

Efficient Building Energy Management System Based on Ontology, Inference Rules, and Simulation

Jinsoo Han¹, Youn-Kwae Jeong¹ and Ilwoo Lee¹

¹ Green Computing Department, Electronics and Telecommunications Research Institute,
Daejeon, Republic of Korea

Abstract. Energy use in the building sector shares a great portion of world energy and accounts for a lot of green house gas. It is necessary to increase energy efficiency in the building sector to reduce energy cost and green house gas emissions. This paper proposes a building energy management system based on ontology, inference rules, and simulation. Ontology modeling has the advantages of information reusability, extensibility, and interoperability. It enables the BEMS to be easily deployed in the field. Building energy simulation helps the inference rules accumulated. The efficiency will be increased in proportional to the number of inference rules. The feasibility of the proposed BEMS model is shown through the pilot system. The proposed model is expected to greatly contribute to the energy saving and the reduction of green house gas emissions.

Keywords: Building Energy Management System, Energy Efficiency, Simulation, Rule Sets, Inference

1. Introduction

In the international energy outlook 2010, total world energy consumption of marketed energy increases by 49 %, or 1.4 % per year, from 2007 to 2035 [1]. Energy use in the residential and commercial sector accounted for about 21 % of world delivered energy in 2007. It grows at an average rate of 2.6 % per year from 2007 to 2035. In the United States, it is estimated that total energy consumed in the building sector amounts to 41 % of total energy consumption [2]. Carbon dioxide emissions in the building sector are prospected to be nearly doubled in 2050 compared to 2007, and they can be reduced by two-thirds through low-carbon electricity, energy efficiency and the switch to new technologies [3]. Energy use is the single largest operating expense in commercial office buildings, representing approximately one-third of typical operating budgets and accounting for almost 20 % of the nation's annual greenhouse gas emissions [4]. It is necessary to increase energy efficiency in the building sector to reduce energy cost and carbon dioxide emissions.

Energy management is an essential procedure of energy efficiency, since it is considered as a key factor to the energy savings of an operating expense. A building energy management system (BEMS) is similar to a building management system (BMS), yet is specifically focused on energy efficiency and energy management. The BEMS is considered important for the management of the daily energy operations of a typical building. Various BEMS were being developed to be applied in buildings. The prototype simulation-assisted control in BEMS was developed and tested [5]. The intelligent decision support model using rule sets based on a typical BEMS was presented [6]. The innovative intelligent decision support model for assessing energy-saving measures in a typical building based on the systematic incorporation of BEMS data was studied [7]. The new automated BEMS-assisted commissioning tool was introduced to improve the energy performance of HVAC systems [8]. However, the previous simulation-assisted control system just focuses on optimum start times of the facility. The above decision support models do not use simulation. The automated commissioning tool is limited to just heating, ventilating, and air-conditioning (HVAC).

Therefore, it is necessary to integrate building energy simulation and to consider the whole building context for more efficient energy management in buildings.

This paper proposes efficient BEMS based on ontology, inference rules, and building energy simulation. The second section describes the proposed BEMS model. The third section shows the pilot system based on the proposed BEMS model. The last section summarizes the paper and talks about future works.

2. Proposed BEMS Model

2.1. System Architecture

Our proposed model's system architecture is illustrated in Fig. 1. It is based on ontology and inference engine. It is necessary to gather various sensors data and equipments state data to decide the status of the building and to output control commands. Indoor and outdoor sensors include temperature, humidity, air quality, occupancy, and luminance. BAS sensors include boiler, ventilation, chiller, lighting, humidifier, and so on. Information from building automation system (BAS), indoor sensors, and outdoor sensors, is transferred to the sensors database. It is filtered, summarized, and converted on the basis of the conversion rules to be used in the inference engine. The BEMS model includes inference rules to analyse the context of the building, to decide whether the current building status is normal or abnormal, and to output control commands for building operation by inference engine. The inference engine infers on the basis of gathered sensors data with the inference rules and the knowledge database of the building. The proposed model has four kinds of ontology: building architecture, context, cause, and control. The building architecture ontology contains the building's areas and zones, its elements, and BAS equipments. The context ontology includes information to analyse whether the building operational data deviates from the normal values. The cause ontology derives the cause of the abnormal state of the building context. The control context provides the solution to solve the cause of the context such as energy waste or indoor condition degradation. The latter three ontology databases have their own inference rules. Additional inference rules can be added through the building energy simulation. The result of the simulation derives the building energy characteristics, which are converted into inferences rules. Simulation-assisted inference rules can be accumulated as time goes by.

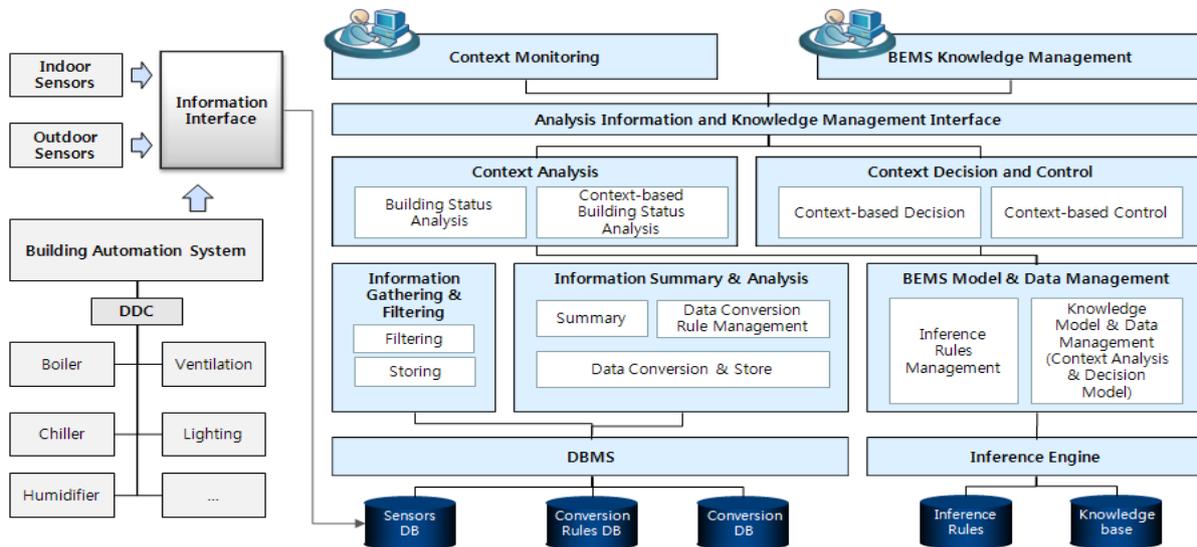


Fig. 1: System architecture of the proposed BEMS model

Ontology model has various classified concepts: sensor, equipment, zone, building, equipment action, zone evaluation, indoor environment, operating values, zone type, time zone, etc. Each concept has subconcepts and attributes. The attributes are classified into rule data, static data, and dynamic data. The rule data describes the relation between concepts. The static data is unchangeable data such as identification, label, name, address, and etc. The dynamic data is varying data according to the building status, such as sensor value and time information. On the basis of the above ontology model design, data modelling is performed via ontology modelling tool. A variety of inference rules between concepts are added to the ontology model. Fig. 2 shows an instance of inference rules generation. The sensor object has four attributes

such as type, season, zone, and working time. The reserved sensor values object has the same attributes. And inference rules comparing corresponding attribute value between the sensor object and the reserved sensor values object are generated. With the generated inference rules, inference engine is reasoning the context of the object. A zone can have several kinds of objects such as sensors, BAS equipments, lights, and etc. Inference engine infers the zone context by reasoning on the basis of inference rules related between the objects in the same zone.

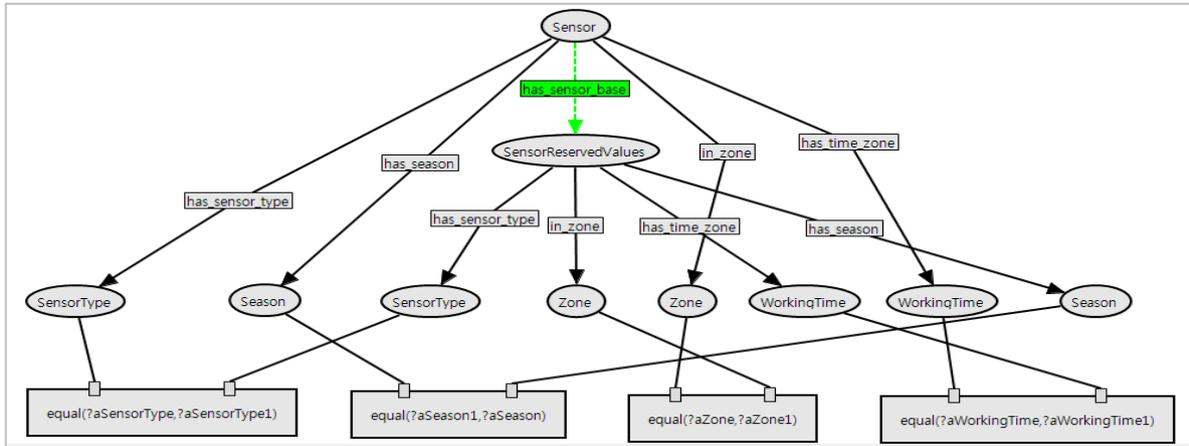


Fig. 2: Instance of inference rules generation

2.2. System Operation

Fig. 3 shows the system operation flow of the proposed model. Various sensors data and BAS data are aggregated, converted into analyzable data for summary. The summarized data is converted into the context information. Then, the inference engine infers the context on the basis of building architecture ontology and context ontology with the context inference rules. The inferred result specifies the state of the zone or the building. If the inferred context is abnormal, the inference engine reasons the cause of the abnormal state on the basis of the cause ontology and the cause inference rules. Finally, it infers the control command to solve the cause of the abnormal state through the control ontology and the control inference rules. According to the control command, the building is controlled until the abnormal state is solved.

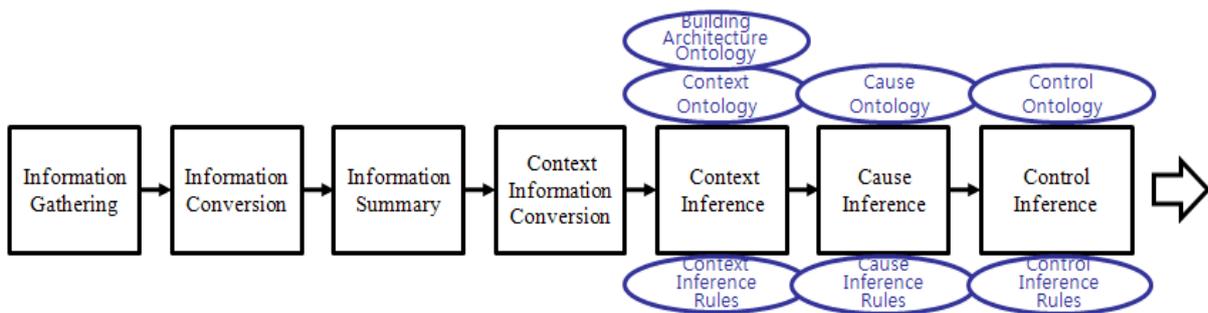


Fig. 3: Proposed model's system operation flow

2.3. Simulation-Assisted Inference Rules

As mentioned above, inference rules can be added through the result of the building energy simulations. To get a building energy characteristics of a specific building, our office building is selected and modelled for simulation. The target building's information is as follows:

- Location: Daejeon, Republic of Korea
- Building Usage: Office
- Floor: Seven Floors, One Basement
- Building Area: 15,250.07 m²
- Ventilation Area: 11,616.91 m²
- Window to Wall Ratio: 48.4 %

- HVAC System: CAV + FCU

We analysed the building energy performance by changing the ventilation rate according to the variation of occupants in the fifth floor in January. The per person basis ventilation was compared to the per unit area basis ventilation. Fig. 4 shows the comparison of those two kinds of ventilation. When the ventilation rate was changed from 0.7 air changes per hour (ACH) to 2.5 litres per second•person (L/s•person), 33.5 % of energy was reduced in heating and ventilation. The result can be used as an inference rule.

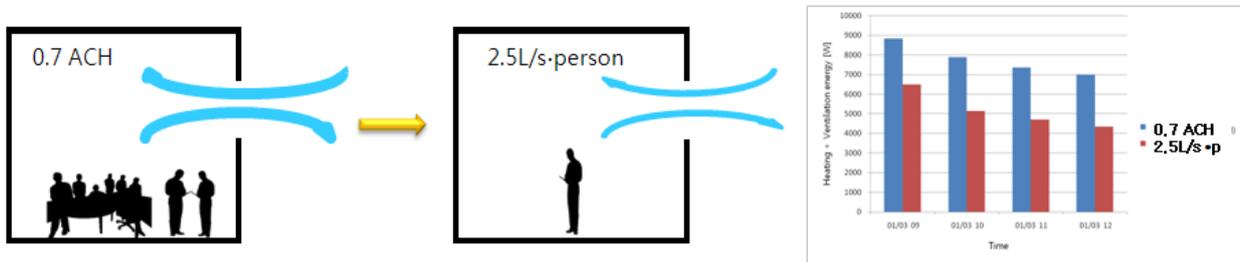


Fig. 4: Comparison of two kinds of ventilation

Another analysis was achieved to compare the energy performance by balancing the electric lighting and the day lighting through the window blind usage in August. The use of the day lighting reduces the electric lighting energy, but increases the cooling energy because of the day light heating. It has a trade-off between lighting energy and cooling energy. Fig. 5 shows the result of building energy simulation using the day lighting. The left figure illustrates the target building’s office location. The centre figure illustrates the daily cooling and lighting energy consumption in the office # 1. The advantage of the day lighting differs from day to day. The right figure illustrates the daily cooling and lighting energy consumption in the office # 6. In most cases, using the day lighting reduces the total energy consumption. It attributes to the fact that the office #6 in the north does not receive the day light heat. The above simulation results are very useful building energy characteristics to derive the inference rules for the target building.

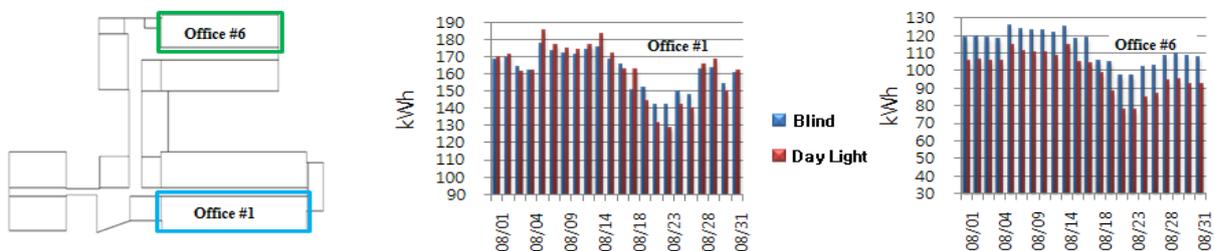


Fig. 5: Comparison of energy consumption in the day lighting simulation

3. Pilot System

On the basis of the above mentioned philosophy, we made a pilot system to confirm the feasibility of our proposed model. The target building is our office building. The building objects are modelled to ontology and inference rules are generated between the objects. Inference engine operates on the basis of the modelled ontology and generated inference rules. Fig. 6 shows the function diagram of the pilot system. EOM is our proposed BEMS and stands for energy optimisation and maintenance.

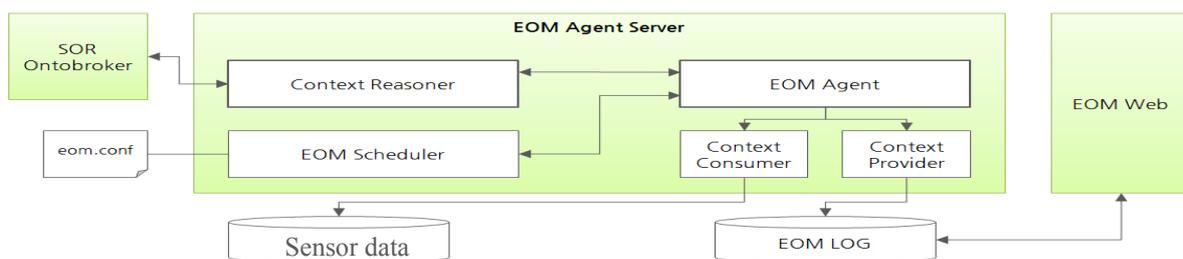


Fig. 6: Comparison of energy consumption in the day lighting usage simulation

The context consumer aggregates sensor data every fifteen minutes and queries the inference result through the context reasoned and the inference engine, Ontobroker. The inferred result from the inference engine is stored in the EOM log through the context provider. EOM web reads the EOM log periodically and displays the building operating guidelines. Fig. 7 shows the captured EOM web UI, which displays context (status), cause (diagnosis), and control (action).

Time	Building	Floor	Room	Category	Status	Diagnosis	Action
2011-02-10 12:15:00	ETRI 12동	6	608	회의실	비정상	608호 회의실 공실인데 조명켜 있음, 조명 점검	조명 소등하세요.
2011-02-10 12:15:00	ETRI 12동	6	608	회의실	비정상	608호 회의실, 공실인데 FCU켜져 있음, FCU 점검	FCU를 꺼주세요.
2011-02-10 12:00:00	ETRI 12동	6	608	회의실	비정상	608호 회의실 공실인데 조명켜 있음, 조명 점검	조명 소등하세요.
2011-02-10 12:00:00	ETRI 12동	6	608	회의실	비정상	608호 회의실, 공실인데 FCU켜져 있음, FCU 점검	FCU를 꺼주세요.
2011-02-10 10:30:00	ETRI 12동	6	605	사무실	비정상	605호 사무실 공실인데 조명켜 있음, 조명 점검	조명 소등하세요.
2011-02-10 10:30:00	ETRI 12동	6	605	사무실	비정상	605호 사무실 공실인데 블라인드 내려져 있음, 블라인드 점검 필요	남쪽 Blind 올리세요.
2011-02-10 10:15:00	ETRI 12동	6	605	사무실	비정상	605호 사무실 공실인데 조명켜 있음, 조명 점검	조명 소등하세요.
2011-02-10 10:15:00	ETRI 12동	6	605	사무실	비정상	605호 사무실 공실인데 블라인드 내려져 있음, 블라인드 점검 필요	남쪽 Blind 올리세요.
2011-02-10 09:30:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 18.9도, Door점검	Door 닫으세요.
2011-02-10 09:30:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 18.9도, Window점검	Window 닫으세요.
2011-02-10 09:30:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 18.9도, FCU점검	FCU를 꺼주세요.
2011-02-10 09:15:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 17.6도, Door점검	Door 닫으세요.
2011-02-10 09:15:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 17.6도, Window점검	Window 닫으세요.
2011-02-10 09:15:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 17.6도, FCU점검	FCU를 꺼주세요.
2011-02-10 09:00:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 15.0도, Window점검	Window 닫으세요.
2011-02-10 09:00:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 15.0도, Door점검	Door 닫으세요.
2011-02-10 08:00:00	ETRI 12동	6	605	사무실	비정상	605호 사무실, 적정온도: 19.0-21.0, 현재 온도 15.0도, FCU점검	FCU를 꺼주세요.

Fig. 7: Captured web UI showing the inferred results

4. Conclusions

We proposed an efficient BEMS model to reduce the energy consumption in building sector. The model is based on ontology, inference rules, and simulation. The pilot system based on the model is implemented. Ontology has the advantages such as information reusability, extensibility, and interoperability. It enables the BEMS to be easily deployed in the field. Inference rules can be accumulated through the building energy characteristics and the domain knowledge. They are also added from the building energy simulation result. Therefore, as time goes by, the proposed BEMS is going to be more efficient. The proposed model is expected to greatly contribute to the energy saving. In the future, it is necessary to compare the energy usage between the normal system and the proposed BEMS system.

5. Acknowledgement

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