The International Journal of Soft Computing and Software Engineering [JSCSE], Vol. 3, No. 3, Special Issue:
The Proceeding of International Conference on Soft Computing and Software Engineering 2013 [SCSE'13],
San Francisco, CA, U.S.A., March 1-2, 2013
Doi: 10.7321/jscse.v3.n3.132 e-ISSN: 2251-7545

Smart Simulating Energy Consumption System in Home/Building Networks

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***Abstract*—This paper presents a simulating energy consumption (SEC) system which has real-time energy monitoring and virtual energy simulation capabilities for a specific real home environment. The energy monitoring function provides in real time not only the total amount of energy usage in a target house but detailed energy usage profiles for individual home appliances. Based on the real-time measurement of energy usage, the energy simulation function predicts energy consumption when one or more home appliances are removed or newly added virtually. All operations are visualized with 3D spatial information developed from the Building Information Modeling (BIM) database of a target house. Spatial information is integrated with device information in the home resource management middleware, where device information is directly obtained from home appliances interconnected via bridging function of home networks. The interoperability with various home appliances is also achieved by home resource management middleware. Our experimental testbed shows that the SEC system could be used as an efficient energy management tool to meet energy saving goals.**

Keywords—real-time energy monitoring; simulating energy consumption; residential energy management; smart home networks

I. INTRODUCTION

As the field of information technology is developing so rapidly and a variety of home appliances and consumer electronics are installed, there is a greatly increasing demand to manage energy consumption in home and office environments. It has been estimated that application of more sophisticated management to residential electricity consumption has the potential to save 3% to 26% of residential electricity use [1].Energy management in the residential sector, however, is far behind recent technologies developed for the commercial and industrial sectors. As one of approaches to handle it, Building Information Modeling (BIM) has been used to meet energy savings goals during the whole life cycle of building from design to maintenance and applied to various fields [2].

But the current BIM model offers information of a building's components and elements and not able to provide the detailed online information, for example, the amount of energy consumed at a specific moment, at an exact location, or for a particular load [3].

To save residential energy, users need to monitor not only the total amount of energy consumption of a house but detailed energy consumption of individual home appliances. This monitoring work should be online and in real time. In addition to the real-time feedback of energy consumption, the capability of panning energy consumption is also needed. The energy planning capability simulates the amount of energy consumption for virtually added or removed home appliances. Since it is critical to identify which home appliance wastes energy and where it takes place exactly, both real-time monitoring and virtual planning capabilities need to know spatial information of a specific real home. This spatial information could be obtained from the BIM database and then needs to be integrated with device information. The device information could be directly obtained from home appliances interconnected via bridging function of home networks or manually set by users.

Conventional energy management systems in the construction sector and telecommunication sector take a different approach, as depicted in Fig. 1 (a) and (b), respectively. And the necessity of integrating spatial information of a house and device information of home appliances led our approach, as depicted in Fig. 1 (c). This approach enables it possible to support real-time monitoring of energy usage and simulating energy consumption with BIM-based user friendly 3D user interface and spatial usage visualization. Interoperability with various home appliances

* This work was supported by the IT R&D program of MKE/KEIT. [2009-F-027-01, Development of Interoperable Home Network Middleware forsettling Home Network Heterogeneity]

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could also be achieved through home device management middleware.

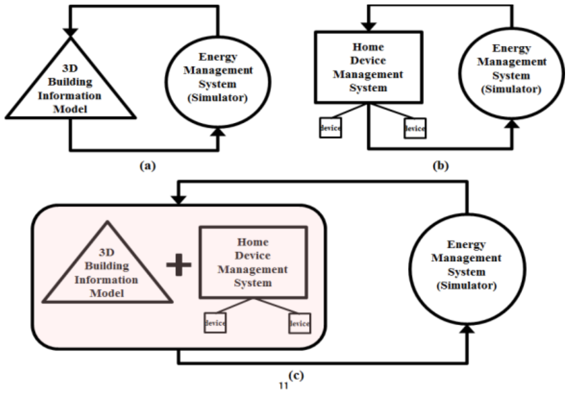

Fig. 1. The concept of energy management system

This paper describes an energy consumption planning system, so called *Simulating energy consumption*(SEC) system. The two key features of the SEC system are monitoring current energy usage of home appliances with exact spatial information by sensing them periodically through home network middleware and simulating and planning energy usage when one or more home appliances are removed or added virtually. All operations are visualized with 3D spatial information. Our experimental results show that the SEC system could be used as an efficient energy management tool for the whole life cycle of home from design to maintenance.

The remainder of this paper is organized as follows. Section 2 reviews the related works to provide background information. In Section 3, we describe the proposed system architecture and functions in more details. Section 4 presents its implementation details to show the effectiveness and possibility of our system and finally section 5concludes this paper.

II. Related Works

A number of researches have been conducted for efficient energy management of a building using the BIM model. T. Laine [4] proposes the method of designing energy-efficient buildings which focuses on the initial design stage of building construction and presents benefits of BIM in energy analysis. S. Yoon [5] utilizes BIM as a data source of energy analysis for energy-efficient building so that data are more efficiently entered to the system and the existing data are more reusable. The Real Time Power Monitoring(RTPM) System [3] provides detailed energy consumption data of end-user for each load level, where data is integrated with a BIM model to create a real-time on-line electronic BIM model. H. Xie [6] discusses in detail about the framework of integrating Radio Frequency Identification(RFID) with BIM technologies for structural steel components, such as a steel beam or column. Most of researches thus have focused on the design and analysis of energy-efficient building construction using the BIM model.

Nowadays there are a few online services have been introduced for enhancing energy utilization and reducing wasted resources of individual houses, for example, Google Power Meter and Microsoft Hohm. Both only show the total energy consumption of a house using a user-friendly web interface. Power Meter needs an advanced metering infrastructure (AMI) attached to individual home appliances and Hohm obtains measurement data from energy suppliers [7].

In telecommunication sector, many efforts have been devoted to the development of efficient home energy management system. D. Han proposed a new Smart Home Energy Management System (SHEMS) [8] based on an IEEE802.15.4 and Zig Bee. Y. Son implemented the home energy management system (HEMS) [9] using power line communication. The HEMS monitors smart meter and controls home appliances remotely from internet, providing auto-configuration, remote monitoring, and flexible controlling. G. Song [10] suggested a wireless power outlet for the remote control of home appliances. The outlet has mesh networking capabilities by adding a Zig Bee radio into its architecture. A sensor and actuator network can be formed by deploying the power outlet module together with other sensor nodes into the home environments. S. Park [7] proposes a simulation framework that can model a house equipped with various home appliances and next-generation smart metering devices. This simulator can predict the power dissipation profiles of individual appliances as well as the cumulative energy consumption of the house in a realistic manner. R. Mediand [11] deals with a smart energy systems as an application area for pervasive computing. With five full papers in companion he has presented, including a comprehensive survey spanning four decades of smart energy research, recent results from a UK study of home-deployed smart energy systems. They include diverse energy-consumption sensing, nonintrusive load identification and estimation, and minimally intrusive load shedding. To the best of authors' knowledge, none of current researches has integrated the BIM model into home network management middleware for efficient energy management with the capabilities of simulating energy consumption and 3D spatial visualization of individual home appliances.

III. System Architecture

The major requirements of the SEC system are:

- To enable users to check in real time not only the total energy consumption of a house but detailed power profiles of individual appliances within the house so that they could manage operating time of each device efficiently,
- To provide users with user-friendly three dimensional spatial visualization, as depicted in Fig. 2, which makes

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use of the location mapping between spatial information from BIM and device information from home networking resource management middleware,

- To offer users with the capability of the simulating energy consumption which performs a simulation of virtual planning based on the industry energy cost policy, and
- To support a variety of home appliances through a general middleware bridge for device interoperability on different home networking middleware[11] .

Fig. 2. Three dimensional spatial visualization of a house

To meet the requirements we have developed the SEC system and its operation follows two phases in sequence and repeatedly. One is to measure the current usage of energy for individual home appliances in real time and visualize it in three dimensional user interface which represents an exact location of each home appliance. Based on the measurement, the other is to simulate an estimated amount of energy usage when one or more home devices are removed or newly added to the current configuration virtually. The devices information should be mapped with the spatial information to know exactly where a device is located and how much it consumes energy. With the help of the SEC system users could thus make decisions on which existing devices should be removed or where new devices should be installed to minimize the energy waste.

The overall architecture of the SEC system consists of three main modules: *spatial information aggregation (SIA)*, *resource core layer (HCL)*, and *energy management service(EMS)* modules, as shown in Fig. 1.

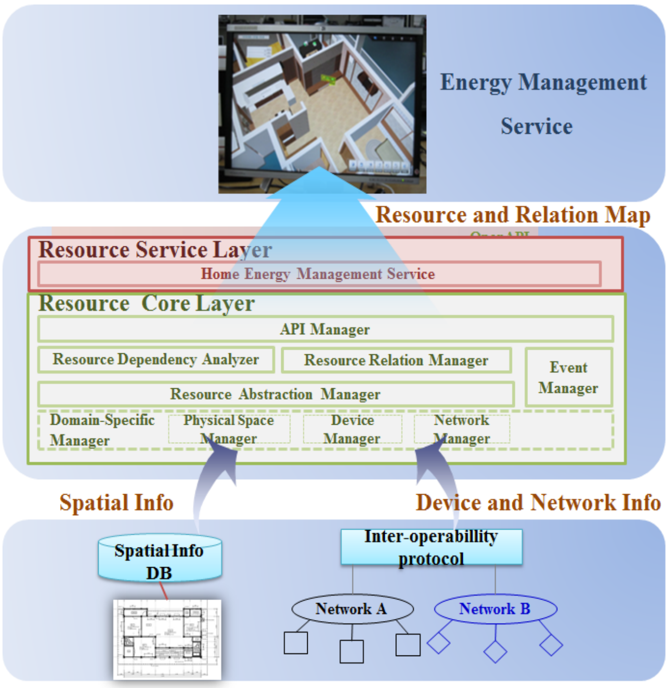

Fig. 3. The simulating energy consumption(SEC) system

The SIA module makes use of a user-friendly drawing tool which produces a 3D BIM output with lots of information such as architecture, space, and plumbing. We adopt BIM as a data source for energy analysis by generating spatial information of home to and extracting from a database [3]. The database provides detailed object attributes such as name, type, ID, 3D position, and scale value of each object. The main role of the SIA module is to aggregate those spatial information from database, identify sections of home such as living room, kitchen, or main room, make spatial information lists, and send them to the HCL module.

The HCL module is then to combine the spatial information with device information from home networks and sensing data obtained from power outlet devices. For example, we can see with the module exactly that a light in the living room consumes a certain amount of energy. There are three main components in the module: *device manager*, *resource abstraction manager*, and *resource relation manager*. The device manager collects all information such as device description from home appliances and sensing data from power outlet devices. The device description includes type, name, ID, object lists and device properties such as physical address, version, manufacturer, location and distributed data of each device. Fig. 4 represents device description schema used in our system. With this device and sensing information the device manager makes device information lists and sends them to the resource abstraction manager.

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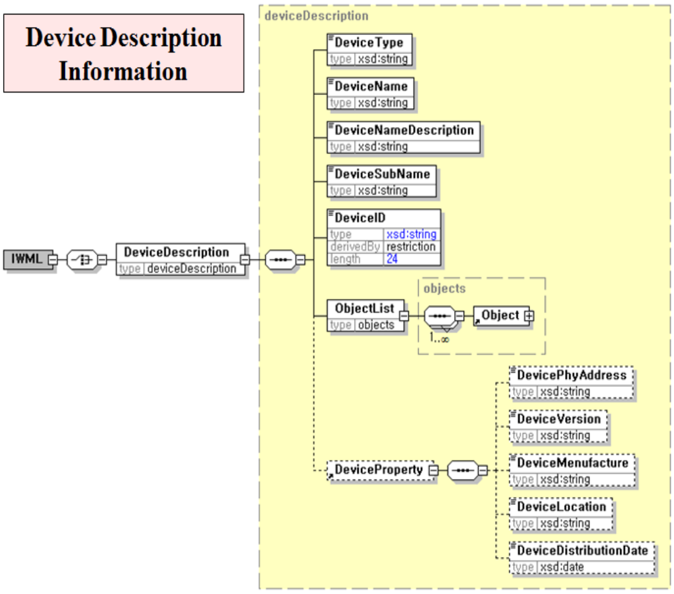

Fig. 4. Device description schema

The resource abstraction manager then combines device information from the device manager of the HCL module with spatial information from the SIA module, producing resource lists with a unified pattern so that searching time and communication cost to find a specific resource is reduced considerably, as depicted in Fig 5. Each resource object has a unique resource ID which consists of both a domain ID and an object ID. The domain ID indicates one of physical space, device, network, service domains. The field of the resource type in each resource object indicates either a device type, for example, light and gas valve or a space type, for example, wall, door and room. The resource name comes from the name of the corresponding device or spatial object. The unified resource lists are then sent to the resource relation manager.

The resource relation manager creates a relation map among home resources to provide a current home configuration comprehensively. For example, spatial information contains space information such as living room, kitchen and main room. Each space consists of several building components such as walls, windows, and doors. And each component has a specific three dimensional position. Thus the resource abstraction manager can trace spatial information from specific position or component information. Furthermore, spatial information also has object information about home devices which are already deployed inside a home such as power outlets, LAN ports, and TV outlets.

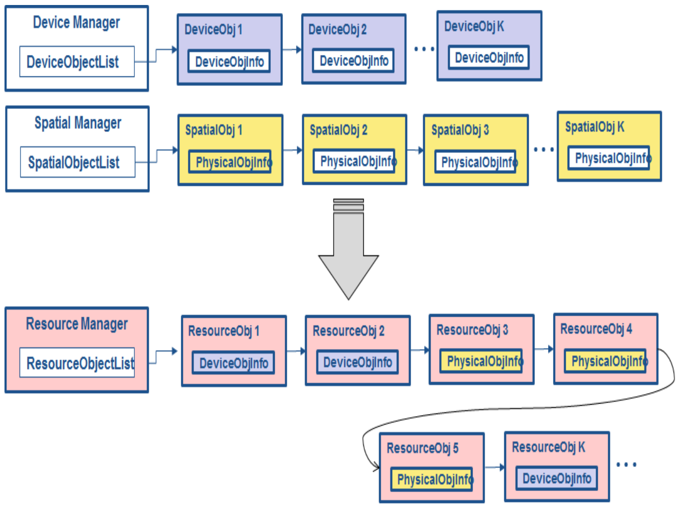

Fig. 5. Unified resource lists

To make a relation map among home resources, the resource relation manager firstly searches the same object ID (for example, "1004") among resource lists. When it finds the same ID in the spatial information lists and device lists, it can extract space information(for example, "living room") from the spatial information and other device information(for example, name="power outlet1"). Finally, it can make a relation map which indicates that the power outlet1 is located in living room.

In case that it cannot find relationship during the first phase, it proceeds to the second phase. At the second phase, the resource relation manager searches device information to find the location of a resource. The device information which each device sends periodically contains location information. Thus the resource relation manager resolves and maps location information to space information and makes a relationship. Although we provide automatic methods of making relationship, it is not always feasible. For these cases, our system provides an alternative that users can enter relationships. Those relationships between device domain and physical spatial domain are presented in the left part of Fig. 6.

The left part of Fig. 6illustrates an example of home network resources for energy management service. The right part of Fig. 6 is a resource relation map which reflects the physical resource configuration of the left part of Fig. 6. It shows that the energy management service binds to camera, wallpad, PIR (Passive Infra-Red), and gas valve controller. The camera and wallpad gateway are connected to Ethernet installed in the living room. PIR, gas valve controller and wallpad gateway are also connected to RS-485 network link. Camera and PIR are located at the entrance and gas valve controller is located at the kitchen. A resource object and a relation are represented as a rectangle node and a circle node, respectively, in the resource map. The label of the relation represents a relation identifier. An edge is directional, starting from a source relation object to one or more target resource

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objects. The algorithm to construct a relation map is out of scope in this paper and described in [12].

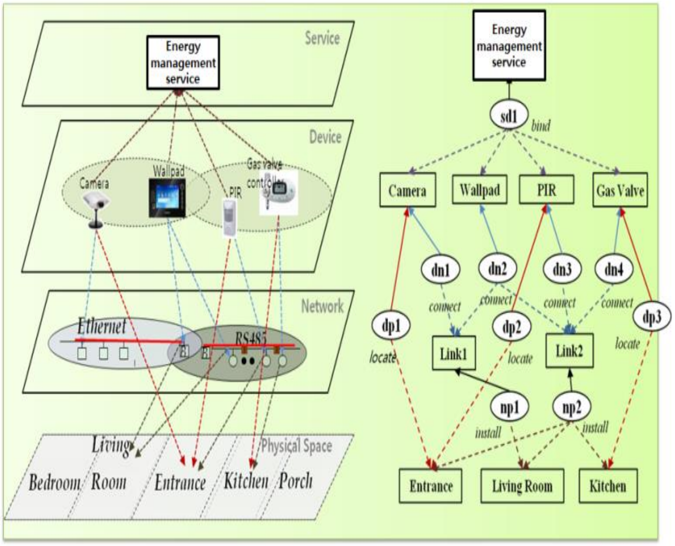

Fig. 6. Relation map between spatial and device domains

The EMS module is an application of home resource management middleware. It receives resource and relation information from the middleware and then shows current energy consumption and estimated results of energy planning to users. To show the current consumption, this simulator provides not only a real-time energy usage from sensing data of power outlet devices, but also the spatial energy visualization based on relation information from the middleware. For example, when the simulator receives energy sensing data from a device, it traces power outlet's space from the relation map and then classifies the device according to the same space. Finally, it aggregates classified sensing data based on the space and presents spatial visualization of energy usage. In addition, it provides a simulating energy consumption function that is similar to energy simulation. This function provides cost estimation by deploying virtual devices and setting time and period. The user can select virtual devices to simulate by clicking and selecting icons and conveniently specify simulation parameters and options such as operating time and schedule of appliances. Our system shows the cumulative energy consumption at home as well as detailed power profiles of individual appliances.

Finally, complete content and organizational editing before formatting. Please take note of the following items when proofreading spelling and grammar:

IV. Implementation Detail

To construct spatial information, we make use of a user-friendly 3D drawing tool on window systems and a database to save spatial information. The power outlet devises use RS-485 protocol to send their sensing data periodically to the home resource management module and make it possible to monitor the energy usage of home appliances in real time. The home resource management module has been developed on top of the Linux system and provides the interoperability engine and adaptor to communicate with various home appliances which have different network protocols. The details of the interoperability engine and adaptor are presented in the previous work [13]. We developed all the related hardware and software for our system.

A. Testbed Environments

We have developed a testbed which consists of BIM model, power outlet devices, home resource management middleware and a smart home energy system as shown in Fig. 7. To build BIM model we make use of the commercial tool with window OS and general database to save building information.

Fig. 7. Testbed environments

B. Simulating energy consumption scenario and outputs

In order to show the functions of our system, we present a scenario of the simulating energy consumption system. The process of the experiment is shown in Fig 9.

1. When the BIM model draws 3D UI and saves building information to database, the home resource management middleware receives these information including architecture, space, material, and object information.
2. Home devices send their device description information to the middleware.
3. The home resource management middleware updates resource lists.
4. When the resource building timer is expired, the middleware finalizes resource lists and makes the resource relation map.
5. The middleware sends resource and relation information to the smart energy system.
6. This smart energy system draws home and resource graphically using 3D UI.

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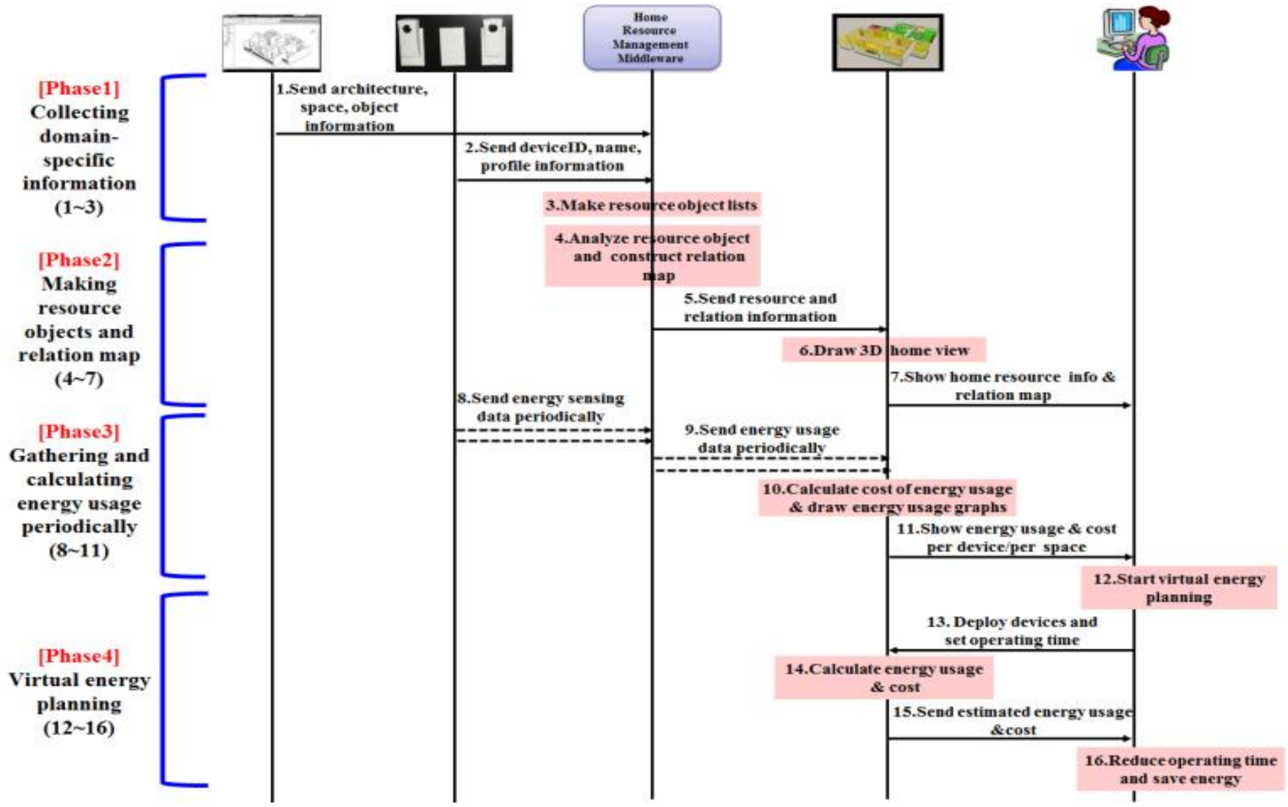

7. A user can see home and resource view with user friendly interface. The output is shown in Fig. 8 (a), (b), and (c)
8. Power outlet devices send sensing data to the middleware periodically.
9. The middleware sends energy usage data to the smart system periodically.
10. This system calculates energy usage price and makes energy usage graphs.
11. The user checks the energy usage and price with graphs by device unit or by spatial visualization. Fig. 8 (d) shows spatial visualization and Fig. 8 (e) presents current energy usage graph.
12. The user starts virtual planning to know the estimation of energy usage and price with virtual device.
13. The user deploys virtual devices and sets operating time and period. This output is shown in Fig. 8 (f)
14. The SEC system calculates energy usage and price with virtual devices.
15. The SEC shows the estimation usage and price to the user such as in Fig. 8 (e)
16. The user makes a plan for reducing energy consumption and adjusts operating time in practical environment.

Fig. 8 shows experimental results of proposed simulating energy consumption system. We have designed 3D UI and Fig. 8 (a) shows the general drawing of BIM. Fig. 8 (b) and (c) present apartment complex and an apartment unit of our system. From Fig. 8 (d) we can find the spatial visualization of energy usage and Fig 8 (e) shows the current energy usage graphs. Fig. 8 (f) depicts the simulating energy consumption by deploying virtual devices in the living room.

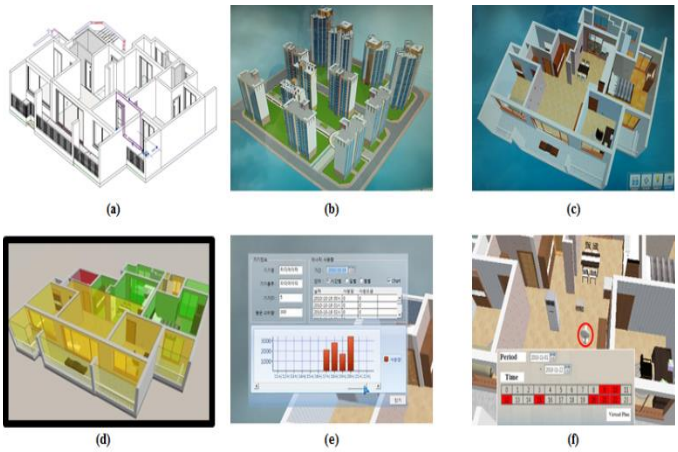

Fig. 8. Experimental results: (a)(b)(c)3D UI, (d)spatial visualization, (e)energy usage graph, (f)simulating energy consumption

V. CONCLUSION

We have presented an energy consumption planning system, so called *Simulating Energy Consumption*(SEC) system. The

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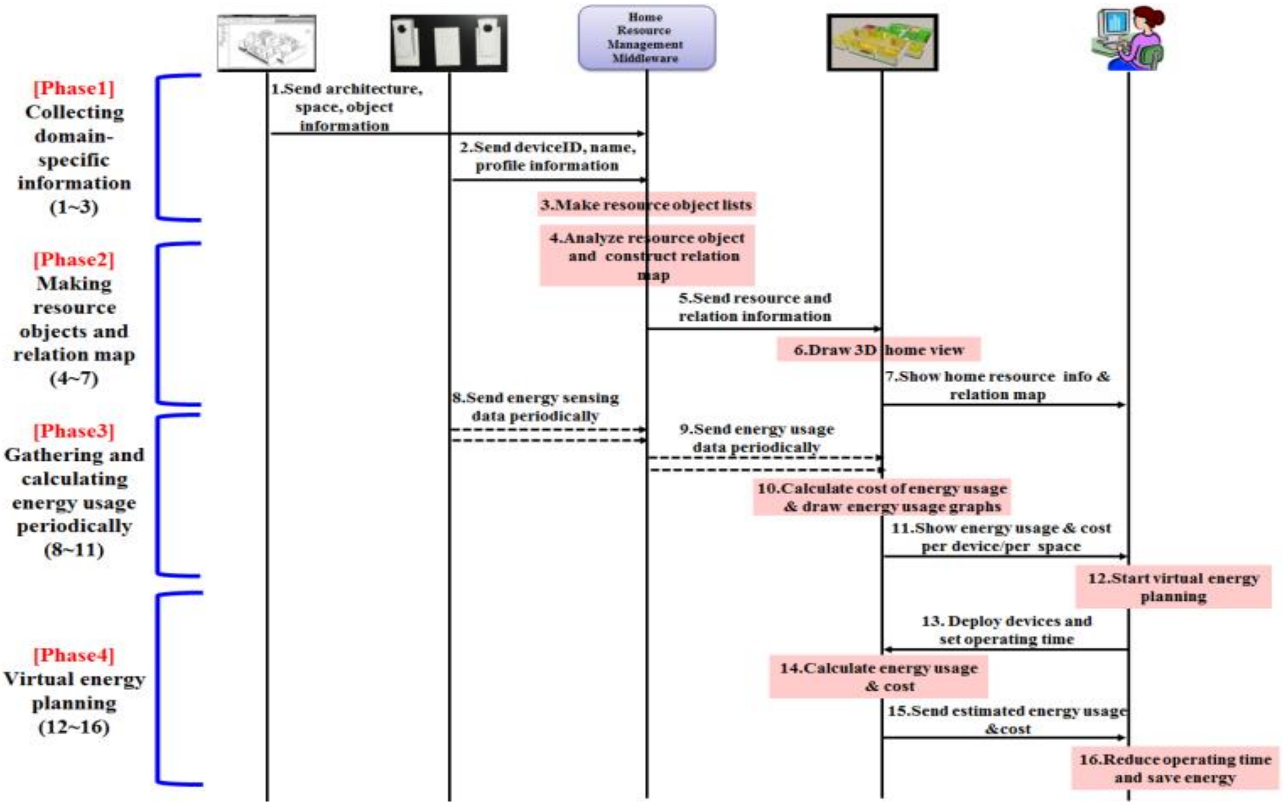

Fig. 9. Experimental scenario of the SEC system

two key features of the SEC system are monitoring current energy usage of home appliances with exact spatial information by sensing them periodically through home network middleware and simulating and planning energy usage when one or more home appliances are removed or added virtually. All operations are visualized with 3D spatial information. Spatial information is integrated with device information in the home resource management middleware, where device information is directly obtained from home appliances interconnectedvia bridging function of home networks. The interoperability with various home appliances is also achieved by home resource management middleware.The experimental results of the proposed SEC system have shown a good evidence to monitor energy consumption in real time with a realistic home environment and to predict energy usage by using virtual planning so that users can meet their energy saving goal. Even though the current SEC system has been implemented using RS-485 protocol, our middleware bridge makes it possible to extend our solution to whole home network appliances, as discussed in [13]. As a future work, wehave a plan to extend the SEC system by considering weather conditions, building geometry, heating, ventilating, and air-conditioning(HVAC) systems for spatial information.

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BIOGRAPHIES

Jihyun Lee received an M.S. Degree in Information and Communication at KNU in 2005. In 2009, she received Ph.D degree in Computer Science at KNU in Korea. She worked as a visiting research scholar in Computer Engineering at Arizona State University in 2007. Since 2009, she has been a senior researcher of Smart Convergence Middleware Research Team at Electronics and Telecommunications Research Institute (ETRI). She is interested in the areas of resource management in home networks, energy management systems, wireless communication networks, and context-aware middleware.

Jun Hee Parkreceived the B.S., M.S., and PhD degrees in computer science from Chung-Nam University, Korea in 1995, 1997, and 2005 respectively. He was a researcher at System Engineering Research Institute from 1997 to 1998 where he had worked on network computing and clustering system. From 1998 to 2009, he was a senior researcher at Electronics and Telecommunications Research Institute, where he had worked on home network middleware especially interoperability framework. Since 2010, he has been the team leader of Emotion-IT convergence Middleware Research Team. He have researched on Ship and ICT convergence area, and developed ship area network technology. His recent research interests are smart home and smart ship.

Kyeong-Deok Moonreceived the B.S. and M.S. degrees in computer science from Hanyang University, Korea in 1990 and 1992 respectively. He received Ph.D degree in information engineering from KAIST ICC, Korea in 2005. From 1992 to 1996, he was researcher at System Engineering Research Institute where he worked on high performance computing and clustering computing. Since 1997, he has been a principal researcher of Green Computing Research Department at Electronics and Telecommunications Research Institute, where he develops the home network middleware and Java embedded architecture. His research interests in home network middleware, Java, active network, and pervasive computing.

Kyungshik Limreceived his M.S. degree in Computer Science from the Korea Advanced Institute of Science and Technology, Seoul, Korea, in 1985 and his Ph.D. degree in Computer and Information Sciences from the University of Florida, Gainesville, FL, in 1994. From 1985 to 1998, he had been a principal member of the research staff and the head of the Computer Communications Section of the Electronics and Telecommunications Research Institute, Daejon, Korea. Since March 1998, he has been a faculty member of the Computer Science Department in the Kyungpook National University, Daegu, Korea. His research interests include mobile computer communications and computing, wireless networks, high-speed communications networks, and parallel and distributed systems.