Analysis on Design Data of Low Energy Housing in Japan

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Abstract

Purpose / Context – In order to achieve low energy housing, it is important to quantitatively and comprehensively determine the effectiveness of energy saving technologies and to evaluate the energy conservation performance of an entire house. Low Energy Housing with Validated Effectiveness (LEHVE) is one of the measures for home energy saving in Japan. The evaluation procedure of LEHVE can quantitatively show the energy saving effect of each technology, such as insulation and equipment, and total energy consumption of a house in the design phase. The LEHVE's evaluation procedure is not mandatory, however it is widely used in Japan and its outcome has developed into Japan's Energy Saving Standard.

Methodology / Approach – Design data of newly-built houses are investigated using the LEHVE's evaluation procedure to evaluate the energy conservation performance in both mild climate region and hot humid climate region in Shikoku island, Japan. The present situation of energy conservation performance of newly built housing is analysed using the obtained data of the both regions. In the analysis, energy consumption, energy reduction rates and adoption rates of elemental technologies, such as natural energy application technology, heat control technology of building envelopes and energy-efficient equipment technology, have been yielded.

Results – 370 cases of design data of newly built timber houses in Japan, which were obtained between FY 2013 and FY 2015, have been analysed based on the LEHVE's evaluation procedure. 265 cases of design data were obtained in mild climate region and 105 cases were obtained in hot humid climate region. As the analysis results, it is suggested that the energy conservation performance of the newly built houses has been improved year by year in the both regions.

Key Findings / Implications – The energy conservation performance of the newly built houses in both mild climate region and hot humid climate region has been improved year by year. However, some natural energy application technologies, such as wind utilisation or daylight utilisation, have not been widely adopted in the houses even though the both regions have suitable climates for use of natural energy.

Originality – Energy conservation performance of housing can be estimated by using the LEHVE's evaluation procedure. 370 cases of the latest design data of newly built housing have been obtained in Shikoku island where only dozens of data had been available by previous studies.

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Keywords – Low energy housing, Primary energy consumption, Energy conservation performance, Energy saving technology

1. Introduction

Efforts to prevent global warming are important issues internationally. In Japan, carbon dioxide emissions have been increasing especially in the household sector (Agency for Natural Resources and Energy, 2015). In order to reduce energy consumption of housing, various measures have been conducted such as developing the Japan's Energy Saving Standard for newly built housing.
Analysing the specific energy consumption of housing is essential to take energy-saving measures. The Low Energy Housing with Validated Effectiveness (LEHVE) is one of the measures for evaluating energy consumption of housing. LEHVE is defined as "housing that uses much natural energy as possible according to the way of living and housing site conditions, such as climate and site characteristics, while increasing the standards of liveability and convenience by carefully designing and selecting buildings, equipment and appliances. Thereby such housing is able to reduce energy consumption during occupancy by up to 50% compared to housing that was common around 2000, and it will be able to be put to practical use by 2010" (Building Research Institute, 2010). The LEHVE's evaluation procedure is not mandatory, however it has been widely used by engineers in Japan and its outcome has developed into Japan's Energy Saving Standard and the International Standard (ISO 13153, 2012).

There are loads of researches about housing's energy consumption by measurement surveys and questionnaire surveys in Japan (Hasegawa and Inoue, 2004; Inoue, Mizutani and Tanaka, 2006; Murakami et al., 2006). However, most of these research works have not investigated the energy consumption of each energy use, such as heating, cooling, ventilation and so on, but just the total energy consumption of a house. Because it is not easy to estimate the energy consumption of the each energy use simultaneously with considering structures, areas of housing, lifestyles and family structures. Therefore, the LEHVE's evaluation procedure, which is conducted by fixing some conditions such as living conditions of family and attributes of a house itself, is useful.

Statistical analyses of home energy consumption are important to better understand present situations of the energy conservation performance of housing. In this study, an investigation for design data of newly built housing has been conducted for three years.

2. Method

2.1 LEHVE's evaluation procedure

Design guidelines for LEHVE are published targeting three climate regions, which are cold climate region, mild climate region and hot humid climate region (National Institute for Land and Infrastructure Management, Building Research Institute and IBEC, 2010; 2012). The target regions of this study are mild climate region and hot humid climate region in Sikoku island (Shown in Figure 1). The evaluation procedure of LEHVE can quantitatively show energy saving effect of each technology, such as insulation and equipment. In this evaluation procedure, 13 elemental technologies (shown in Table 1) are evaluated: five types of "natural energy application technology" which are use and control of wind, daylight utilisation, photovoltaic power generation, solar radiation heat utilisation and solar water heating; two types of "heat control technology of building envelopes" which are insulated building envelope planning and solar shading method; and six types of "energy-efficient equipment technology" which are heating and cooling system planning, ventilation system planning, domestic hot water system planning, lighting system planning, introduction of high-efficiency consumer electronics and treatment and efficient use of water and kitchen waste.
Most of the evaluations on energy saving effect are conducted by using a model house plan established under certain given conditions, such as a permanent condition of an approximately 120

m² wooden house plan (shown in Figure 2) and living conditions for a family which consist of a husband and a wife with two children.

In the evaluation, numerical values indicating energy saving effect are presented in the form of “energy consumption ratio”. The higher number of level means that higher energy saving effects can be achieved. Quick references for the energy consumption ratio of each elemental technology level for mild climate region and hot humid climate region are shown in Table 2 and 3. The reference values (Level 0) are set based on common design details of wooden house for family of four as typical primary energy consumption at 2000 in each region. The resent Energy Saving Standard levels are include in some elemental technologies, for example, level 3 technology of the insulated building envelope planning is same as the level of the Energy Saving Standard.

The design value of primary energy consumption is calculated by multiplying reference values and the energy consumption ratio for adopted technologies in each energy use, which are heating, cooling, ventilation, domestic hot water, lighting and home electronics. The total value of annual primary energy consumption is given by totalling up the each calculated value of the every use.

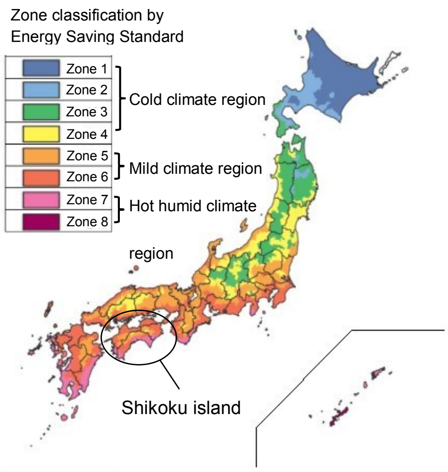

Figure 1 Zone classification map of Energy Saving Standard in Japan

Table 1 List of elemental technogies

Elemental technology		Use of energy to be reduced
① Natural energy application technology	Use/control of wind	Cooling
	Daylight utilisation	Lighting
	Photovoltaic power generation	Electricity
	Solar radiation heat utilisation	Heating
	Solar water heating	Domestic hot water
② Heat control technology of building envelopes	Insulated building envelope planning	Heating
	Solar shading method	Cooling
③ Energy-efficient equipment technology	Heating and cooling system planning	Cooling / Heating
	Ventilation system planning	Ventilation
	Domestic hot water system planning	Domestic hot water
	Lighting system planning	Lighting
	Introduction of high-efficiency consumer electronics	Consumer electronics
	Treatment and efficient use of water and kitchen waste	Water

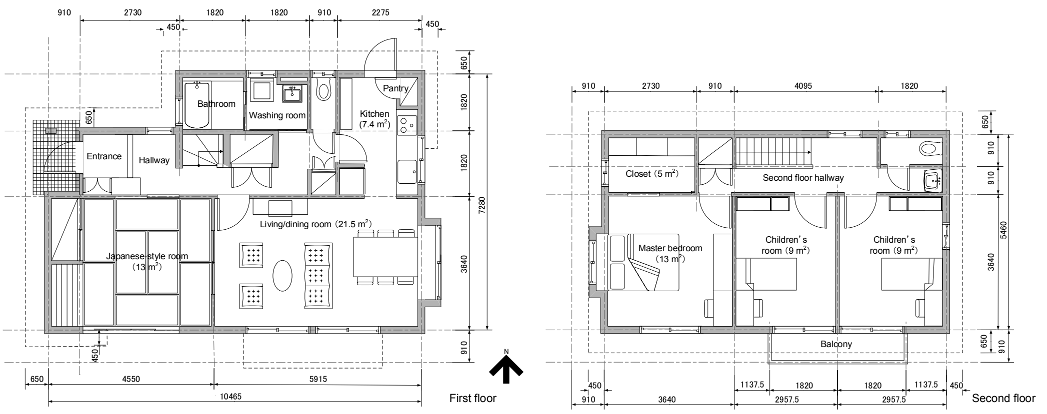

Figure 2 Plan view of LEHVE’s model house

As for photovoltaic power generation, the total design value of home energy consumption including P.V.’s effect is calculated by subtracting the annual primary energy consumption reduction based on the capacity of solar cells from the total annual primary energy consumption of the other use.

Table 2 Quick reference for energy consumption ratio of elemental technology level
(for mild climate region / in the case of partial intermittent heating and cooling)

Use	Reference energy consumption	Elemental technology	Energy consumption ratio (reference consumption is 1.0)				
			Level 0	Level 1	Level 2	Level 3	Level 4
Heating	12.7GJ	Insulated building envelope planning	1.0	0.8	0.65	0.55	0.45
		Solar radiation heat utilisation	1.0	0.95	0.9	0.8	0.6
		Heating system planning	1.0	0.8	0.7	0.6	
Cooling	2.4GJ	Wind utilisation/control	1.0	0.9	0.8	0.7	
		Solar shading method	1.0	0.85	0.7	0.55	
		Cooling system planning	1.0	0.8	0.7	0.6	
Ventilation	4.7GJ	Ventilation system planning	1.0	0.7	0.6	0.4	
Domestic hot water	24.5GJ	Domestic hot water system planning	1.0	0.9	0.8	0.7	0.5
Lighting	10.6GJ	Daylight utilisation	1.0	0.98	0.95	0.9	
		Lighting system planning	1.0	0.7	0.6	0.5	
Consumer electronics	23.5GJ	Introduction of high-efficiency consumer electronics	1.0	0.8	0.6		
Cooking	3.9GJ	—					
Total	82.3GJ	—					
Electricity		Photovoltaic power generation	-	▲30.2GJ	▲40.3GJ		

In regard to energy consumption in "cooking", since there are no significant differences among devices, only reference energy consumption is set.
"Treatment and efficient use of water and kitchen waste" is not included in this table.

Table 3 Quick reference for energy consumption ratio of elemental technology level
(for hot humid climate region / in the case of partial intermittent heating and cooling)

Use	Reference energy consumption	Elemental technology	Energy consumption ratio (reference consumption is 1.0)				
			Level 0	Level 1	Level 2	Level 3	Level 4
Heating	5.7GJ	Insulated building envelope planning	1.0	0.7	0.5	0.45	0.35
		Solar radiation heat utilisation	1.0	0.95	0.9	0.8	0.6
		Heating system planning	1.0	0.95	0.85	0.75	0.7
Cooling	5.0GJ	Wind utilisation/control	1.0	0.95	0.88	0.82	
		Solar shading method	1.0	0.85	0.7	0.55	
		Cooling system planning	1.0	0.95	0.85	0.75	0.65
Ventilation	1.0GJ	Ventilation system planning	1.0	0.8			
Domestic hot water	19.2GJ	Solar water heating	1.0	0.9	0.7	0.5	0.3
		Domestic hot water system planning	1.0	0.9	0.8	0.7	0.6
Lighting	11.3GJ	Daylight utilisation	1.0	0.98	0.95	0.9	
		Lighting system planning	1.0	0.7	0.6	0.5	
Consumer electronics	19.9GJ	Introduction of high-efficiency consumer electronics	1.0	0.8	0.6		
Cooking	4.4GJ	—					
Total	66.5GJ	—					
Electricity		Photovoltaic power generation		▲32.7GJ	▲43.6GJ		

In regard to energy consumption in "cooking", since there are no significant differences among devices, only reference energy consumption is set.
"Treatment and efficient use of water and kitchen waste" is not included in this table.

2.2 Outline of investigation on housing's design data

In the investigation, design data of newly built housing in mild climate region and hot humid climate region are obtained at Shikoku island via home builders from FY 2013 to FY 2015. The design data include lists of adopted elemental technologies based on the LEHVE's evaluation procedure and other design data such as various drawings, building materials' specifications and facilities' specifications.

Annual primary energy consumption and energy reduction rates to the total reference value are calculated using the LEHVE's evaluation procedure by analysing the obtained data. Moreover, in order to grasp average adopted technologies in each region, adaption rates of the levels of each elemental technology are investigated. Furthermore, yearly changes of energy conservation performance of newly build housing have been analysed using the "average plan". The average plan is defined as a house employing elemental technology levels with the highest adoption rates.

3. Results and Discussion

In the investigation, 370 cases of design data of newly built timber houses in Japan are obtained for three years from FY 2013 to FY 2015. 265 cases are obtained in mild climate region and 105 cases are obtained in hot humid climate region (shown in Table 4). The figure in parentheses indicates the adoption number of photovoltaic power generation as an included number. All of the obtained data are just adopted partial intermittent heating and cooling use.

As shown in Table 2 and Table 3, each elemental technology have energy conservation target levels. The higher number of level shows the higher energy saving effects can be achieved.

Table 4 The number of obtained data by year

	FY 2013	FY 2014	FY 2015	Total of 3 years
Mild climate region	106 cases (36 cases)	91 cases (31 cases)	68 cases (32 cases)	265 cases (99 cases)
Hot humid region	41 cases (2 cases)	40 cases (10 cases)	24 cases (4 cases)	105 cases (16 cases)

2.3 Adopted technologies and energy consumption in mild climate region

2.3.1 Level of adopted technologies

Adoption rates of each Elemental technology level have been found by analysing all of the obtained data in mild climate region over three years, shown in Table 5. The darker collar cell represents higher adoption rates. The results are indicated for each category of elemental technologies.

(1) Natural energy application technology
Wind utilisation and control technology is popular as over 70% of the houses have adopted the level 1 or higher level technologies. Daylight utilisation is also popular. Solar radiation heat utilisation technology is not widely popular but 66% of the houses are achieving level 2 or higher level technologies considering improvements in the thermal performance of windows. Photovoltaic power generation system is installed in 37% of the houses.

(2) Heat control technology of building envelopes
In insulated building envelope planning technology, almost all the house have adopted level 3 or higher level of insulation which is equivalent to the latest Energy Saving Standard in Japan. From the view point of solar shading, 63% of the houses have level 2 technologies which is equivalent to the latest Standard and remaining houses have higher level's solar shading technologies.

(3) Energy-efficient equipment technology
96% of the heating equipment has consisted of air conditioners. Focusing on the cooling data, 37% of the houses have adopted a low efficiency air conditioner with coefficient of performance (COP) of less than 4.0, and 19% of the houses have high efficiency equipment with a COP of 6.0 or higher. 61% of ventilation systems are level 1 and most of them are through-the-wall ventilation systems optimising the combination of a fan and an outside air unit (exhaust-only). 88% of water heaters are installing electric water heaters with natural refrigerant heat pump (CO_2HP water heaters) or latent heat recovery water heaters as level 2 technologies. 68% of the houses have installed high-frequency lamps. However 32% of the houses have installed not high-frequency lamps but incandescent lamps. From the view point of consumer electronics, over 90% of the houses are equipped with energy efficient products that use low standby power.

Table 5 Adoption rate of elemental technology level (for mild climate region / three-year totals)

Use	Reference energy consumption	Elemental technology	Level 0	Level 1	Level 2	Level 3	Level 4
Heating	12.7GJ	Insulated building envelope planning	0%	1%	0%	87%	12%
		Solar radiation heat utilisation	32%	2%	43%	21%	2%
		Heating system planning	31%	32%	18%	15%	
Cooling	2.4GJ	Wind utilisation/control	27%	46%	23%	4%	
		Solar shading method	0%	0%	63%	37%	
		Cooling system planning	37%	28%	16%	19%	
Ventilation	4.7GJ	Ventilation system planning	19%	61%	18%	2%	
Domestic hot water	24.5GJ	Domestic hot water system planning	3%	6%	88%	1%	2%
Lighting	10.6GJ	Daylight utilisation	26%	25%	26%	22%	
		Lighting system planning	32%	34%	20%	14%	
Consumer electronics	23.5GJ	Introduction of high-efficiency consumer electronics	6%	15%	79%		
Cooking	3.9GJ	—					
Total	82.3GJ	—					
Electricity		Photovoltaic power generation	63%	7%	30%		

2.3.2 Annual primary energy consumption and energy reduction rate

The energy reduction rate of newly built houses for each year from FY 2013 to FY 2015 in mild climate region is shown in Figure 3. In this figure, two types of energy reduction rates are indicated. One is including P.V.'s effect and another one is not including P.V.'s effect. The number above the box plots indicates the mean value. The mean value of the energy reduction rate including P.V. of FY 2015 is 10.7 percentage points higher than the value of FY 2013 and is 8.9 percentage points higher than FY 2014's value. Moreover, the mean value of energy reduction rate not including P.V. of FY 2015 is also higher than the previous years. As the results, the energy conservation performance of newly built houses has been improved year by year.

The levels of adopted elemental technologies and the primary energy consumption of the average plan for each year are shown in Figure 4. The grey parts in the radar chart indicate the level of adopted technologies. The levels of some natural energy application technologies such as solar radiation heat utilisation and daylight utilisation have been improved. The levels of Heating, cooling and lighting system planning technologies have been also improved. In FY 2015, the annual primary energy consumption is 4.8 GJ less than the value of FY 2013 and the energy reduction rate is 5.7 percentage points higher than the value of FY 2013.

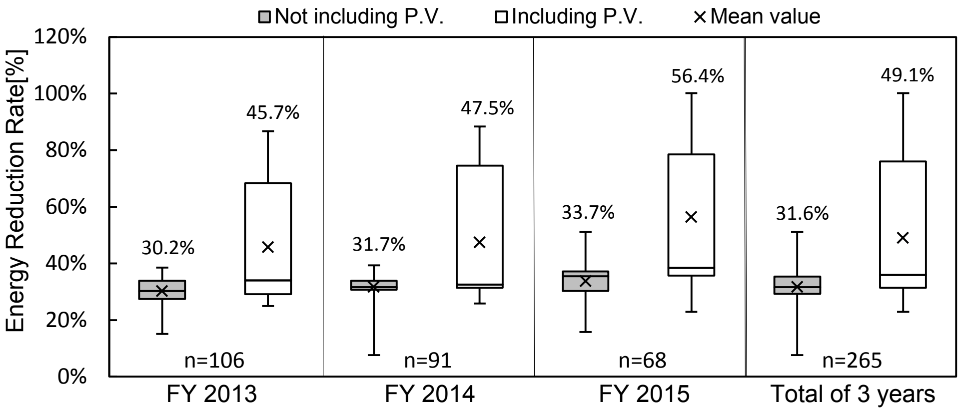

Figure 3 Energy reduction rate of newly built house in mild climate region

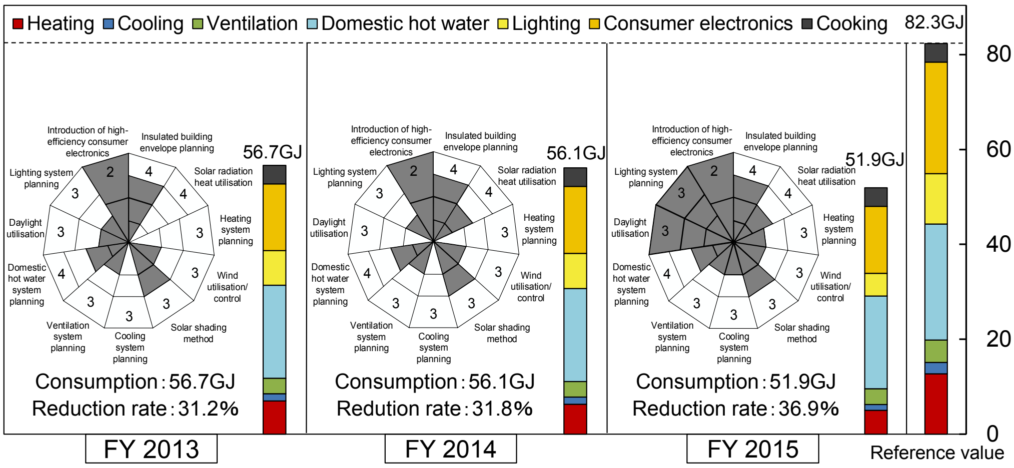

Figure 4 Levels of adopted elemental technology and yielded annual primary energy consumption of "average plan" in mild climate region

2.4 Adopted technologies and energy consumption in hot humid climate region

2.4.1 Level of adopted technologies

Adoption rates of each Elemental technology level have been found by analysing all of the obtained data in hot humid climate region over three years, shown in Table 6.

(1) Natural energy application technology

Solar radiation heat utilisation technology is not popular as 54% of the houses have not adopted any technologies. Regarding to the wind utilisation and control technology, 52% of the houses have adopted level 2 and higher level technologies, however 40% of the houses have not adopted any technologies. The highest level of daylight utilisation technology has been adopted in 22% of the houses; however, 44% of the houses have not adopted any daylight utilisation technologies. Only 4% of the houses have adopted solar water heating technologies. Furthermore, Photovoltaic power generation systems have been adopted in only 15% of the houses. In hot humid climate region, natural energy application technologies have not been adopted widely even though there are high possibilities of energy reduction using the natural energy.

(2) Heat control technology of building envelopes

In insulated building envelope planning, 90% of the houses adopted the level 3 technology which is equivalent to the latest Energy Saving Standard and remaining houses have the higher level technologies. From the view point of solar shading method technology, all of the houses have the solar shading performance above the latest Energy Saving Standard's level. Moreover 53% of the houses adopted the highest level of solar shading technologies.

(3) Energy-efficient equipment technology
All of the heating and cooling equipment have consisted of an air conditioner. Focusing on the heating data, 82% of the houses have adopted the level 2 or higher level technologies, which have been installed the systems with a COP of 4.0 or higher and considered about an adjustment of device capacities. 89% of ventilation systems are exhaust-only use and 58% of houses have not adopted any elemental technologies. In hot water system planning, 84% of the houses have adopted water heaters of level 3 technology, which are mostly CO_2HP water heaters. In hot humid climate region, the adoption rate of level 1 or higher level technologies in lighting system planning is 89% which is higher than the value of mild climate region. From the view point of consumer electronics, 96% of the houses have adopted energy efficient products.

Table 6 Adoption rate of elemental technology level
(for hot humid climate region / three-year totals)

Use	Reference energy consumption	Elemental technology	Level 0	Level 1	Level 2	Level 3	Level 4
Heating	5.7GJ	Insulated building envelope planning	0%	0%	0%	90%	10%
		Solar radiation heat utilisation	54%	1%	29%	14%	2%
		Heating system planning	18%	25%	11%	18%	28%
Cooling	5.0GJ	Wind utilisation/control	40%	10%	41%	10%	
		Solar shading method	0%	0%	47%	53%	
		Cooling system planning	13%	5%	45%	37%	0%
Ventilation	1.0GJ	Ventilation system planning	58%	31%			
Domestic hot water	19.2GJ	Domestic hot water system planning	5%	6%	6%	63%	21%
Lighting	11.3GJ	Daylight utilisation	41%	27%	10%	22%	
		Lighting system planning	11%	57%	19%	12%	
Consumer electronics	19.9GJ	Introduction of high-efficiency consumer electronics	3%	23%	74%		
Cooking	4.4GJ	—					
Total	66.5GJ	—					
Electricity		Photovoltaic power generation	85%	3%	12%		

2.4.2 Annual primary energy consumption and energy reduction rate

The energy reduction rate of newly built houses for each year from FY 2013 to FY 2015 in hot humid climate region is shown in Figure 5. In this figure, two types of energy reduction rates are indicated. One is including P.V.'s effect and another one is not including P.V.'s effect. The number above the box plots indicates the mean value. The mean value of energy reduction rate including P.V. of FY 2015 is 12.9 percentage points higher than the value of FY 2013. Though it is 2.0 percentage points lower than the FY 2014's value, the mean value of energy reduction rates not including P.V. in FY 2015 is higher than the value of the previous years.

The levels of adopted elemental technologies and the primary energy consumption of the average plan for each year are shown in Figure 6. The grey parts in the radar chart indicate the level of adopted technologies. Comparing the technology levels for each year, technology levels of solar radiation heat utilisation and daylight utilisation have decreased from FY 2013 to FY 2015. On the other hand, the levels of heating system planning technologies have been improved to the highest level in FY 2015. Therefore, in FY 2015, the annual primary energy consumption is 4.0 GJ less than the value of FY 2013 and the energy reduction rate is 6.0 percentage points higher than the value of FY 2013.

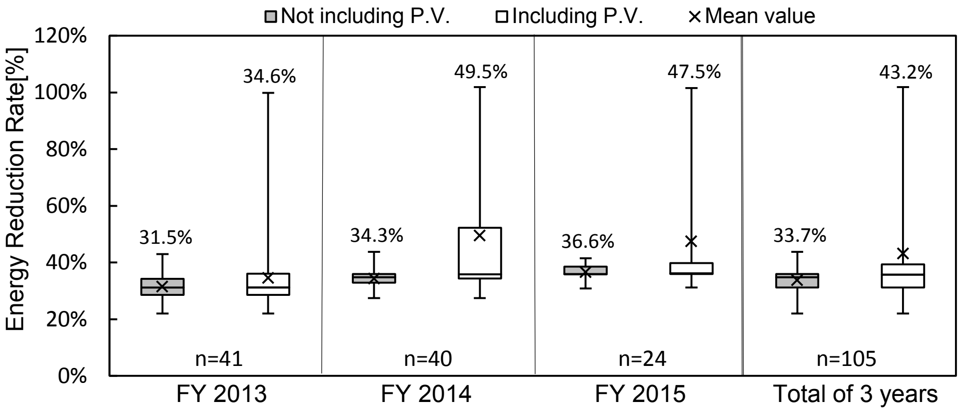

Figure 5 Energy reduction rate of newly built house in hot humid climate region

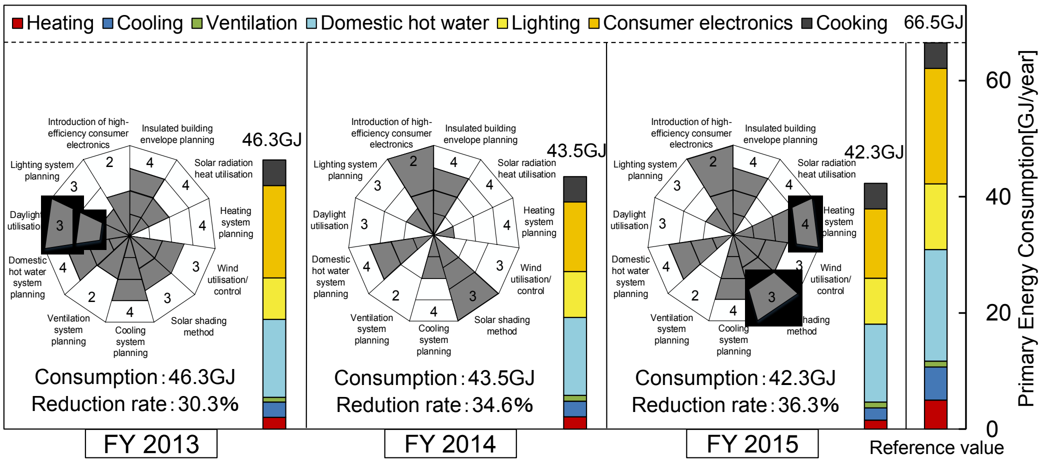

Figure 6 Levels of adopted elemental technology and yielded annual primary energy consumption of “average plan” in hot humid climate region

4. Conclusion

In this study, the investigation of newly built housing’s design data have been conducted for the purpose of evaluating the energy conservation performance from FY 2013 to FY 2015. Totally 370 cases of design data of newly built timber houses have been obtained in Japan. 265 cases of design data have been obtained in mild climate region and 105 cases have been obtained in hot humid climate region. The obtained data have been analysed based on the LEHVE’s evaluation procedure. In the analysis, energy consumption, energy reduction rates and adoption rates of elemental technologies, such as natural energy application technology, heat control technology of building envelopes and energy-efficient equipment technology have been estimated. Furthermore, Adaption rates of the levels of each elemental technology have been investigated. Yearly changes of energy conservation performance of newly build housing have been analysed using the “average plan”. The average plan is defined as a house employing elemental technology levels with the highest adoption rates.

As the results, the levels of adopted technologies have been generally improved yearly. Moreover, from the comparison results of energy reduction rates of each year, it is indicated that the energy conservation performance of the newly built houses have been improved year by year in both target regions. In most of the houses, the performance of insulation and solar shading has been better than or equal to the performance required by the latest Japan’s Energy Saving Standard. Regarding to energy-efficient equipment technologies, it can be considered a sort of energy conservation levels. However, there are certain possibilities of improvement for energy conservation of some technologies such as the heating, cooling and lighting systems planning. On the other hand, especially in hot humid climate region, the adoption rates of solar radiation heat utilisation technologies and photovoltaic power generation technologies are low even though there are high potentials of utilising solar radiation. In addition, wind utilisation technologies have not been employed generally. Therefore, Natural energy application technologies are recommended to be adopted more widely in newly built housing in Shikoku Island, Japan.

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