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Farabi-Asl, Hadi
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University

Chapman, Andrew
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University

Itaoka, Kenshi
International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University

Noorollahi, Younes
2Department of Renewable Energy and Environmental Engineering, Faculty of New Sciences and Technologies, University of Tehran

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Zero Emission Buildings and Challenges in Japan

Hadi Farabi-Asl[1], Andrew Chapman[1], Kenshi Itaoka[1], Younes Noorollahi[2]
[1]International Institute for Carbon-Neutral Energy Research (WPI-I2CNER), Kyushu University, Fukuoka 819-0395, Japan
[2]Department of Renewable Energy and Environmental Engineering, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran
Farabi@i2cner.kyushu-u.ac.jp

Abstract: *By increasing the share of buildings in final energy consumption and* CO_2 *emission, increasing the energy efficiency in the buildings is getting more important. Zero emission buildings (ZEBs) are energy efficient and self-sufficient in producing energy, which can be helpful of achieving the energy security and also controlling global warming issues in different countries. Japanese target for* CO_2 *emission reduction is 25% in 2030, in comparison with 2013 level. In this target, the emission reduction from the residential and commercial buildings are 39% and 40%, respectively. This paper aims for bringing together the definitions of ZEBs and also the common and possible methods to achieve ZEB, with focus on Japan. The current status of ZEB and successful examples are introduced and supportive policies are mentioned. Finally, the challenges for further deployment of ZEB concept in Japan are discussed.*

Keywords: Zero emission building; Energy; Efficiency; Photovoltaic; Insolation.

1. INTRODUCTION

Japan has the 5th rank in CO_2 emission worldwide. Fig. 1 shows the CO_2 emission (Mt-CO_2) and also primary energy consumption (Mtoe) for top 8 countries in the world in 2015 [1]. Japan has ambitious goals for cutting CO_2 emission in the upcoming years based on the international agreements, which need effective and practical actions. Fig. 2 shows the energy self-sufficiency rate for the same couturiers as Fig. 1 in 2015. Japan has the lowest energy self-sufficiency rate among those countries. Reducing energy consumption in different sectors in Japan and power production from renewable energy sources will help Japan to cut the CO_2 emission and increase the energy security for the coming decades.

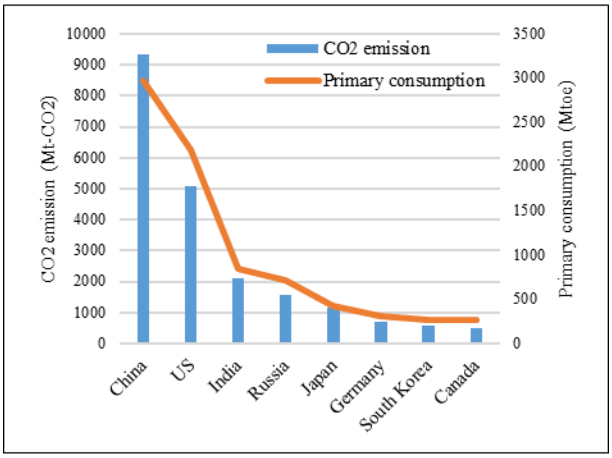

Fig. 1. CO_2 emission (Mt-CO_2) and primary energy consumption (Mtoe) in top 8 countaries, 2015 [1]

Buildings have considerable share in final energy consumption worldwide. In Japan, 27.3% final energy in 2015 was consumed in buildings (Fig. 3) [2]. Fig. 4 shows the ratio of CO_2 emission from different sectors to their base value at 1990, between 1990 to 2016. The CO_2 emission ratio in 2016 is 0.83 and 1.04 for industry and transport, respectively. However, this factor is as high as 1.37 and 1.68 for residential and commercial buildings, respectively [1]. It shows the importance of establishing firm policies and effective technologies to control and reduce the CO_2 emission from buildings. Table 1 shows the goals in CO_2 emission reduction in Japan at 2030 [3]. The CO_2 emission reduction goals for buildings is very ambitious and only will be achievable by big efforts.

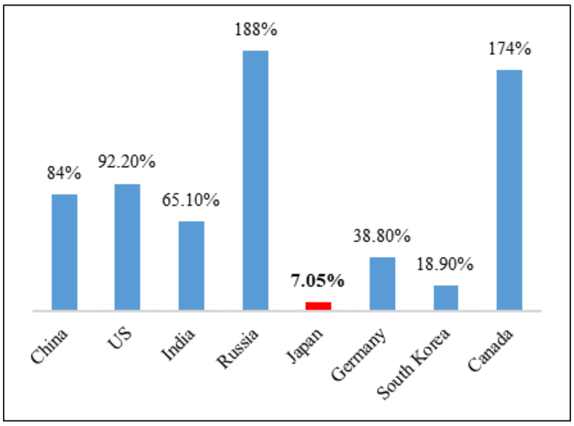

Fig. 2. Energy self-sufficiency in top 8 enegy consuming countries, 2015 [1]

Zero emission buildings (ZEB), or net zero energy buildings are the buildings which have higher energy efficiency than the conventional standard buildings and possibility to produce energy (power) by renewable sources, at least until the self-sufficiency level. The adequate definition of ZEB concept in different countries are presented in section 2. In recent years, especial attention was given to ZEBs, both in research and energy policy point of views. Many countries could achieve the ZEB goal, at least in prototype level. However, there are some challenges for further deployment and commercialization of ZEBs [4,5]. Commercializing ZEB will have several benefits for the societies, including:

- Energy-related emission reduction

- Improving energy security and decreasing dependency to fossil fuels
- Improving disaster-resiliency for buildings [6]

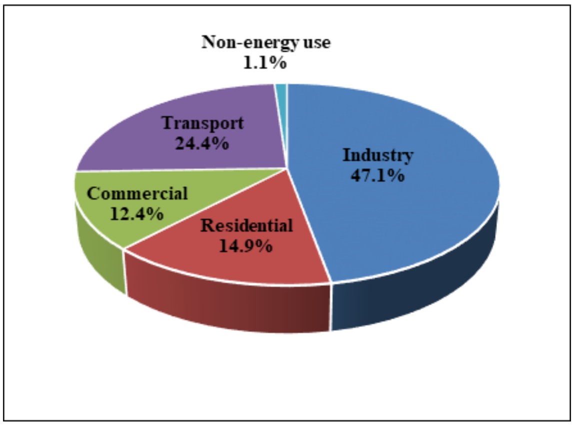

Fig. 3. Sectoral shares in final energy consumption in Japan, 2015 [2]

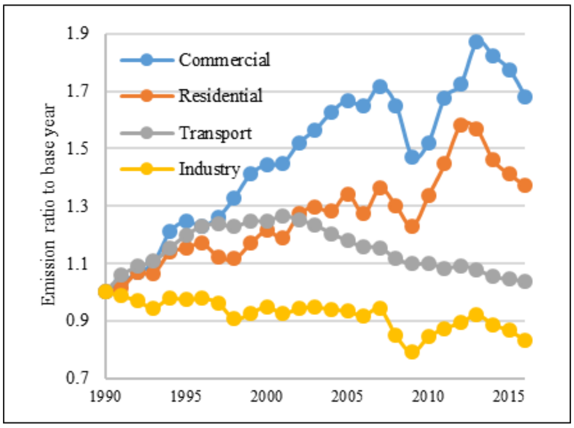

Fig. 4. CO_2 emission ratio to base year (1990) in Japan [1]

Table 1. Energy-related emission reduction goals in Japan [3]

Sector	2013	2030 (target)	Reduction (%)
Industry	429	401	7%
Transport	225	163	28%
Commercial	279	168	**40%**
Residential	201	122	**39%**
Energy Conversion	101	73	28%
GHG-CO_2	1235	927	25%

Wells et al., (2018) explored the existing ZEB models and assessed the progression of ZEB literature according to Australian building market. They identified key policies encouraging ZEB development and recognized potential areas of ZEB research [7].

Asaee et al., (2018) investigated the status of the housing stock in a set of cold-climate countries (i.e., Northern Europe and Canada) with the goal of identifying the barriers to achieving net zero emission status in the residential sector. After analyzing several effective parameters, results showed that the existing houses are not energy efficient, and it will be a challenge to reduce the GHG emissions of the residential sector in cold climate condition [8].

Vanga et al., (2018) focused on the power production in ZEBs. They carried out numerical and experimental study of storage capacity and the dynamic behavior of a solar facade module that can accumulate solar energy to reduce heating and cooling loads in ZEBs [9].

Rabani et al., (2017) reviewed the relevant solutions and the effect of their corresponding consequences on building energy efficiency as well as recommending renewable energy technologies, considering various technics of buildings retrofitting towards nearly zero energy level [10].

Xing et al., (2018) reviewed the development of ZEB technologies during 2015-2017 in China. Results of their study suggested that in order to widely implement ZEB, China should (1) lower the energy service demand in high-rise buildings and consider realizing a high population density with low-rise buildings; and (2) promote efficient cooling technologies and the energy saving behavior of occupants [11].

Wiik et al., (2018) worked on the calculation methodology and embodied greenhouse gas (GHG) emission results from zero emission building (ZEB) case studies from the Norwegian ZEB research center, to extract design drivers and lessons learnt. The embodied GHG emission results show that the building envelope (ca. 65%) and production and replacement of materials (ca. 55 - 87%) are the main contributors to total emissions across the Norwegian ZEB case studies [12].

This paper is aiming for providing the definition of the ZEB concept in different countries and regulations, including Japan and possible methods and technologies to achieve ZEB or nearly ZEB concept in Japan. The current activities and supportive policies for achieving commercial ZEB in Japan are presented and ambiguous points in regulations and also challenges for commercializing the ZEBs are discussed.

2. ZEB DEFINITION AND REQUREMENTS

Zero emission buildings are having several definitions in different countries and regulations. Most of the times these definitions have close meanings. However, sometimes they can have fundamental differences and maybe some ambiguous points.

Department of Energy (DOE) in United States defined ZEB as a building which its annual primary energy use is recovered by on-site renewable energy production [4].

National Renewable Energy Agency (NREL) in United States has the same definition for ZEB as DOE. However, they have a definition for Near ZEB which has built as ZEB, but does not met because of weather or operational circumstances [13].

Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) defined the ZEBs based on their net Annual non-Renewable Energy Use (AnREU) in kWh/m^2/year. If net AnREU will be less than zero, the building is Positive Energy Building (PEB). The ZEB concept will be achieved if AnREU will be less than zero and building is self-sufficient. Net Zero Energy Building (nZEB) is a building which net AnREU of zero. Nearly Net Zero Energy Building (nnZEB) concept is achievable when net AnREU is more than zero, but less than the limit of individual country [5].

In Japan, Zero Energy Building (ZEB) and Zero Energy House (ZEH) are defined based on the Primary Energy Consumption (PEC). In this definition, ZEH is representative of detached houses. ZEB or ZEH is a building with PEC which is 100% less than standards. Nearly ZEB/ZEH (nZEB/nZEH) is achievable when PEC will be 75% less than standards. ZEB/ZEH Ready is a building which PEC is 50% less than standards [14] (see Fig. 5).

All of the above mentioned definitions have two factors in common for ZEB:

1) Decreasing building energy consumption by improving the energy efficiency of the building and also devices, and
2) On-site energy (power) production, using renewable energy sources (see Fig. 6).

The target devices are not same in of the above-mentioned regulations. However, the common example devices for improving the energy efficiency are:

- Heating, ventilation and air conditioning (HVAC),
- Water heating,
- Lighting,
- Power outlet,
- Energy exchanged and transformed in building
- Elevators and moving stairs

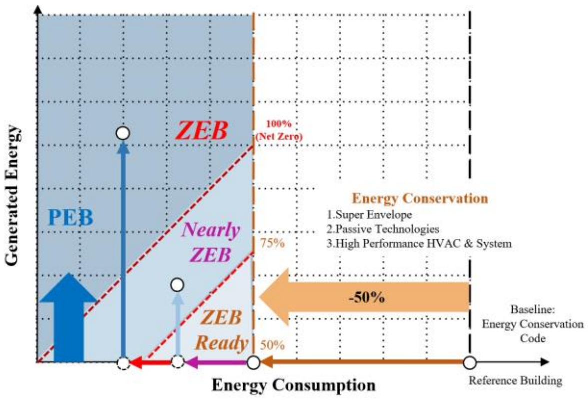

Fig. 5. ZEB concept in Japan

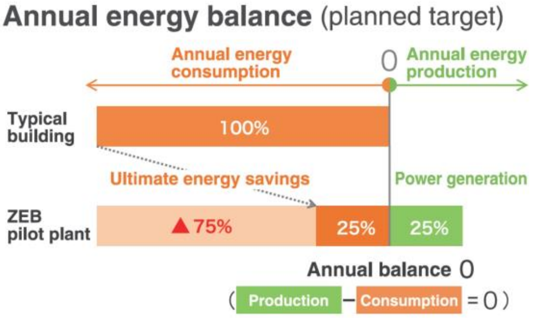

Fig. 6. ZEB achievement diagram

However, the definitions have some differences, specifically in net-energy consumption and renewable power production sources. For example, in DOE definition, the both on-site and off-site renewable power production is acceptable for small ZEBs. In NREL definition, the renewable energy integration has classified to two categories:

- Only on-site production
- Both on-site and off-site production

In REHVA and Japan definitions, only on-site renewable energy production is acceptable for achieving the ZEB concept.

The ZEB/ZEH technologies in Japan are categorized in 4 main groups:

Group 1) Passive technology

- Insulation and shading (insulation of building envelope, insulation of windows and shadings)
- Building design (passive ventilation)

Group 2) Active technology

- Air conditioning (both heating and cooling)
- Lighting
- Active ventilation
- Water heating

Group 3) Renewable energy integration (e. g. PV)

Group 4) Energy management (e. g. using HEMS: home energy management systems).

3. ZEB STATUS IN JAPAN, POLICIES AND CHALLENGES

Japan has ambitious goals in achieving commercial ZEBs. In the definition provided by Japanese Ministry of Economy, Trade and Industry (METI) on December 2015 [15], it is mentioned that A ZEH is a house with an annual net energy consumption around zero (or less) by saving as much energy as possible while maintaining comfortable living environment. This can be achieved through better heat insulation, high-efficiency equipment, and creating energy with photovoltaic power generation. Japan's Strategic Energy Plan (adopted at the Cabinet Council in April 2014) sets the following goals to realize and promote ZEHs.

- Achieve zero emission in standard newly-constructed houses by 2020
- Achieve average zero emission in newly-constructed houses by 2030 [15]

There are many research units and also some private companies are working on commercialization of ZEB and nZEB concepts in Japan. One of the successful and famous examples of ZEBs in Japan is Taisei Corporation Research Center building in Yokohama (Fig. 7). This building has 3 aboveground floors, and 1 penthouse floor, with total floor area of 1,277 m^2. The structure of building is reinforced concrete structure and its construction has finished at May 2014. It is the first urban building in Japan which achieved annual zero energy balance, with five-star BELS (Building Energy Labeling System). The photovoltaics system is crystalline on roof and organic thin film on external walls. The lighting conservation is -86%, using natural light, LED, organic EL, illumination control technologies. The Air-conditioning conservation is -75%, using T-smart focus (human detection sensor), radiation cooling from slab and other thermal recovery technologies [16]. The other examples of ZEB or nZEB in Japan are including (but not limited to):

- Kajima Technical Research Institute building, OT building, SH building, IN building, HL building, 21 Komaba Center for Educational Excellence building, Akasaka K tower building (Tokyo)
- YM building, Hokusetsu Office of the Kansai Electric Power Co., Inc. (Osaka)
- Kawagoe town hall (Mie Pref.)
- Taisei Sapporo building (Sapporo)
- Itoman City hall (Okinawa Pref.)
- Tochigi Prefectural Government building (Tochigi Pref.)
- KB building (Kobe)
- OI building (Kanagawa Pref.)
- Unnan City hall (Shimane Pref.)
- MN building (Yamanashi Pref.)
- SK building (Tsukuba)
- TC building (Tachikawa Pref.) [17]

Fig. 7. ZEB example: Taisei Corporation Research Center in Yokohama, Japan [16]

The leading private company in promoting and commercializing the nZEB and ZEB in Japan is Sekisui House. They are contributing to the reduction of residential CO_2 emissions since adopting their own specifications that meet the next-generation energy saving specifications standard at all their residential housing from August 2003. In addition, since June 2005 Sekisui House has been implementing Action Plan 20 and their Green First ZERO initiatives won the 2016 Minister of the Environment Award for the Promotion of Measures to Cope with Global Warming in November 2016 [18].

One of the Sekisui House's famous works was the "Zero Emission House" which was prepared for the G8 Hokkaido Toyako Summit on July 2008. It was a single-story building with steel structure with around 200 m^2 area. After improving the insulation of the building envelope, windows, doors, using passive technologies and also energy efficiency of the devices, the south face of the roof was covered with PV panels (14.5 kW) and its north face with sunagoke moss vegetation. They also added a household fuel sell unit and a footbath facility close to the building which uses hot water from a fuel cell [19]. Fig. 8 shows the CO_2 emission reduction rate of the daily energy consumption in Sekisui sold detached houses for 2007 – 2016. They also developed new methods for renovating the existing houses in order to improve the energy efficiency [18].

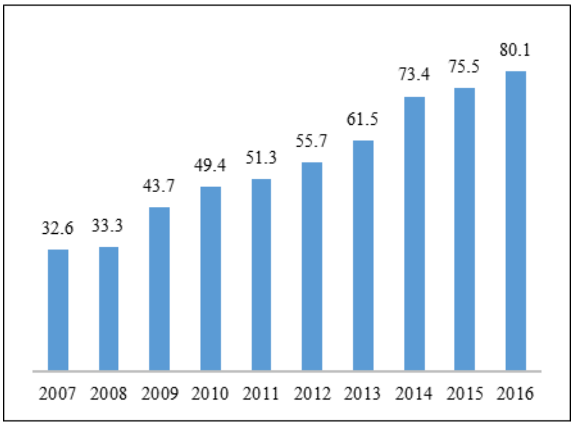

Fig. 8. CO_2 emission reduction rate (%) of the daily energy consumption in Sekisui sold detached houses (compared to 1990) [18]

One of the challenges in reducing the CO_2 emission from building sector is that achieving the ZEB level in big buildings is harder than smaller ones, due to limited rooftop area for photovoltaic (PV) panels installations, in comparison with the building's energy consumption. However, the big buildings have huge share in CO_2 emission in the cities, in comparison with small ones. Fig. 9 shows the breakdown of the CO_2 emission for Tokyo at 2010 [20].

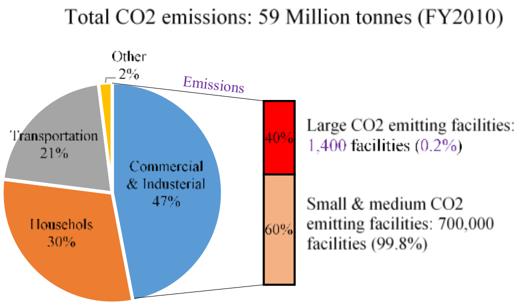

Fig. 9. Breakdown of the CO_2 emission for Tokyo at 2010 [20]

One of the main challenges in promoting and commercialization of the ZEB is its higher initial cost, due to higher insulation costs, higher costs for lighting and HVAC systems and also sometimes the customized design and structure of the buildings. Table 2 shows the standards for the average heat transfer coefficient of the envelope (UA value), both for Energy Saving Standard and ZEB Standard [15].

Table 2. Standards for the average heat transmission coefficient of the envelope in Japan (UA value) [15]

Region	ZEH standard	Energy Saving Standard
Region 1 (Asahikawa, etc.)	0.4	0.46
Region 2 (Sapporo, etc.)	0.4	0.46
Region 3 (Morioka, etc.)	0.5	0.56
Region 4 (Sendai, etc.)	0.6	0.75
Region 5 (Tsukuba, etc.)	0.6	0.87
Region 6 (Tsukuba, etc.)	0.6	0.87
Region 7 (Kagoshima, etc.)	0.6	0.87

In April 2017, Asia-Pacific Economic Cooperation (APEC) published the report of "APEC 100 Best Practice Analysis of Nearly/Net Zero Energy Building" [17]. Fig. 10 shows the cost increment for 42 examples in APEC report. The minimum cost increment rate is 6% and the maximum rate is 465%, with average of 67% for these 42 cases. A report from Sekisui House company shows that the sale price per detached home in FY2016 was 37.29 million JPY, up by about 6 million JPY compared to 2009, when Sekisui started sales of Green First homes in Japan [18].

In order to facilitate and support the early-stage ZEB constructions, different countries have the policies to overcome the high initial costs of the ZEBs. These supportive policies are mainly in the form of research grants for the universities, companies and research institutes, as well as the loans and grants for ZEB buyers. Achieving ZEB concept is Japan is facilitating by:

Group 1) Regulations

- Energy Efficiency Building Codes [21]

- Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) [22]
- Top Runner Program [23]

Group 2) Regulations Economic Instruments

- Low Carbon Cities Promotion Act [24]
- Eco-point Housing Program [21]
- Zero‐Energy Housing Grant Program [21]
- Flat 35 loan by Japan Housing Finance Agency [25]
- Subsidy Programme for Residential PV systems [21]

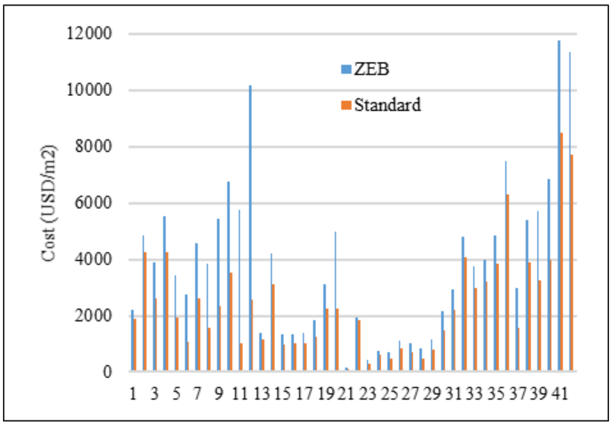

Fig. 10. Comparison of NZEB cost and standard building cost (USD/m^2) [17]

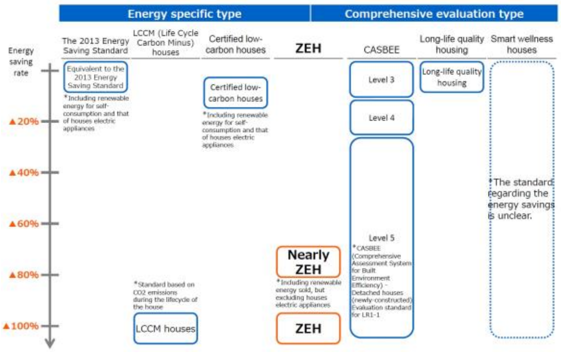

Fig. 11. Energy saving indexes and standards for buildings in Japan [15]

Fig. 11 shows the comparison of energy saving indexes in Japanese buildings [15]. METI was also operating the Sustainable Open Innovation Initiative in Japan and run “Demonstration project for ZEB”. The subsidy for this program was 1/3 of initial cost of the project or less than 40,000 $, with total budget of 33 M$ for 2013. At the same year, 98 buildings were qualified for the support under these requirements:

- 30% decrease in annual primary energy for new building
- 25% decrease for retrofitting [26]

However, there are some concerns and challenges attributed to above-mentioned definitions and goals of ZEB in Japan:

- Since the definition and goals for ZEHs are unclear, house-builders and building contractors cannot highlight the benefits of ZEHs.
- Should ZEHs be evaluated at the design or management phase?
- To what extent should walls and roofs be insulated?
- Which equipment (cooling, heating, lighting, hot water supply, etc.) should be included in the evaluation?
- Is it OK to install a lot of solar panels? How will the surplus power be evaluated?
- Is the grid in Japan ready to accept high penetration of surplus intermittence PV power from ZEBs?
- In the phrase “Realizing ZEHs in standard newly-constructed houses by 2020”, what constitutes a “standard newly-constructed house”?
- What efforts should house-builders and building contractors make?

One of the other challenges in achieving ZEB is the share of non-electric energy carriers in providing energy demands of the buildings, especially in residential buildings. For example, the necessary energy for space heating in Japanese residential buildings (in the unit of 1000 kcal/household in 2015) provides by electricity (354), city gas (384), LPG (75) and kerosene (1258) [1]. As shown in Fig. 12, share of electricity in providing space heating energy for residential buildings in Japan is limited to 17% and further deployment of ZEB in Japan need electrification of energy consumption in buildings by changing the HVAC technologies.

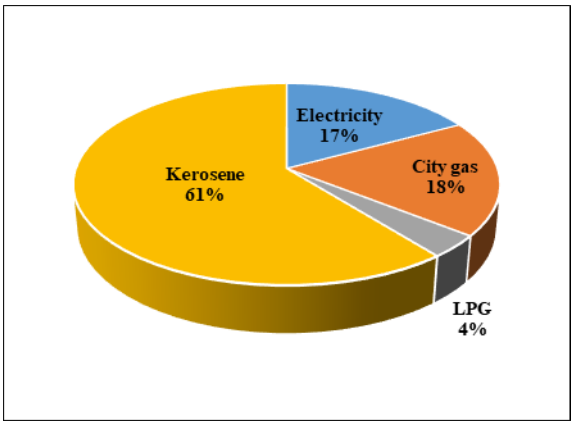

Fig. 12. Household space heating energy source in Japan, 2015 [1]

Fig. 13 shows the residential energy consumption (per household) in selected developed countries [26]. The amount of energy consumption per household in Japan is considerably lower that other developed countries and it gives us the sign that reducing energy consumption by improving the residents’ usage habits and consumption patterns will be harder than other countries. Achieving ZEB in Japan should be focused on proper technological tools and also on-site power production and special attention should be given to maintaining comfortable living environment for the residents.

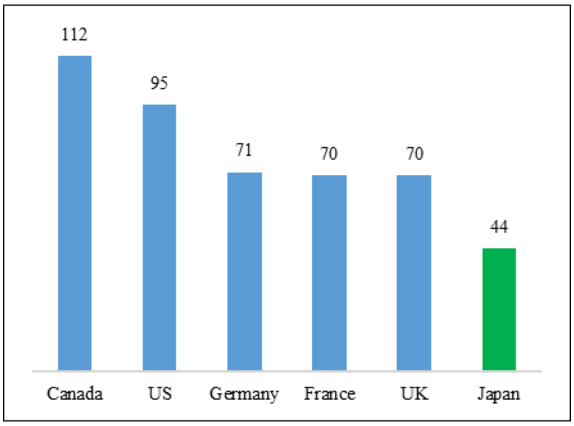

Fig. 13. Household energy consumption per year for sellected countries (GJ/household/year) [26]

4. CONCLUSION

This paper provided the definition of ZEB and its achieving tools based several countries and standards. A brief overview of energy consumption in Japanese buildings has presented and the current status of ZEB development and supportive policies and also attributed challenges have been discussed.

Japan has ambitious goals in cutting the emission from buildings in the upcoming years (e. g. 40% by 2030 in comparison with 2013 level). There are some ambiguous points of definitions and the supportive tools, which is necessary to become clear, in order to accelerate commercialization of ZEBs in Japan. So far, some of the research institutes and even private companies achieved high level of emission reduction in their products.

However, increment of the construction cost in ZEB in comparison with conventional standards houses is a big issue. Increasing the energy efficiency and approaching to ZEB level increased the building construction cost from 6% to 465%, with average of 67% for the 42 investigated ZEB and nZEB in several countries. Further deployment of ZEBs in this stage needs more adequate and long-term supportive loans and grants. Dependency of Japanese buildings (especially residential buildings) to non-electric energy carriers (kerosene, city gas and LPG) is another challenge for ZEB deployment. As the last point of conclusion, it is necessary to notice that the energy consumption per unit of residential building in Japan is already much lower than other developed countries. Reducing the energy (emission) from this sector, while maintaining comfortable living environment for the residents is a challenge which needs adequate and careful attention on choosing and applying the tools and technologies.

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