Intelligent building using hybrid Inference with building automation system to improve energy efficiency.

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Abstract. Most existing building automation systems are operated with rule-based settings. These systems are wasting a lot of energy because the systems can not properly cope with changes in indoor/outdoor environments. In this paper, we propose hybrid inference for inferring indoor environments in the building using real-time stream data coming from BAS. Hybrid inference consists of Runtime Stream Processing and Semantic Lift Processing. Runtime Stream Processing deduces occupancy and thermal comfort using machine learning technology with historical data. Semantic Lift Processing uses the semantic inference to extract new knowledge based on inferred results from Runtime Stream Processing. On the basis of stored semantic-based data in the ontology, Semantic Lift Processing derives energy waste space based on occupancy and thermal comfort by using semantic technology.

Keywords: Intelligent Building, Internet of Things(IoT), Building Energy Management System(BEMS), Building Automation System(BAS)

1 Introduction

Korea is also under pressure to achieve its 37% reduction target of greenhouse gas(GHG) emissions (comparison on BAU) by 2030, due to Paris Climate Agreement. In Korea, GHG emission accounted for industry (50.1%), buildings (25.2%), transportation (17.6%) and others (7.1%)[9]. To achieve the reduction goals, the government is grappling with preparing reduction of emission quantity for each GHG emission sector. In the case of buildings(25.2%), there are residential and commercial buildings. Especially for commercial buildings, 30% of the energy consuming spaces are not in use[1]. Therefore, if the unused space inside the building could be efficiently managed, it is expected that it will save a lot of energy and reduce unnecessary building operation cost. Currently, building automation system(BAS) in the most of the buildings in Korea are automatically operated according to their schedules. Most of them are sequential control types

[1] https://www.ibm.com/internet-of-things/iot-zones/iot-buildings/forum/

that change settings in a time-dependent manner. The latest buildings also use this method in same way. There are two major problems in BAS. The first problem is that precise control is impossible due to the lack of micro monitoring for individual space. The second problem is that it is difficult to create and apply a control algorithm for individual space.

In this paper, we analyze energy waste space based on real-time data from Researcher Hotel of Alto University in Espoo, Finland. The Researcher Hotel is a dormitory-type building for the researchers with total floor area of 8,206 m^2 and each floor area of 2,450 m^2. The building automation system is composed of the Fidelix BAS system in Finland and can collect data in real time using the SOAP protocol.

Classification		Details
Scale		5 floors
Usage		Researcher Hotel
Area Summary	First Floor	2,450㎡
	Second Floor	2,450㎡
	Third Floor	2,450㎡
	Fourth Floor	2,450㎡
	Fifth Floor	2,450㎡
Total ground area		8,206㎡
Finish material		Concrete

Fig. 1. Finland Researcher Hotel

Total 4,199 data points which consist of HVAC, indoor/outdoor temperature, illuminance, and other environment properties are connected to our inference system. In this paper, we determine the internal thermal comfort based on each apartment's temperature and humidity. Also, we detect the occupancy status which is highly related to the CO_2 concentration level. The extracted semantic based information is updated, integrated with the building meta information and the real-time sensing information that is constructed by the ontology. Then we generate the SPARQL query for this ontology of the wasted space inside the building, to visualize on a web service. By providing such user interface to the building manager, the manager can easily identify the status of the building and learn the elements necessary for management at a glance which can lead to energy savings.

The Internet of Thing (IoT) produces the data from the sensors by connecting to the Internet. Although, the BAS, is still under controversy whether it is IoT technology or not. If the BAS transmits its data via Internet, it could be an excellent example of IoT.

2 Related Work

A variety of building energy saving technologies have been studied since the Paris Climate Agreement. In most cases of building energy savings, research topic is how to use energy more efficiently than before. We claim that the most important problem in energy saving is to determine whether the space is occupied or not. A. Caucheteux[1] also stresses that determining whether there are occupants in the building is the most necessary factor for building energy efficiency. They utilize various sensors such as occupancy detection, door or window opening/closing, temperature, and humidity to extract environmental information and occupancy information by space for energy savings.

Another research on building energy is about state inference technology through ontology connection of existing BAS data. Hendro Wicaksono[2] and Joern Ploennigs[3] aim to infer the state of the building by integrating sensor data and ontology. Hendro Wicaksonso's study represents various sensors in a building as ontology and suggests inference system using SWRL(Semantic Web Rule Language). In their study, they use two concepts: knowledge-driven and data-driven analysis. Ploennigs extended SSN[2] (Semantic Sensor Network) ontology using data collected from various sensors and BAS. Ploennigs also uses terms in Semantic Lift and Runtime Stream Processing which are similar to Wicaksonso. We use same terminology as Ploennigs' in this paper, but there are differences in Runtime Stream Processing: we use time series stream data analysis by using machine learning techniques, but Ploennigs and Wicaksono use these term as the inference on the RDF. They use the data not only from BAS but also from additional sensors which they install for the detail monitoring. The fundamental difference from our method is that we perform analysis only using BAS data without installing additional sensors.

Some of other IoT-based ontology studies[6][7] are based on interoperability. In this paper, we construct representation system of building data using ontology and study the technology built on top of ontology which can be used in actual real-world operation.

3 Architecture

The BAS system at the Researcher Hotel provides SOAP-based interface, so that data can be retrieved easily from outside through SOAP request. The Linked Open Data Adapter in Fig. 2 transmits these SOAP requests periodically and collects real-time data at 10 seconds intervals through the response. Collected data is stored through two interfaces: OpenTSDB[3]for storing historical data and Apache Fuseki's[4] triple store for the semantic-based data repository. OpenTSDB is used to analyze runtime streaming of history-based time series data, and triple store stores the data needed for Semantic Lifting. Fuseki is used as an ontology

[2] http://purl.oclc.org/NET/ssnx/ssn
[3] http://opentsdb.net
[4] https://jena.apache.org/documentation/fuseki2/

repository since it is not suitable for storing history data. Therefore our system only updates the latest value of BAS data on the ontology.

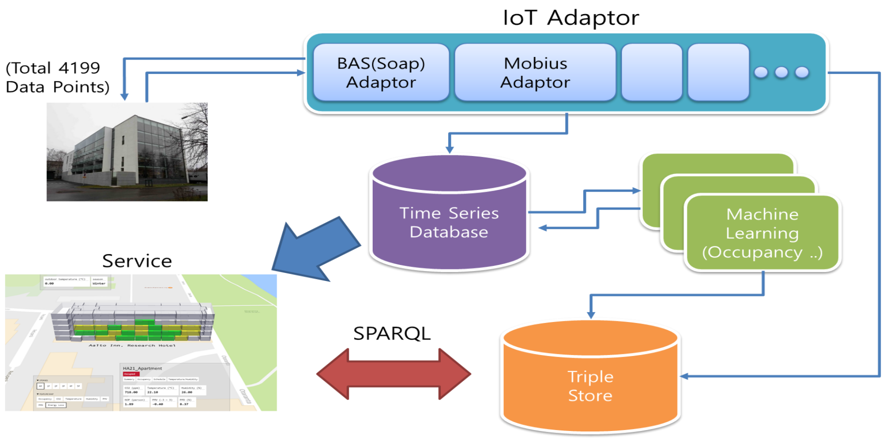

Fig. 2. Data collection linkage system

The IoT(Internet of Things) adapter shown in Fig. 2 could be connected to various legacy systems and IoT devices. It can translate the sensing data to RDF schema using the semantic annotation.

The system proposed in this paper uses hybrid inference of Semantic Lift Processing and Runtime Stream Processing as shown in Fig. 3. Runtime Stream Processing is composed of two algorithms: one is to determine occupancy state according to historical data stored in OpenTSDB, and the other is to calculate internal thermal comfort by using real-time temperature and humidity data. The semantic-based information generated by Runtime Stream Processing and the latest data of BAS are stored in the triple store and will be provided to the building manager. Stored semantic-based information is used to perform inference of energy waste space according to Description Logic in Semantic Lift Processing. This will make the building manager can identify which space wastes the energy by using the ontology.

The adapter layer in Fig. 3 shows the architecture of hybrid inference. In this architecture, IoT adaptor translates the data to semantic-based information using the domain ontology and semantic annotation. Time series data and semantic-based information will be published to the Pub/Sub Message Broker for delivering to the OpenTSDB, triple store, and the upper application.

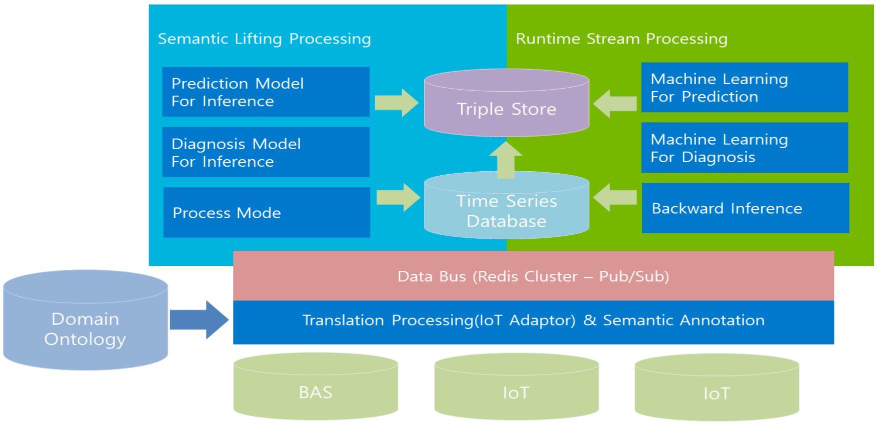

Fig. 3. Hybrid inference system architecture

4 Runtime Stream Processing

4.1 Room Occupancy Detection Algorithm

Runtime Stream Processing extracts semantic-based information from historical time series data by using machine learning. In this paper, there are two ways of analysis processes: one is occupancy detection based on CO_2, and the other is that analyzes thermal comfort based on temperature and humidity. Occupancy is monitored by CO_2 data transmittied from Researcher Hotel. We refer to the Tachikawa's equation[4] to calculate the number of people. Tachikawa evolved his equation based on Seydels equation[5].

$$C = C_0 + (C_S - C_0)e^{-\frac{Q}{V}t} + (1 - e^{-\frac{Q}{V}t})\frac{M}{Q} \quad (1)$$

In the Seydel's Equation which is Equ. 1 above, the amount of M pollution emission can be calculated as the concentration of CO_2 emitted by a person, which is changed to k(amount of CO_2 emission per person) and n(number of people), and the ventilation efficiency coefficient is applied to the ventilation amount of Q to determine the number of occupants. By solving the equation(1)'s n (number of people) in terms of other variables, we get Tachikawa's equation(2) shown below.

$$n = \frac{aQ}{k(1 - e^{-\frac{aQ}{V}t})} C - C_0 - (C_S - C_0)e^{-\frac{aQ}{V}t} \quad (2)$$

In Equ. 2, the variables consist of C(Current Pollution Level), C_0(Lowest Pollution Level), C_S(Normal Pollution Level), Q(Ventilation Amount), V(Space Size), k(CO_2 emission amount per person), α(Ventilation Efficiency). Based on history based CO_2, the lowest, average, and current pollution levels of past CO_2

concentrations are selected to determine the number of occupants on Tachikawa's equation basis. Q, V, k, and α are fixed values belongs to the space, thus they are set to constant values based on building information. Based on the above equation, we compute the coefficients of each room and calculate the number of occupants with CO_2 data based on the coefficients.

Since CO_2 concentration baseline values are different in night, daytime, weekday, weekend, and semester breaks, we need to take different criteria on past historical data. Then, we can get a precise answer by implementing the algorithm. The number of occupants in each room is calculated as follows when the algorithm is executed. If the occupancy rate is 0.75 or more, it is judged that occupancy of the individual space is occupied or it is judged that it is vacant. The reason is that because the number of occupants increases as the concentration of CO_2 increases, the standard of around 0.75 can be judged more quickly.

4.2 Thermal comfort algorithm

The spatial thermal comfort analysis algorithm calculates temperature and humidity from BAS data. The features used in this algorithm are PMV(Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) from the ISO 7730 standard[5]. The PMV index is represented in real number from -3 to +3, with 0 being the most pleasant, negative being cold, and positive being positive. The PPD is a dissatisfied index indicating how many percentage people are currently dissatisfied with the PMV thermal comfort index.

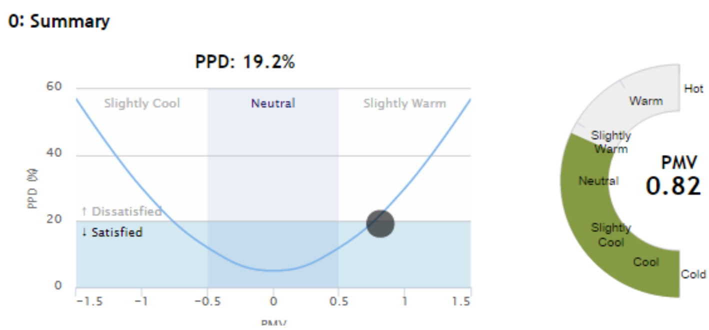

Fig. 4. PMV(Predicted Mean Value) and PPD(Predicted Percentage Dissatisfied)

PMV is the value that is calculated by various variables such as amount of activity, external work, insulation value of clothes, heat transfer coefficient and so on. This value predicts the average temperature sensed by people who are in the same exposed environment. We calculate the PMV by using real-time transferred temperature value from BAS. Other various variables are used as

[5] https://www.iso.org/standard/39155.html

input by defining constant values for each season. PMV is the thermal comfort that a person can feel, PPD predicts how many people are dissatisfied. By using these two indicators, it is possible to estimate how much the individual space consumes the energy of heating/cooling properly compared to the season and outdoor temperature, and the energy consumption of the individual space can be efficiently controlled.

5 Semantic Lift Processing

In Semantic Lift Processing, an instance of a BAS data point of the Researcher Hotel is constructed by the ontology. The building semantic model proposed in this paper extends the SAREF[6] (the Smart Appliance REFerence ontology) to build the ICBMS [7] ontology. In addition to SAREF, OM[8] (Ontology of Units of Measure) and Time Ontology[9] are used for the unit and time of data measured by the sensor. However, ppm units of CO_2 concentration are not defined in OM, so we define it through ICBMS ontology. And sensor types not provided by SAREF are also extended and defined.

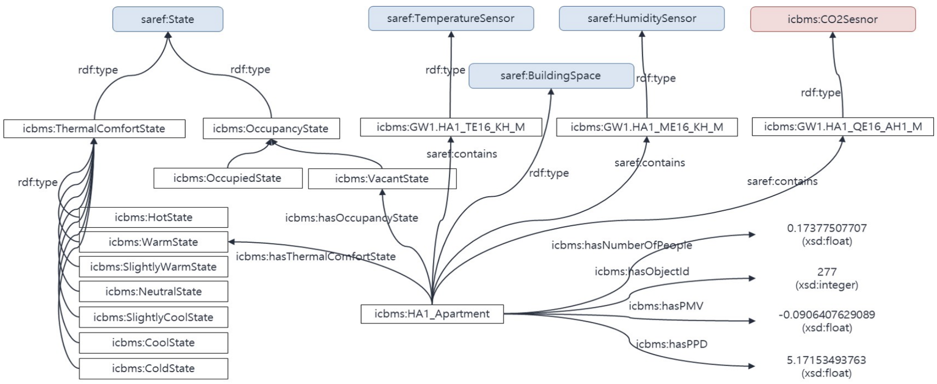

Fig. 5. Semantic model of Apartment number 1

Fig. 5 shows the semantic model of each room. It has the number of occupant, PMV, and PPD deduced from the sensor data. In order to define the state information of each room, *hasOccupancyState* and *hasThermalComfortState* are defined on the ICBMS ontology to express the inferred state information in Runtime Stream Processing. *hasOccupancyState* represents the state of the room as

[6] https://w3id.org/saref
[7] The name of our project is "Development of Smart Mediator for Mashup Service and Information Sharing among ICBMS (IoT, Cloud, Big-Data, Mobile, Security) Platform". That's why we use "ICBMS" as the name of the ontology.
[8] http://www.wurvoc.org/vocabularies/om-1.6/
[9] https://www.w3.org/TR/owl-time/

VacantState or *OccupiedState*. *hasThermalComfortState* represents the thermal comfort index of seven stages as the PMV.

We use the internal structural information of Researcher Hotel to create the instance of the whole building, floor, room, and sensor unit. Then, we build the state information of each room into the ontology. This will make such structure that enables SPARQL queries can query information such as occupancy state of the room, the room that has good thermal comfort, and etc.

GW1.HA10_ME16_KH_M

GW1 : Sub Station GW1
HA10 : Apartment Number 10
ME16 : Electronic Humidity Sensor 16
KH : Bathroom
M : Measurement

Fig. 6. Semantic annotation using BAS naming rules

The system creates an instance using the received data from the BAS based on the ICBMS ontology. The semantic-based information of the BAS data is converted by a semi-automatic format similar to the internal label mapping tool[8]. Fig. 6 is a classification of the meanings of the data names provided by the BAS system. Semantic annotation of BAS data is automatically performed by using the above naming rules and domain ontology. Fig. 7 shows the result of automatic semantic annotation. It is the result that is automatically converted by Semantic annotation using name rule.

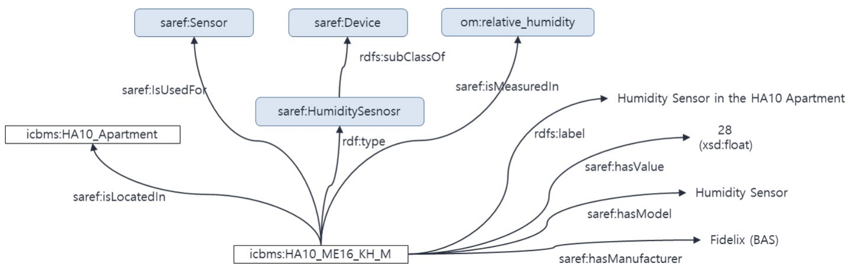

Fig. 7. Description of the Humidity Sensor

Fig. 8 shows a IoT Adaptor for collecting BAS data generated by buildings. The legacy adapter provides connectivity through the protocol interface (SOAP) used by BAS. The semantic annotation converts data as RDF schema according to BAS naming rules, and stores them in triple store. However, storing history-based sensing data in the triple store causes performance degradation. Therefore, only the latest data value is updated in the triple store, and the historical data is stored in the Time Series Database which is called OpenTSDB.

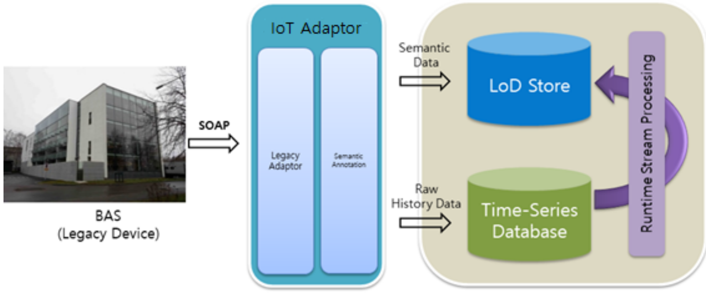

Fig. 8. BAS Data Acquisition Architecture

By using the constructed ontology, we can infer the space in which energy is currently wasted inside of the building. We infer the energy use state of space inside the building using Description Logic. Equ. 3 is the Description Logic for inference; it infers a place where has good thermal comfort even if a person is not in the place and a place where has excessive thermal comfort when a person is in the place. Our software does not use semantic reasoning such as SWRL(Semantic Web Rule Language)[10]. Our inference software loads the semantic information into the memory and deduces the relationship in Equ. 3.

$$\begin{gathered} Room \sqcap (hasOccupancyState.VacantState) \\ \sqcap(\forall hasThermalComfortState.NeutralState) \\ or \\ Room \sqcap (hasOccupancyState.OccupiedState) \\ \sqcap(\forall hasThermalComfortState.SlightlyCoolState) \end{gathered} \tag{3}$$

List 1.1 shows the SPARQL statement for querying the data stored in the ontology. This query can be used to verify the sensing information and the inference result of each room.

```
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
PREFIX om:    <http://www.wurvoc.org/vocabularies/om-1.8/>
PREFIX rdf:   <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX xsd:   <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs:  <http://www.w3.org/2000/01/rdf-schema#>
PREFIX time:  <http://www.w3.org/2006/time#>
PREFIX icbms: <http://keti1.energyiotlab.com/icbms#>
```

[10] https://www.w3.org/Submission/SWRL/

```
PREFIX saref: <http://ontology.tno.nl/saref#>
PREFIX ic:    <http://imi.ipa.go.jp/ns/core/210#>

SELECT ?room ?humidity ?temperature ?co2 ?nop ?oid ?pmv ?ppd
?occstate WHERE{
        ?room saref:contains ?o.
        FILTER (regex(str(?o), "QE16_AH1_M", "i")).
        ?o saref:hasValue ?CO2.
        ?room saref:contains ?o3.
        FILTER (regex(str(?o3), "ME16_KH_M")).
        ?o3 saref:hasValue ?humidity.
        ?room saref:contains ?o2.
        FILTER (regex(str(?o2), "TE16_AH1_M")).
        ?o2 saref:hasValue ?temperature.

        ?room icbms:hasNumberOfPeople ?nop.
        ?room icbms:hasObjectId ?oid.
        ?room icbms:hasPMV ?pmv.
        ?room icbms:hasPPD ?ppd.
        ?room icbms:hasOccupancyState ?occstate.
}
```

Listing 1.1. SPARQL query

Fig. 9 shows the results of the query in List 1.1. In the application of intelligent building, this query is used to get the required data for visualization to show the internal state of building.

QUERY RESULTS — Raw Response | Table — Search: — Show 50 entries

	room	humidity	temperature	CO2	NOP	OID	PMV	PPD	OCCSTATE
1	icbms:HA1_Apartment	46	23.899999618530273	594	0.087385396879	277	-0.161091075943	5.54221422791	icbms:VacantState
2	icbms:HA2_Apartment	45	21.799999237060547	512	-0.00842789002174	275	-0.821589140854	19.3353872159	icbms:VacantState
3	icbms:HA3_Apartment	43	23.399999618530273	531	0.0772959068544	273	-0.336933494275	7.38014796983	icbms:VacantState
4	icbms:HA4_Apartment	41	23.899999618530273	510	1.16420895281	271	-0.194113634624	5.78767917269	icbms:OccupiedState
5	icbms:HA5_Apartment	42	23	521	0.0512540467902	269	-0.467732032472	9.60331434484	icbms:VacantState
6	icbms:HA6_Apartment	41	23.700000762939453	573	0.335847742486	267	-0.256470918872	6.37658252541	icbms:VacantState
7	icbms:HA7_Apartment	36	23.399999618530273	516	0.0364493734216	265	-0.381793295749	8.05968307753	icbms:VacantState
8	icbms:HA8_Apartment	43	24	624	0.116151278616	253	-0.149616436217	5.46765147465	icbms:VacantState
9	icbms:HA9_Apartment	47	24.5	502	0.0361682184216	261	0.0345141509136	5.024863952	icbms:VacantState

Fig. 9. The result of SPARQL Query

Visualization

Based on the hybrid inference system described above, we develop a service that could be monitored by the building manager. On the screen, the administrator can grasp each internal state that inferred from data in the building. As shown in Fig. 10, based on the CO_2, temperature, humidity, the air quality of the room, the occupancy status, and the thermal comfort index information of the each room are implemented through the ICMBS ontology. The service is configured to extract and monitor a specific state of the space using the SPARQL query. In this sevice, various kinds of sensor data are visualized so that the building manager can monitor the entire state at a glance.

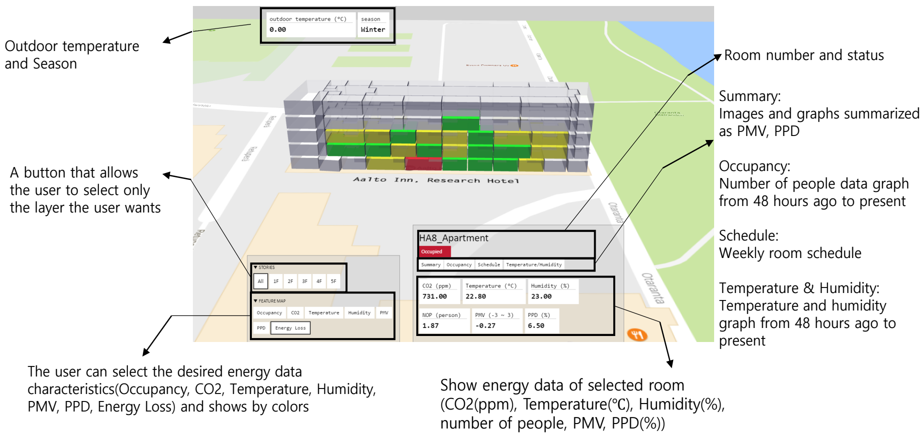

Fig. 10. Building Manager Interface Screen

Conclusion

In this paper, we have studied intelligent building which prevents energy waste by hybrid inference based on machine learning and the semantic ontology. However, it does not directly control HVAC and heating/cooling facilities inside the building. In the future, we plan to expand the study to verify the effect of intelligent inference to control the inside of the building by using IoT technology. In addition, we plan to study intelligent building optimized for energy saving by utilizing neural network and reinforcement learning based on historical data.

Acknowledgement

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