28 Ontology-Based Semantic Retrieval Method of Energy Consumption Management

Ya-Qi Xiao, Zhen-Zhong Hu, and Jia-Rui Lin

Abstract

A large number of different forms of energy consumption information are generated during facility management. In addition, due to the uncertain and ambiguous external and internal environment of construction project, it is an important issue in energy consumption for operation staff to query required information efficiently. Moreover, implementations of BIM technology can provide visualization and integrated information models for FM. In view of the above two aspects, this paper introduces ontology as the modeling approach for information exchange and put forward a semantic retrieval method based on ontology for building energy management. Then this paper realizes the integration between ontology based semantic retrieval system and energy consumption information under BIM environment. In the case study, this paper constructs a domain ontology of energy consumption and then conducts retrieval expansion based on this information model, and the discussion of example provides support for further research.

Keywords

Ontology • Energy consumption • BIM • Query language

28.1 Introduction

A relevant fraction of worldwide energy consumption is tightly related to indoor systems for residential and commercial buildings; it has been estimated that these buildings are responsible for about 20% of the world's total energy consumption today [1, 2]. Take into consideration the whole Building Lifecycle (BLC), construction and operation of the built environment account for at least 50% of all energy consumption in Europe [3]. The EU has established the Energy Performance of Buildings Directive, which aims to promote conservation and rational use of energy in buildings. New solutions to reduce energy consumption in the O&M phase are important to achieve this goal.

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In the future, some integrated systems which monitor and display the different factors that contribute towards building energy consumption, while also be capable of automatically retrieving the information required and provide knowledge about the entire built environment for enhanced decision support, are required [4]. This kind of method is considered in the literature important as the conventional thermal insulation of walls or insulating glazing to improve energy efficiency in buildings [5]. The basis of intelligent control to support energy management is visualizing actuators status and historical data

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based on different time stamps and ranges. Due to the uncertain and ambiguous external and internal environment of construction project, it is an important issue in energy conservation for operation staff to query required information efficiently.

In this paper, ontology is considered as the modeling approach for information exchange and put forward a semantic retrieval method based on ontology for energy consumption information. The information model is used in the knowledge base that allows intelligent analysis on the relations between energy consumption, building related information (geometry, boundary conditions, etc.) and surrounding factors, such as temperature, weather condition, and operating status of equipment. The knowledge base is represented using ontologies. Ontology can be used as generic model to facilitate the integration [6]. The ontology is not only used to describe functionalities of building automation systems, but also to represent states of building. The core link model is represented with OWL, which includes the capabilities of model management and decision support [7].

To support the integration of multiple data sources and achieve information retrieval, the solution makes use of building information modelling (BIM) principles and ontologies in the form of a holistic knowledge base. The paper is structured as follows: the following section discusses relevant existing work. Next, the requirements and implementation of the integrated system are presented. Finally, an example of energy analysis through ontology query will be evaluated given.

28.2 Existing Researches

Within the existing research, numerous methodologies have been proposed to provide different kind of intelligent control to support energy management [1]. In order to achieve comprehensive energy management by taking into account as much as related data resources and factors, an integration of building energy information model is required. Building energy management systems (BEMS) data integration requires consideration of the data structure and their representation. Building Information Modelling (BIM) describes an integrated approach to structuring all information relevant to the BLC. The Industry Foundation Classes (IFC) [8] standard, an open and neutral data file format for data sharing and exchange within AEC, is the leading standard developed around the concept of BIM. IFC is an object-oriented data standard that can describe physical objects, such as ducts and pipelines, as well as abstract concepts, such as space, organization, relationships, and processes. Modelling all this data remains a challenge, particularly for older buildings where the issue of fragmented and hard to access building data increases. Linked Data (LD) refers to the recommended best practices for exposing, sharing, and connecting data on the Web [9]. In particular, on the Ontology Web Language (OWL) as a data model for representing structured content. OWL languages do not contain any information about the content in the information sources, and hence can be used to represent general information queries from various domains. Ontology language OWL is based on RDF and provides information framework for representing ontology. This kind of structured ontology can be queried with SPARQL query language [10].

Using OWL as a schema modelling language, transforming EXPRESS schemas into ontologies was proposed by numerous authors [5, 11–14]. Ontology can be used as generic model to facilitate the integration [6]. Some scholars [15] gives a literature overview of semantic web technologies' potential applications, while referring to numerous example implementations worldwide. This paper summarizes examples in three categories: (1) interoperability, (2) linking data across domains, and (3) logical inference and proofs. The usage of semantic web technologies appears to achieve more in the latter two categories. The generic ontology represents domain knowledge for building holistic energy management. It contains definitions, and taxonomies that are aligned with IFC. The ontology is not only used to describe functionalities of building automation systems, but also to represent states of building, and relations with behavior model and surrounding factors. In this paper, an ontology model is proposed for building energy management data based on user events and building specific information.

To monitor the built environment and provide information for management, BEMS data integration requires a sensing infrastructure to measure data such as temperature, humidity, CO_2, and occupancy. This is achieved through the use of sensing technologies like thermostats, CO_2, ultrasound, cameras, and tag based system, like RFID, Bluetooth [16, 17], etc. A multi-scale BIM management system was developed for FM of large public buildings based on a self-developed graphic engine, containing the upstream and downstream relationship management of MEP components [18]. The basic management of these measured data can adapt device behavior to reduce energy consumption, some of MEP subsystems can also maintaining comfort levels, for example, the automatic control of HVAC based on a desired temperature. A common issue for commercial BEMS is the limitation of the sensing infrastructure [19]. For example, the data abstracted from different

MEP subsystems is unable to management in an integrated commercial system, and movement detection for calculating numbers of occupants is difficult.

The above researches about energy consumption do not strongly consider the alignment of existing standards, such as IFC, with the integrated information model. They do not include the modeling of occupant behavior as one of the factors that affects the energy consumption. This paper proposes an approach that addresses these points.

28.3 An Integrated BIM System to Query Sensor Data Based on Ontological Knowledge

In this study, an intelligent system which integrate many kinds of sensor data with BIM is proposed to help users to have an overview of energy data collected from different sensor in their building. With the help of domain query language and BIM, operation staff can query required information efficiently within visualized and integrated information models for FM. Figure 28.1 depicts the proposed approach of the intelligent system developed in this paper.

The generic ontology represents domain knowledge for building holistic energy management. It contains definitions, and taxonomies that are aligned with IFC. The generic ontology created by domain experts should be applicable in most kinds of building. The development of ontology will be discussed further in Sect. 28.3.1.

Another important module is the data collector and aggregator which is developed for collecting monitoring data from different building automation systems installed in the building. It contains an interface to communicate with different building automation logic control units or gateways via web services. The module is also responsible to integrate different kinds of data in BIM. For this, a BIM-based interface to collect energy data is developed. Section 28.3.2 will specify the realization of collecting sensor data within BIM environment.

The sensor data are collected and stored in a database. For the sake of visual representation of related data, pre-processing is necessary for data such as removing singular point, data transformation, data selection and data conversion. The data are prepared for further analysis in different criteria based on relation between rooms, appliances, time, and so on. Therefore, it

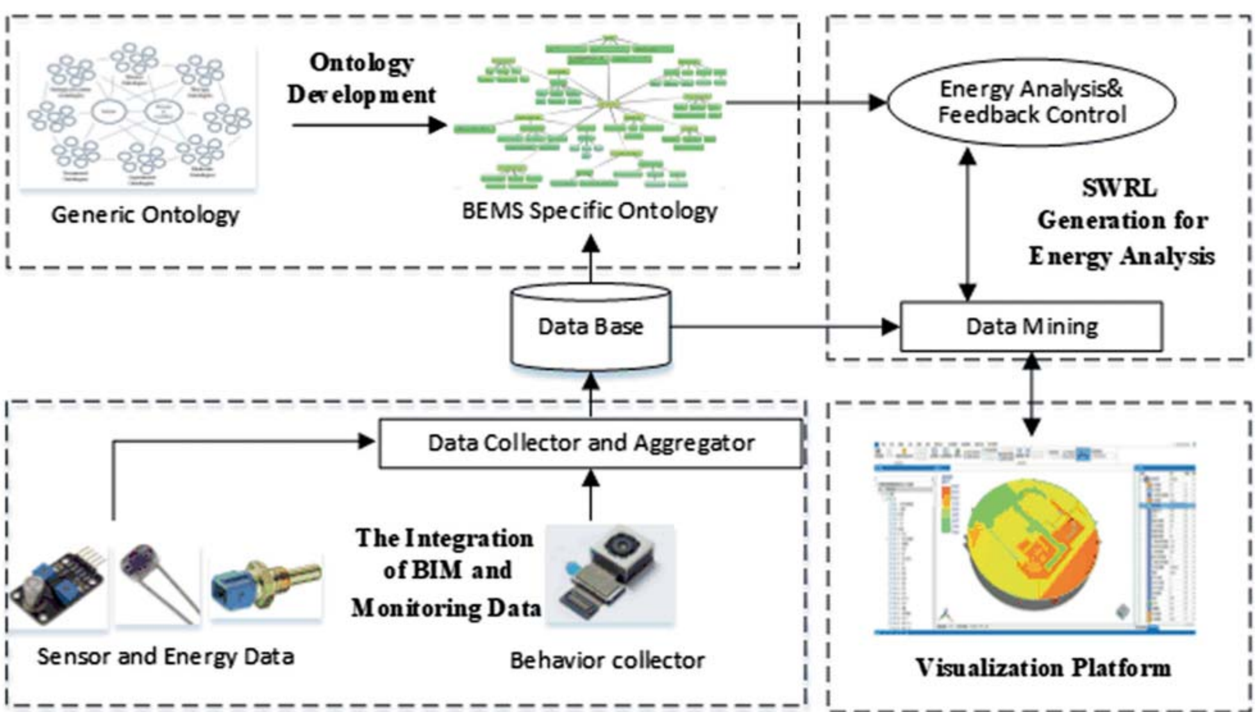

Fig. 28.1 The framework of building energy management with ontology knowledge

allows a data-driven analysis that is conducted directly on the collected data by performing SQL-query, simple calculation, or visualization. The ultimate goal of data-driven analysis is to provide efficient decision support for reducing energy consumption.

The visualization and analysis tool facilitates the visual interaction between the user and the system. The BIM provides geometry information for 3D visualization. In addition, users can query the ontology by using the tool, the facility manager is able to identify sensor data, to examine the building states, e.g. the light of which room is on, etc. The tool also allows the building occupants to have better understanding of the current building environment of the zones, where he is responsible for, thus it empower their engagement in balancing comfort and energy efficiency.

28.3.1 Building Energy Management Specific Ontology Development

Ontology classes and their properties as well as relationships representing the resources required for building energy management are developed firstly. The ontologies that contain basic elements are called generic ontologies. It only contains the ontological classes that describe the knowledge structure, definitions and terminology. Ontology main classes for the energy management in building are shown in Fig. 28.2.

The class MonitoringData models the sensor data that are collected, examined and analyzed in energy management activities. The class BuildingElement and its sub classes represent the fundamental of BIM. It is aligned with the domain layer in IFC4. The class BuildingControl indicates the entities related to building automation system elements in the building. It represents the sensors, actuators, controller, alarm, etc., which are elements of a building automation system. It

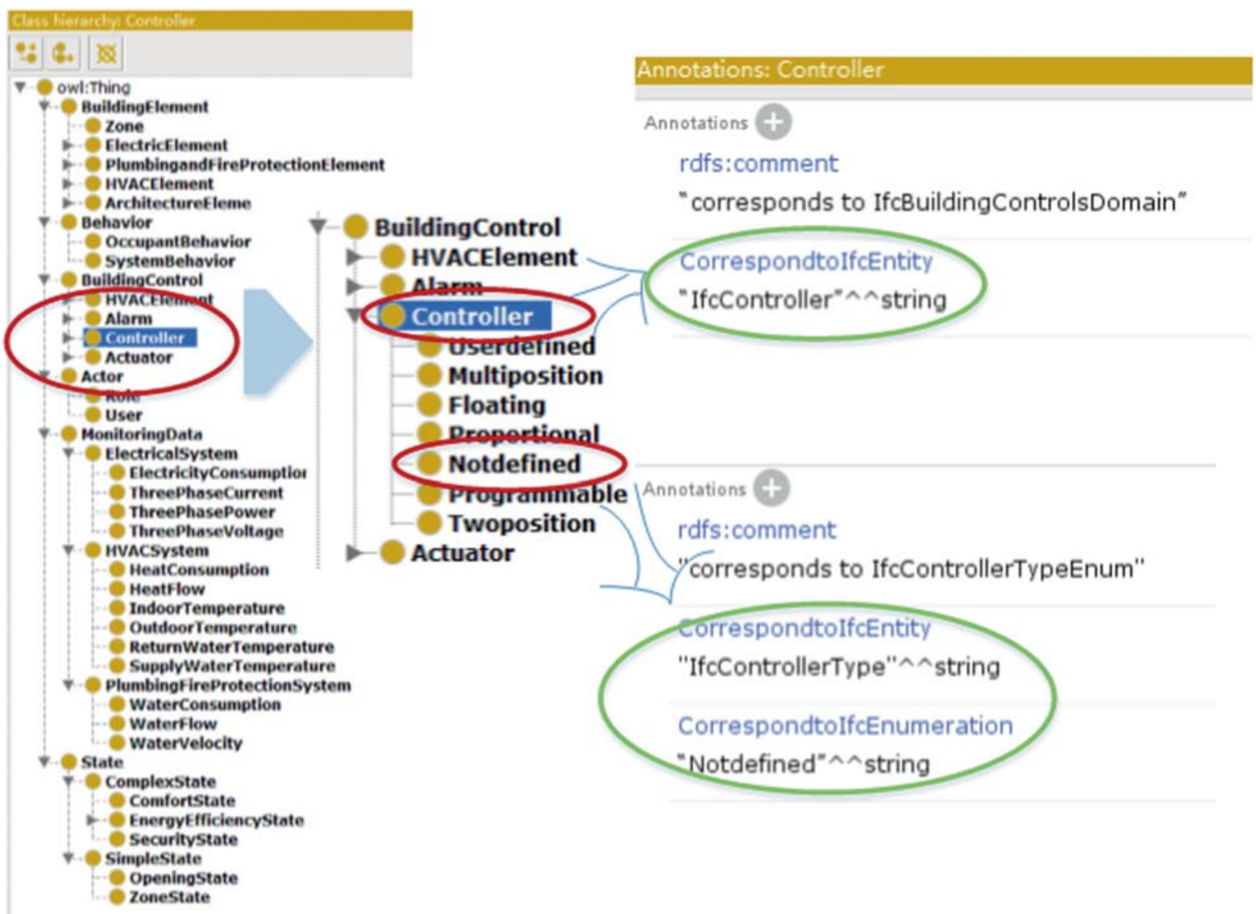

Fig. 28.2 Ontology main classes

has capabilities to measure, to observe, and to control the state of BuildingElement. It aligns with entities in the IFC4 domain IfcBuildingControlsDomain.

The class Actor defines all actors or human agents involved in a project during its FM. It is aligned with the IfcActorResource in IFC4. The class Behavior represents behavior performed by Actor, such as working, sleeping, etc. The Behavior can affect the state of BuildingElement. The class State represents the state of BuildingElements. It can be divided as ComplexState and SimpleState. Examples of ComplexState are ComfortState and EnergyEfficiencyState, whereas examples of SimpleState are WindowState, LightState, etc.

28.3.2 The Integration of BIM and Monitoring Data

The monitoring information of the MEP equipment of the building contains two aspects: the sensor information and the monitoring data. The sensor information of monitoring points contain is the description of the characteristics of information of MEP equipment monitoring subsystem including the basic information of monitoring points: location description, system, equipment type, equipment number, and feature information of monitoring points: monitoring point description, data point type, data point numerical range, alarm value, data length, information object address, etc. In MEP monitoring system, the monitoring point information is usually stored and transmitted in the form of point table. There is usually a fixed point table format which can be developed as interface for transition, monitoring point information is stratified according to building, system, zoon, equipment, monitoring point.

The monitoring data is the current and historical data of the monitoring points of the MEP equipment. The type of monitoring data includes digital quantity and analog quantity, namely discrete quantity and continuous quantity, in which digital quantity can be a switch quantity containing only two kinds of value states or a combination of multiple switches. Monitoring data are usually stored in the controller or database of electromechanical monitoring system. There are differences between different monitoring systems or related database.

In the process of data fusion, the monitoring point is the main body, and the BIM information as well as monitoring data are related to the MEP equipment. The relationship between the model information of MEP equipment and the monitoring point is many to one. Each device in the monitoring point can correspond to multiple BIM entities or regions. For the structure of monitoring point, each device can contain multiple monitoring points, for example, one air conditioning unit has many monitoring points, such as temperature, humidity, air volume, and so on. The relationship between the monitoring point structure and the monitoring data is one to many. For each monitoring point, the monitoring data is a number of records in the database.

28.3.3 SWRL Generation for Energy Analysis

In this paper, energy consumptions that do not occur normally in the building should be recognized. To finish this task, it is necessary to discuss how energies are consumed normally regarding occupant events and surroundings. For example, normally when an occupant is currently sleeping or left, or intensity of illumination in the room is enough for working, for instance greater than 100 lx, the light should be turn off. If in the same pre condition, the light in the room switching state is on, then it is considered as a usage anomaly.

It is not friendly for users if they always have to input their activities. The system contains simple sensors like different kinds of cameras to recognize user activities automatically. For instance, a camera can strongly give a clue whether somebody is currently sleeping, working or left. Of course it should be combined with some algorithms of appliance image recognition.

The query of ontology is based on SWRL language which consists of two main parts connected with the symbol "→", antecedent and consequent, both of them are collection of atoms. For example, the created rule represents a condition that if the activity is working while inside intensity of illumination is greater than 100 lx with the light in the room is on would normally occurs. The rule is transformed to (2), in order to represent an anomaly condition, by negating the consequent part of the rule.

$$\begin{aligned} \text{Event} = \text{``working''} \wedge \text{InsideIllumination} \geq 100 \\ \rightarrow \text{SwitchingofLight} = \text{On} \end{aligned} \tag{28.1}$$

Table 28.1 Competency questions to get states

Question	Competency questions	Example of answers
Q1	Which lights are currently in energy inefficient state in the zone?	Light2, Light4
Q1.1	Which lights are currently switched on?	Light1, Light2, Light4
Q1.2	Which users are currently sleeping?	User2, User3, User4
Q1.3	Which lights and users are currently located in the same zone?	Light1&User1, Light2&User2, Light3&User3, Light4&User4

$$\begin{aligned} &\text{UserBehavior}(?e)\wedge\text{``hasName}(?e,\text{working})''\wedge\text{InsideIllumination}(?ii)\\ &\wedge\text{hasValue}(?ii,?iit)\wedge\text{swrlb:greaterThanOrEqual}(?iit,100)\\ &\wedge\text{Light}(?l)\wedge\text{hasValue}(?l,?iit)\wedge\text{swrlb : Equal}(?l,1)\\ &\rightarrow\text{UsageAnomaly}(?e) \end{aligned} \tag{28.2}$$

The intelligent achieve the interaction between OWL knowledge base, SWRL rule, and rule engine through SWRL API. The SWRL API implements the retrieval of the OWL knowledge base using SWQRL. Furthermore, BIM data is integrated into the application framework and automatically processed by the relevant data mining algorithms to generate ontology knowledge.

28.4 Energy Analysis Through Ontology Query

In knowledge base represented in ontology, all conditions of energy wasting and anomalies are represented as SWRL. Real-time monitoring data extracted from building automation system will integrate with ontology information. These data given by installed monitoring point used to correspond to different kind of states, simple state or complex state.

The SWRL illustrated in (28.3) implies a complex state of energy inefficiency, if a user is sleeping, a light is turned on, and they both are located in the same zone. The necessary classes are created based on the formulated competency questions. For example, as seen in Table 28.1, the classes LightSwitchedOn and Sleeping are created based on competency questions Q1.1 and Q1.2. The simple state class LightSwitchedOn is represented as axiom.

$$\begin{aligned} &\text{Q1.1LightSwitchedOn}(?l)\wedge\text{Q1.2Sleeping}(?s)\wedge\text{Inside}(?z)\\ &\wedge\text{Q1.3isLocatedIn}(?s,?z)\wedge\text{Q1.3isLocatedIn}(?l,?z)\\ &\rightarrow\text{Q1EnergyInefficient}(?h) \end{aligned} \tag{28.3}$$

Under BIM environment, data processing program provides the interface of retrieval rules definition. When the rules are required to be executed, the BIM data engine extracts spatial and monitoring information based on the TBox (shown in Fig. 28.3) and the rules engine has semantic reasoning. After that the new value of attribute that are made will be set into the OWL ontology class through the SWRL query. For example, if camera attached to office space gives the occupant a state “sleeping”, then the attribute has Value of corresponding ontology instance of concept UserBehavior is set to “sleeping”. After the rule engine executes the SWRL rules, the instance of class Light is additionally assigned to EnergyInefficient class as shown in Fig. 28.3.

According to the above design, when the occupant is asleep in the office, the light in the relevant area will be automatically closed. In addition, if there are energy inefficient conditions, the related equipment or zone will be marked in different colors under BIM environment to be recognized by user. In addition, the historical monitoring data can also be retrieved with ontology knowledge. With this mechanism, user can have more directly understanding of management and have a better performance of energy conservation.

28.5 Conclusions

In this paper a system of intelligent energy analysis based on ontology is proposed under BIM environment. In the developed system, BIM information is combined with knowledge-driven energy analysis through ontology query. The ontology supported analysis approach provides intelligent assistance to improve energy efficiency in buildings, by strongly

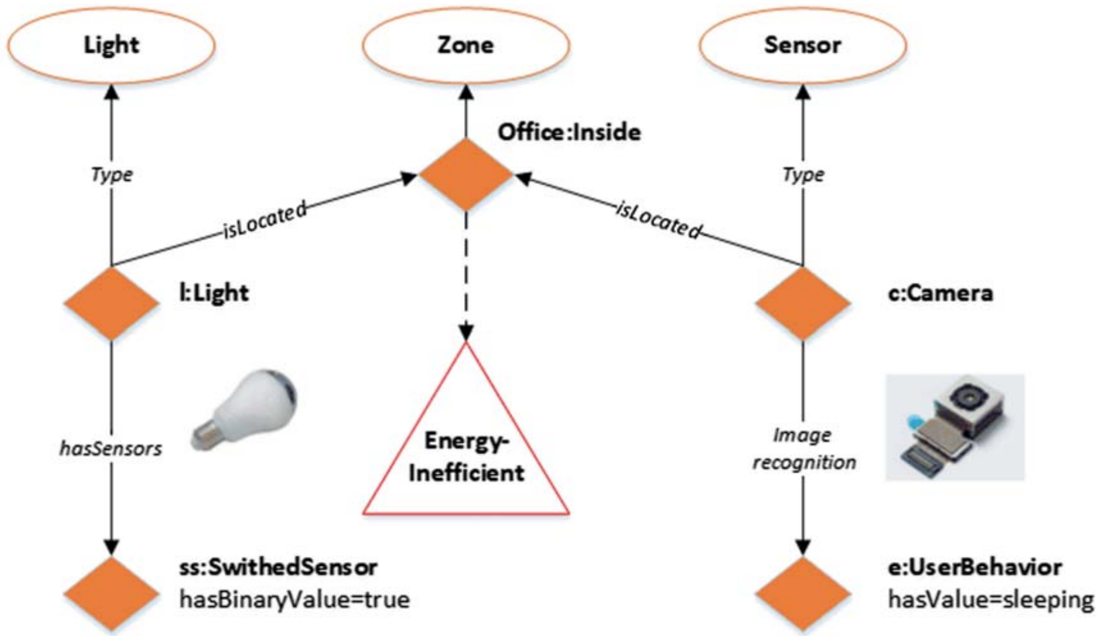

Fig. 28.3 Example of energy inefficiency identification with ontology knowledge

considering user behavior and real-time states in the building. The system will give out the energy usage pattern through monitoring data, and notify user whether energy inefficient conditions occur.

An approach is proposed to develop the ontology as the knowledge base of the intelligent energy management system. There are different methods and steps to generate building specific ontology containing the building specific information. It achieved the integration of BIM system and monitoring data. The monitoring point structure and query of monitoring information is also discussed in this paper.

Future works will focus on improving the accuracy of the approach and exploring efficient control methods of energy conservation combined with BIM models and ontology theories. Based on the experiences gained from this application, additional functions can be developed for energy management depending on a thorough exploration and comprehensive application of BIM and related information technology.

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