Ontologies for Formalizing the Process of Configuring and Deploying Building Management Systems

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1 Introduction

For tackling the current energy crisis and increasing energy demand worldwide, it has become urgent to rationalize energy use and decrease energy waste. Buildings are responsible for about one third of the global energy consumption in the world [1], and 30% of this energy is even wasted due to e.g. malfunctions of heating, ventilation and air conditioning systems (HVAC), wrong operation strategies or unaware user behavior. Building management systems (BMS) can bring support through optimal control and continuous monitoring of building energy systems, but their design and configuration is a complex process that requires much expert knowledge and labor cost.

This paper presents a method relying on knowledge graphs to automate this process. Starting from a semantic description of a building, it characterizes its energy system to identify applicable monitoring and control tasks. Following a risk paradigm, it then configures and deploys these tasks as BMS functions selecting for each their required sensor data. The industrial adoption of the method is foreseen as an expert system add-on to BMS that would accelerate and scale up their deployments for energy saving.

2 System and Process Ontologies

The expert system is composed of ontologies which conceptualize the domains of building energy systems and automation. In the field, several metadata schemas have emerged and are for a part reused in the ontology system. These include ifcOWL that was released by buildingSMART as an OWL (Web Ontology Language) representation of IFC (Industry Foundation Classes) [2]. The automation domain was formally described into SSN/SOSA [3] and CTRLont [4]. The Brick ontology [5] has emerged a few years ago for representing HVAC systems. The Building Topology Ontology (BOT) is a lightweight ontology for describing the spatial structure of buildings [6], and the QUDT ontologies were initiated by the Constellation Program at NASA [7].

As each ontology covers a specific domain with its limitations, we developed further ontologies [8] that enable a full description of a building in its operation phase (see Fig. 1). Additional ontologies consist of the Energy System Information Model (ESIM) that extends Brick with concepts about energy systems at building and urban levels. The Metric model consists of a set of quantities that complement QUDT and SSN/SOSA with specific metrics for HVAC engineering. The Risk model provides a catalog of possible faults that can lead to energy wastes, together with corrective energy conservation measures. The BAF (Building Automation Functions) model is a catalogue of generic control functions usually implemented by automation engineers.

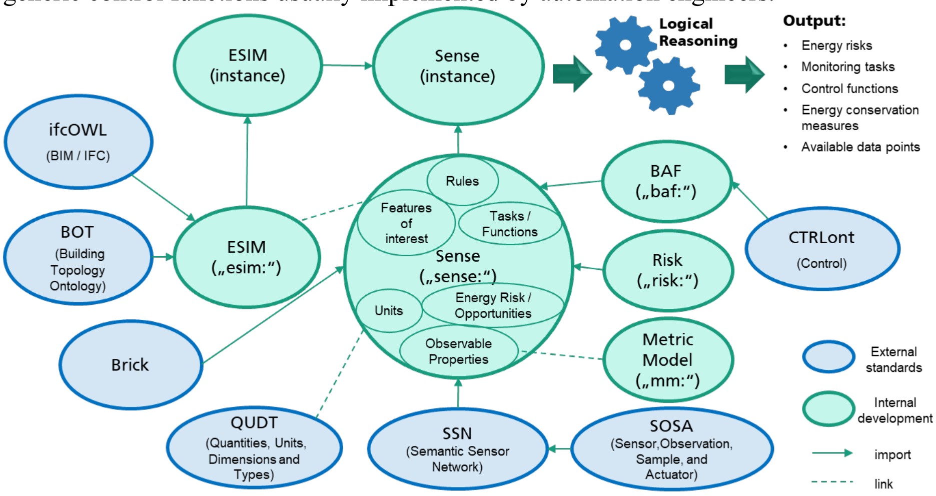

Fig. 1. Ontology system

Finally, the Sense ontology represents the central knowledge model that aggregates all the concepts, and in which logical axioms and rules are encoded for formalizing expert knowledge. This contrasts with the other ontologies that rather focus on system description while the Sense ontology aims at emulating the process of BMS setup by characterizing the system and prescribing BMS functions. These functions consist of algorithms that can process real-time data of buildings gained from sensors and meters in order to detect faults or energy waste. If energy is being wasted, different actions can be taken by a facility manager or a building user. Accordingly, a set of corrective actions are formalized as energy conservation measures inside the ontology. Fig. 2 represents some fundamental concepts composing the Sense ontology that share causal relationships to support the setup of BMS functions for e.g. fault detection. More specifically, Table 1 shows some examples of rules written in SWRL (Semantic Web Rule Language). They are used by a reasoner for identifying potential energy risks in air handling units and deploy related monitoring functions to check if they occur.

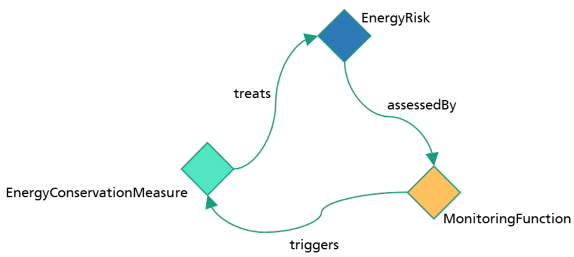

Fig. 2. Some fundamental concepts and their relationships for configuring fault detection

Table 1. Examples of SWRL rules for energy risk identification.

id	Rule definition in human-readable syntax
R1	brick:AHU(?ahu) ∧ brick:Heating_Coil(?hc) ∧ brick:Cooling_Coil(?cc) ∧ brick:hasPart(?ahu, ?hc) ∧ brick:hasPart(?ahu, ?cc) → risk:hasRisk(?ahu, risk:SimultaneousAirHeatingAndAirCooling)
R2	brick:AHU(?ahu) ∧ brick:Heating_Coil(?hc) ∧ brick:Supply_Fan(?sf) ∧ brick:hasPart(?ahu, ?hc) ∧ brick:hasPart(?ahu, ?sf) → risk:hasRisk(?ahu, risk:AirHeatedButNotVentilated)
R3	risk:hasRisk(?e, ?ri) ∧ risk:assessedBy(?ri, ?mf) ∧ sense:MonitoringFunction(?mf) → sense:hasFunction(?e, ?mf)

3 Knowledge Extraction for Task Configuration

A prerequisite for an automated configuration process is on the one hand the availability of building information i.e. metadata to create assertions in the ontology. On the other hand, real-time sensor data are necessary for BMS functions. While sensor data can be nowadays extensively supplied in modern or retrofitted buildings, metadata are rather difficult to gather for easy ontology instantiation which remains a work in progress. Basically, there exist three possible use cases which consist of getting metadata from either 1) a sensor database, 2) a graph database, or 3) a building information model (BIM) gained from CAD design. Then a two-step workflow consisting of metadata processing followed by data processing can be realized (see Fig. 3).

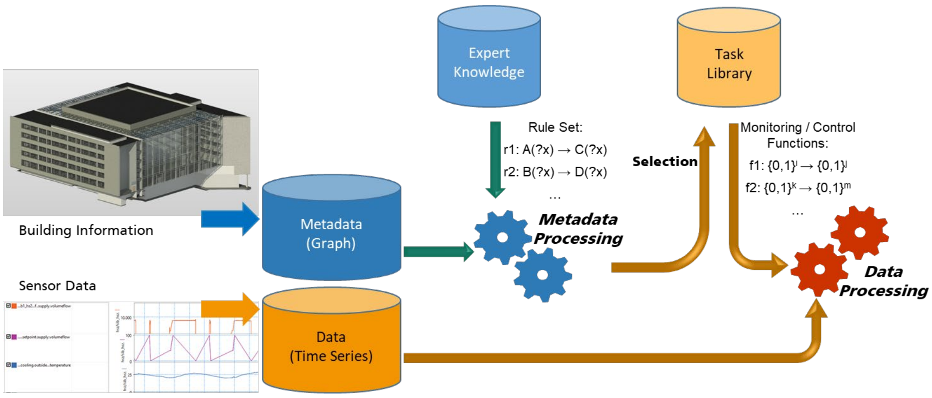

Fig. 3. Workflow for automated building energy system monitoring and control

A first prototype workflow was developed as part of an energy assistant system [9]. In that context, some metadata from a sensor database could be reused in the ontology. They describe topological objects and locations in the building that relate to specific sensor data points. During metadata processing which is performed using a reasoner, the Sense model enables to classify thermal zones and associate them with relevant monitoring functions. As an example, if a room hosts one or more radiators, it will be classified as a heating zone and associated with a function that checks potential overheating using indoor temperature data. During data processing, it can then generate as output notifications to reduce heating in this zone if overheating really occurs.

The second use case was tested using the Brick schema that aims at generalizing the use of graphs for modeling building energy systems [5]. While a classical sensor database may only provide few metadata, Brick can describe HVAC systems in sufficient detail. On that basis, the rules from table 1 were used to automatically select all entities that should be analyzed for some fault detection if they are threatened by some energy risk. Potential risks can be identified in an air handling unit (AHU) according to its built-in components (e.g. heating coil, cooling coil, fans, humidifier, air filters…). Accordingly, if an AHU carries a certain energy risk, the metadata processing will select relevant monitoring functions in order to identify related faults from real operation data.

4 Industrial Application - Barriers and Opportunities

First tests proved that BMS functions can be derived from an ontological description of an energy system. A necessary pre-condition for the proposed method is the availability of building information to populate the instance ontologies. Digitalization in building sector, supported by the Brick paradigm and the BIM method, shall ensure availability of computer-readable data models to generate graphs in an automated manner. Since BIM models consist of comprehensive descriptions of buildings at high level of detail, they can provide larger amount of metadata that can serve an extensive configuration of BMS systems. This BIM use case is currently under development.

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