Analysis of Energy Saving Effects on Korean Style Residential Buildings using Energy Information Device for Smart Metering

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Abstract— **The paper focuses on monitoring and analyzing the energy consumption load profile patterns of consumers and implementation of integrated operation monitoring system using distributed energy information device to attract active energy conservation. This paper also analyzes the electric power consumption patterns in energy consumption data gathered from the monitoring system according to Korean style residential building type and discuss the feasibility of considering of energy saving effectiveness factor.**

Keywords-Monitoring; Analysis; Load Profile; Energy Savings; IHD; Smart Metering

I. INTRODUCTION

Reducing energy demand in the residential buildings is an important problem worldwide. Recently, the trends toward case of using energy information device such as heterogeneous In-Home Displays (IHDs) by consumers are gradually growing. In addition, studies for analyzing energy saving effect depending on the use of IHD are ongoing actively. Consumers using IHD mainly receive feedback from energy information of that for energy saving. Related researches are as follows. Faruqui et al. covers 12 direct feedback trials using an IHD device between 1989 and 2009, including time of use and prepayment trials. Ehrhardt-Martinez et al. [2] covers 57 studies from 1974 to 2010. This is the most comprehensive review to date and splits the conservation effects from feedback by study size, era, type of feedback and region. In [3], companies with specific, proven expertise in making attractive consumer products are quickly changing the IHD industry and competition is growing. For example, General Electric (GE) recently announced its Brillion suite of home energy management products, including an IHD. Other researches discuss about direct feedback [4][5] and the inexpensive IHD device [6]. IHD is also provided with important information using various communication interfaces (Ethernet, ZigBee [7][8], and WLAN [9]) and security policy [10]-[12].

So, in aspect of usage effectiveness of heterogeneous IHD, we developed Integrated Operation Monitoring System (IOMS) in order to monitor meter data and analyze the effect of the energy saving of heterogeneous IHD as an extension study of [13].

We completed the prototype level development of the IOMS, and gather and manage the metering data from the IHD server. Therefore, the main purpose of this paper is to develop the IOMS that can be monitored by the integrated management of metering data of the distributed IHD server, and the second objective is to analyze the pattern of metering data using the IOMS. Finally, based on the results of the pattern analysis, we are about to proceed to reflect to the government policy or promote to the energy savings policy.

Eventually, this IOMS is useful for integrated management and analysis of metering data of the customers, and has the usefulness for the taking advantage of the energy savings policy and promotional material.

The remainder of this article is organized as follows: In Section II, we introduce IOMS implementing architecture. In Section III, we analyze energy consumption patterns of experimental result. Finally, we present the conclusion in section IV.

II. IOMS IMPLEMENTING ARCHITECTURE

In this section, we implement the IOMS and collect metering data. After that we examine the empirical results.

A. IOMS Interoperable Networking

IOMS is connected with each heterogeneous IHD server through 70Mbps Ethernet (IEEE 802.3). The heterogeneous IHD server and AMR server are also connected with 100Mbps Ethernet. The IHD server is connected to several AMR servers, and accesses directly many IHDs through the internet. Two types of IHD can be divided into IPTV-based IHD and Dedicated Terminal-based IHD. Electricity meters to measure the power usage are linked to the AMR server through 0.2Mbps RS-485 communication line. The AMR server gathers power usage information from each electricity meter and transmits the aggregated data to the IOMS. Fig. 1 describes interoperable networking with each heterogeneous IHD server and IOMS.

B. Implementation Requirement and Function

The IOMS sends TCP/IP protocol-based control to IHD server and receives communication messages from IHD server for collecting and saving the meter data. The IOMS collects meter data from heterogeneous IHD server periodically. The IOMS checks the status of heterogeneous IHD server. If the heterogeneous IHD server is off, the IOMS saves the status of the heterogeneous IHD server to the DB of IOMS and stops the collecting of meter data. After

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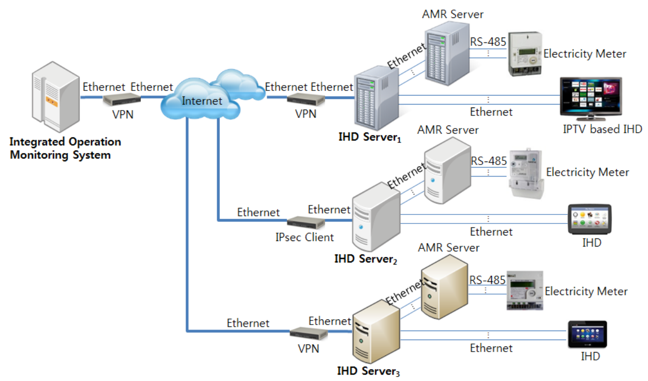

Figure 1. Interoperable Networking Configuration

that, if the status of heterogeneous IHD server is on, the IOMS collects and saves meter data again. In order to these functionalities of the IOMS, the following requirements must be met.

- Ethernet-based communication interface with IHD server must be satisfied.
- Meter data received from IHD server should be encrypted.
- Meter data of IOMS must be synchronized with that of IHD server.
- Scheduler must read meter data of IHD server periodically.
- In order to user-friendly meter data lookup, web-based user interface should be implemented.

To satisfy IOMS requirement, functional blocks can be divided into Network Layer, Data Processing/Management Layer and Data Presentation Layer. The Network Layer consists of TCP/IP-based data communication block for meter data collection and monitoring. The Data Processing/Management Layer consists of management engine block, analysis engine block and web service application server block. The Data Presentation Layer consists of operator web portal block for web-based user retrieval. Fig. 2 shows IOMS layered architecture.

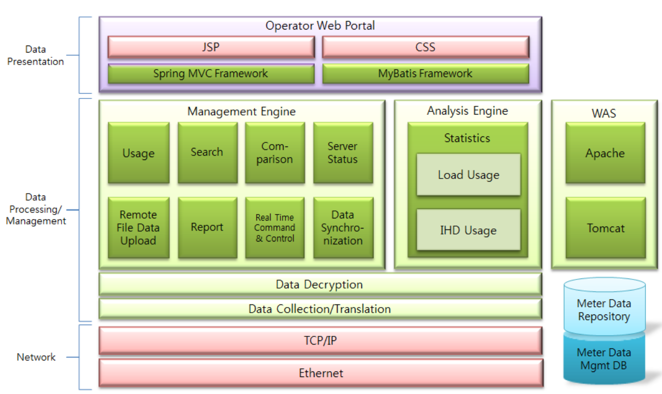

Figure 2. IOMS Layered Architecture

TABLE I. SEARCH CRITERIA ITEMS IN IOMS

Event Item	Event Time Zone	Load Usage	Energy Items	Search Period	Customer Number	Search Area
Selection	Hourly, Daily, Monthly, Yearly	Average, Maximum, Total	Electricity, Gas, Water	Hour, Day, Month, Year	Unique number of IOMS	The whole country
IHD Service	Current Month Charges, Monthly Charges, Hourly Statistics, Daily Statistics, Monthly Statistics, Daily-Monthly Usage, Annual Usage, Usage Comparison					

At first, the management engine block includes following meter data management functions: energy usage view and retrieval, which is decrypting the collected metering data and then stored in the meter data repository, comparison, business IHD servers status identification, file-based remote meter data upload, documenting for energy usage result and extracting to its report, and IHD usage. Secondly, the analysis engine block includes energy consumption statistics and IHD usage analysis. And finally, the web service application server block provides the meter data to web services. The Data Presentation Layer consists of user interface block for intuitively understanding graphs, provided by a java-based GUI in the local and remote meter data query, search, and comparison through the web.

Looking at the main features offered by the IOMS, the IHD server status identification function checks that all the IHD severs are basically connected on the network for collecting the meter data. If the IHD server makes an error during collecting the meter data of the IOMS, the IOMS attempts to resolve the status of the IHD server for three times at 10-second intervals. The IOMS recognizes the normal state of the IHD server if the IHD server responds to the IOMS during the checking of the IHD server status. However, otherwise, the IOMS recognizes abnormal state of the IHD server and should retry to check the status of the IHD server on every hour.

Energy usage search and query function retrieves related information, applied with meter data which were collected from the IHD server through various search criteria, and confirms the results of search query. Search criteria could be divided into search item, energy type item, period (hourly, daily and monthly), business and search region. In this point, we can select the item of “date”, “time zone”, “weekday” or “weekend + holiday” if want to look up the period as a time zone average usage. And we do not need the item of time zone if we want to look up the period as an average daily usage or an average monthly usage, but only can select the item of “date”, “weekday” or “weekend + holiday”. The items of search and lookup are shown in Table I.

The energy usage comparison function can compare the experimental group and the control group by setting the search criteria and selecting the item that we want to compare on the time zone, daily, monthly. The file-based remote meter data upload function provides meter data of a

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TABLE II. INTERACTIVE OPERATION ENVIRONMENT

Type	IOMS	IHD Server$_1$	IHD Server$_2$	IHD Server$_3$
OS	Windows Server	Linux Redhat	Windows Server	Linux CentOS
DB	MSSQL	Oracle	MSSQL	MySQL
VPN	IPSec VPN Server (HW)	IPSec VPN Client (HW)	IPSec VPN Client (SW)	IPSec VPN Client (HW)

missed section to the IOMS through web GUI by administrator directly among meter data that were collected from IHD servers.

From the items of search criteria, the administrator can also upload file-based meter data to the IOMS after confirming the missed section with selecting energy item, business, search period, and search region. The reporting function for documenting and extracting the results of energy consumption supports easy documentation, analysis from remote client, and energy meter data lookup in the web with search criteria. According to these search criteria, the energy usage statistics function provides analytical data, which can be used for analysis of various results, with identifying the information about the energy average usage, the energy peak usage and the consumption total energy. The IHD usage statistics function supports the ability to analyze the IHD utilization level of customer from current month price lookup, monthly fee views, hourly statistics, daily statistics, monthly statistics, daily usage inquiry, monthly usage inquiry, annual usage inquiry, and usage comparison.

The Operator web portal block using JSP user interface also provides users with location-based graphic UI of AMR server and IHD server depicted as Fig. 3. Operation

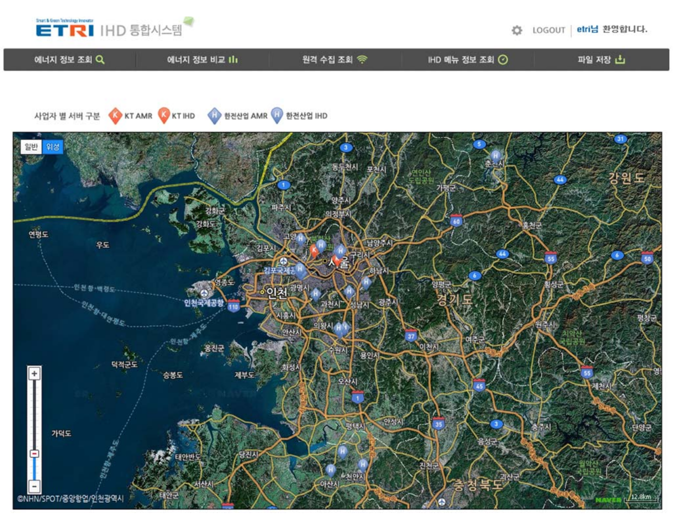

Figure 3. Location-based UI of AMR server and IHD server

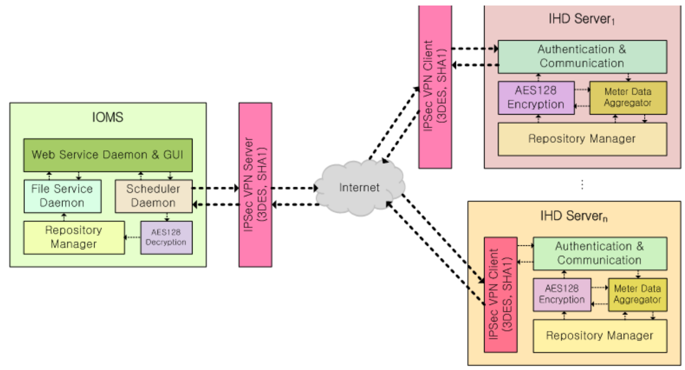

Figure 4. Secure Internetworking Architecture for Metering Data

environments of each heterogeneous IHD server to interact with IOMS are depicted as Table II.

C. *Secure Internetworking Architecture*

The IOMS is connected to all the IHD server through VPN tunneling. The IPSec VPN server is installed on the external network side of the IOMS and The IPSec VPN client is installed on the external network side of the IHD server. In other words, the IPSec VPN hardware-based client is installed in front of some IHD server and the IPSec VPN software-based client is installed in the rest internal IHD server. Therefore, the VPN tunnel must be formed between the VPN server and the VPN client if we want to complete the VPN connection between the IOMS and the IHD server. The VPN tunnel is formed if the encryption key value is matched between the VPN server and the VPN client after the encryption key value is exchanged between VPN server and the VPN client. When the VPN tunnel is established, the authentication is completed through Secure Hash Algorithm 1 (SHA1) between the VPN server and the VPN client and the data is encrypted with 3 Data Encryption Standard (3DES) between the IOMS and the IHD server. We are considering the security aspects for collecting the metering data from the public network via the IHD server. This means that we need to collect the metering data from the public network via the IHD server in aspect of security. In addition, the metering data of all the IHD server is encrypted with Advanced Encryption Standard (AES 128) in order to protect more securely. Therefore, the metering data is encrypted with AES 128 in the IHD server and the encrypted data is re-encrypted to 3DES in VPN, and finally the re-encrypted data is delivered to the IOMS. The Fig. 4 shows the secure internetworking architecture for collecting the metering data.

D. *Data Internetworking Procedure*

The VPN-based data flow for collecting and saving the metering data between the IOMS and the IHD server is depicted as Fig. 5. At first, the VPN tunneling is negotiated and established between the VPN server and the VPN client. Then, the VPN tunnel is completed between the IOMS and

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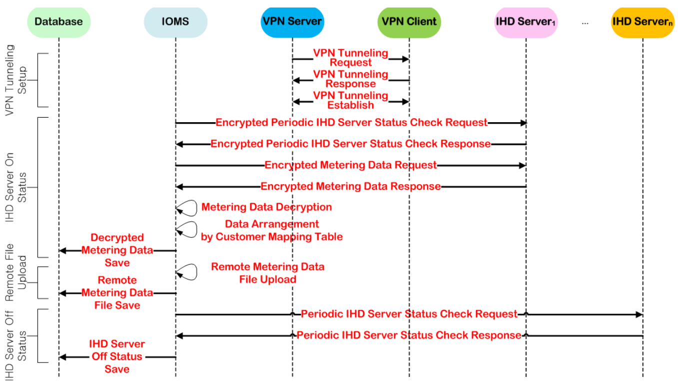

Figure 5. Data Flow of VPN-based Metering Data Gathering and Save

the IHD server. The IOMS also identifies the IHD server status periodically through VPN tunnel and collects and saves the metering data to the DB. The metering data collected from the IHD server decrypts the encoded data due to encryption of the metering data, and because subscriber numbers are different from each IHD servers, the metering data is stored in the DB after converting into the unique subscriber numbers. Among the metering data collected from the IHD server, we upload the missed meter data with file format through the web GUI of the IOMS, and manage and save the missed metering data. Additionally, when the IHD server is off state, the IOMS saves its state in the DB and stops collecting metering data.

III. ENERGY CONSUMPTION ANALYSIS

In this part, we monitor meter data through IOMS and analyze the power consumption patterns in according to usage of heterogeneous IHD. The consumer uses the IHD for identifying the energy usage information. So the IHD function is inducing energy saving actively. From this perspective, we expected different energy saving rate in according to these energy information display infrastructure. So we distinguished IPTV-based IHD (IIHD) from Dedicated Terminal-based IHD (DIHD) by information display infrastructure. Mandatory information is the same in all IHD, but optional information may be different depending on the type of terminal.

In case of Apartment on a weekday in 2012, we analyzed the hourly average power consumption. But in case of Commercial Building and Apartment-type Factory, we only analyzed the hourly average power consumption pattern. The customers of the number of 19,720 were participated in the survey for the Apartment, and the customers of the number of 2,780 and 4,000 were involved in the survey respectively for the Individual Commercial Building and the APT-type Factory. Table III represents the hourly power consumption in the Apartment between the experimental group of the IIHD and the control group of the DIHD.

As a result, the average daily power consumption per household is 10 kWh. Fig. 6 describes load profile of hourly average power consumption of apartment in case of IIHD

TABLE III. HOURLY POWER CONSUMPTION BETWEEN EXPERIMENTAL GROUP AND CONTROL GROUP

Type / Time (Hour)	Hourly Power Consumption (kWh)				
	Experimental Group				Control Group
	$IIHD_1$	$IIHD_2$	$IIHD_3$	$IIHD_4$	$DIHD_5$
1	0.56	0.61	0.56	0.56	0.42
2	0.46	0.48	0.46	0.45	0.34
3	0.37	0.4	0.38	0.37	0.29
4	0.32	0.35	0.34	0.32	0.26
5	0.3	0.33	0.33	0.3	0.26
6	0.3	0.3	0.32	0.3	0.25
7	0.31	0.32	0.34	0.3	0.29
8	0.38	0.38	0.41	0.37	0.37
9	0.49	0.51	0.51	0.46	0.43
10	0.5	0.49	0.51	0.49	0.43
11	0.45	0.46	0.48	0.44	0.39
12	0.41	0.42	0.43	0.42	0.36
13	0.39	0.4	0.41	0.39	0.36
14	0.39	0.37	0.38	0.38	0.36
15	0.37	0.38	0.37	0.39	0.35
16	0.37	0.36	0.37	0.38	0.35
17	0.39	0.38	0.38	0.42	0.39
18	0.43	0.41	0.4	0.43	0.43
19	0.48	0.46	0.46	0.48	0.46
20	0.56	0.54	0.56	0.54	0.53
21	0.61	0.63	0.63	0.57	0.55
22	0.63	0.66	0.63	0.61	0.58
23	0.66	0.65	0.65	0.6	0.58
24	0.64	0.64	0.64	0.6	0.54
Mean	0.45	0.46	0.46	0.44	0.40
Total	10.77	10.93	10.95	10.57	9.57

and DIHD. As we can identify this graph, households using DIHD reduce more 0.05 kWh than that of households using IIHD. This result implies as follows. The more the customer is exposed to the energy usage information, the more the energy saving consciousness can be affected. In other words, DIHD provides energy usage information during 24-hour-a-day, but IIHD provides energy usage information during watching TV. Therefore, we can expect to provide the motivation to participate in active energy savings in case of using DIHD.

And energy saving factors can be considered as the method of information and the time of information. In this paper, we focused on the comparative analysis of the heterogeneous IHD users and Korean Style Residential Buildings. However, for the qualitative analysis, we will study the research topic of comparative analysis issues between metering data and questionnaire survey. In other words, in order to gain some qualitative insight from collected metering data, we will study the energy saving index through conducting a survey of participants.

As shown in Fig. 7, for the seasonal hourly average power consumption among the weekday, we can see that the apartment residents who use the IHD consume more 1.7 kWh in the summer than compared to other seasons with the average daily power consumption. Due to using the air

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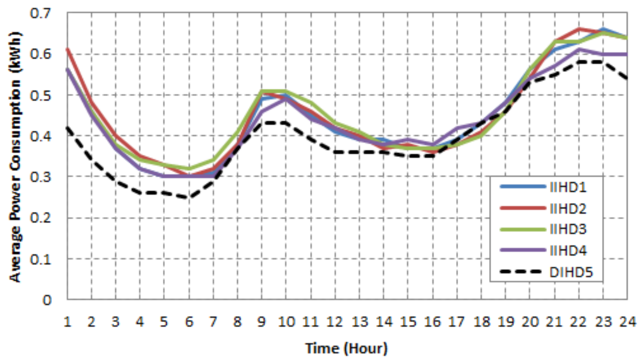

Figure 6. Hourly Power Consumption Load Profiles among Heterogeneous IHDs

conditioning in the summer, we can see that the power consumption in the summer compared to the other seasons will be used more.

Also, we compared the hourly average power consumption among the DIHD-based APT, the DIHD-based APT-type Factory and the DIHD-based Individual Commercial Building. Because the APT-type Factory and the Individual Commercial Building use only DIHD, we cannot compare directly the DIHD and the IIHD. Thus, depending on the type of each building, we are about to distinguish the intuitive difference from the hourly average power consumption. As shown in Fig. 8, in case of the APT-type Factory, the hourly average power consumption is approximately 5 times more than that of the Apartment. And in case of the Individual Commercial Building, we know that the hourly average power consumption is approximately 6 times more than that of the Apartment. In addition, the APT-type Factory consumes more 3.21 times than that of the Apartment in terms of the average daily power consumption and the Individual Commercial Building consumes more 3.42 times than that of the Apartment in terms of the average daily power consumption.

In future research, we will analyze the energy saving rate using DIHD through the power statistical reports of the APT-type Factory and the Individual Commercial Building.

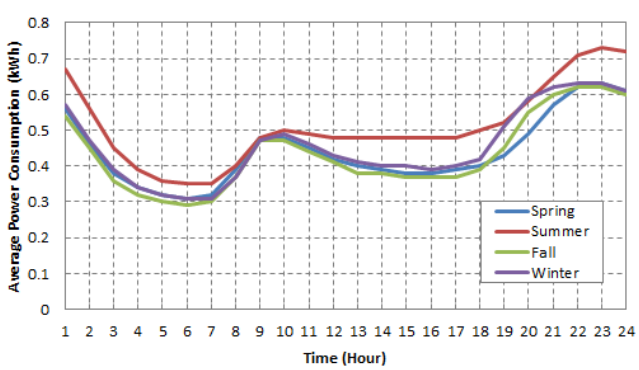

Figure 7. Hourly Power Consumption Load Profiles for Seasonal among Apartment Residents

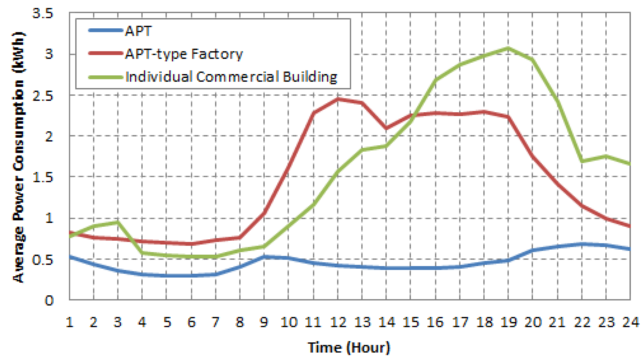

Figure 8. Hourly Power Consumption Load Profiles among Korean Style Residential Buildings

IV. CONCLUSION AND FUTURE WORK

In this paper, we designed the IOMS layered architecture, and developed IOMS to interact with Heterogeneous IHD server. The IOMS monitors energy usage information from the Korean style residential building which is installed with Heterogeneous IHD, and collects energy usage information. When we analyzed energy usage information patterns in IOMS, we found that the increasing frequency of information providing of the energy consumption is proportional to the energy savings. Therefore, we concluded that the method of information and the time of information as well as seasonal factors, residential building types are important factors in energy saving effectiveness through this study.

For future study, we will analyze a wide variety profile-based energy usage pattern of Korean style residential building type and will research the correlation of energy saving effectiveness through comparative analysis between non-IHD user and IHD user.

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