Feasibility Study on the Use of HEMS for Thermal Comfort and Energy Saving in Japanese Residential Buildings

K. C. Rajan, H. B. Rijal, Kazui Yoshida, Masanori Shukuya

***Abstract*—**The electricity consumption in the Japanese household sector has increased with higher rate than that of other sectors. This may be because of aging and information oriented society that requires more electrical appliances to make the life better and easier, under this circumstances, energy saving is one of the essential necessity in Japanese society. To understand the way of energy use and demand response of the residential occupants, it is important to understand the structure of energy used. Home Energy Management System (HEMS) may be used for understanding the pattern and the structure of energy used. HEMS is a visualization system of the energy usage by connecting the electrical equipment in the home and thereby automatically control the energy use in each device, so that the energy saving is achieved. Therefore, the HEMS can provide with the easiest way to understand the structure of energy use. The HEMS has entered the mainstream of the Japanese market. The objective of this study is to understand the pattern of energy saving and cost saving in different regions including Japan during HEMS use. To observe thermal comfort level of HEMS managed residential buildings in Japan, the field survey was made and altogether, 1534 votes from 37 occupants related to thermal comfort, occupants' behaviors and clothing insulation were collected and analyzed. According to the result obtained, approximately 17.9% energy saving and 8.9% cost saving is possible if HEMS is applied effectively. We found the thermal sensation and overall comfort level of the occupants is high in the studied buildings. The occupants residing in those HEMS buildings are satisfied with the thermal environment and they have accepted it. Our study concluded that the significant reduction in Japanese residential energy use can be achieved by the proper utilization of the HEMS. Better thermal comfort is also possible with the use of HEMS if energy use is managed in a rationally effective manner.

***Keywords*—**Energy reduction, thermal comfort, HEMS market, thermal environment.

I. Introduction

THE challenge of modern society is to save energy and to use energy in an effective way for sustainable energy use. In one hand, high energy use for modern appliances is increasing the scarcity of energy for our future generation and in other hand it has been degrading the environmental quality. Currently, different systems like BEMS, FEMS etc. have been applied for effective energy management. HEMS is one of the energy management systems that have been practiced in residential houses in different regions. HEMS is a visualization of the energy usage by connecting the electrical equipment in the home. It is a system to control smart home appliances by computers. HEMS is categorized for each function [1]. If we choose poor application HEMS (only energy consumption monitoring), the consumption energy is small, but if we choose rich application such as human motion tracking or continues data acquisition, it needs more energy [1]. HEMS is never influenced by common people because of high initial cost, location dependence and personal unconcern for energy saving.

The global HEMS revenue market was 1.5 billion USD in 2013 which increased by 1.7 times by the end of 2015 [2]. It has been expected to reach 4100 million USD by the end of 2017. The HEMS sector is growing rapidly [3]. The rapid expansion of HEM market and the desire for increasing levels of interoperability between the products and platforms has led to the emergence of new types of communication protocols and alliances [3]. Different companies have been providing their HEMS services and products all over the world. From the government to service providers, all are working effectively to make HEMS effective wherever it has been practiced.

The HEMS concept has entered to Japanese market since 2008 [2]. On 1st April 2011, KDDI, Sharp and many other Japanese electrical companies made an alliance in order to rapidly lunch HEMS businesses [4]. In September 19, 2012, Energy and Environment Council Japan articulated HEMS policy [4]. From 2008 to 2020 the growth rate of HEMS and BEMS has been estimated to increase by 48% [2]. The government of Japan aims to set up HEMS to all of the new dwelling by 2030 [2]. HEMS have gained the support of Japanese government, including the issuing of subsidies, following the earthquake of 2011. As of 2015, it is estimated that twenty thousand HEMS have been introduced to individual homes in Japan [5]. The interview result of the participants showed that HEMS is indeed a broader market these days, one with a number of viable subsectors forming [6].

The effectiveness of HEMS has been evaluated by many researchers but most of the research pointed out the usefulness of HEMS. The behavioral and psychological side of HEMS users has been ignored in most of the researches. The energy and cost saving percentage of HEMS varies in different places [5], [12]-[17]. It is the concern of all of us to understand the reason of this energy saving percentage variation. It was found that HEMS are less effective. Recently, research has started to explore not only the saving but also the role that the design of

Mr. KC Rajan is a Ph.D. student of Graduate School of Environmental and Information Studies, Tokyo City University, Japan (Phone: +81-45-910-2616, e-mail: rkcrajan@gmail.com).

Dr. Rijal H.B., Assoc. Professor, and Dr. Shukuya Masanori, Professor, are in the Department of Restoration Ecology & Built Environment, Tokyo City University, Japan (e-mail: rijal@tcu.ac.jp, shukuya@tc.ac.jp).

Mr. Yoshida Kazui is Senior Researcher in Tokyu Fudosan Next Generation Engineering Center Inc., Japan (e-mail: kazui_yoshida@tokyu-land.co.jp).

HEMS has on their effectiveness and their ability to effectuate behavior change [7].

Very few studies have focused the behavioral influence in HEMS [3] [8]. They have pointed that the behaviors of the users have influenced the HEMS. The global adoption and implementation of energy management technology, the coherent and steady involvement of consumers is required for the successful use of available technology. The changing behaviors of the consumers are always the challenge for the proper implementation of HEMS [8].

To support the extension of electricity monitoring and effective implementation of HEMS, convincing design models should be created to target major factors which would appeal to consumers towards saving money and environmental impacts. With the visualization of the energy use some occupants feel empowered to take action to reduce their energy use with an increased sense of control given the knowledge of their usage. Other users feel despondent and fatalistic that their contribution was futile in the larger social and environmental contexts [8]. This fact implies that having users, saving electricity usage and sustainable energy reduced level may not be in linear relationship. Some special measures should be taken for the effectiveness and sustainable energy reduction. Most of the smart home users prefer smart thermostats for controlling the energy use. In some studies, pre-trial baseline consumption measurements are made [7]. HEMS are installed and meters are read after a specific time period the meters are read and HEMS uninstalled. The two readings are subtracted with each other [7]. In some cases, the savings are calculated over a limited period of time. The following measures might be required to encourage the sustainable, preventive behaviors of energy reduce.

1. Human behaviors should be influenced to increase the interest in such an energy visualization system so that the users determine for energy reduction and adopt different behaviors for energy saving.
2. The concern to environmental issues and normal electricity usage should be increased. Generally, people are less concerned to environmental issues and participating less in normal electricity use activities. It is important to increase the people's participation for environment related activities so that they could understand how excessive use of electricity is degrading the environment.
3. The technical aspects of HEMS devices deployment and implementation should be made accessible to common people. The users may not use the provided system due to lack of the knowledge like handling the devices. So the technical knowledge of using the system and handling the devices should be focused. The service provider should focus to provide the information in an easy way.

One of the essential topics with energy management is thermal comfort. Thermal comfort is the satisfaction of the mind with thermal environment [9]. As people use different electrical appliances to increase the comfort. How thermal comfort can be maintained with less energy use is important to be analyzed. The knowledge of adaptive behaviors that people do to maintain thermal comfort with less energy use might be useful for better energy management in the future. Generally, using HEMS, the excessive use and the waste can be easily seen, it helps people to manage the power saving. By HEMS device the indoor temperature can be controlled so it is also a better tool for creating comfortable indoor environment and adjust the thermal comfort. But there are few researches done to understand the thermal comfort level of the occupants with HEMS management. Occupants' behavior is different according to the building types [10]. It is important to understand the thermal comfort level of the occupants especially when they are living in the smart houses for proper management of smart houses in coming days [11].

Our objectives in this paper are to review energy saving and cost saving under HEMS and to discuss the activities carried out for energy saving and cost saving during HEMS use. We will also observe the thermal comfort level and the occupants' behaviors of the HEMS managed buildings. Our results might be fruitful to the building designers to design more comfortable homes and HEMS service providers to make HEMS more effective in the days to come.

II. Methodology

A. Surveyed Building

Residential building as shown in Fig. 1, located at Katsushima Tokyo with their floor plan as shown in Fig. 2 was selected to understand the level of thermal comfort of the occupants' behaviors residing in the building. This building is facing south with beautiful view around. This survey is conducted among the dwellers of Katsushima building only. The building was selected to understand the level of thermal comfort because this building is brought in use for 356 families with HEMS management since November 2015. The studied HEMS managed residential building has been constructed with the concept of low energy use and energy saving concept. The ENE-FARM for condominiums was adopted in Katsushima building for the first time in the world.

The "ENE-FARM" fuel cell co-generation system generates electricity through a chemical reaction between oxygen in the atmosphere and hydrogen extracted from gas, which is used at home. The heat generated as a byproduct of this process is also used for hot water supply. This system is eco-friendly as the electricity is generated and used in same location, leading to no loss during transmission [18].

B. Thermal Measurement

The device as shown in Fig. 3 has been installed to every resident dweller on a table nearly 1 m above the floor which records indoor temperature, relative humidity and luminance and sends to the cloud. The outdoor temperature has been taken from the nearest Japan Meteorological to observe the change occurred in the clothing insulation conditions with outdoor temperature variation.

Fig. 1 Surveyed building

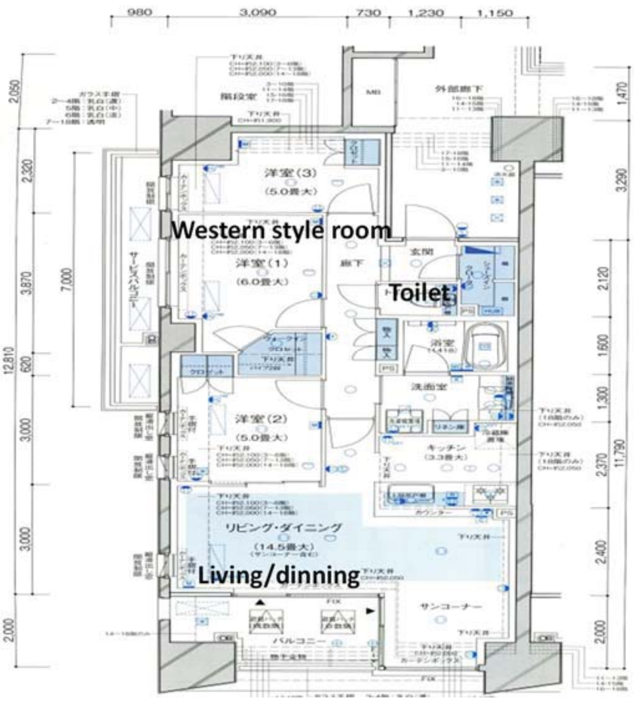

Fig. 2 Floor plan of the studied buildings

Fig. 3 Indoor temperature, relative humidity and illuminance measuring device

C. Thermal Comfort Survey

A questionnaire related to thermal sensation, thermal satisfaction and overall comfort was provided to every resident dweller to understand the level of thermal comfort of the occupants and the votes were collected online. Altogether 1534 votes were collected from 18 females and 19 males form the age groups 15-64 in the month of November 2015. Votes related to occupants' behaviors and clothing insulation were also collected. The collected data was classified according to their nature related to thermal comfort and behavior separately and analyzed. To know the wide range of thermal condition of the study area, a thermal comfort scale as shown in Table I, was used for the survey. The meaning, relationship, and the evaluation method of the questionnaire were clearly detailed to the dwellers of the building in advance to obtain the data accurately and remove any types of confusion related to the questionnaire in details.

TABLE I
THERMAL COMFORT SCALE

Scale	Thermal sensation	Thermal satisfaction	Overall comfort
1	Very cold	Very unsatisfied	Very uncomfortable
2	Cold	Moderately unsatisfied	Moderately uncomfortable
3	Slightly cold	Slightly unsatisfied	Slightly uncomfortable
4	Neutral	Slightly satisfied	Slightly comfortable
5	Slightly hot	Moderately satisfied	Moderately comfortable
6	Hot	Very satisfied	Very comfortable
7	Very hot		

III. RESULTS AND DISCUSSION

A. Energy Saving and Cost Saving under HEMS

It is obvious that HEMS is one of the important and effective tools for energy saving, cost saving and to maintain indoor environment as the electrical devices can be controlled. But the amount of energy saving from HEMS is not same in different areas. Different journal papers, conference papers are reviewed and the data are collected to understand energy saving and cost saving in different regions including Japan while using HEMS. The mean cost saving percentage was taken if the cost saving percentage was between two ranges and overall percentage of energy saving and cost saving was calculated. Table II shows that different researches showed the amount of energy saving and cost saving differently. Different concept and methods are applied with proper time management to achieve energy saving and cost saving. The automatic device control system showed significant energy saving [14] but the behavioral factors of the users resulted effective use of HEMS [8], [13], [16]. Our study shows mean energy saving 17.9% and mean cost saving 8.9%.

The reason for energy saving and cost saving variation in Table II is important to be analyzed for the effectiveness of HEMS in coming days and to bring the uniformity in the percentage of energy saving and cost saving. The researches have been conducted in different areas and in different seasons with short and long studies. A preliminary factor for the successful implementation of smart grid technology is changing consumer behavior towards adopting smart grid technology and leveraging it to its full potential [8]. The achieved savings decrease over time [7]. Some measures can be taken to bring uniformity in the way of electricity use and change the behaviors towards energy saving focusing the occupants' behaviors. Social media may be useful to increase the user involvement. The role of social media cannot be underestimated and needs to be researched further, particularly as the consumer community grows over time to include more individuals who have had life-long constant exposure to social media [8]. Electricity is used by all people from different demographic. Especially, it is regulated and operated by adults in homes as well as in commercial areas. So, adult from one home should be taken as target consumer including HEMS users. Special policy from the government as well as concern authorities should be applied to involve every target in the activities for providing technological knowledge and environmental knowledge so that they could deliver that knowledge to change the behaviors of other members at homes.

TABLE II
LITERATURE REVIEW OF ENERGY SAVING AND COST SAVING

No	**References**	**Place of study / Studied samples/ Studied period**	**Method / Concept**	**Energy saving (%)**	**Cost saving (%)**	**Identified activities for energy and cost saving**	**Remarks**
(1)	Ueno et al. 2006 [13]	Japan / 9 residential houses / 2 months	Household survey / Energy Consumption Information System (ECOIS) was developed to display the power use.	9	-	1) Energy saving activity such as change in the use of heating appliances was carried out. 2) Due to awareness provided the pattern of television use was changed. They were conscious to power off when not in use. 3) Refrigeration capabilities were adjusted. The disconnection of the appliances was increased when not in use. 4) The hours of keeping warm the rice cooker after boiling rice was reduced.	City gas and kerosene consumption for heating was not measured.
(2)	Yang 2013 [14]	Taiwan / 8 months	Experiment method / Web-service-based Information Agent System (WIAS) was developed and the consumers can easily get the complicated information service as well as the tips to change the behaviors like "Change the light, change the behavior", " Don't leave things turned on".	22.44	-	1) The devices are automatically controlled, the sensors laid out decides whether air conditioning should operate fan or compressor. If the temperature is over 28 °C, the compressor turns on. If the humidity or CO2 increased compressor turn off and fan turn on. 2) If the lighting value is high, the lights would be turned off one by one around the outer circle.	Automatic device control system was noticed as one of the efficient way to reduce energy because the energy saving is high.
(3)	Ito and Nishi 2013 [15]	Japan / A typical house in Japan / 5 days in November	Experiment and observation method / HEMS was installed	20	-	Real time management for HVAC control reduces power use without interfering with environmental amenity.	-
(4)	Iwafune & Yagita 2016 [5]	Japan / 532 detached houses and 208 apartment types houses / 1 year	Household survey / Household characteristics on electricity consumption	20	-	1) Use of electric central air conditioning for heating and cooling was noticed as the main cause of high electricity consumption so non electric space heating used to reduce the energy. 2) Use of LED light also reduced electricity than incandescent or fluorescent lamps.	-
(5)	Ruth et al. 2015 [12]	US (southeast) / 20 well insulated houses / 1 month (summer)	Simulation method	-	5	Power use time has been shifted from peak hours to less expensive times so that the house can be pre-cooled before peak electricity price.	The electricity expenses varied because of variations in desired temperature and their profiles between homes.
(6)	Rastegar 2016 [16]	Canada / Users, customers and utility company	Interaction method / A price based HEM framework is designed. 2 cases are determined and mathematical optimization models are used.	-	12	1) Appliances are categorized into controllable and uncontrollable and the consumption level of these appliances is controlled. 2) The lower limit use of the devices was focused. 3) The plug-in hybrid electric vehicle (PHEV) batteries are charged in low tariff time and discharged at high tariff time.	Period of study is not mentioned.
(7)	Abushnaf et al. 2015 [17]	Australia / Residential hourly loads data collected by National Energy Modeling System / 1 year	Simulation method / Demand Response (DR) program is used to simulate the energy use reduction minimizing inconvenience to the consumption.	-	9.8*	The system decides the request to run appliances according to the priorities. Once the priority is listed HEMS decides to shift the time of use or switch off certain appliances.	-
Overall Mean Saving				**17.9**	**8.9**		

* The mean percentage has been taken from the lowest 7.8 % in winter and the highest 11.8 % in summer.

It was found that the energy saving action once performed did not last long since the consumer's comfort reduced [13]. It is important to analyze how interested each consumer is in the power consumption of each appliance and how these interests change over time. Some apps can be added with energy management software that could attract or motivate people towards regular use of the system. For example, if some health related apps are included which could provide tips to the users to remain healthy and fit, they could use it regularly. As smart grids continue to be developed worldwide, an interface to communicate more detailed energy information is becoming readily available for an increasing amount of homeowners [8]. The bias towards saving money was identified as pivotal extrinsic factors in participants' self-reported app adoption motives. So HEMS should be developed into adoptive technology which could lead the sustainable behaviors of the users towards energy saving. Then only, HEMS use seems to be uniformly.

B. Thermal Sensation

The mean sensation is 3.72 on 7 point sensation scale as shown in Table I. Out of 1534 votes, around 1100 votes feel neutral at the moment of voting as shown in Fig. 4. The result clarifies that the dwellers are satisfied with the thermal sensation of the buildings. Even though the dwellers of the building used heating and cooling in some conditions but it can be said that the thermal sensation level of the studied buildings is high. The thermal environment under HEMS management shows the thermal sensation level of the occupants is high.

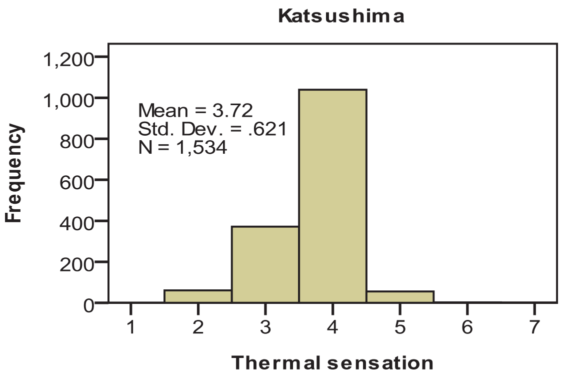

Fig. 4 Thermal sensation condition of the studied building

C. Thermal Satisfaction

To evaluate the thermal satisfaction of the study area, we had offered a questionnaire of 6 points scale. From Fig. 5, it can be assumed that dwellers are achieving thermal satisfaction. In some situations, they have been using different appliances and modes of ventilation like opening the window or internal door. Under HEMS management the environment seems comfortable. The dwellers were able to control the indoor temperature using HEMS. The report shows that they have achieved this satisfaction by adopting some behaviors like changing clothing to adjust their thermal satisfaction as well. Very few seem unsatisfied with the thermal environment. Though the cause has not been analyzed yet but it might be because of the body condition to adjust thermal heat or cold. Another reason might be the age difference. Regarding to age, we had provided the option of different age groups. The minimum age group was 15-19 years and the maximum age group was 60-64 years. The highest voters were from the age group 25-29 years. Maybe, higher aged citizens have felt colder in comparison to the young ones. Especially, the age group from 50 to 64 years voted slightly unsatisfied in thermal satisfaction scale.

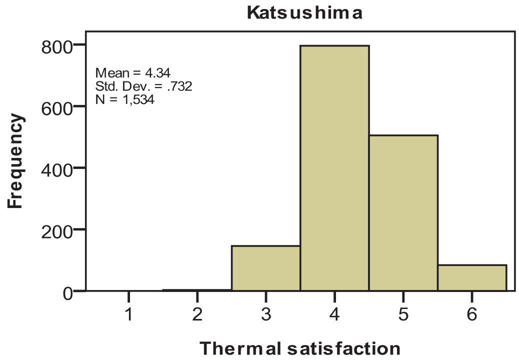

Fig. 5 Thermal satisfaction conditions of the studied building

To evaluate the feeling of the dwellers about the thermal environment, we had also taken their cognitive temperature and temperature setting. Fig. 6 shows the differences between their guess temperature and temperature setting. Their cognitive temperature was lower than temperature setting. We found that the dwellers are slightly unknown about indoor temperature.

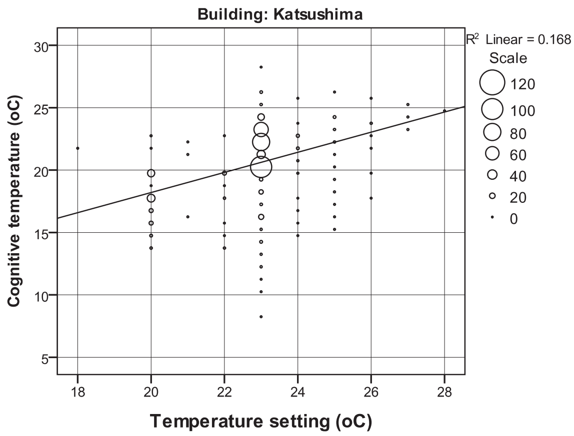

Fig. 6 Relation between cognitive temperature and temperature setting

D. Overall Comfort

The mean overall comfort is 4.32. According to the thermal comfort scale as shown in Table I, the highest votes are feeling slightly comfortable as shown in Fig. 7. Around 500 votes voted 5 which is slightly uncomfortable. The reason could be the slightly changing outdoor environment towards winter. The overall comfort result showed that the occupants prefer slightly warmer environment.

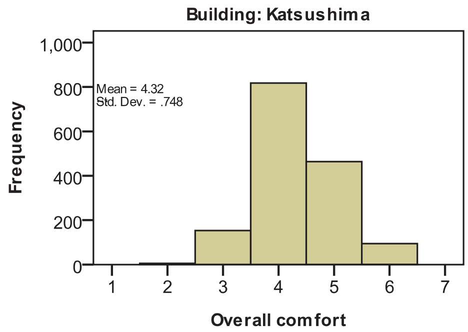

Fig. 7 Overall comfort distribution

E. Clothing

The mean with 95% confidence interval diagram in Fig. 8 shows the difference in clothing pattern of male and female of the study area. Females seem using slightly thicker than males. The mean clothing of the male was 0.69 clo whereas the mean clothing of females was 0.79 clo. There is significant difference of 0.1 clo between male and female clothing insulation. The reason might be the female seem more sensible to the environment than male. The time spent for exercise of male is slightly higher than female. The mean clothing insulation value at the end of the November seems slightly increased than the beginning of the month. The result showed that the building dwellers slightly increased the insulation with the decreasing outdoor temperature.

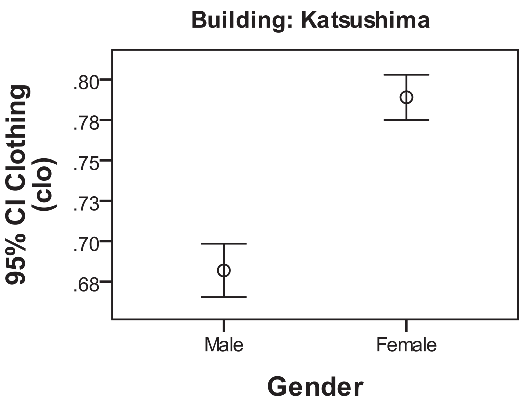

Fig. 8 Clothing insulation male and female

IV. Conclusions

From the review of the previous researches done on the HEMS and energy management, the present status of global HEMS market and the increasing scope of HEMS globally and in Japan were observed and also the thermal comfort level of HEMS-managed residential buildings located in Tokyo Japan was identified. We obtained the following result from this study;

1. It has been understood that energy saving and cost saving is possible with the use of HEMS in buildings. In HEMS buildings so far 17.9 % of energy saving and 8.9% of cost saving is possible if it is effectively applied.
2. HEMS developed so far is not strong enough to focus the behaviors of the occupants so that there is not uniformity in energy saving between the HEMS users. Some apps related to the behaviors should be included with HEMS in the future.
3. The thermal comfort level of HEMS managed residential buildings located in Tokyo was satisfactory and the occupants have accepted the thermal environment under HEMS management.
4. There was a significant difference between male and female clothing insulation. The difference was 0.1 clo. The female clothing was higher than male.

Acknowledgment

We would like to thank all the researchers whose report we have used and to all the dwellers of the investigated HEMS managed building at Katsushima.

References

[1] T. Yoshikawa, "Novel concept for HEMS apparatus", *Energy Procedia,* vol. 14, 2012, pp.1273-1279.
[2] Transparency Market Research's new market research report, "Home energy management systems market - global industry analysis, size, share, growth, trends and forecast 2013 – 2019", 2015.
[3] B. Karlin, R. Ford, A. Sanguinetti et al. "Characterization and potential of Home Energy Management (HEM) technology", Pacific Gas and Electric Company report, January 20, 2015.
[4] Marketing Handouts of HEMS Alliance, Institute of Industrial Science, "Creating Fascinating HEMS Apps", 2013, the University of Tokyo.
[5] Y. Iwafune, Y. Yagita, "High-resolution determinant analysis of Japanese residential electricity consumption using home energy management system", *Energy and Buildings*, vol. 116, 2016, pp.274-284.
[6] K. Bojanczyk, "Redefining home energy management systems", GTM research report, 2013.
[7] S. S. van Dam, C. A. Bakker, J. C. Buiter, "Do home energy management systems make sense? Assessing their overall lifecycle impact", *Energy Policy,* vol. 63, 2013, pp. 398-407.
[8] P. Morreale, J. J. Li, J. McAllister, S. Mishra, T. Dowluri, "Mobile Persuasive Design for HEMS Adaptation", *Procedia Computer Science,* vol. 52, 2015, pp.764-771.
[9] ASHRAE Standard 55 2004. "Thermal environment conditions for human occupancy", Atlanta, Georgia, American Society of Heating Refrigeration and Air-conditioning Engineers.
[10] H. B. Rijal, M. Honjo, R. Kobayashi and T. Nakaya, "Investigation of comfort temperature, adaptive model and the window-opening behavior in Japanese houses", *Architectural Science Review*, vol. 56, 2013, pp. 55-58.
[11] R. KC, H. B. Rijal, Y. Kazui, "Investigation of thermal comfort and clothing insulation in HEMS managed residential building", AIJ Conference (Kanto), 2016, pp. 209-212.
[12] M. Ruth, A. Pratt, M. Lunacek, S. Mittal, H. Wu, W. Jones, "Effects of home energy management systems on distribution utilities and feeders under various market structures", International Conference on Electricity Distribution, 2015.
[13] T. Ueno, F. Sano, O. Saeki, K. Tsuji, "Effectiveness of an energy-consumption information system on energy saving in residential houses based on monitored data", *Applied Energy,* vol. 83, 2006, pp.166-183.
[14] S.-Y. Yang, "A novel cloud information agent system with web service techniques: Example of an energy-saving multi-agent system", *Expert system with applications*, vol. 40, 2013, pp. 1758-1785.
[15] M. Ito, H. Nishi, "A practical case study of HVAC control with MET measuring in HEMS environment", Department of system design, faculty of science and technology report, Keio university, 2013, pp. 223-8522
[16] M. Rastegar, M. Fotuhi-Firuzabad, H. Zareipour, "Home energy management incorporating operational priority of appliances", *Electrical Power and Energy Systems,* vol. 74, 2016, pp. 286-292.
[17] J. Abushnaf, A. Rassau, W. Gornisiewicz, "Impact of dynamic energy pricing schemes on a novel multi-user home energy management system", *Electric power systems research,* vol. 125, 2015, 124-132.

[18] Panasonic Newsroom Global (Headquarters News), "World's first "Ene-Farm" home fuel cell for condominiums to be released", October 21, 2013.

K. C. Rajan is a Ph.D. 1st year student of Tokyo City University, Yokohama Campus. Currently, he is doing research on thermal comfort and occupants' behaviors in HEMS managed residential buildings in Japan under the supervision of associate professor Dr. Hom Bahadur Rijal. He completed his Masters in 2007 from Tribhuvan University, Nepal in Sociology and Anthropology. He had a research on festivals of Tharu community for Masters Level in 2009. After his Master's Degree from Thibhuvan University, DAV Sushil Kedia Vishwo Bharati higher secondary school in Kathmandu. He also worked as a Research officer in Rural Community Health Centre Kavreplanchok. Then after, he came to Japan for his further studies in 2013.