Web Objects Based Energy Efficiency for Smart Home IoT Service Provisioning

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***Abstract* – Reducing energy consumption while satisfying user living comfort is a challenging issue in IoT environment for utilities and service providers. Energy consumption needs to be reduced without compromising user comfort that depends not only on current environment condition but also real world knowledge, history data and user preferences. Web Objects based IoT environment allows objects virtualization and use of semantic ontology to create real world knowledge and applies cognitive functionalities to learn user preferences. Web Objects based IoT environment allows integration of connected objects and isolation of information from multiple application domains. Depending on user current situation, location, time, history data and future prediction, energy efficiency on WoO make intelligent decision to offer services for user comfort living and reduce energy consumption. This paper proposes an architecture that supports Web Objects based energy efficiency for smart home IoT services. To realize knowledge-based intelligent IoT services, a use case scenario has been studied.**

***Keywords*— Internet of Things; Web of Objects; virtualization; energy efficiency; smart home.**

I. INTRODUCTION

Due to a huge number of connected objects and available service features in the ubiquitous environment, offering Internet of Things (IoT) services becomes complex that consumes a lot of energy. Utilizing use of energy in households to reduce energy consumption while satisfying user comfort becomes an essential part of IoT ecosystem. Energy efficiency is an increasingly focus area in IoT environment for utilities and service providers. Energy consumption needs to be reduced without compromising user living comfort in terms of appropriate temperature, humidity, CO_2 level, *etc*. Thus, a system should have capabilities that ensure user living comfort and optimizes energy consumption for lighting, heating, security, multimedia, ventilating, air conditioning, *etc*.

Ensuring user living comfort and reducing energy consumption requires not only measuring environment condition but also considering history data, knowledge of the environment and user preference. Web of Objects (WoO) [1] is a service platform that allows object virtualization for application deployment, maintenance, and operation. WoO allows the use of semantic ontology to create and update real world knowledge, and cognitive functionalities to learn user preferences. Thus, knowledge-based intelligent services are offered in Web Objects based IoT environment that ensures user comfort.

Offering smart home IoT services in Web Objects based IoT environment requires measuring and analyzing indoor and outdoor environment parameters, such as temperature, humidity, CO, *etc*. To access these parameters, real world objects are virtualized in WoO to form virtual objects (VO) using semantic ontology that allows interoperability and interconnection among multiple VOs. Services are realized in terms of composite virtual objects (CVO) that are created by combining functionalities of multiple VOs. Comparing to existing work, main advantages of WoO includes the discovery of relevant VOs, approximation and reuse of VOs and CVOs, and knowledge-based intelligent decision making. WoO allows integration of connected objects and isolated information from multiple application domains. Fig. 1 shows three layer system architecture of WoO.

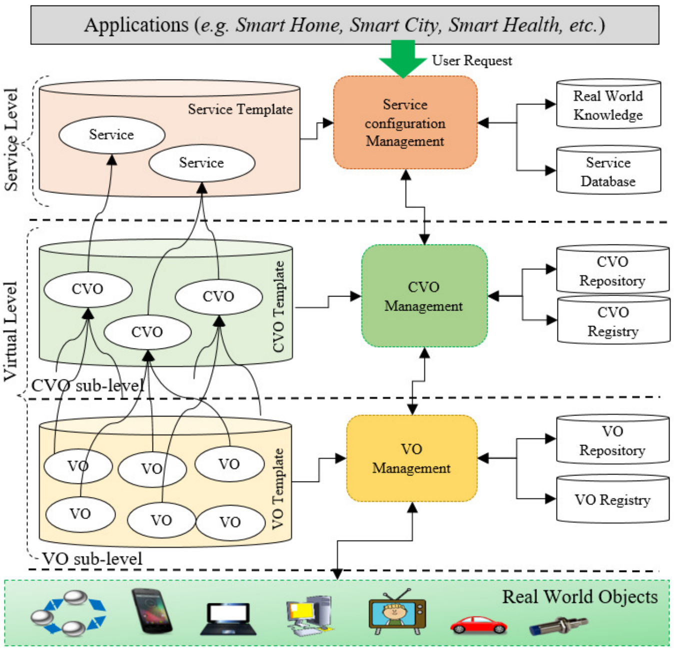

Fig. 1 Three layer architecture of Web Objects platform.

IoT allows interaction and intercommunications among connected objects that share information among them to offer intelligent services. Still, IoT faces a lack of efficiency at network and application level. To overcome this lack, WoO facilitates the integration of information that is isolated in heterogeneous ontologies. WoO also facilitates application deployment and operations. Cognitive functionalities of WoO enables monitoring of current situation based on current environment condition, creating real world knowledge, and offering user-centric services. At WoO based smart home, different energy efficiency functionalities monitor daily energy consumption, detect a pattern of energy usage, maintains home appliances to support user comfort living. History data and real world knowledge (RWK) are analyzed in this issue.

A lot of research works have been going on to reduce energy consumption on IoT environment, where reducing energy depends on energy usage and its pattern. In WoO, energy efficiency is achieved by offering user comfort services that considers surrounding environment condition, user preferences and real world knowledge, and subsequent output is reducing energy usage by adjusting home appliances.

Energy efficient services are provided through the efficient use of energy with energy-optimization capability for energy consumer and provider. Reducing energy consumption and offering user preferred services requires updated RWK and history of service. Object virtualization, VO composition, collaboration and harmonization and RWK in WoO provides energy efficiency in smart home services.

To support these issues, this paper focuses on real world object virtualization, intelligent service creation, and proposes a Web Objects based architecture that supports energy efficiency for smart home IoT services. Section III discusses WoO service features, three levels of WoO architecture and their relation. Section IV discusses functional components and RWK in WoO platform. This section also proposes and discusses an architecture that supports energy efficiency for smart home IoT services. To realize knowledge based smart home services, Section V presents a use case scenario on smart home. Section VI concludes the paper.

II. RELATED WORKS

VOs are harmonized and composed to satisfy knowledge based service requirements in Web Objects based IoT environment. Real world objects virtualization and their composition to form CVO for information reusability, extensibility, and interoperability among VOs in WoO have been presented in [2-6]. RWK is an important element in WoO for context-aware service provisioning. Discovering appropriate correlated VOs requires monitoring the context, hence real world knowledge is analyzed at the service level. RWK creation and expression have been discussed in [7-10].

Smart service provisioning requires sensed data of the user to identify user health status, user activity. Offering service features at smart home require monitoring and analyzing indoor and outdoor condition, also resident's behavior is observed to make an intelligent decision. Smart home and its associated mechanism to offer services have been discussed in [11-13].

Integration of connected objects and information from multiple application domains, and service composition and collaboration are important issues in energy efficiency management. Service composition and its methodology have been discussed in [14].

III. WEB OF OBJECTS PLATFORM FOR ENERGY EFFICIENCY

Even though objects share data to achieve the complex task in IoT environment, it lacks common standard at network and application level. WoO facilitates distributed application by integrating objects and combining isolated information from multiple domains. WoO is a service platform that includes VO, CVO and service level. WoO facilitates application deployment, maintenance, and operations. WoO allows the use of semantic ontology to virtualize real world objects.

Real world objects are not connected to the application directly, semantic ontology is used in WoO to communicate, access, control, and to achieve intelligence, interoperability, and interconnection among VOs. Each real world object is represented by individual VO, where properties and attributes of real world object are defined in RDF. Multiple VOs are combined to create CVO. A service may be offered by a CVO or multiple CVO that depends on the service request.

To define VO, domain specific VO information model is used to describe properties and attributes of real world objects that contain the information regarding the object. RDF/XML format is used to describe the attributes and properties and OWL is used to make relationship among VOs. OWL enables VO relation as a hierarchy of classes and subclasses that are stored as semantic web documents. VOs are stored in VO repository and its data is stored in a database.

CVO is created by combining multiple VOs and service rules. Depending on the threshold values and reasoning the VOs, CVOs and service rules, an intelligent decision is inferred. Domain specific CVOs need to be defined earlier for service execution. Components and cognitive functionalities in CVO level allow reuse of VOs and CVOs for efficient and optimized service. Properties and features of relevant VOs are inherited by concerned CVO, functionalities of VOs are combined and orchestration is maintained with entities that are available inside or outside of the domain. To offer domain specific service, CVO is defined using CVO information model and stored in CVO template repository. Defined CVO includes reference of VO, VO function, owner, access right, *etc*. CVO template is defined so that if similar new CVO is required then that can be created from the template. Access control information is used to restrict access to CVO.

Service is the logical mash-up of multiple VOs, CVOs and service policies and sequence of execution. Different cognitive functionalities at this level observe the real world situation and create and modify the knowledge. Based on the RWK and service request, service execution request is generated to execute the service at the service level. At this level, machine learning algorithm is applied to process the context information to update the real world knowledge.

In WoO based smart home, the user is always connected to their home virtually as they are at home physically. To offer intelligent and user preferred services, indoor and outdoor environment parameters are collected and transmitted for analyzing. Thus real world objects including physical devices, information, and conceptual entities are virtualized. Each real world object is represented by individual VO.

IV. WEB OBJECTS BASED ENERGY EFFICIENCY IN SMART HOME

A. Functional Components for Energy Efficiency in WoO

Functionalities at each level in WoO platform enable a system to discover, compose, and offer services based on user request, current situation and real world knowledge. Fig. 2 shows the functional architecture of WoO that includes necessary functional components for energy efficient smart home services.

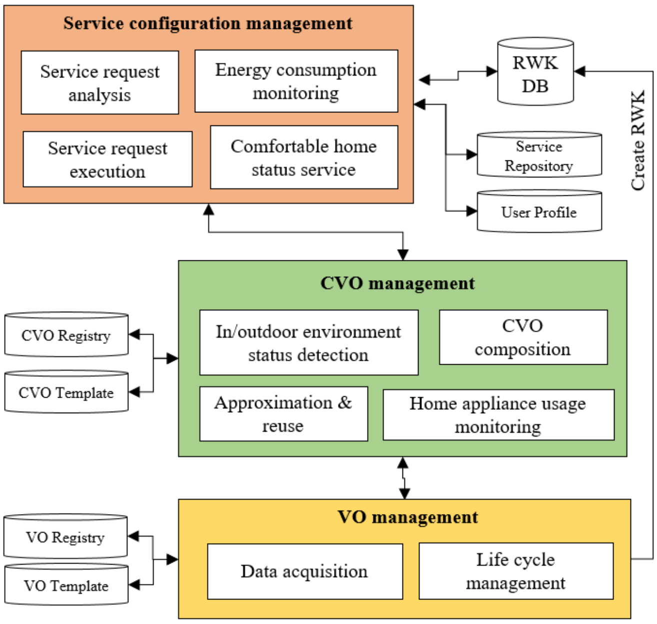

Fig. 2 Functional components in WoO for energy efficient smart home services.

Service level functionalities perform as an interface to the user that receives, analyses and responses service request to the user. RWK is created and update at the service level. Based on a service request, service request analysis function consult with RWK and considers user preference to select appropriate service template. Service request analysis identifies and provides request and situation parameters and service template to service request execution function to execute the service. Service request execution provides necessary parameters and references of CVOs to CVO Management Unit. Functional elements at service level also include user comfortable home status service, energy consumption monitoring. Service level is responsible for monitoring energy consumption, load forecasting, and energy awareness.

Based on the request from the service level, CVO level functions identifies appropriate CVO template to execute the service. Hence CVO composition searches available CVO in CVO registry and reuse. Approximation and reuse function is used to approximate similar types of CVOs that can support similar types of functionalities. This unit requests VO Management for relevant VOs. Function at VO level also allows approximation and reuse of VO.

Even though service level performs as a brain that analyses knowledge and history of services for knowledge-based services, but the requested services are executed by CVO level functionalities. Different functionalities including in/outdoor environment status detection and home appliance usage monitoring functions at CVO level monitors indoor and outdoor environment status, such as temperature, humidity, wind flow, *etc.* based on the user activity, location, status of the environment, these functions controls home appliances to provide user comfort and reduce energy consumption.

Inference engine runs on service relevant CVOs, VOs and service rules to make a decision to execute a service. Hence, CVO relevant VOs need to be composed. CVO level functionalities discover relevant VOs through VO management unit. Data acquisition function monitors, filters and collects data using VO. For uninterrupted data, VO lifecycle monitors and maintain life cycle of a VO. If any error found such as sensor disconnection due to low power, or erroneous data, this function informs CVO Management Unit to update VO references. VO lifecycle manager maintains a VO registry up-to-date. It continuously analysis environment for associations with real world objects. A VO changes its states such as active, idle, life cycle manager monitors the transitions and updates of the current state.

B. Energy Monitoring and Measurement

Energy monitoring and measuring provide an improvement in energy efficiency and user satisfaction. Thus, calculating energy consumption patterns is important that might be used to tailor energy and increase user satisfaction. An energy consumption data model is trained, where consumers are segmented based on social class, the number of rooms in a home, the number of the user, type of tariff, *etc*. It is found that families using non-flat tariff consume less electricity. That's why several factors need to be analyzed intensively to calculate energy consumption patterns to efficiently use of services.

To monitor and measure, energy consumption data can be collected through smart meter VOs. Collected data is converted into useful information to identify usage patterns of user and neighborhoods. Useful information is made available on the web that allows open access that increases awareness of energy usage.

Energy is consumed and adapted by different households, such as sensors, lights, heater, ventilator, AC, *etc*. All of these real world objects are represented by VOs. To monitor and measure energy consumption and offer services, we have defined VOs to represent real world objects using semantic ontology that maintain relation among the VOs.

C. Energy efficiency based on real world knowledge

It is not easy to reduce energy consumption while satisfying user comfort. Energy efficient service provisioning in WoO requires analyzing knowledge of the current situation, user preferences and history of services. Usually, user preferences for a specific service remain similar and do not vary that much, hence previous service history needs to be considered to compose and offer a service. A service request in a specific location is relevant to RWK of that location. It implies that a user requested service is related to RWK of the user. RWK is analyzed in service level along with user current request and situation information, thus satisfying user comfort and reduce energy consumption. So, when a service is requested, functionalities at service level in WoO searches similar services in a service registry and user profile for user preference to be analyzed.

Creating RWK is an iteration process that uses machine learning mechanism. Raw data collected through VOs is detected and aggregated at VO level, reasoned and classified at CVO level and projected at the service level to create and update real world knowledge. The outcome of RWK is a prediction of a situation, such as prediction of user activity or prediction of service at next step. This prediction is analyzed along with current request parameters to make an intelligent decision. In WoO, knowledge can be captured, used and expressed using semantic ontology. Fig. 3 shows the flow of instructions in WoO platform that creates RWK from sensed data, and creates and provides energy efficient services.

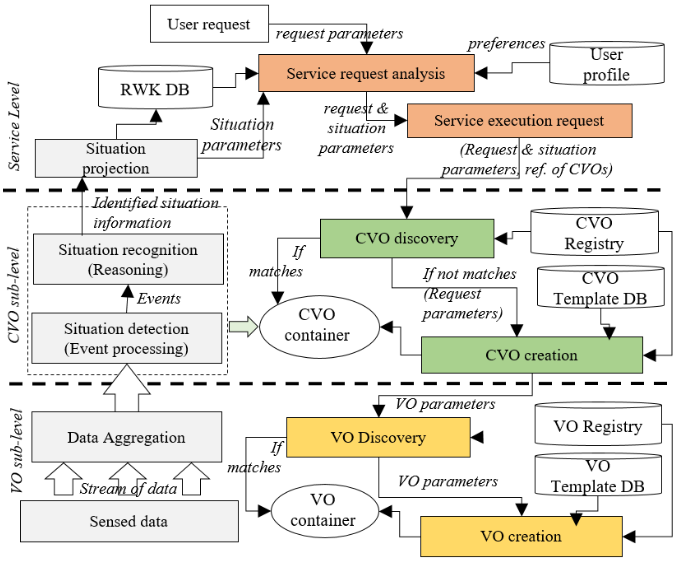

Fig. 3 Knowledge-based energy efficient service provisioning.

Raw data collected by VO are processed that form meaningful information that is converted to process knowledge. Data is collected at VO level and these data is processed to get the situation. At the starting of this process, a stream of data collected by VO is aggregated and a time window is added. Statistical function including average, median, standard deviation are used to convert this data into an event. Event processing engine such as Esper is used to process the aggregated data and provides a stream of events, such as room temperature, humidity, *etc*. The Stream of events are then inferred in situation recognition to identify the situation information, as an example, current room status is inferred from temperature and humidity data. Machine learning algorithm is applied to the inferred situation to project future prediction.

Several machine learning techniques are applied to create real world knowledge. A data stream can be categorized using Support Vector Machines (SVM) that classify set of objects to build RWK model. SVM is used to classify various entities, such as users, home appliances, *etc*. New features of real world information can be identified by using Principal component Analysis (PCA) that assists in growing RWK model. PCA is treated as the first step in developing RWK model. Self-Organizing Maps (SOM) is applied to receive near real-time data that gradually update RWK model. SOM features include mapping of similar data on an adjacent cell. Trained map in SOM represents similarity as well as classification of sensed data. To classify user preferences, Bayesian Networks (BN) is applied. BN is also applied to estimate suitable service template and probability on different data.

D. *Web Objects based Energy Efficiency*

Web Objects based smart home IoT services focusing on user satisfaction and energy optimization requires not only indoor and outdoor environment measurements but also requires the history of services, real world knowledge, user preferences, location, temporal data of services, *etc*. Comparing current indoor and outdoor environment measurement, identifying user activity and location, and previous history data are inferred to make intelligent decision to offer user preferred services that fulfill user comfort and reduce energy consumption. Machine learning mechanisms are applied on inferred decisions to validate user satisfaction rate. Real world information is also processed to update real world knowledge. Fig. 4 shows an architecture that supports energy efficiency for smart IoT services.

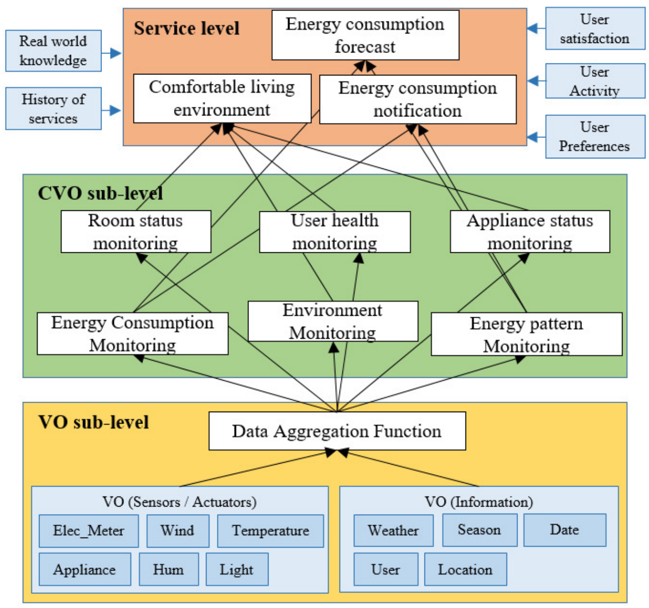

Fig. 4 WoO enabled architecture supports energy efficiency for smart home IoT services.

Indoor and outdoor environment data that are collected through VOs, user activity, and user satisfaction rate are input parameters in Energy Efficiency Monitoring and Measurement Unit that are analyzed to generate service request parameters. This unit includes functional components mentioned earlier.

Generated parameters are provided to an inference engine that runs reasoner to make an intelligent decision and triggers Command Control Unit to execute services through sensors and actuators. The decision from Command Control Unit is taken back to validate user satisfaction rate.

V. PROTOTYPE IMPLEMENTATION

A. *Use case scenario*

An adult family member Mr. X is on his way to home from his office. It takes almost two hours to reach his home. As usual Mr. X prefers normal room condition while he lives in his home. During his absence in the home, light, HVAC, *etc.* are turned off to save energy. Prior to his arrival at home, the system collects current data, searches history data of normal room status and preferred room condition, and analyses them to make room condition in a normal condition. The system finds that in normal condition, the range of temperature is in 23℃ to 25℃ and humidity is 40% to 45%. The system also finds that there are three different combination options to make room comfortable and each of these options has different energy consumption and savings. All of these factors are analyzed and computed to make the decision to set the parameter values so that the room condition becomes normal at the arrival time of Mr. X. Indoor and outdoor environment are measured by deployed sensor at home. These data is inferred along with RWK and history data of service. Due to an adult member, winter season, time and preferred temperature and humidity, inference engine triggers Command Control Unit to execute actions, such as increasing room temperature gradually and setting humidity based on the recommendation of the option. Fig. 5 shows the use case scenario.

B. *Prototype implementation*

A conceptual semantic ontology model has been designed for use case smart home scenario that has been shown in Fig. 6. The prototype has been designed using ontology editing tool Protégé that allows description of VOs and CVOs using RDF format and store in OWL.

Necessary VOs have been defined in use case scenario including temperature, humidity, location, user, season, weather, date, heater, light, boiler, ventilator, *etc.* From use case scenario different CVOs have been defined including environment monitoring CVO, user health status monitoring CVO, energy consumption monitoring CVO, *etc.*

VO and CVO have been described as a hierarchy of classes and subclasses that are supported in Protégé. CVO has been created using class expression editors in Protégé. A VO description in RDF format has been shown in Fig. 7.

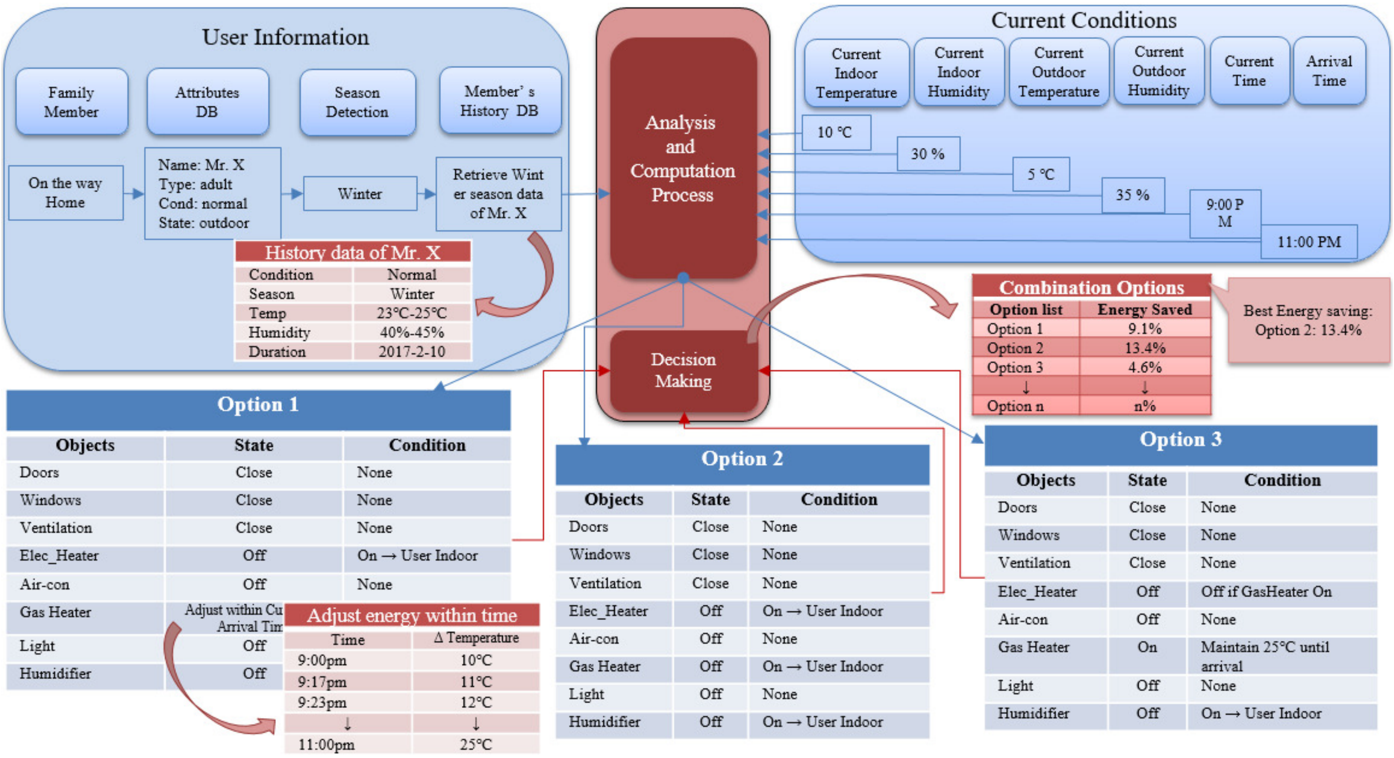

Fig. 5 Use case scenario, combination options of user preferred room condition and recommendation of the option.

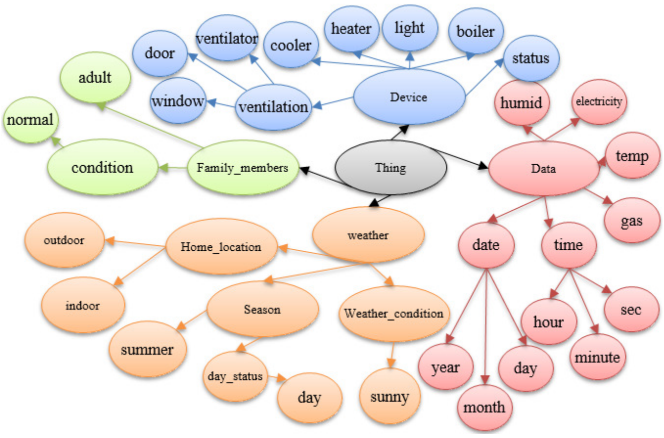

Fig. 6 Smart home semantic ontology model for energy efficient IoT services.

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<rdf:Description
rdf:about="http://woo.hufs.ac.kr/rdf/thing.rdf#adult">
    <db:home_location>indoor</db:home_location>
    <db:in_temp>25</db:in_temp>
    <db:in_humid>45%</db:in_humid>
    <db:time>22:04:33</db:time>
    <db:date>2017.02.10</db:date>
    <db:heater>on</db:heater>
    <db:cooler>off</db:cooler>
    <db:boiler>off</db:boiler>
    <db:light>on</db:light>
<db:elec>224kWh</db:elec><db:gas>2923kWh</db:gas>
<db:window>close</db:window> <db:door>close</db:door>
<db:ventilator>close</db:ventilator>
</rdf:Description>
```

Fig. 7. VO description in RDF – describing indoor room status

For the comfortable living environment, different combination options are executed that is instructed by CVO that combines different VOs as shown in Fig. 5. Energy savings for these options vary. Fig. 8 shows the percentage of energy savings for the combination options. Even though these options provide user comfortable living environment, but the second option saves more, hence application recommends the second option.

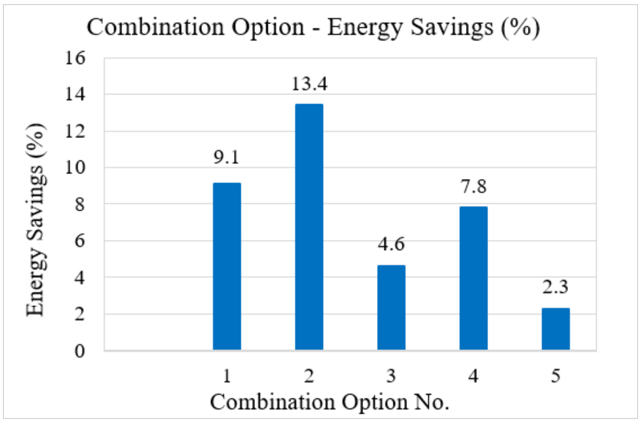

Fig. 8. Percentage of energy savings for different combination options.

VI. Conclusion

Satisfying user comfortable living environment and saving energy is a complex task. Energy consumption needs to be reduced without compromising user comfort. In WoO, energy efficiency is achieved by offering user comfort services that consider surrounding environment condition, user preferences and real world knowledge, and subsequent output is reducing energy usage by adjusting home appliances. Energy efficient services are provided through the efficient use of energy with energy-optimization capability for energy consumer and provider. This paper has proposed an architecture that supports energy efficient comfortable living services for the smart home. A conceptual ontology model has been designed using Protégé and finally, a use case scenario has been implemented.

Acknowledgment

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