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**Article**

## Smart communities in Japan: Requirements and simulation for determining index values

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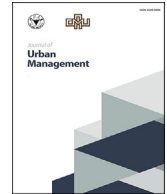
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## Research Article

## Smart communities in Japan: Requirements and simulation for determining index values



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## ARTICLE INFO

## ABSTRACT

Recently, smart communities are heeded to in Japan as a solution to community issues. To properly evaluate the underlying concept, it is necessary to analyze smart cities in terms of local energy and environmental aspects, as well as disaster resilience. This research aimed to summarize the requirements for Japanese smart communities, and provide this information to municipalities, city planners, and regional developers in warmer climates, or countries where few precedents exist. Nine cases were reviewed in Japan, and four in Europe and the US to organize smart community requirements into three areas: environment, social, and safety-security. Additionally, bottom-up simulations were used to quantitatively evaluate the effects of energy technology introduction, emergency Life Continuity Plans (LCPs), and changes in energy performance owing to household compositional differences. The results showed that a typical Japanese smart community (containing Fuel cell, PV, and battery) has the capacity to become a positive energy district, generating 1916 GJ yr<sup>-1</sup>, and maintain power throughout a one-week power outage if shared within the community (save for the highest temperature week in August). Conversely, Japanese smart communities lacked consideration of residential diversity and creative landscapes.

## 1. Introduction

Recently, more attention has been given to creating a decarbonized society. For example, based on the Paris Agreement, Japan aims to reduce total CO<sub>2</sub> emission by 46% in 2030 compared to 2013 levels, including a 66% reduction in the residential sector. In addition, the United Nations has created 17 Sustainable Development Goals (SDGs) for urgent social issues.

The vision of environmentally friendly cities and communities has a long history in Japan. In 1989, the Environmental White Paper (Ministry of the Environment, 1989) posited an ideal city (an eco-polis) where people and the environment coexist in harmony, and identified a set of ideal environmental policies aimed at achieving this environmentally friendly lifestyle. In 1993, the Ministry of Construction (now the Ministry of Land, Infrastructure, Transport and Tourism [MLIT]) (Ministry of Construction (now the Ministry of Land et al., 1993) launched an environment-symbiotic model city project that aimed to create a more favorable urban environment by reducing the environmental burden, coexisting with nature, and creating amenities. Since 2000, the government has been selecting and promoting “eco-model cities” whose requirements impose aggressive environmental goals, and have taken on the challenge of

*Abbreviations:* LCP, Life continuity plan; OPSIS, Technique for order performance by similarity to ideal solution; ZEC, Zero energy community.

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pioneering initiatives to demonstrate an ideological, low-carbon society. The terms “smart city” and “smart community” appeared around 2010. MLIT (MLIT, 2018) defined a smart city as “a sustainable city or district that manages various issues with the city using new technologies to achieve overall optimization.” From 2010, the Ministry of Economy, Trade and Industry (METI) (METI, 2010) has been working on the Next Generation Energy and Social System Project, in which Kitakyushu City and three other communities have been selected to introduce renewable energy sources, next-generation automobiles, and new energy management systems using Information and Communication Technology (ICT).

Accordingly, more sustainable socioeconomic visions, as well as environmental designs, are gaining prominence throughout Japanese society. One such aspect, disaster prevention measures, has received high levels of interest because Japan is quite disaster-prone, as evidenced by the 2011 Great East Japan Earthquake. In recent years, damaging typhoons and torrential rainfall disasters have also become more frequent (MLIT, 2020); therefore, disaster prevention and resilience measures that increase the recovery ability represent additional important elements during community planning. For community resilience, in particular, there is the need to secure energy for implementing community “life continuity plans” (LCPs), which means developing measures to allow residents to continue living independently when disasters strike. Furthermore, addressing the social issues of modern communities is also essential. It is thus important to conduct detailed community planning that meets the unique characteristics and challenges of modern communities, so as to provide adequate measures across the wide array of current social issues.

Furthermore, the development of ICT and the growth of the Internet of Things is steadily changing the nature of society. Indeed, recent research has turned towards the effective use of ICT for the betterment of cities and urban spaces (Lytras et al., 2021). Furthermore, due to the rapid acceptance of cyberspace activities and interactions, including remote work, distance learning, and online shopping due to the COVID-19 pandemic, the construction and maintenance of a strong cyber-infrastructure have become another essential element of community development. However, while some studies have used ICT indicators to assess cities based on technology and smartness criteria (Akande et al., 2019; Escolar et al., 2019), they focus solely on the current level of ICT usage, and the authors are not aware of any research examples assessing the effects of ICT on connecting people, products, and services to manage an entire city. Therefore, it remains important to define and implement concrete measures for optimizing ICT for the creation of a prosperous community.

Thus, Japanese community issues can be divided into three disciplines – Environment and Energy, Town Planning (community development), and Information Technology – and the relationship among them is shown in Fig. 1. The text in each circle is the requirements in each field. The arrows indicate social issues that affect each requirement. For example, in the field of “town planning,” the social trend toward the environmental model city, or issues related to earthquakes and the environment require, for example, “disaster prevention” and “low-carbon city.” In the field of environment and energy, global and national rules, such as the Paris Agreement and the Japan Basic Energy Plan, require efforts toward de-carbonization. Renewable energy and mobility sharing and rental have accordingly become important. In the field of information technology, the development of communication technology and governmental policy to increase the use of photovoltaics (PV) require energy management and grid flexibility. Thus, we conclude that the development of smart communities in Japan is one of the solutions to address each of these fields.

In this context, “community” is considered a functioning part of a city, and it can be a municipality or smaller sub-area, such as a district or neighborhood (International Energy Agency, 2017). The community-level emphasis stems from the fact that district approaches to energy can offer more cost-effective ways to achieve zero energy, along with financial, resiliency, and environmental benefits (Pless et al., 2018). Accordingly, existing definitions of smart communities were explored. The Smart Community Alliance, a collaboration of Japanese industry, government, and academia under the auspices of the METI, defines a smart community as, “a community where various next-generation technologies and advanced social systems are effectively integrated and utilized, including: efficient energy use, heat utilization, and unused energy sources, the improvement of local transportation systems, and transformation citizens’ everyday lives” (JSCA, 2010). Moreover, Smart Cities & Communities, one of the EU’s research and innovation programs from 2014 to 2020, stated that sustainable development of urban areas should be sought by using energy and information technologies (INEA, 2014).

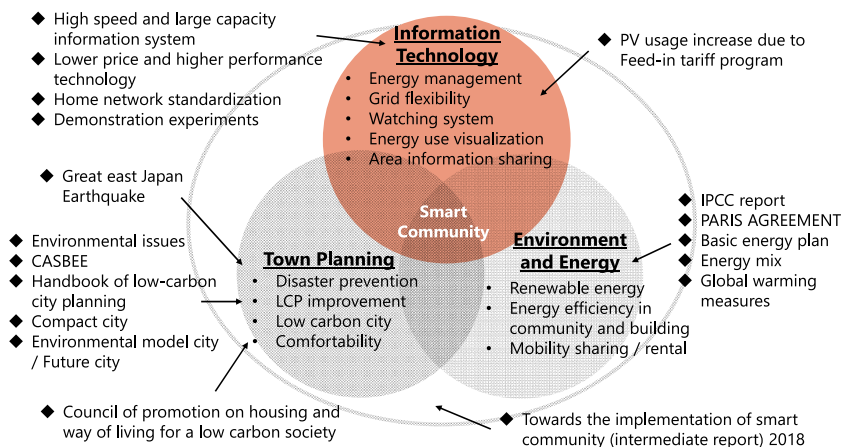


Fig. 1. Issues and needs in Japanese communities.

Accordingly, the definition of a smart community can vary; however, as mentioned earlier, with the diversification of needs in Japanese town planning, a smart community can be defined as a new concept of community development capable of responding to the multi-faceted needs at the district level.

In Japan, a number of smart communities have already been developed. Although most of Japanese smart communities receive governmental subsidies, the majority of developers are private companies. There are numerous cases where smart communities have been developed by manufacturers on their old factory sites. There are also cases where electric, gas, and home appliance companies and house builders take the lead in smart community development.

Over recent years, many researchers have developed indicator-based methods to evaluate the smartness of cities. Akande et al. (Akande et al., 2019) used hierarchical clustering and principal component analysis to calculate rank scores and their possible association with gross domestic product. Ozkaya and Erdin (Ozkaya & Erdin, 2020) used an analytical network process to weigh the criteria, and compared 44 global cities using the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS). Elsewhere, studies have compared international cities using the aggregate CITYCARD index (Grant & Chuang, 2012) and sustainable cities index (Batten, 2016); however, all of these studies were conducted at the city level, and few have organized indicators at the community level. Kotera (Kotera, 2020) proposed a comprehensive evaluation index for smart communities that can be customized according to developer goals, and more refined indicators are needed for general use. Dall'O et al. (Dall'O et al., 2017) evaluated the smartness of small and medium-sized cities in three Italian municipalities according to seven indicators: energy, environment, mobility, people, living, governance, and economy; however, it is difficult to apply this method directly to Japan due to climatic differences. Distinct from Europe and North America, the Japanese climate results in primary energy uses for cooling, hot water, lighting, and home appliances, as well as energy for heating. In colder countries, energy efficiency can be achieved by improving the thermal insulation and heating system efficiency of buildings. Conversely, in warmer climates, such as Japan, energy demand of various end uses is largely affected by occupant behavior (Taniguchi-Matsuoka et al., 2020), thus increasing the importance of energy management by ICT.

Various energy performance evaluations have also been carried out at the district level. Muto and Muraki (Muto & Muraki, 2016), and Taniguchi and Muraki (Taniguchi & Muraki, 2017) studied energy systems that are suitable for district characteristics and demand patterns. In the smart grid sector, district-level studies have estimated the load curve for residential electricity demand (Ochiai et al., 2013). Further, studies that estimated the load curve for districts with different zoning characteristics, such as residential or commercial areas, have been conducted (Date et al., 2015); however, to date, there is currently no insight regarding the success of replication of the time variation of energy demand at the district scale; as such, summaries of the energy performance at the district scale from various perspectives are required for smart communities. Some studies have also conducted comparative analysis with various mathematical modelling techniques to select the best method for planning renewable energy projects (Prabatha et al., 2020). Such studies are useful tools for decision making regarding community energy planning, but as the authors of the paper state, there remains the problem of insufficient information, such as existing case studies.

In this study, we clarified the requirements that a Japanese smart community should have for resolving the wide range of social issues indicated by the SDGs through case studies based on the three fields shown in Fig. 1. Then, among these requirements, examples of quantification are shown for requirements that can be quantitatively evaluated by simulation. The contribution of this research to the literature is to provide information on the requirements of Japanese smart communities as an example for warm countries to municipalities, city planners, developers, and other stakeholders in similar regions with warmer climates (i.e., lower heating demands) or in

**Table 1**  
Japanese smart communities used as case studies.

Name	Location	Number of detached houses	Reference website and article
Lake Town Miwanomori	Saitama	132	(Daiwa House industry, 2021) (Hazutani & Isozaki, 2021) ("Koshigaya lake town machiaruki, 2016) ("Koshigaya lake town no syo, 2019) (Real Estate Research Institut, 2009)
Ayameike Housing Development	Nara	142	(Nara city, 2012) (MLIT, 2021MLIT) (Kintetsu Real Estate, 2012) (Kintetsu Railway, 2009) (Kintetsu Railway, 2010) (Cabinet Office Government of Japan Okinawa General Bureau, 2015)
Smart city Shioasiya Solar Shima	Hyogo	400	(Panasonic Homes, 2021a) (Panasonic Homes ENERES, 2017) (Panasonic Homes, 2021b) (Panasonic, 2016)
SMAxECO Town Harumidai	Osaka	65	(Daiwa House industry, 2021) (SMA Eco Town harumidai, 2021) (Kobayashi, 2019) (Daiwa House industry, 2015) (Daiwa House industry, 2013) (Daiwa House industry, 2012) (Daiwa House industry, 2017)
Omiya Vision City	Saitama	125	(Eneres, 2013) (Polus group, 2013) (Polus Group, 2021) (Polus Group, 2015) (Japan Institute of Design Promotion, 2015) (Diamond Inc, 2014) (Jyutaku, 2013)
Fujisawa Sustainable Smart Town	Kanagawa	600	(Fujisawa SST Council, 2015) (Fujisawa SST Council, 2018) (Fujisawa SST Council, 2021) (Panasonic Homes and Mitsui Fudosan Residential, 2013) (Ookawara, 2016) ("Shinka sutsuzukeru smart town, 2018)
M-Smart City Kumagaya	Saitama	73	(330navi, 2021) (Misawa Homes, 2014) (Building Research Institute and Japan Sustainable Building Consortium, 2017) (Makita, 2014) (Misawa Homes, 2021) (Tokyo Gas, 2014) (Environment Cloud Service, 2021)
Bonjono Kitakyushu Smart City Project	Fukuoka	350	(Jonohitomachinet, 2015) (Jonohitomachinet, 2021) (Council for Formulating a Treatment Plan for the Site of Jono Garrison, 2012) (Toho Home, 2021) (Seibu Gas, 2020), (Panasonic, 2016)
Senri Maruyama no Oka	Osaka	303	(Building Research Institute and Japan Sustainable Building Consortium, 2017), (Suita-City, 2018) (Obayahi-Shinseiwa Real Estate Corporation, 2021) (Senri Maruyama no oka Official website, 2021)

**Table 2**  
International smart community case studies.

Name	Location	Number of detached houses	Reference website and article
Stadwerk Lehen	Austria	1173	(Strasser et al., 2012) (European Commission, 2021a) (Arnitz & Rieberer, 2018)
Stenlose South	Denmark	750	(European Commission, 2021b) (Roskilde University, 2008) (Marjan & Diu, 2012)
Furuset	Norway	4000	(Nordregio, 2018) (Reinventing Cities, 1268) (The Research Centre on Zero, 2021)
Los Alamos site	US	1600	(Los Alamos Country, 2021)(Amec Foster Wheeler, 2015) (Scott & Sheehy, 2019) (Los Alamos National Laboratory, 2021) (Irie, 2015)

countries where there are few precedents for smart communities to achieve the target of the Paris Agreement. The research questions were as follows:

- A) Based on local characteristics and trends, what are the requirements of Japanese smart communities?
- B) What requirements, if any, are missing from Japanese smart communities compared to other global locations and projects?
- C) How effective is the introduction of each technology in smart communities?
- D) How much does the energy performance of different household structures change?
- E) How much do LCPs affect the performance of existing smart communities?

## 2. Case studies and smart community requirements

### 2.1. Case study selection criteria

The communities listed in Table 1 were selected as the Japanese smart community case studies, and they consist primarily of communities with detached housing that adhere to strict environmental and energy standards and receive corresponding subsidies from the government—for example, The Leading Project for Promoting CO<sub>2</sub> Reduction in Housing and Building (MLIT).

For comparison, four additional smart communities outside of Japan were selected as case studies (Table 2), with the aim of identifying any special characteristics unique to Japanese smart communities and any requirements that require strengthening. These case studies were selected based on the following two criteria: district-level scale and abundant information available to the public. Although the scale and characteristics of the cases in Japan and other countries differ greatly, the purpose of this paper is to find commonalities and differences in the requirements that Japanese and other countries' smart community emphasize by organizing and categorizing the initiatives undertaken in each case study.

Three European smart communities were selected from previous case studies (IEA-EBC Annex63, 2017), as was a site in Los Alamos, US, from the New Energy and Industrial Technology Development Organization's overseas smart community demonstration project.

### 2.2. Existing smart community development indicators and our requirements

Table 3 uses in each case. BREEAM Community,<sup>1</sup> LEED-ND,<sup>2</sup> and CASBEE-UD<sup>3</sup> are comprehensive tools for overall sustainable development assessment that have been widely employed as evaluation indicators of community sustainability. Although there are differences in the evaluation entries, many relate to environmental, economic, social, and energy requirements (Tsukada, 2018). Also, the assessment index proposed by Kotera (Kotera, 2020) for communities in Japan uses a tripartite approach of vitality attraction, environmental symbiosis, and safety and security. By referring to these approaches, the essential requirements were classified into three categories: environmental and energy, social, and safety-security. In addition, due to the existence of some intermediate sub-requirements that cannot be singularly categorized, overlapping requirements that satisfied both environment and society and environment and safety-security were established. The elements were then organized by their main and minor requirements (sub-requirements), and the means to achieve them. These items were selected from the categories covered in the existing indicators, which are appropriate for evaluating smart communities in Japan. While emphasizing items evaluated by representative indicators such as BREEAM and LEED, we have incorporated safety and security, which are indispensable indicators for disaster-prone Japan, into the requirements. In addition, each of the lower-level items (measures) was selected from categories of existing evaluation indicators and elements adopted in at least three cases. This paper does not aim to rank them in any particular order. Since the characteristics of each case study and background in community development vary greatly, the superior smart community may vary depending on the developer's point of view. Therefore, this paper aims to grasp the overall trends and characteristics of Japanese cases by comprehensively organizing the existence and types of initiatives according to the classification listed earlier, and to clarify the direction and development guidelines that smart communities in warm regions such as Japan should aim for.

<sup>1</sup> The Building Research Establishment Environmental Assessment Method.

<sup>2</sup> Leadership in Energy and Environmental Design — Neighborhood Development.

<sup>3</sup> CASBEE-UD: Comprehensive Assessment System for Built Environment efficiency for Urban Development.

**Table 3**  
Case details and implemented measures.

Requirement	Measures	Koshigaya	Ayameike	Shioashiya	Omiya	Harumidai	Kumagaya	Fujisawa	Jono	Maruyama	Lehen	Stenose South	Los Alamos	Furuset
Basic information	Development initiative	Municipality → private	Municipality + private	Municipality → private	Private	Municipality → private	Municipality → private	Private	Municipality + private	Private	Municipality	Municipality	NEDO	Municipality
	Development authority	House builder	Railroad company	House builder Appliance Manufacturer	Real estate company	House builder	House builder	Appliance manufacturer	Municipality	Real estate company	Municipality	Municipality	State government, National laboratories	Municipality
	Completion of construction year	2008	2010	2012	2013	2013	2014	2014	2016	2019	2005–2013	2007–2012	2009–2014	2010–2020
	Scale of development (ha)	3.2	19.7	6.7	2.5	1.6	1.8	19	18.9	7.8	15.5	73	2880	87
Social	Maintaining Asset Value					Sustainable town management		Sustainable town management		Sustainable town management				
	Ethnicity, age, occupation mixing										Kindergarten	Kindergarten	Elderly	Student
	Social Mixing										Student hostel	Elderly	Poor	Elderly
	Support for the socially vulnerable			Universal planning				Universal design (Public facilities)	Barrier-free (district level)				Insurance for disabled people	Multi-ethnic
	Community facilities	Park Common space	Park café	Park Meeting room	Park	Meeting room	Meeting room	Park Meeting room Communication facility	Park Meeting room Resident study room	Meeting room	Hall Exhibition hall	Neural recreational area	Open space Park	Park Community house
	Community organization and activities	Website Events Management association	Website Events Management association	Website Information service	Website Events Plant management	Website Electronic bulletin board Events Tree management	Website Events	Website Event Management association Public relations magazine Delivery center	Website Consultation counter Event Management association Public relations magazine	Electronic bulletin board Tree management Event	Management association Student workshop		Website Event Management association	
	Mobility	EV charging plug	Located near the station E-bike share	EV charging plug	EV charging plug Front of the station E-bike share	EV charging plug EV car share		EV charging plug Front of the station E-bike share Rental car delivery EV quick charging	Walkable Front of the station Car share Bicycle rental EV quick charging	EV quick charging plug		Near to train station		EV charging plug
Infrastructure and Facilities	Commercial facility (nearby)	Restaurant Wedding hall	Café Shop	Commercial facility (nearby)			Cafe Restaurant Bookstore	Cafe Restaurant		Office Commercial facility Exhibition hall	Grocery store Shopping center (nearby)	Golf course Skating rink Swimming pool		
Educational and welfare facility		Tennis club Clinic	Delivery service				Learning facilities Learning classes Nursing home Pharmacy Sports club Clinic Elderly care service	Hospital Pharmacy Childcare center Nursing care service	Physical condition management Kindergarten Library	Primary school Kindergarten Public daycare center	Laboratory Library Health care University	Secondary school		
Environmental & social	Nature	Kitchen garden Local trees Biotope Bird pass	Greening Pond conservation Wetland restoration	Greening	Greening Kitchen garden Fruit trees	Vegetation preferred by surrounding organisms	Greening Cherry blossoms road	Greening Local plants	Greening Community garden Local plants	Greening		A wide range of plants mixed grass types	Nature activities Mountain conservation Wildlife conservation	Diversification of plants and animals through agriculture
	Landscape	Symbol tree Waterfront landscape planning	Symbol tree Utility pole free Waterfront landscape design District landscape guideline	Stain-resistant exterior walls Utility pole free City landscape ordinance Townscape formation guidelines	Reconstruction of historical building Symbolic park	Symbol tree Utility pole free	Townscape unification Landmark tree Wood texture utility pole Township guideline	Utility pole free Symbolic townscape Town guideline	Utility pole free Landscape regulation Township guideline	Utility pole free Guideline				Design competition Environmentally friendly design

Requirement	Measures	Koshigaya	Ayameike	Shioashiya	Omiya	Harumidai	Kumagaya	Fujisawa	Jono	Maruyama	Lehen	Stenlose	Los Alamos	Furuset	
Environment	Passive design	High heat insulating house	Airtight and high heat insulating house	High heat insulating house	High heat insulating specification	High heat insulating house	Daylight use	High heat insulating house	Heat insulating window	High heat insulating house	High heat insulating house	High heat insulating house			
		Wind catch window	Daylight use	Promotion of natural ventilation	High performance sash	Heat shield screen	Ceiling fan	Daylight use	High heat insulating house	Wind catch window	Wind catch window	3-pane glazing	High performance insulation materials		
		Heat shield screen	Promotion of natural ventilation	Promotion of natural ventilation	High performance sash	Heat shield screen	Cool louver	Water retentive pavement	Wind catch window	Daylight use	Promotion of natural ventilation	Ceiling fan	Solar thermal collectors	Efficient ventilation systems	Wood fiber insulation
	Energy efficiency	Visualization of energy use	Deciduous tree and high hedge	Creation of cool air in extension	Creation of cool air in extension	Creation of cool air in extension	Wind catch window	High reflective coating	Ventilation using temperature difference	Promotion of natural ventilation	Creation of cool air in extension	Mechanical ventilation system with heat recovery	Passive solar heating system		
			Creation of cool air in extension					Creation of cool air in extension	Creation of cool air in extension	Creation of cool air in extension	Automatic window opening				
											External blinds	High performance sash			
	Eco-point	Eco-point		Local currency system					Local currency system	Local currency system					
					Energy monitor			HEMS	HEMS	HEMS	HEMS				HEMS
					Visualization by fountain height	HEMS	HEMS	HEMS	Website	Website	Energy conservation report	BEMS	Event		Smart meter
	High efficiency equipment	High efficiency equipment	High-efficiency water heater	Condensation boiler	LED central air conditioning system	High-efficiency water heater	LED	High-efficiency water heater	High-efficiency air conditioner	Smart air conditioner LED	Energy-saving equipment	LED	Heat pumps (HP)	District heating system	Heat pumps (HP)
High-efficiency air conditioner			LED		LED								District heating system	District heating system	District heating system
Equipment and appliance management	Equipment and appliance management				HEMS (TV, air conditioner)	HEMS (Battery · air conditioner)	HEMS (lighting, TV, cool air control)	Air conditioner automatic control		HEMS	CEMS	Demand response	Air conditioner automatic control		
Resource conservation	Resource conservation	Water saving	Rainwater tank	Rainwater tank	Rainwater tank		Sprinklers water using groundwater	Rainwater utilization system	Rainwater utilization system	Rainwater utilization system			Rainwater utilization system		
		Reuse/recycle	Compost		Compost			Water saving function	Water saving function	Compost			Biomass		
		Construction resource material	Reuse of incinerated slag and stone as paving material	Use of local wood								Renovation	Use of existing roof		Renovation
Environmental & safety and security	Power generation & energy management	Battery		Batteries		Batteries V2H	Batteries (only meeting place)	Batteries V2H	Batteries EV	Batteries EV			Batteries	EV	
		Renewable energy	Solar thermal central heating system (Apartment house)	PV	PV	PV	PV		PV	PV	Solar thermal power	Solar thermal power	PV	PV	PV
		CGS, waste heat		Solid Oxide Fuel cells	Solid Oxide Fuel cells		Solid Oxide Fuel cells	Solid Oxide Fuel cells	Solid Oxide Fuel cells	Solid Oxide Fuel cells	Solid Oxide Fuel cells	Industrial waste heat resources		Solid oxide fuel cells	
		Community energy management system			Micro-grid								Micro-grid of heat district		Smart grid

Requirement	Measures	Koshigaya	Ayameike	Shioashiya	Omiya	Harumidai	Kumagaya	Fujisawa	Jono	Maruyama	Lehen	Stenlose	Los Alamos	Furuset
Safety and Security	Disaster prevention		Stockpile warehouse Rainwater tank	Stockpile warehouse Rainwater tank Outlet for power outage	Outlet for power outage	Stockpile warehouse Rainwater tank	Stockpile warehouse Well Outlet for power outage	Stockpile warehouse Rainwater utilization Emergency backup power supply Medium pressure gas		Rainwater tank			Promotion of BCP formulation	
	Disaster prevention measures	Disaster prevention map and event Soil erosion prevention		Evacuation center	Ground improvement for earthquake resilience	Disaster prevention event Disaster broadcasting	Bike parking lot during typhoons	Automatic notification of disaster information Safety confirmation Evacuation center Emergency operation system	Disaster prevention map and training	Evacuation route Disaster prevention event			Evacuation system in public facilities Website hazard map	
	Traffic safety	Image hump Controlling traffic with loop-shaped road	Pedestrian-only road	Pedestrian-only road Car-only road Improving visibility of road by corner cut		Image hump Traffic control	Improving visibility of road by corner cut Traffic control Image hump		Pedestrian-only road Vehicle-only road Traffic control	Pedestrian-only road Pedestrian/vehicle coexistence road Image hump Traffic control			Traffic and street division	
	Crime-prevention	Security camera	Security map Patrol by a guard Security camera	Patrol by a guard Security camera Visibility street	Visibility street	Remote door lock Patrol by a guard Security camera	Electric shutter Remote door lock Window open/close notification	Nighttime patrol Security camera	Patrol by a guard Security camera Crime prevention class	Remote door lock Patrol by a guard Security camera			Patrol by a police	

4

Information on each case study was collected via site visits, literature reviews, and websites. The essential requirements for Japanese smart communities were identified from common elements in Japan and elements not found in Japan but found in other countries; however, it should be noted that the developed information might be incomplete, as all data may not have been released.

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### 2.3. Requirement details

The essential *social* requirements were maintaining asset value, social mixing, community, and infrastructure and facilities.

#### 2.3.1. Social requirements

##### (1) Maintaining asset value

Asset value refers to whether there is a mechanism for economically sustainable community development to maintain and improve the community's attractiveness and value. For example, in Japan, the town management company in Fujisawa aims to improve the town's asset value by conducting sustainable management activities based on town management fees and project income, such as solar power generation.

##### (2) Social mixing

Social mixing refers to the diversity of residential ethnicity, age, and occupation, and support for the socially vulnerable. Each of the smart communities in Japan are high-end residential areas, as they are recently developed and outfitted with the most modern, environmentally friendly equipment. Accordingly, many resident families are from the same generation, with small children. Also, Japanese

<sup>4</sup> Abbreviations: EV – Electric Vehicle, EMS – Energy management system, HEMS – Home energy management system, BEMS – Building energy management system, CEMS – Community energy management system, HP – Heat pump, DR – Demand response, V2H – Vehicle to house.



people tend not to relocate once they have become established in a detached house; therefore, it is highly likely that the community will be aging over the next few decades. In contrast, the community in Los Alamos has a homebuyer assistance program that helps households meet down payments and financial criteria set by the county. The community's developers in Furuset actively work to diversify age ranges by inviting children and seniors into the planning process, and have constructed student dormitories and a kindergarten.

### (3) Community

Community aspects include facilities, organization, and activities. All Japanese communities have parks, meeting places, and other gathering locations, all of which promote residential interaction. However, an interview survey we conducted revealed that there are relatively frequent cases where the meeting places remain unused; accordingly, there is a need to not only create these spaces, but also promote residential interaction as well. As a countermeasure, Jono and Fujisawa have town management organizations that hold events for residents in public spaces. Because all European cases are government-led, there is a greater tendency for interactions between residents and businesses within the development process. Particularly in Lehen, many companies and non-profit organizations were involved in discussions at the planning stages, and industries, government, and the private sector are working together.

### (4) Infrastructure and facilities

Infrastructure and facility aspects include mobility, commercial facilities, and educational and welfare facilities within the smart community. In Japan, there are numerous examples where electric vehicles (EVs) and car sharing have been introduced. For example, the community in Omiya offers an EV car-sharing service. In addition, larger communities such as Fujisawa and Jono tend to have commercial and welfare facilities. Outside of Japan, no information on car sharing or EVs was identified within the smart communities; however, those in Europe tended to have kindergartens and schools that do not exist in the Japanese cases.

#### 2.3.2. Environmental and social requirements

The essential environmental and social requirements revolve around the preservation or creation of nature, landscape, and cultural aspects. Japanese smart communities tend to create natural, beautiful landscapes and locations for residential interaction by increasing greening rates, installing symbolic trees, and operating community gardens. In some cases, local biodiversity is also taken into consideration by planting native species. All cases tend to follow landscape ordinances and guidelines, but because smart communities in Japan often use factory-prefabricated houses, it makes creating a unique landscape with local identity difficult. Conversely, in Furuset, many architects and landscape architects submit creative proposals. For example, creative landscapes were proposed, including townhouse-style residential buildings and a large central garden. In addition, wooden materials, solar hot water panels, and sedum roofs have been incorporated into the design to help visually emphasize environmental efforts. Another example is the urban PV project of Amersfoort, the Netherlands (Bouwmeester & van Ijken, 1999). In Amersfoort, the urban planners, architects, and developers collaborated on the implementation of a PV project, and a variety of designs have shown the citizens that a new age of renewable energy has arrived.

#### 2.3.3. Environmental requirements

##### (1) Energy efficiency

All Japanese and EU case studies used passive designs for residential buildings to maximize the natural light, heat, and air flow for creating a comfortable indoor environment, and reducing energy demand for lighting, heating, and cooling. Japan's hot summers require the incorporation of passive designs for building and outdoor spaces to reduce the cooling load. Remarkably, in five of the nine cases analyzed, outdoor thermal environmental simulations were used to support passive design planning. These may also include a housing layout that encourages air throughflow and uses water retention coating for the roads to enhance evaporation. Other forms of natural energy include ceiling fans, drip louvers, and skylights. A drip louver is a device that runs water over the surface of louvers to lower the louver temperature through evaporative cooling, thus generating a cool breeze downwind, as seen in the communities of Maruyama and Kumagaya. In Japan, cooling accounts for a small percentage of the annual end-use energy consumption for residential buildings (Muto & Muraki, 2016) (Taniguchi-Matsuoka et al., 2020); however, the popularity of these efforts indicate that Japanese residents value cooling in the summer. In Europe, passive house and other similar standards have been established, and all three case study communities were working to meet those standards.

2.3.3.1. *Improved thermal insulation was introduced in most cases, both in Japan and abroad.* In Japan, encouragement of energy conservation was accomplished through the unique initiatives of visualizing energy usage, eco-points, and energy saving advice. Most cases visualize electricity consumption by employing a home energy management system (HEMS); however, in Fujisawa, in addition to the amount of electricity consumed and generated by each household, residents can also check their energy consumption rankings within the community, as well as self-consumption rates of PV-generated electricity. The HEMSs of Omiya maintain additional functions, such as alerting residents to open the windows when appropriate outdoor air temperatures have been reached, and providing information on proper plant maintenance. In many cases, eco-points are awarded by quantifying the energy-saving behavior of each resident, in

conjunction with the visualization. These points can be used for car sharing or shopping in stores supporting the community.

The use of high-efficiency equipment was observed in all Japanese cases. In Japan, LEDs have been installed in almost communities, and high-efficiency water heaters have been installed in half of the cases. Elsewhere, the community in Kosigaya has installed a central heating system employing solar heat. Although rare in Japan, in Europe, heating systems such as solar thermal have been actively introduced due to the large heating demand. As the energy demand in Japan for heating and hot water is also relatively large, and incoming solar radiation is sufficient, the widespread introduction of these systems should be effective.

Equipment and appliance management refers to functions that allow residents to control appliances, facilitated by ICT. In Omiya and Kumagaya, operation and time management of appliances can be carried out by smart phone through a cloud operation center, which controls the HEMS of each household.

## (2) Resource conservation

The aspects of resource conservation include water saving, reuse/recycle, and construction material saving. Almost all Japanese cases have introduced rainwater collection and reuse within the community. Some communities use rainwater for watering plants or non-potable emergency purposes, such as toilet and fire-sprinkler water. In Kumagaya, well water is used in a mist system employing the heat of vaporization to lower ambient temperatures. The community in Stenlose has installed facilities to promote water infiltration into the ground, and reuses rainwater for toilets and laundry.

The communities in Ayameike and Omiya are working on the re-use of waste resources, and have introduced a composting system for organic waste using microorganisms to decompose kitchen waste and scrap wood.

For conservation of construction resources, some Japanese cases have reused paving materials and employed locally sourced wood. In Europe, in addition to the use of local wood, retrofitting older buildings via renovation have helped reduce construction waste; however, because all smart communities in Japan are recently developed, there are no such examples of renovation or conversion at present.

### 2.3.4. Environmental & safety and security

In general, each housing unit includes solar cells (PV), batteries, and/or fuel cells, whereas larger-capacity PV and batteries are placed in the community's public spaces, such as at the community hall, ponds, and parks. In Ayameike, wind power generation has been installed in the public space. Public space PV and batteries are often used for the community hall and streetlights, and in emergency situations, the former can become an evacuation center for the community and surrounding areas, maintaining a local power source. The Shioasiya community has installed PV and large-capacity batteries in the common areas of an apartment building, and the PV system is divided into two parts: one for selling the electricity generated and the other for storage in case of disaster. In Kumagaya, if city gas and water persist during an emergency, residents in each house can use  $\leq 700$  W for a maximum of  $\sim 4$  h, even during a power outage. This combination of PV, fuel cells, and batteries is a common feature of Japanese smart communities. Power generation is also being used in Europe, although mostly to meet heating demands under normal circumstances. For example, the district heating network in Stenlose is based on biomass boilers, large heat pumps, and large solar thermal collectors. The Los Alamos community in the US has installed a large-scale micro-grid (MG), or a decentralized group of electricity resources and demand networks that can be operated independently from wider-area electricity grids during emergencies. There are 1600 smart meters installed across the entire region, and they can perform not only electricity sharing but demand response as well, and are capable of forecasting solar power generation. In Japan, the Shioashiya MG is the only such example of power sharing within a community. Each house has been outfitted with PV, batteries, and a HEMS, and the batteries are connected to a network to enable power sharing between houses.

### 2.3.5. Safety and security

#### (1) Disaster prevention

The essential safety and security requirements revolve around disaster prevention and safety. Disaster prevention plan aspects include a LCP and disaster prevention measures. The LCP entails the planning involved in creating systems for the prevention of and recovery from disaster-like threats. In Japan, most plans include using common spaces to store emergency food and drink, and installing rainwater tanks and wells to help offset water shortages. In addition to stockpile warehouses, the Fujisawa community has manhole toilets, benches that transform into cooking fixtures, and PV chargers to ensure lifelines for up to three days following a disaster. Alternatively, no information on disaster prevention was found in the European cases, although the Los Alamos district has posted their LCP on the local website to ensure resident safety. Furthermore, hazard maps and emergency shelters in public facilities have been developed in Los Alamos as well.

#### (2) Safety aspects

Safety aspects include traffic safety and security. To this end, Japanese and the US communities employ numerous countermeasures to ensure resident security. In Japan, traffic safety is increased by implementing community designs to reduce car flow, reduce car speed, and prevent pedestrian accidents, such as the use of speed bumps and the establishment of separate pedestrian lanes. In addition, if the community has a system for monitoring real-time energy use (e.g., HEMS), anomalous resident activity can be detected.

2.4. Summary of case studies

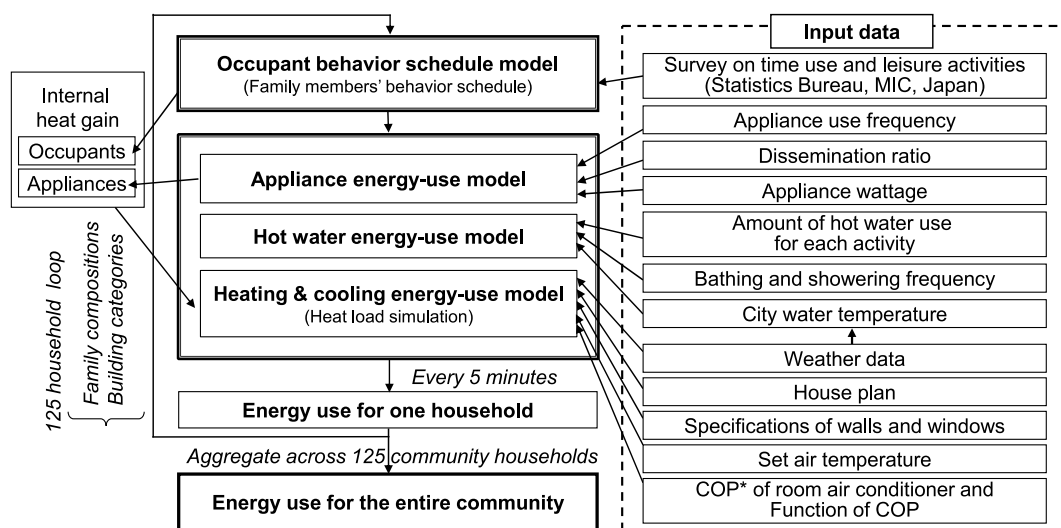
Here, the results of detailed case study analyses for Japanese and non-Japanese communities are presented. The primary characteristics identified for Japanese smart communities were.

- Japanese smart communities tend to reflect industry-oriented intentions (in some cases, appliance manufacturer is directly developed) in their community development, and they tend to employ the latest technologies. As a result, development costs are high, and most smart communities in Japan are high-end residential complexes. Moreover, the payback period for energy systems is as long as 14 years as shown in section 3.2. These reasons are because of the majority of developers in Japan are private companies, as mentioned in the introduction.
- The importance of community activities (e.g., resident interaction) is well understood, and to this end, facilities such as parks and community spaces have been introduced, the management association encourages and support such activities in about half of cases.
- There are various approaches for realizing environmental and energy initiatives, such as EV charging plugs, passive designs, high-efficiency equipment, and energy visualization are among the most often used.
- Distributed power sources are also common, and in nearly all cases use a combination of PV, fuel cells, and batteries. Alternatively, the introduction of community energy management systems, which were common in other cases outside Japan, such as MGs, are relatively rare.
- Disaster prevention measures, for which there was little information available outside Japan, are also well developed. LCPs and other measures, such as disaster prevention maps, training, and securing independent energy resources, are being actively implemented as well.
- Compared with overseas examples, design innovations in particular are insufficient. The lack of interest in landscape in Japanese urban development is evident.

3. Quantitative evaluation of simulated energy performance

Among the requirements for smart communities described in Section 2, quantitative evaluations of the relationship between technology options and energy performance are necessary. Here, a household energy demand model was used to evaluate energy performance in a virtual Japanese smart community containing hundreds of detached houses. To effectively evaluate the community's energy performance, the simulation included the following characteristics:

- (1) Bottom-up model. The model simulated community-level energy demand by summing across each household results, which considered occupant attributes and building specifications.
- (2) Load curve replication. To evaluate the supply-demand balance of electricity, it was necessary to reproduce the PV generation and load curves for each house over a specified time interval.
- (3) Household energy use heterogeneity. The load curve of the community was produced by integrating those of the diverse households making up the community.



\*Coefficient of performance: describe the heating and cooling efficiency of air conditioners.

Fig. 2. Conceptual flowchart of the residential energy end-use model (TREES).

Here, a Positive Energy District (PED) can be generally described as a district within a city that generates more energy than it consumes on an annual basis (Hedman et al., 2021). In this section, a similar concept, a zero-energy community (ZEC) is defined as a district whose annual primary energy consumption is covered by annual PV energy generation, in addition to a reduction of overall energy consumption due to the implementation of more sustainable technologies. The formula for calculating the ZEC achievement rate is presented in Eq. (1):

$$\text{ZEC Achievement Rate} = \frac{\text{total energy production}}{\text{total energy consumption}} \times 100 \quad (1)$$

In Case A, energy performance was evaluated in terms of power generation, self-consumption, ZEC achievement rate, etc., for conventional city-gas supplied houses in Japan, entirely electric houses with PV, houses with two cells and one battery, and solid oxide fuel cell (SOFC)-PV-battery houses (which are common to smart communities in Japan). The energy performance of passive technologies, also common to Japanese smart communities, was considered as well. Case B estimated energy consumption 15 years and 30 years after the initial assumptions for occupants to assess the energy consumption impacts of differences in household composition and living style. Lastly, Case C evaluated disaster resiliency.

### 3.1. Simulation model

#### 3.1.1. Residential energy end-use model

To create an accurate evaluation of smart-community energy performance, we employed the Total Residential End-use Energy Simulation (TREES) model, which was previously developed by the authors (Shimoda et al., 2021). The flowchart for this simulation can be seen in Fig. 2. Examples of the simulated results on a representative day are shown below. First, the occupant behavior model created a schedule for every occupant of each household, according to their attributes such as gender, age, occupation, and presence of children, etc. Then, in the appliance energy-use model, the operation schedule of each appliance was stochastically determined based on the occupant behavior schedule and the probability of appliance use. The appliance energy consumption for each period was estimated from the operation status and electricity consumption during operation and standby. Heating and cooling energy consumption was estimated by thermal circuit calculation, based on building insulation levels and weather conditions. The model considered local weather conditions, thus allowing the heating/cooling energy use simulations to take into account changes in outdoor air temperature and humidity. The amount of PV power generation was calculated according to the same weather data, allowing for the replication of the power flow between the electrical grid and community. Community energy consumption was then estimated by aggregating the simulation results for each household, and examples of the simulated results on a representative day are shown below. More detailed information on TREES can be found in (Shimoda et al., 2021), including specification of the appliances used in this study.

Fig. 3(a) shows a one-day load curve for a representative household with a 4.0-kW PV capacity, whereas Fig. 3(b) shows the results when adapting the model to the community scale. As expected, the aggregated load curve at the community level was smoother than the load curve for individual households, as the form is derived by integrating the various individual curves. In this study, a smart community with a scale of 125 detached houses located in Osaka was simulated, taking specifications and some parameters from the Maruyama community, which is one of the case studies discussed in Section 2, because it is the latest smart community in Japan.

#### 3.1.2. Battery and battery-SOFC models

To promote self-sufficiency in renewable energy, battery storage is among the most essential components, as it permits the economic residential use of PV-generated power when the selling price to the grid is low. Batteries also have a leveling effect on the load curve, absorbing surplus SOFC and PV power. Here, a battery model and battery + SOFC model, each maintaining a different order of power supply, were used to estimate the home battery storage operation (see Table 4 for details on SOFC).

Fig. 4(a) shows the flowchart of the battery model, where for each time step, the PV power generation and housing power consumption estimated according to the residential energy end-use model determined the battery's operational status. PV-generated power was prioritized for self-consumption, and when surplus power was available, it was stored in the batteries. Conversely, electricity from

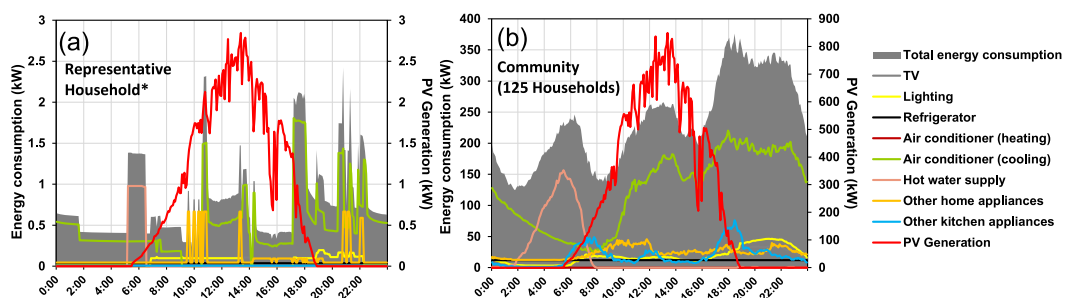
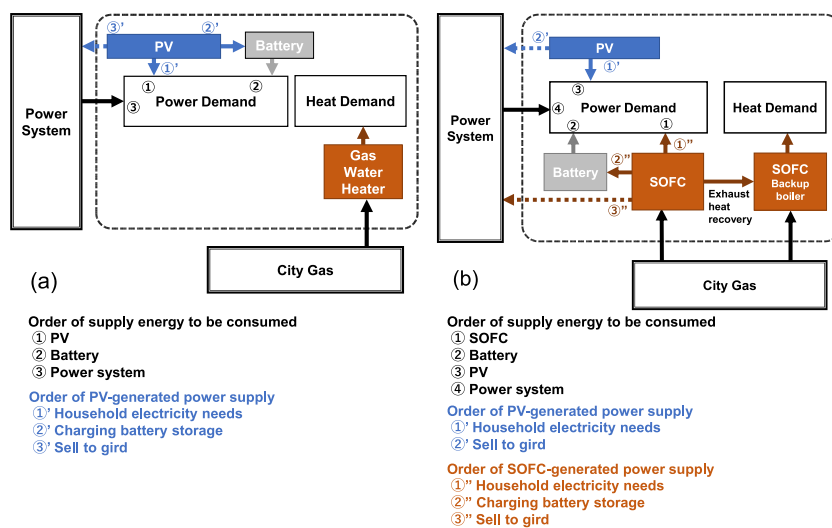


Fig. 3. Simulated daily load curves for (a) a representative household containing four people, a single-income couple with two elementary-aged children, and (b) the community.

**Table 4**  
SOFC specifications.

Power generation	700 W
Power generation efficiency	46.4%
Exhaust heat recovery efficiency	30.9%



**Fig. 4.** Conceptual flowchart of the (a) battery model system and (b) battery + SOFC model system.

the batteries was consumed when the PV-generated energy was insufficient to meet household demand, and purchases from the grid were made if battery power was still insufficient.

Fig. 4(b) shows the battery + SOFC model flowchart. Similar to the battery model, the PV power generation and power consumption estimated by the residential energy end-use model determined the battery and SOFC operation at each time step. The SOFC, battery, and PV supply priorities were as follows:

- 1 SOFC: Household electricity needs → Charging battery storage → Sell to the grid
- 2 Battery: Household electricity needs
- 3 PV: Household electricity needs → Charging battery storage → Sell to grid
- 4 When electricity supply from all household sources is insufficient to meet the household electricity needs, the deficit is supplied from the power grid.

### 3.1.3. Microgrid model

Because all buildings and distribution networks of a smart community are developed simultaneously, it is possible to form a MG that

**Table 5**  
Simulation conditions.

	Type 1: Gas-powered house	Type 2: All-electric house	Type 3: House with three batteries
PV capacity	–	4.0 kW	
Insulation standard	ZEH-standard $U_a^a$ 0.6 W·(m·K) <sup>-1</sup>		
Family composition	<ul style="list-style-type: none"> <li>• 2 people: single/double-income couple (single: 13 households; double: 23 households)</li> <li>• 4 people: single/double-income couple, 2 elementary school students (single: 33 households; double: 56 households)</li> </ul>		
House application	Air conditioning, LED Light, High efficiency home appliance		
DHW	Gas boiler	Heat pump	Gas boiler
Power generation equipment	–	PV + Battery	PV + Battery + SOFC
Weather data	Apr. 2016–Mar. 2017, Osaka Pref., Japan, 5-min data		
Annual average of total solar radiation in Osaka (2022 Japan Meteorological Agency)	14.2 MJ/m <sup>2</sup> (Apr. 2016–Mar. 2017)		

<sup>a</sup> Average heat transfer rate.

allows for electric power to be interchanged via private lines laid between the houses. By managing electricity within the community, the MG allows the community to be independent of the centralized electric power system. Importantly, in the case of a general power outage, such as during a disaster event, power generation from PV systems within the community can be shared by all the houses.

In the MG model used here, the community power interchange system was simplified. Power consumption, PV generation, and total battery storage for the community were treated as a large-scale building with a PV system and battery, and the battery operating conditions were thus estimated using the same calculation method as used in the battery model.

### 3.2. Case A: Evaluation of energy performance in a typical Japanese smart community

To evaluate the energy performance of a typical smart community in Japan, the following three cases were simulated (Table 5):

- Type 1: Japanese conventional house using city gas for hot water.
- Type 2: All-electrified house, common in many global smart communities.
- Type 3: House with PV, fuel cell, and battery, typical of Japanese smart communities.

Fig. 5 Shows the annual primary energy consumption. Here, a primary energy conversion factor of  $9760 \text{ kJ}\cdot\text{kWh}^{-1}$  was used for electricity. First, in conventional gas-powered houses, purchased electricity accounted for 71% of the total energy consumption, the primary energy consumption of the entire community was 7163 GJ, and the ZEC achievement rate was 0%. For Type 2, energy consumption decreased by 1220 GJ due to the electrification of all equipment. In addition, during the daytime, ~32% of the house's electricity consumption was supplied by PV, and the remaining 68% was purchased from the grid. If possible to sell surplus electricity to the grid, the overall primary energy consumption was 643 GJ, and the ZEC achievement rate was 89%. In Type 3, the ratio of electricity self-consumption increased to 92%. Although gas consumption was greatly increased due to the presence of the SOFC, the amount of gas used for the hot water supply was reduced compared to that in Type 1 because of the recovery of waste heat from the SOFC. Also, if the surplus electricity could be sold to the grid, the ZEC achievement rate was 113%, making it a positive energy district, capable of generating 1449 GJ of energy. Thus, the energy consumption for the hot water supply and reduced consumption from the grid exceeded the gas consumption of the SOFC. Lastly, the results of the case where the passive technology was installed in the Type 3 house, including external blinds, high sashes, automatic window openings, and the passive district with low outdoor air temperatures due to greening and housing layout, all common to Japanese smart communities, is shown as Type 3' in Fig. 5. As a result, total energy consumption decreased by 103 GJ and the ZEC achievement rate increased slightly to 114%. However, the initial cost of installing the equipment was high: if the installation costs of PV, batteries, and SOFCs are 1.2 million Japanese yen (JPY), 1.5 million JPY, and 1.5 million JPY, respectively, the payback period for the initial cost is about 14 years for Type 2 and 7 years for Type 3 (Table 6).

### 3.3. Case B: Energy demand changes due to differences in constituent households

In Japan, residents of new housing tend to live in this location for an extended period of time. Thus, even if housing and appliance specifications remain unchanged, household compositional changes due to aging will affect the home's energy performance over time. Accordingly, energy performance within the community was evaluated considering a systematic change in constituent households. Assuming the Type 3 community evaluated in Case A, and defining Stage 1 as the 15-year period immediately following the completion of community construction, household composition was examined for this period, in addition to the two subsequent 15-year periods (Stages 2 and 3) (Table 7). During Stage 1, the distribution of family classification was determined based on the 2016 housing market trends, the Gender Equality White Paper (Gender Equality Bureau Cabinet Office, 2016), and interviews with house builders. Stage 2 assumed that the household composition had diversified, and the number of family types increased, such as when individual couples

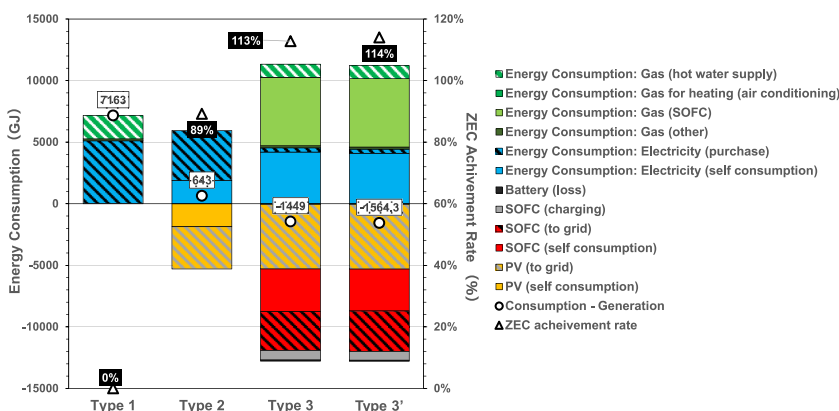


Fig. 5. Annual energy consumption and generation.

**Table 6**  
Initial and utility costs.

	Electricity bills	Gas bills	Power selling incomes	Equipment installation cost	Balance of payments
Type 1	102,012 JPY	92,329 JPY			+194,341 JPY
Type 2	78,492 JPY		87,081 JPY	120,000 JPY	-8652 JPY
Type 3	6162 JPY	88,902 JPY	153,866 JPY	420,000 JPY	- 58,803 JPY

decided to have children. Stage 3 assumed an aging community, and set a new type of household composition, which might include an elderly couple or two generations living in the family home.

Relative to Stage 1, annual energy consumption increased by 439 GJ in Stage 2, and 1069 GJ in Stage 3 (Fig. 6). Stage 3 energy consumption for lighting, hot water supply, TV, home appliances, and kitchens increased by  $\geq 10\%$  relative to Stage 1. The number of homemakers and elderly who were in the house for longer hours during the day increased with the stages, as did the correlated energy consumption of appliances during the day. Among them, the change in energy consumption for TVs and kitchens in particular increased by  $>40\%$ . As both types of appliances tend to be operated in conjunction with the act of eating, this indicates that the increase in energy consumption during meals is relatively large. Fig. 7 shows the power generation and consumption by SOFC and PV systems, and the ZEC achievement rate. The self-consumption rate improved across stages, although the ZEC achievement rate decreased in stage 3.

### 3.4. Case C: LCP evaluation by distributed energy system

In Japanese smart communities, LCP-related activities, such as the installation of distributed energy systems, stockpile warehouses, and disaster prevention events, are employed, and the community is expected to serve as an assistance hub in the event of a disaster. Here, the disaster (power outage) resiliency of a city block was evaluated quantitatively during a simulated disaster to assess its strength against disasters. Based on the Japanese norm of maintaining a week's worth of stockpile in the event of a major earthquake, the amount of electricity demand for home appliances that could be covered by intra-district-distributed power sources was assessed. The reason for evaluating the power shortage time is that it is more effective to maintain living conditions if the power shortage time is as short as possible. In addition, based on the idea that the indoor environment is guaranteed due to the highly insulated housing, air conditioning was excluded, and the duration of operation of lighting, home appliances, and information equipment was evaluated. Because the residential energy end-use model simulated energy demand in detail for virtually all appliances, it was possible to replicate a load curve for any given set of appliances. The selected appliances that would be used in an emergency are shown in Table 8.

The evaluation periods are shown in Table 9. The power outage started at 7 p.m., to impose a worst-case scenario because the power shortage would be the greatest due to diminished PV power generation and increased power demand as residents return home.

In *Battery*, a battery was installed in each house; whereas in *MG*, an MG was formed to interchange power within the community. Figs. 8 and 9 show the energy consumption of appliances in an emergency and the operational status of the in-house battery in summer and winter, respectively. Notably, the time during which a power shortage occurred in  $>50\%$  of the community households was not observed in *MG*. Table 10 shows the total weekly (168 h) power shortage time. In Week 2, the week with the greatest amount of solar

**Table 7**  
Family composition at each stage.

		Stage 1: Initial Conditions (400 people)	Stage 2: 15 Years After (438 people)	Stage 3: 30 Years After (455 people)
2 people	Single income couple	10%	5%	20%
	Double income couple	18%	15%	
	Elderly couple			15%
3 people	Single income couple+ Child		10%	
	Double income couple + Working man			
4 people	Single income couple + Elementary school students	27%		
	Double income couple + Elementary school students	45%		
	Double income couple + Children		30%	
	Single income+ High school student + Middle school student		20%	
	Double income couple + High school student + Middle school student		20%	
	Double income couple + Working man			10%
	Double income couple + Double income couple			10%
	Elderly couple+			45%
	Single income couple + Middle school students			

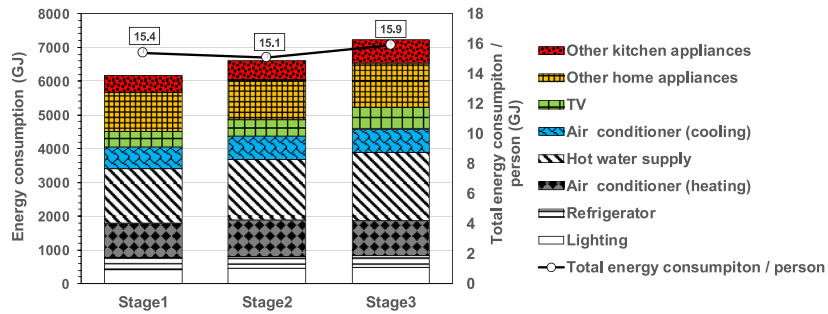


Fig. 6. Estimated annual energy consumption.

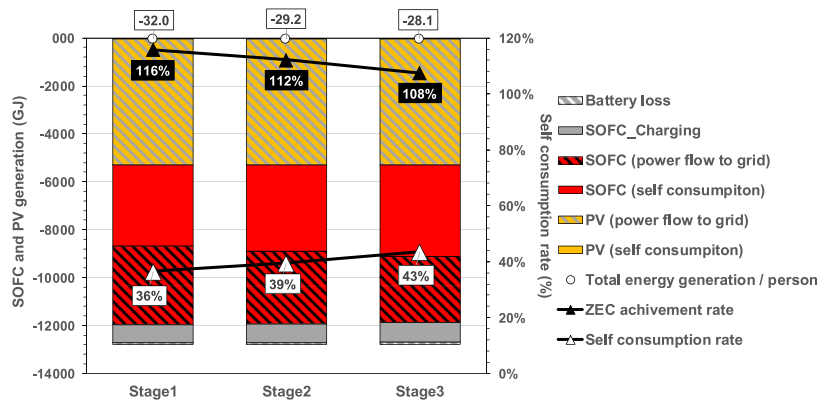


Fig. 7. Percent ZEC achievement and self-consumption.

Table 8

LCP evaluation content.

Emergency Appliances	
Light	LED light in living room
Information	TV in living room
Meals	Kitchen appliances: refrigerator, electric rice-cooker, microwave oven, hot water pot, Induction Heating (IH)
Evaluation (i.e., Power Outage) Week	
Week 1	Solar irradiance (min.): Dec. 22, 2016–Dec 28, 2016
Week 2	Solar irradiance (max.): May 17, 2016–May 23, 2016
Week 3	Average temperature (min.): Jan 20, 2017–Jan 26, 2016
Week 4	Average temperature (max.): Aug 19, 2016–Aug 25, 2016

Table 9

Simulation conditions.

	Battery	MG
Battery	Capacity 3.2 kWh/Charging 0.7 kW/Discharging 1.0 kW/Loss Rate 90%	
Sharing electricity	Absent	Present
Insulation standard	ZEH-standard	
Family composition	2 people (Single/Double income couple) & 4 people (Single/Double income couple, 2 elementary aged children)	
PV Capacity/Angle/Orientation	4.0 kW/2/1 Slope (25.6°)/South-facing roof	
Weather data	Apr. 2016–Mar. 2017, Osaka Pref., Japan, 5-min data	
House layout	2-story house	

radiation, the power shortage time was only 0.11 h (7 min) per day, even in *Battery*. The effect of power sharing was significant for all weeks, except Week 2. In Week 1 (minimum solar irradiance week), and Week 3 (minimum temperature week), power shortages occurred frequently in *Battery*, from evening to early morning, when no electricity was being supplied from PV; however, this power



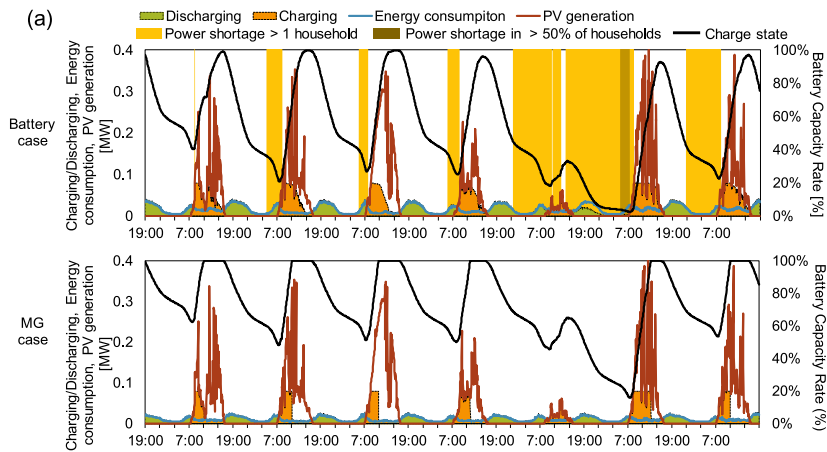


Fig. 8. LCP evaluation for Week 1 – Dec (minimum solar irradiance).

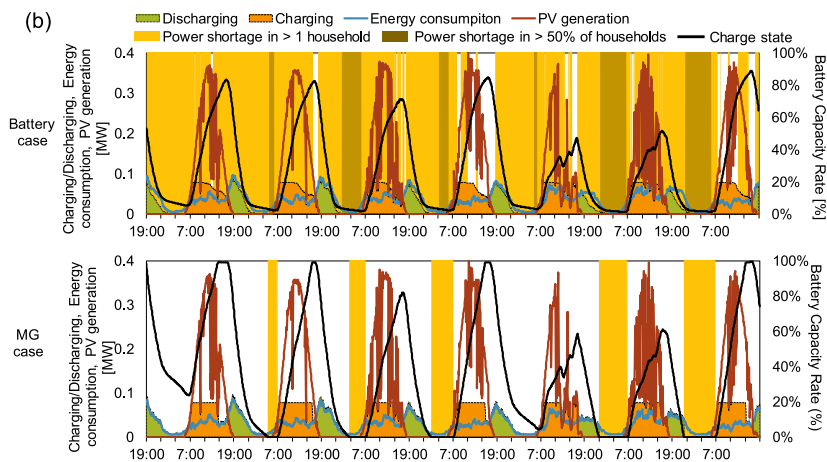


Fig. 9. LCP evaluation for Week 4 – Aug (maximum temperature).

Table 10  
Total power shortage time.

	Power shortage time (h-week <sup>-1</sup> )	
	Battery	MG
Week 1 - Dec	7.31	0
Week 2 - May	0.11	0
Week 3 - Jan	3.14	0
Week 4 - Aug	20.81	4.15

shortage time disappeared in MG. In Week 4 (maximum temperature week), the power shortage time was also substantially shorter, with >80% fewer hours in MG case compared to Battery case; although, the community as a whole still had >4 h of power shortage per day, and the power shortage was not eliminated without stopping the use of air conditioners. It is necessary to solve the power shortage during emergencies not only through power sharing, but also to increase storage capacity and promote the use of PV surplus power.

#### 4. Conclusion

The analysis of current Japanese smart community trends, when compared with other global cases, revealed certain essential requirements. Here are the answers to research questions A and B presented in Section 1:

- A) Japan has a high level of interest and development effort related to both environmental and energy technologies, as well as disaster prevention measures. EV charging plugs, passive designs, high-efficiency equipment, and visualization of energy consumption are among the most often used methods. Also, distributed power sources combining PV, fuel cells, and batteries were common in the studied communities. In the area of disaster prevention, LCPs and other measures, such as disaster prevention maps, training, and securing independent energy resources, are being actively implemented as well.
- B) Japan has some issues that have not been sufficiently addressed compared to other world cases, such as the participation of local residents in the development process, social mixing to increase resident diversity, and creative landscapes.

Future smart communities in Japan will need to comprehensively improve the quality of each requirement listed in Table 3, and it will be necessary to actively encourage developers to work on these requirements where efforts are insufficient. Additionally, although ICT was used in some cases, implementation was limited to the visualization of energy use and the control of specific equipment and facilities through HEMS. In warmer regions such as Japan, the energy demand for various uses other than heating is relatively high, and this demand in turn is affected by resident composition and behavior; thus, it is necessary to promote efforts for sharing and managing energy by optimizing the use of ICT.

In Section 3, the environmental and energy performance of Japanese virtual smart communities was evaluated quantitatively. The main findings for research questions C through E presented in Section 1 are as follows:

- C) The energy performance evaluation of the typical smart community in Japan, which has PV, fuel cells, and batteries, indicating it is a positive energy district.
- D) In the energy demand evaluation due to differences across constituent households, it was found that the annual energy consumption increased by 17% due to aging household populations.
- E) In the LCP evaluation with distributed energy systems, it was found that no power shortage occurred for most weeks when an MG was present.

Given that household composition within a community changes over time, it is important to consider not only technological options when planning for the aging of smart communities, but also the anticipated status of community residents. Especially in the coming era, it will be necessary to respond flexibly to aging populations, as well as other changes in lifestyle (e.g., the prominence of telework) that have come about with COVID-19. In the future, there is a possibility that societal values and family structures will be further diversified as social situations change; therefore, to adequately manage the energy performance of a community and create a safe and secure environment for residents, it is necessary to create a broad and flexible community, unbounded by conventional concepts.

Disclosure statement.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Data availability statement

The data that support the findings of this study are openly available in <http://www.see.eng.osaka-u.ac.jp/seeue/seeue/trees>, reference number 2.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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