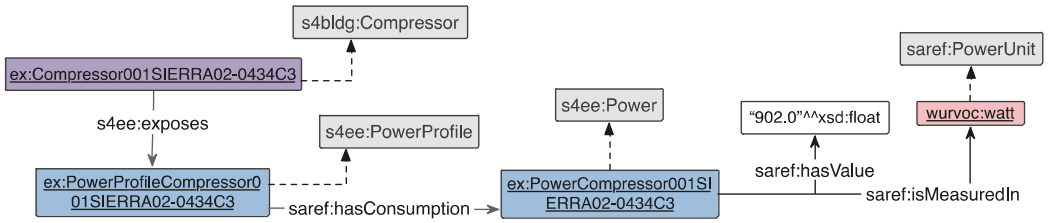


Figure 15: Compressor related to the energy extension example

7 Conclusion

The present document defines the process and guidelines for the extension, maintenance, specification, implementation and publication of SAREF and its extensions. Furthermore, it identifies five domains (energy, environment, building, health/ageing well and agriculture) for which extensions to SAREF are relevant. For the first three domains (energy, environment and building) the present document describes use cases and requirements for the creation of the extensions. For the other domains (health/ageing well and agriculture) only the motivation for which an extension is relevant is described. The main reason for not elaborating more in detail is that these two domains were identified rather late in the process of defining extensions in 2016 and, furthermore, only limited input was available. This also results in one of the lessons learned from the process of identifying and defining extensions, namely that defining an extension can be done properly only if sufficient input is available from external parties that are active in the domain and willing to work together with the modellers to create the extension. A second lesson learned is that it is difficult to get a complete picture of one domain, as domains overlap and are often broad. It is therefore recommended to work together with the major players in a domain to be able to get a complete picture and define an extension that properly reflects the domain under consideration.

The present document is concluded with a number of instantiations of SAREF and its extensions that provide examples of how SAREF can be used and extended. It is recommendable for the community around SAREF to provide more examples and more instances of SAREF and its extensions, so that it will become more clear for implementers how SAREF can be used and extended.

Annex A:
RDF code for SAREF example

```
# baseURI: http://ontology.tno.nl/examples/saref/lightswitch
# imports: https://w3id.org/saref

@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix saref: <https://w3id.org/saref#> .
@prefix saref-ls: <http://ontology.tno.nl/examples/saref/lightswitch#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://ontology.tno.nl/examples/saref/lightswitch>
  rdf:type owl:Ontology ;
  owl:imports <https://w3id.org/saref> ;
  .

  saref-ls:LightSwitch_LS1001
  rdf:type saref:LightSwitch ;
  rdfs:label "Light switch LS1001"^^xsd:string ;
  saref:accomplishes saref:Lighting ;
  saref:consistsOf saref-ls:Switch_A6372J ;
  saref:controlsProperty saref-ls:Light ;
  saref:hasDescription "Light switch LS1001 is an example of how to instantiate a light switch using
SAREF"^^xsd:string ;
  saref:hasFunction saref-ls:OnOffFunction ;
  saref:hasManufacturer "manufacturer-abc"^^xsd:string ;
  saref:hasModel "890-09w"^^xsd:string ;
  saref:hasState saref:Off ;
  saref:hasState saref:On ;
  saref:offers saref-ls:SwitchOnService ;
.
saref-ls:Switch_A6372J
  rdf:type saref:Switch ;
  rdfs:label "Switch A6372J"^^xsd:string ;
.
saref-ls:Light
  rdf:type saref:Light ;
  rdfs:label "Light"^^xsd:string ;
  saref:isControlledByDevice saref-ls:LightSwitch_LS1001 ;
.
saref-ls:OnOffFunction
  rdf:type saref:OnOffFunction ;
  rdfs:label "On off function"^^xsd:string ;
  saref:hasCommand saref:Off ;
  saref:hasCommand saref:On ;
.
saref-ls:SwitchOnService
  rdf:type saref:SwitchOnService ;
  rdfs:label "Switch on service"^^xsd:string ;
  saref:isOfferedBy saref-ls:LightSwitch_LS1001 ;
  saref:represents saref-ls:OnOffFunction ;
.
```

Annex B:
RDF code for SAREF4ENER example

```
# baseURI: http://ontology.tno.nl/examples/saref4ener/heatingsystem
# imports: https://w3id.org/saref4ener

@prefix heatingsystem: <http://ontology.tno.nl/examples/saref4ener/heatingsystem#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix s4ener: <https://w3id.org/saref4ener#> .
@prefix saref: <https://w3id.org/saref#> .
@prefix time: <http://www.w3.org/2006/time#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<http://ontology.tno.nl/examples/saref4ener/heatingsystem>
  rdf:type owl:Ontology ;
  owl:imports <https://w3id.org/saref4ener> ;
  .

time:Beginning_PowerProfile-1-HS0001
  rdf:type time:Instant ;
  rdfs:label "Beginning Power profile-1-HS0001"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T00:01:01.01"^^xsd:dateTime ;
.
time:Beginning_PowerSequence-HS0001_afternoon
  rdf:type time:Instant ;
  rdfs:label "Beginning Power sequence-HS0001 afternoon"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T15:30:00.00"^^xsd:dateTime ;
.
time:Beginning_PowerSequence-HS0001_morning
  rdf:type time:Instant ;
  rdfs:label "Beginning Power sequence-HS0001 morning"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T08:45:00.00"^^xsd:dateTime ;
.
time:DateTimeInterval_PowerProfile-1-HS0001
  rdf:type time:DateTimeInterval ;
  rdfs:label "Date time interval Power profile-1-HS0001"^^xsd:string ;
  time:hasBeginning time:Beginning_PowerProfile-1-HS0001 ;
  time:hasEnd time:End_PowerProfile-1-HS0001 ;
.
time:End_PowerProfile-1-HS0001
  rdf:type time:Instant ;
  rdfs:label "End Power profile-1-HS0001"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T00:23:59.59"^^xsd:dateTime ;
.
time:End_PowerSequence-HS0001_afternoon
  rdf:type time:Instant ;
  rdfs:label "End Power sequence-HS0001 afternoon"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T00:18:00.00"^^xsd:dateTime ;
.
time:End_PowerSequence-HS0001_morning
  rdf:type time:Instant ;
  rdfs:label "End Power sequence-HS0001 morning"^^xsd:string ;
  time:inXSDDateTime "2016-12-15T00:12:00.00"^^xsd:dateTime ;
.
time:PowerSequence-HS0001_afternoon
  rdf:type time:DateTimeInterval ;
  rdfs:label "Power sequence-HS0001 afternoon"^^xsd:string ;
  time:hasBeginning time:Beginning_PowerSequence-HS0001_afternoon ;
  time:hasEnd time:End_PowerSequence-HS0001_afternoon ;
.
time:PowerSequence-HS0001_morning
  rdf:type time:DateTimeInterval ;
  rdfs:label "Power sequence-HS0001 morning"^^xsd:string ;
  time:hasBeginning time:Beginning_PowerSequence-HS0001_morning ;
  time:hasEnd time:End_PowerSequence-HS0001_morning ;
.
s4ener:AlternativesGroup-1-HS0001
  rdf:type s4ener:AlternativesGroup ;
  rdfs:label "Alternatives group-1-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:PowerSequence-1-HS0001 ;
  s4ener:alternativesGroupID 1 ;
  s4ener:belongsTo s4ener:PowerProfile-1-HS0001 ;
.
```

```
s4ener:AlternativesGroup-2-HS0001
  rdf:type s4ener:AlternativesGroup ;
  rdfs:label "Alternatives group-2-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:PowerSequence-2-HS0001 ;
  saref:consistsOf s4ener:PowerSequence-3-HS0001 ;
  s4ener:alternativesGroupID 2 ;
  s4ener:belongsTo s4ener:PowerProfile-1-HS0001 ;
.
s4ener:EndTimeDurationDescription_PS-1-HS0001
  rdf:type s4ener:EndTimeDurationDescription ;
  rdfs:label "End time duration description PS-1-HS0001"^^xsd:string ;
.
s4ener:EndTime_PS-1-HS0001
  rdf:type s4ener:EndTime ;
  rdfs:label "End time PS-1-HS0001"^^xsd:string ;
.
s4ener:Energy_1
  rdf:type s4ener:Energy ;
  rdfs:label "Energy 1"^^xsd:string ;
  saref:isMeasuredByDevice s4ener:HeatingSystem ;
.
s4ener:Heating
  rdf:type saref:Task ;
  rdfs:label "Heating"^^xsd:string ;
.
s4ener:HeatingSystem
  rdf:type s4ener:Device ;
  rdfs:label "Heating system"^^xsd:string ;
  saref:accomplishes saref:EnergyEfficiency ;
  saref:accomplishes s4ener:Heating ;
  saref:hasDescription "Heating system HS0001 is an example of how to instantiate a heating system
with hot water tank using SAREF4ENER"^^xsd:string ;
.
s4ener:Measurement_1
  rdf:type saref:Measurement ;
  rdfs:label "Measurement 1"^^xsd:string ;
  saref:hasValue "0.2"^^xsd:string ;
  saref:isMeasuredIn <http://www.wurvoc.org/vocabularies/om-1.8/kilowatt_hour> ;
  saref:relatesToProperty s4ener:Energy_1 ;
.
s4ener:Measurement_2
  rdf:type saref:Measurement ;
  rdfs:label "Measurement 2"^^xsd:string ;
  saref:hasValue "0.2"^^xsd:string ;
  saref:isMeasuredIn <http://www.wurvoc.org/vocabularies/om-1.8/kilowatt> ;
  saref:relatesToProperty s4ener:Power_1 ;
.
s4ener:PowerProfile-1-HS0001
  rdf:type s4ener:PowerProfile ;
  rdfs:label "Power profile-1-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:AlternativesGroup-1-HS0001 ;
  saref:consistsOf s4ener:AlternativesGroup-2-HS0001 ;
  saref:hasTime s4ener:Time_PowerProfile-1-HS0001 ;
  saref:isAbout s4ener:Energy_1 ;
  saref:isAbout s4ener:Power_1 ;
  s4ener:alternativesCount 2 ;
  s4ener:belongsTo s4ener:HeatingSystem ;
  s4ener:nodeRemoteControllable "true"^^xsd:boolean ;
  s4ener:supportsReselection "true"^^xsd:boolean ;
  s4ener:supportsSingleSlotSchedulingOnly "true"^^xsd:boolean ;
  s4ener:totalSequencesCountMax "1"^^xsd:unsignedInt ;
.
s4ener:PowerSequence-1-HS0001
  rdf:type s4ener:PowerSequence ;
  rdfs:label "Power sequence-1-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:Slot-1-HS0001 ;
  saref:hasTime time:PowerSequence-HS0001_morning ;
  saref:hasTime s4ener:StartTime_1 ;
  s4ener:belongsTo s4ener:AlternativesGroup-1-HS0001 ;
  s4ener:isPausable "false"^^xsd:boolean ;
  s4ener:isStoppable "false"^^xsd:boolean ;
.
s4ener:PowerSequence-2-HS0001
  rdf:type s4ener:PowerSequence ;
  rdfs:label "Power sequence-2-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:Slot-2-HS0001 ;
  saref:hasTime time:PowerSequence-HS0001_afternoon ;
  saref:hasTime s4ener:StartTime_1 ;
```

```
  s4ener:belongsTo s4ener:AlternativesGroup-2-HS0001 ;
  s4ener:greenest "true"^^xsd:boolean ;
  s4ener:isPausable "false"^^xsd:boolean ;
  s4ener:isStoppable "false"^^xsd:boolean ;
.
s4ener:PowerSequence-3-HS0001
  rdf:type s4ener:PowerSequence ;
  rdfs:label "Power sequence-3-HS0001"^^xsd:string ;
  saref:consistsOf s4ener:Slot-3-HS0001 ;
  saref:hasTime time:PowerSequence-HS0001_afternoon ;
  saref:hasTime s4ener:StartTime_1 ;
  s4ener:belongsTo s4ener:AlternativesGroup-2-HS0001 ;
  s4ener:cheapest "true"^^xsd:boolean ;
  s4ener:isPausable "false"^^xsd:boolean ;
  s4ener:isStoppable "false"^^xsd:boolean ;
.
s4ener:Power_1
  rdf:type s4ener:Power ;
  rdfs:label "Power 1"^^xsd:string ;
  saref:isMeasuredByDevice s4ener:HeatingSystem ;
  saref:relatesToMeasurement s4ener:Measurement_2 ;
.
s4ener:Slot-1-HS0001
  rdf:type s4ener:Slot ;
  rdfs:label "Slot 1 HS0001"^^xsd:string ;
  s4ener:belongsTo s4ener:PowerSequence-1-HS0001 ;
  s4ener:hasEnergyValueType s4ener:Energy_1 ;
  s4ener:hasPowerValueType s4ener:Power_1 ;
  s4ener:slotNumber "1"^^xsd:unsignedInt ;
.
s4ener:Slot-2-HS0001
  rdf:type s4ener:Slot ;
  rdfs:label "Slot 2 HS0001"^^xsd:string ;
  s4ener:belongsTo s4ener:PowerSequence-2-HS0001 ;
  s4ener:slotNumber "2"^^xsd:unsignedInt ;
.
s4ener:Slot-3-HS0001
  rdf:type s4ener:Slot ;
  rdfs:label "Slot 3 HS0001"^^xsd:string ;
  s4ener:belongsTo s4ener:PowerSequence-3-HS0001 ;
  s4ener:slotNumber "3"^^xsd:unsignedInt ;
.
s4ener:StartTimeDurationDescription_1
  rdf:type s4ener:StartTimeDurationDescription ;
  rdfs:label "Start time duration description 1"^^xsd:string ;
  s4ener:xsdDuration "PT0H5M"^^xsd:duration ;
.
s4ener:StartTime_1
  rdf:type s4ener:StartTime ;
  rdfs:label "Start time 1"^^xsd:string ;
  time:hasDurationDescription s4ener:StartTimeDurationDescription_1 ;
.
s4ener:Time_PowerProfile-1-HS0001
  rdf:type saref:Time ;
  rdfs:label "Time Power profile-1-HS0001"^^xsd:string ;
  saref:consistsOf time:DateTimeInterval_PowerProfile-1-HS0001 ;
.
```

Annex C:
RDF code for SAREF4ENVI example

```
@prefix : <http://saref.linkeddata.es/data/envi/example1> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix prov: <http://www.w3.org/ns/prov#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix vann: <http://purl.org/vocab/vann/> .
@prefix saref: <https://w3id.org/saref#> .
@prefix s4envi: <https://w3id.org/def/saref4envi#> .
@prefix s4ener: <https://w3id.org/saref4ee#> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#> .
@prefix time: <http://www.w3.org/2006/time#> .
@prefix wurvoc: <http://www.wurvoc.org/vocabularies/om-1.8/> .
@base <http://saref.linkeddata.es/data/envi/example1> .

:Bluetoothv2-1 rdf:type owl:NamedIndividual ,
                        s4envi:CommunicationInterface ;
   s4envi:hasVersion "v2.1"^^xsd:string ;
   rdfs:label "Bluetooth v2.1"@en .


:FequencyMeasurementTESS005-UCM rdf:type owl:NamedIndividual ,
                                        s4envi:FrequencyMeasurement ;
   saref:isMeasuredIn wurvoc:reciprocal_second-time ;
   saref:hasValue "10.0"^^xsd:float ;
   rdfs:label "FequencyMeasurementTESS005-UCM"@en .


:LocationTESS005-UCM rdf:type owl:NamedIndividual ,
                             geo:SpatialThing ;
   geo:latitude "40.451"^^xsd:float ;
   geo:longitude "-3.7261"^^xsd:float ;
   rdfs:label "Location of photometer TESS stars5"@en .


:MQTT-Broker rdf:type owl:NamedIndividual ,
                      s4envi:CommunicationProtocol ;
   rdfs:label "MQTT-Broker"@en .


:TransmissionPeriodTESS005-UCM rdf:type owl:NamedIndividual ,
                                       s4envi:PeriodMeasurement ;
   saref:isMeasuredIn time:unitSecond ;
   saref:hasValue "30.0"^^xsd:float ;
   rdfs:label "TransmissionPeriodTESS005-UCM"@en .


:PowerProfileTESS005-UCM rdf:type owl:NamedIndividual ,
                                  s4ener:PowerProfile ;
   saref:hasConsumption :PowerTESS005-UCM ;
   rdfs:label "Power profile of photometer TESS stars5"@en .


:PowerTESS005-UCM rdf:type owl:NamedIndividual ,
                           s4ener:Power ;
   saref:isMeasuredIn wurvoc:watt ;
   saref:hasValue "20.0"^^xsd:float ;
   rdfs:label "Power of photometer TESS stars5"@en .


:RS232v24 rdf:type owl:NamedIndividual ,
                   s4envi:CommunicationInterface ;
   s4envi:hasVersion "v24"^^xsd:string ;
   rdfs:label "RS232 v24"@en .


:TESS005-UCM rdf:type owl:NamedIndividual ,
                      s4envi:TESS ;
   s4envi:hasFrequencyMeasurement :FequencyMeasurementTESS005-UCM ;
```

```
   s4envi:hasTransmissionPeriod :TransmissionPeriodTESS005-UCM ;
   saref:makesMeasurement :Measurement2016-10-05T08:15:30TESS005-UCM ,
                                                                  :Measurement2016-10-
05T08:15:40TESS005-UCM ;
   saref:measuresProperty s4envi:LightMagnitude ;
   s4envi:usesCommunicationInterface :Bluetoothv2-1 ,
                                                                        :RS232v24 ,
                                                                        :Wi-Fiv802-11ah ;
   s4envi:usesCommunicationProtocol :MQTT-Broker ;
   geo:location :LocationTESS005-UCM ;
   s4ener:exposes :PowerProfileTESS005-UCM ;
   s4envi:hasVersion "v1"^^xsd:string ;
   saref:hasManufacturer "Universidad Complutense de Madrid"^^xsd:string ;
   saref:hasName "stars5"^^xsd:string ;
   rdfs:label "TESS photometer stars5"@en .


:Wi-Fiv802-11ah rdf:type owl:NamedIndividual ,
                        s4envi:CommunicationInterface ;
   s4envi:hasVersion "802.11ah"^^xsd:string ;
   rdfs:label "Wi-Fi v802.11ah"@en .


:mgPerarcsec2 rdf:type owl:NamedIndividual ,
                       saref:UnitOfMeasure ;
   rdfs:label "mgPerarcsec2"@en .


:Measurement2016-10-05T08:15:30TESS005-UCM rdf:type owl:NamedIndividual ,
                                                    saref:Measurement ;
   saref:relatesToProperty s4envi:LightMagnitude ;
   saref:isMeasuredIn :mgPerarcsec2 ;
   saref:hasTimestamp "2016-10-05T08:15:30"^^xsd:dateTime ;
   saref:hasValue "0.1"^^xsd:float ;
   rdfs:label "Measurement 2016-10-05T08:15:30 TESS005-UCM"@en .


:Measurement2016-10-05T08:15:40TESS005-UCM rdf:type owl:NamedIndividual ,
                                                    saref:Measurement ;
   saref:relatesToProperty s4envi:LightMagnitude ;
   saref:isMeasuredIn :mgPerarcsec2 ;
   saref:hasTimestamp "2016-10-05T08:15:40"^^xsd:dateTime ;
   saref:hasValue "0.8"^^xsd:float ;
   rdfs:label "Measurement 2016-10-05T08:15:40 TESS005-UCM"@en .


s4envi:LightMagnitude rdf:type owl:NamedIndividual ,
                                                          s4envi:LightProperty .


time:unitSecond rdf:type owl:NamedIndividual ,
                               time:TemporalUnit .


wurvoc:reciprocal_second-time rdf:type owl:NamedIndividual ,
                                                               s4envi:FrequencyUnit .


wurvoc:watt rdf:type owl:NamedIndividual ,
                          saref:PowerUnit .
```

Annex D:
RDF code for SAREF4BLDG example

```
@prefix : <http://saref.linkeddata.es/data/bldg/example1> .
@prefix dc: <http://purl.org/dc/elements/1.1/> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix prov: <http://www.w3.org/ns/prov#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix vann: <http://purl.org/vocab/vann/> .
@prefix saref: <https://w3id.org/saref#> .
@prefix s4bldg: <https://w3id.org/def/saref4bldg#> .
@prefix s4ener: <https://w3id.org/saref4ee#> .
@prefix dcterms: <http://purl.org/dc/terms/> .
@prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#> .
@prefix time: <http://www.w3.org/2006/time#> .
@prefix wurvoc: <http://www.wurvoc.org/vocabularies/om-1.8/> .
@base <http://saref.linkeddata.es/data/bldg/example1> .

:Compressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                       :Compressor ;
   :compressorSpeed :CompressorSpeedCompressor001SIERRA02-0434C3 ;
   :idealCapacity :IdealCapacityCompressor001SIERRA02-0434C3 ;
   :impellerDiameter :ImpellerDiameterCompressor001SIERRA02-0434C3 ;
   :isContainedIn :RefrigerationStoreComputerScienceBuilding1 ;
   :nominalCapacity :NominalCapacityCompressor001SIERRA02-0434C3 ;
   geo:location :LocationCompressor001SIERRA02-0434C3 ;
   s4ener:exposes :PowerProfileCompressor001SIERRA02-0434C3 ;
   :hasHotGasBypass "false"^^xsd:boolean ;
   :powerSource "MotorDriven"^^xsd:string ;
   :refrigerantClass "HFC"^^xsd:string ;
   saref:hasManufacturer "SIEMENS"^^xsd:string ;
   saref:hasName "SIERRA 02-0434C3"^^xsd:string ;
   rdfs:label "CompressorSIERRA02-0434C3"@en .


:CompressorSpeedCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                                      saref:Measurement ;
   saref:isMeasuredIn :cyclesPerSecond ;
   saref:hasValue "3.0"^^xsd:float ;
   rdfs:label "Compressor speed of compressor001 SIERRA02-0434C3"@en .


:ComputerScienceBuilding1 rdf:type owl:NamedIndividual ,
                                   :Building ;
   geo:location :LocationComputerScienceBuilding1 ;
   rdfs:label "Computer Science Building 1"@en .


:IdealCapacityCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                                    saref:Measurement ;
   saref:isMeasuredIn wurvoc:watt ;
   saref:hasValue "1800.0"^^xsd:float ;
   rdfs:label "Ideal capacity of compressor001 SIERRA02-0434C3"@en .


:ImpellerDiameterCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                                      saref:Measurement ;
   saref:isMeasuredIn wurvoc:inch-international ;
   saref:hasValue "5.9"^^xsd:float ;
   rdfs:label "Impeller diameter of compressor001 SIERRA02-0434C3"@en .


:LocationCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                              geo:SpatialThing ;
   geo:latitude 40.405155 ;
   geo:longitude -3.839203 ;
   rdfs:label "Location of compressor001 SIERRA02-0434C3"@en .


:LocationComputerScienceBuilding1 rdf:type owl:NamedIndividual ,
                                            geo:SpatialThing ;
   geo:latitude 40.405013 ;
```

```
   geo:longitude -3.839349 ;
   rdfs:label "Location of Computer Science Building 1"@en .


:LocationRefrigerationStoreComputerScienceBuilding1 rdf:type owl:NamedIndividual ,
                                                            geo:SpatialThing ;
   geo:latitude 40.405152 ;
   geo:longitude -3.839209 ;
   rdfs:label "LocationRefrigerationStoreComputerScienceBuilding1"@en .


:NominalCapacityCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                                 saref:Measurement ;
   saref:isMeasuredIn wurvoc:watt ;
   saref:hasValue "680.0"^^xsd:float ;
   rdfs:label "Nominal capacity of compressor001 SIERRA02-0434C3"@en .


:PowerCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                       s4ener:Power ;
   saref:isMeasuredIn wurvoc:watt ;
   saref:hasValue "902.0"^^xsd:float ;
   rdfs:label "Power of compressor 001 SIERRA02-0434C3"@en .


:PowerProfileCompressor001SIERRA02-0434C3 rdf:type owl:NamedIndividual ,
                                              s4ener:PowerProfile ;
   saref:hasConsumption :PowerCompressor001SIERRA02-0434C3 ;
   rdfs:label "Power profile of compressor 001 SIERRA02-0434C3"@en .


:RefrigerationStoreComputerScienceBuilding1 rdf:type owl:NamedIndividual ,
                                                 :BuildingSpace ;
   :isSpaceOf :ComputerScienceBuilding1 ;
   geo:location :LocationRefrigerationStoreComputerScienceBuilding1 ;
   rdfs:label "Refrigeration store of Computer Science Building 1"@en .


:cyclesPerSecond rdf:type owl:NamedIndividual ,
                          saref:UnitOfMeasure ;
   rdfs:label "cycles per second"@en .


wurvoc:inch-international rdf:type owl:NamedIndividual ,
                                                                  saref:UnitOfMeasure ;
   rdfs:label "inch international"@en .


wurvoc:watt rdf:type owl:NamedIndividual ,
                           saref:PowerUnit .
```

Annex E: Bibliography

- ETSI TS 103 267: "SmartM2M; Smart Appliances; Communication Framework".
- oneM2M TS-0001: " Functional Architecture".
- oneM2M TS-0002: "Requirements".
- European Commission and TNO: "Study on Semantic Assets for Smart Appliances Interoperability", final report, April 2015.

NOTE: Available at https://sites.google.com/site/smartappliancesproject/deliverables.

History

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