Use Cases for Analysis and Energy Effect Based on Energy Management System for Solar Energy at Home

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Abstract— **Generally, home energy management system (hereinafter "HEMS") provides energy management consulting service of environment based on digital home environments, and defines the essential requirement. It also provides the guideline of the related technology development and infrastructure. In this paper, we describe the architecture of HEMS and suggest economic analysis and energy conservation effect with the introduction of green home energy management platform in testbed.**

Keywords-Home Energy Management System; Energy Analysis; Energy Conservation Effect

I. INTRODUCTION

The introduction of Smart Grid to the home caused promoting itself to zero-energy management technology and the built-environment related technology development, thus making the management of climate change possible and attaining improvement for the quality of life for citizens. The government provides 1 million green homes by 2018 by supporting the public housing corporation's annual target of 100,000 green homes between 2009 and 2018 and reducing energy consumption in the residential sector by 30% [1].

We develop the home energy management system (HEMS) type of platform for green home, which is composed of home clients (server) and operation (complex home) server. The energy management platform technology for green homes monitors and controls all detailed energy usage to provide an efficient energy management function, which reduces carbon-emission from the house by optimizing the energy consumption such as electric consumption in the home. The aim of the technology is to achieve no-carbon emission in the home, which is based on interfacing the home area network and service and includes IT convergence hardware and software technologies. It consists of an integrated monitoring interface module and energy management framework technologies which provide functions for green energy management, remote energy control, and energy service management.

Testbed for Zero Carbon Green Home located in Korea Institute of Construction Technology (KICT) is R&D project with Electronics and Telecommunications Research Institute (ETRI) and Korea Institute Energy Research (KIER). Testbed is being constructed to conserve energy by active energy technologies (energy management system, renewable energy, etc.) and passive energy technologies (heat-shield, smart-window system, ventilation, etc.). To manage the energy, we are developing Home Energy Management System. HEMS provide energy management and optimization system, connecting devices and equipment that create, store and save energy. Energy flow and consumption within household can be monitored on displays such as wall pad (In-Home Display) by using green home server to connect up smart meter, water meter and smart appliances [2].

In this paper, we provide economic analysis of energy and payback period by using HEMS. We also describe the energy saving for home. This paper is organized as follows. In Section 2, we explain the related works of testbed for the green home. We describe scenario of the energy economic and energy savings when we equipped with HEMS in each household in Section 3, and present our conclusions in Section 4.

II. RELATED WORKS

The home energy management platform technology for green homes monitors and controls all detailed energy usage to provide an efficient energy management function by optimizing the energy consumption such as electric power consumption in the green home test-bed. Green home testbed located in KICT are made of fifteen households on the 3rd through 8th floors and control (operation) center on 2nd floor for total energy management. HEMS is composed of two parts: green home server, which is part of each household, and control center, which covers the entire green home complex with respect to all households energy management [3]. Green home testbed to verify and monitor energy performance had planned to complete by the end of 2012. But, Construction was delayed and completed in March 2013. It been delayed for three month. Figure 1 shows the overview of green home testbed.

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Figure 1 . Green home test-bed in KICT

Green home server interacts with advanced metering infrastructure server and green home complex server in order to gather the smart meter measurements such as electricity, gas and water meters and analyse energy usage for each household. The Configuration of HEMS is shown in Figure 2.

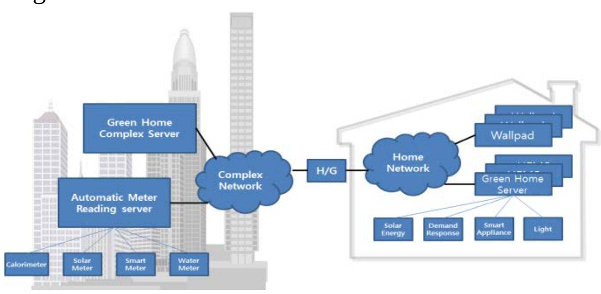

Figure 2 . Composition of home energy management system

Also, green home is a no-carbon emission house in which all required energy for its life is provided by itself based on renewable energy. The testbed is equipped with solar energy and connected to the grid with an installed capacity of 34.66 kW and 34kW solar inverter. It consists of an integrated monitoring interface module with solar energy which provides functions for renewable energy management, remote energy control, and energy service management (see Figure 3).

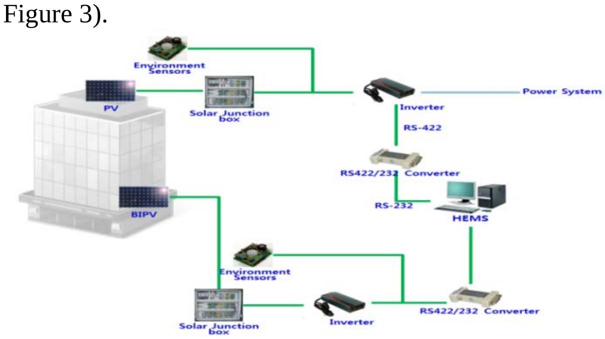

Figure 3 . Green home connected with Solar energy

III. SCENARIO

A. *Conceptual model for analysis*

In this paper, we described the development of HEMS which is interconnecting with various smart appliance and renewable energy. We need to analyze how much energy we save, as much as how much energy we use after we equip each household with HEMS.

To analyze the energy saving, we categorized each testbed based on the size of the floor space. The Energy Consumption of home changes according to testbed floor spaces. The testbed is composed of three floor space: 38.36 ㎡, 62.25 ㎡, 84.75 ㎡. Table 1 shows the electric energy consumption that is classified as monthly and yearly (see Table. I).

TABLE I. ELECTRIC ENERGY CONSUMPTION BY USE

Sort	Floor space (㎡)		
	38.36	62.25	84.75
A monthly average of electric use (kWh)	180.8	235.9	305.8
A yearly average of electric use (kWh)	2,169.6	2,830.8	3,669.6

Testbed was completed in March 2013. It been delayed for three month. For that reason, the interior was not equipped with smart appliances for analysis of energy use. We estimated the energy consumption based on the data of KPX in Table II. The energy consumption patterns are classified into eight types by floor spaces. We choose energy us to compare testbed floor spaces.

TABLE II. ELECTRICITY CONSUMPTION PATTERNS BY FLOOR SPACE

Sort(㎡)	Rate (%)	Electric use (kWh)
Under 33.06	5.4	151.1
36.36~49.59	13.7	180.8
52.89~66.12	19.8	235.9
69.42~82.64	23.4	264.6
85.95~99.17	15.9	305.8
102.48~115.70	15.3	331.7
119.01~165.29	6.1	374.0
Upper 168.6	0.5	448.8

Source : Survey on electric consumption and characteristic of home appliance, KPX, (Oct. 2009)

In this paper, we assume that energy saving rate is an 11.12 percent based on the other project (2012) named 'smart home network industry infrastructure development'. The other project is now under way in Naju, Korea. It replaced an old-fashioned home network infrastructure with a new one. The other project has no regard for renewable

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energy system in home. Figure 4 shows a comparison of the household electric charge before and after the installation of the home area network system.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	'Regency Ville Apt., Daeho-dong, Naju-si, Jeollanam-do, Korea																									
2	A monthly amount of electric meter (2010)													A monthly amount of electric meter (2011)												
3																							Date : 2011-12-15 dhgn 3:14:33			
4																								Unit : kWh		
5	Apartment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noc	Dec	Apartment	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Noc	Dec
240	0102-1404	369	414	373	396	395	376	382	446	416	361	389	419	0102-1404	461	494	382	431	388	356	375	454	409	378	381	374
241	0102-1405	384	386	337	346	297	336	335	409	413	357	356	441	0102-1405	480	506	369	462	447	423	410	485	382	341	352	345
242	0102-1406	315	316	259	253	224	202	213	253	226	191	225	251	0102-1406	256	273	250	275	240	230	242	245	246	227	254	257
243	0102-1407	376	431	384	351	334	367	371	467	415	340	400	396	0102-1407	435	460	389	393	371	352	330	400	373	352	388	365
244	0102-1408	147	149	142	164	187	190	179	208	215	226	201	210	0102-1408	195	173	129	157	168	173	177	199	187	181	168	165
245	0102-1501	215	211	190	199	171	146	158	191	200	170	165	171	0102-1501	174	202	247	370	406	338	329	361	359	341	412	471
246	0102-1502	525	623	547	561	513	507	478	422	386	482	529	523	0102-1502	564	598	469	472	449	403	389	493	428	293	436	464
247	0102-1503	215	262	291	341	354	342	364	192	158	147	135	122	0102-1503	133	149	110	137	169	176	184	199	192	158	164	134
248	0102-1504	584	605	536	547	487	468	484	579	501	458	464	447	0102-1504	427	417	407	465	437	415	427	446	437	387	407	427
249	0102-1505	427	415	362	374	382	408	422	538	528	387	344	328	0102-1505	335	404	380	397	400	402	396	476	424	416	414	407
250	0102-1506	412	408	351	375	347	333	341	328	361	322	364	404	0102-1506	455	489	410	421	385	375	355	378	415	367	364	402
251	0102-1507	432	417	371	409	370	393	399	545	460	402	376	403	0102-1507	384	347	272	278	285	288	302	348	345	324	372	379
252	0102-1508	282	263	243	254	247	244	260	276	265	258	266	286	0102-1508	332	337	245	323	302	309	312	385	330	314	328	311
253	0102-1601	230	208	220	249	224	190	150	170	180	210	254	279	0102-1601	322	368	274	262	213	180	180	182	150	206	222	226
254	0102-1602	336	266	293	256	306	258	275	338	319	268	290	304	0102-1602	336	299	345	316	330	387	350	418	425	358	329	402
255	0102-1603	447	504	424	398	415	336	327	408	396	360	448	445	0102-1603	460	500	444	408	355	308	387	464	412	331	331	392
256	0102-1604	297	336	277	246	219	224	177	200	159	194	219	251	0102-1604	269	316	229	278	258	192	208	192	175	234	248	278
257	0102-1605	434	458	287	241	200	187	236	249	255	235	357	388	0102-1605	373	473	386	404	319	299	314	346	357	314	329	384
258	0102-1606	321	333	306	292	310	305	313	359	350	292	329	345	0102-1606	352	371	309	317	337	347	355	406	381	323	318	311
259	0102-1607	320	248	245	259	190	180	135	142	205	260	276	376	0102-1607	389	269	302	326	289	247	259	192	241	229	334	361
260	0102-1608	621	729	596	550	458	256	183	213	211	257	299	255	0102-1608	319	370	280	287	276	245	258	254	217	276	296	223
261	0102-1701	435	443	368	359	343	376	369	435	394	372	383	362	0102-1701	368	417	360	365	378	366	342	402	377	351	365	388
262	0102-1702	117	153	137	135	160	189	213	219	201	183	189	240	0102-1702	226	176	147	156	189	189	174	183	183	165	176	184
263	0102-1703	387	402	373	359	297	281	197	295	284	200	200	197	0102-1703	280	294	241	289	202	196	195	233	249	225	181	177
264	0102-1704	440	431	360	399	411	412	413	538	483	380	371	363	0102-1704	387	396	344	293	232	232	218	539	329	245	210	228
265	0102-1705	255	216	213	200	230	211	265	266	270	250	265	250	0102-1705	306	264	286	296	304	267	291	301	303	270	290	238
266	0102-1706	459	546	354	304	224	36	175	247	247	201	204	162	0102-1706	172	214	163	161	137	142	161	222	229	183	192	182
267	0102-1707	387	394	307	301	296	307	310	377	339	284	304	300	0102-1707	341	385	334	310	313	294	293	309	309	276	289	286
268	0102-1708	655	664	602	653	614	506	627	656	765	644	617	684	0102-1708	675	724	533	569	599	642	598	781	682	648	595	594
269	Total	89,763	94,025	82,437	83,265	81,295	81,230	80,726	98,641	94,394	80,708	83,594	85,240	Total	90,566	96,821	80,488	83,326	82,599	78,600	80,037	96,027	86,291	78,737	81,466	82,409

Figure 4 . The measurement for Electric charge of household

Figure 5 . Green Home Server User Interface

We developed low-power energy metering and control module based on wireless communication (IEEE 802.15.4) for smart appliance. It is plugged to each smart appliance and communicates with green home server [10]. We can check the information measured instantaneous power and accumulated power (see Figure 5).

Since the household is equipped with HEMS, we can check the status of energy usage of home. In Fig. 6, we can see the monitoring of energy consumption for each smart appliance.

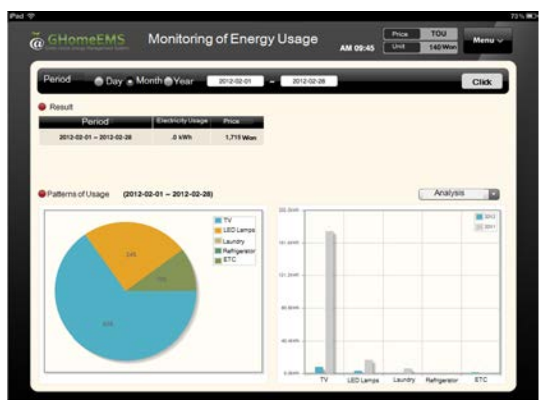

Figure 6 . Green Home Server Consumer's User Interface

B. *Case study energy saving*

In this paper, we calculate the average of energy saving after the home energy platform was installed. We have calculated two averages: a monthly average and a yearly

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average. Table III shows the energy saving with HEMS. The larger floor space is the more energy saving than smaller.

TABLE III. ENERGY SAVING WITH HEMS

Sort	Floor space (㎡)		
	38.36	62.25	84.75
A monthly average of energy saving (kWh)	20.1	26	34.0
A yearly average of energy saving (kWh)	241.3	315	408.1
A yearly average of energy saving cost ($/household)	29.55	57.00	106.83

As testbed was equipped with the solar energy, we are considering energy saving with renewable energy.

The capacity of PV module is 34.66kW. The amount of average solar radiation in Korea is 3.92 kWh/㎡·day, total design factor is 0.75. We calculate the amount of solar energy generation. It is 37,193.65 kWh/㎡ and the monthly amount of solar energy generation is 206.63 kWh/㎡ in testbed. Table IV shows the amount of energy consumption when equipped with solar energy. People who live on bigger floor space consume more energy than those who live on smaller floor space.

TABLE IV. THE AMOUNT OF SOLAR ENERGY GENERATION

Sort	Floor space (㎡)		
	38.36	62.25	84.75
A monthly average of energy use (kWh)	-45.9	3.0	65.2
A monthly average of energy saving cost ($/household)	20.88	26.37	38.92
A yearly average of energy saving cost ($/household)	250.51	316.46	467.09

Energy saving of the house increased after the solar energy installed. A yearly average of energy saving cost is $344.69. People who live on the smallest house can sell electricity 45.9kWh each month to utilities companies. Also, the largest house saved quadruple the energy (money) compared to the amount of energy used before the installation of home network. The largest house in testbed will save $467.09 after their installation of solar energy (see Table. IV).

C. Case stugy economic analysis

For an economic analysis, we calculate the energy saving with HEMS. We assume the annual electric charge saving is $106.83 in each household because the 84.75 square meters is the average of floor space. Next, we estimate HEMS installation cost when HEMS is universally available in home. As a result, the payback period is 4 years. Table V shows the estimation of total cost and payback period.

TABLE V. ESTIMATION OF TOTAL COST

Sort	Value ($/Household)
Annual electric charge saving **(A)**	106.83
HEMS installation cost **(B1)**	367.65
Measurement and control module for smart appliance **(B2)**	45.96
Total cost **(B=B1+B2)**	413.61
Pay Back period **(C=B/A)**	3.9 year

For an economic analysis, we calculate the energy saving with HEMS and renewable energy. We assume the annual electric charge saving is $467.09 in each household because the 84.75 square meters is the average of floor space. Next, we calculate solar energy installation cost when HEMS is universally available in home. As a result, the payback period is 7.23 years. Table VI shows the estimation of total cost and payback period.

TABLE VII. ESTIMATION OF TOTAL COST (include solar energy)

Sort	Value ($/Household)
Annual electric charge saving **(A)**	467.09
HEMS installation cost **(B1)**	367.65
Measurement and control module for smart appliance **(B2)**	45.96
Solar energy installation **(B3)**	2,962.14
Total cost **(B=B1+B2+B3)**	3,375.75
Pay Back period **(C=B/A)**	7.23 year

IV. CONCLUSIONS AND FUTURE WORK

The Korean government announced an obligatory plan for new houses that mandates 90% reduction in cooling/heating energy consumption starting from 2017 and a zero energy house level starting from 2025. In order to accomplish these goals, passive and active systems need to be in place.

In this paper, we described the development of HEMS, which is interconnecting with various smart appliance and

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renewable energy. Also, we calculated the average of energy saving by month and year when the home energy platform and renewable energy were installed. These results are expected to contribute the support of the government-driving green home supply project, and reduce the energy saving cost).

For the future work, we will apply energy storage system and electric vehicle charging station in home. They will be controlled and managed by HEMS. And we calculate and estimate energy savings and payback period when installing energy storage system near the future.

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