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Proposal of Energy-efficient Living Strategies based on Traditional Japanese Environmental Design: the Project of "Kisekae House"

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Keywords: Traditional Japanese environmental design, Passive design, Net zero energy house, ZEH, Residents' behavior, High thermal performance of envelope, High efficiency appliances.

Abstract: We proposed the Kisekae House as a net-zero energy house for the 2017 Enemane House Competition. The traditional Japanese environmental design based on the traditional lifestyle, which is unique as it is adjustable according to the local climate conditions, was arranged to suit to the current lifestyle and incorporated into the Kisekae House. The main concept of the house is to maintain good relations with neighbors and to be in contact with the surrounding natural environment. Specifically, the house design enhanced the thermal performance of the house envelope, installed the high efficiencies of household appliances, introduced a superior energy-utilization control system, and incorporated energy generation using solar photovoltaics. In addition, the resident's behaviors, including controlling the high-thermal-performance doors, partitions, and shades, also facilitated energy savings and allowed the creation of a comfortable environment. The Kisekae House was evaluated in terms of reduction in energy consumption and the energy self-sufficiency, the environmental conditions were also evaluated in winter. The proposed design facilitated a 143% reduction in the primary energy consumption based on that of a standard house. The proposed design strategies are expected to contribute to achieving the goals outlined in the Paris Agreement to mitigate global warming.

1. Introduction

According to the Paris Agreement to mitigate the increase in the global temperature due to global warming, it is essential to reduce greenhouse gas emissions by 45% from the 2010 level by the year 2030 and to reach net-zero emissions by 2050 (IPCC 2018). To achieve these goals, it is important to further reduce our energy consumption and utilize renewable energy resources. However, the energy consumption by households and offices, which now accounts for 30% of the total energy consumption in Japan, has increased by 24% in the past quarter century (1990–2015) (METI 2017a,b). Although energy consumption has been declining since 2005, the change is not significant enough to realize the targets set forth by the Paris Agreement. Thus, it is necessary to pursue additional decarbonization through additional energy conservation efforts and further utilization of renewable energy resources.

In this interest, the Japanese government has been promoting as its policy the zero energy house (ZEH), which is a house in which the net primary energy consumption on an annual basis is zero (METI 2015, 2016). Large energy savings can be achieved by improving the thermal performance of envelope of the house, implementing high-efficiency equipment and appliances, and generating energy from natural resources; it is also important that ZEHs provide comfortable indoor living conditions.

In addition to these technical changes, the residents' behavior, such as ventilation by opening and closing windows to attain a comfortable temperature and other energy-saving practices, can also have a significant impact on energy consumption (Endoh et al. 2015). Such behaviors and the factors that encourage these behaviors are ubiquitous in the traditional Japanese lifestyle and designs (Okazaki 2012a,b, Awa 2015), which can be adjusted on the basis of the local climate conditions. By leveraging these traditional customs and adapting them to the modern lifestyle, we can realize additional energy savings and effectively utilize natural energy resources.

Furthermore, facilitating continued use of buildings over long periods is important for realizing energy savings and reducing the greenhouse gas emissions. This can be done by designing houses to be adaptable to the residents' social situation like family sizes, lifestyles, and relationships with the neighbors.

By leveraging these strategies for reducing the environmental load, the students and teachers in the architectural major at Mukogawa Women's University proposed the Kisekae House for a ZEH competition, Enemmane House 2017[Note1,2)]. The Kisekae House introduces elements based on the traditional Japanese customs. The proposed design offers energy savings through hardware, such as high-performance exterior walls and windows and high-efficiency appliances, as well as "software," encompassing the residents' behaviors. Furthermore, the design facilitates good communication with neighbors and makes high contact with the surrounding natural environment.

In this paper, we present the proposed Kisekae House ZEH design that is adapted to the modern Japanese lifestyle as well as satisfies the required environment. We present the concept, describe the various techniques used to satisfy the design requirements, and evaluate the impacts on energy consumption and the environmental conditions during the winter season.

2. Climate in Osaka

Figure 1 shows climographs for Osaka and Istanbul including the monthly average temperature and relative humidity. The proposed house was constructed in Osaka, which is located in a relatively temperate, humid subtropical climate (Cfa in Keppen code). The climate of Osaka differs from that of Istanbul, which is located on the west side of the Silk Road in a Mediterranean climate (Csa in Keppen code). Compared with Istanbul, Osaka is hotter and has a higher humidity in the summer and is colder in the winter. The average annual temperature in Osaka is 16.9 C; the temperature can fall below 0 °C in the winter and has exceeded 37°C in the summer in recent years. The average relative humidity is 64% and can reach 70% in the summer. Thus both heating in winter and cooling in summer are required in Osaka.

3. Application of the Traditional Japanese Environmental Design in the Kisekae House

The environmental design and lifestyle elements of the traditional Japanese town house, such as “Kyo Machiya” (Okazaki 2012a), were implemented in the Kisekae House. The Kyo Machiya includes unique designs involving control over lighting, temperature, and humidity. The eaves, window roofs, can control the lighting which vary seasonally. And the residents create the suitable lighting condition to control lattice windows, bamboo blinds, and sliding doors (Okazaki 2012b:14-17).

To manage the hot and humid conditions of the summer for feeling cool by tough the earth floor with large thermal mass and cany mattings, which are relatively low in temperature. (Okazaki 2012n:19-22). The bamboo screens provide shading and heat from the sun. The reed screen or doors and cany mattings also provide sensation of coolness visually to the residents (Hirai 2013). The open floor plan and summer-style interior doors facilitated cross-ventilation. In the winter, the summer interior doors could be exchanged for *Fusuma* doors and *Shoji* screens to reduce the heat loss and to keep the house air-tight. The residents also adapt the cold condition by wearing warmer clothes and by using heaters rather than air conditioners (Okazaki 2012b). In addition to these traditional lifestyle features and techniques, basic passive architectural elements, such as large skylights, were used to heat the house from natural resources in the winter (Shokokusha 1980:41-43).

By adopting these passive elements of the traditional Japanese environmental design in the Kisekae House and combining them with recent technical improvements in energy-efficient appliances, thermal insulation, solar energy generation, and air tightness, these strategies can be leveraged more effectively. In this way, the energy requirements for heating, cooling, lighting, and hot water supply can be substantially reduced to realize a ZEH.

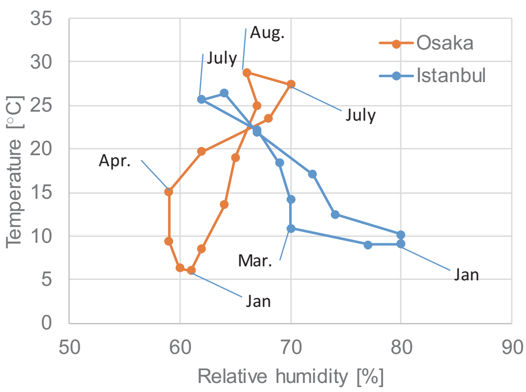


Figure 1 Climographs for Osaka (a humid subtropical climate) and Istanbul (a Mediterranean climate) (adapted from JMA 2018).

Figure 2 South facade of the Kisekae House.

4. Energy-efficient Design Concepts in the Kisekae House

The main concept of the house proposed is *kisekae*, which means to change clothes in Japanese. As we change our clothes with season, weather, or occasion, the plans and facilities in Kisekae House can be changed to adjust with the resident’s life style and the surrounding climate. The Kisekae House has several Kisekae devices, like partition, doors, and facilities, which can be moved easily.

Figure 2 and Figure 3, and Table 1 show the constructed Kisekae House, the floor plan, and its design parameters, respectively. The main concept of the Kisekae House is to establish good relations between residents and neighbors as well as maintain contact with the surrounding environment. Several Kisekae devices are incorporated in the house: they can be easily controlled or modified by the residents to create comfortable living conditions. The techniques were developed on the basis of the traditional Japanese environmental design and included doors

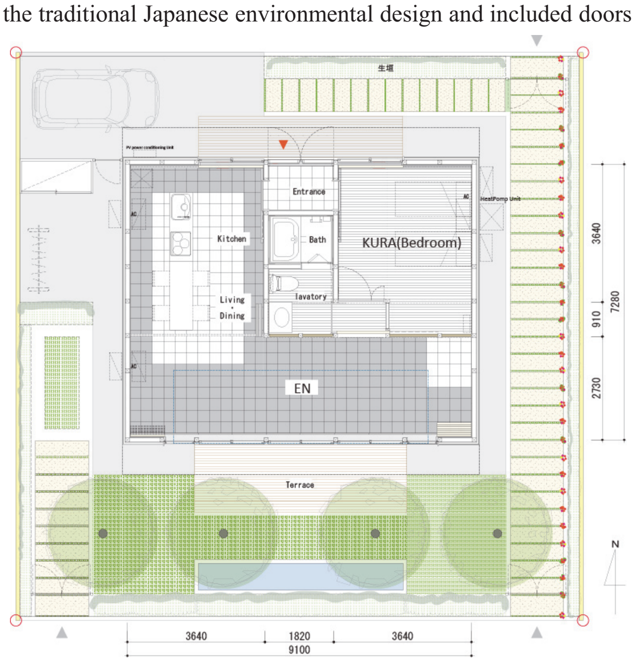


Figure 3 Floor plan of the Kisekae House.

Table 1 General parameters of the Kisekae House.

Location	Osaka, Japan (35.7°N, 135.5°E)
Floor area	66.25 m^2
Eave height	FL+2.210 mm
Building use	Model house
Energy source	Solely electric

and partitions that can be changed daily or seasonally, flooring with high thermal mass, shading devices, large openings to facilitate ventilation, etc.

4.1. FLEXIBLE FLOOR PLAN

The Kisekae House has two different spaces: one is open to the outside, called "*en*" in Figure 4; the other has controlled environmental conditions, called "*kura*" as shown in Figure 5.

The *en* design concept is based on *engawa*, which is placed between the living room and outside like the intermediate space. Traditionally *engawa* had been used as entrance of the house. When the partition between the *engawa* and the living room was open, the 2 spaces are used as one wide space, and when the outside openings of *engawa* are opened, the *engawa* becomes a continuous space between room and outside. People can change the size and connecting pattern of room-*engawa*-outside easily. Although *engawa* space was used as entrance, in later years, people commonly use *engawa* spaces as a corridor or an intermediate space to enjoy cool breezes in the summer and sunshine in winter.

The *en* space of the Kisekae House is included inside the house and connected to the living room. The *en* space obtains most of the solar energy through the large windows facing to the south (Figures 3 and 4) and large skylights (Figures 4 and 9), to reduce the energy required for heating. Although the significant solar radiation increases the energy demand for cooling in the summer, this can be mitigated by moving the highly insulated shades and rolling blinds into place (Figures 9 and 10).

The *kura* space, which is used as the bedroom (Figures 3 and 5), is a very stable environment: it is thermally isolated from the surrounding rooms by highly insulated walls. As the partition wall connected with *en*, which temperature varies widely, the clay walls with high thermal mass are used for the stable condition.

The configuration and sizes of the *en* and *kura* spaces can be changed by moving the partitions depending on the residents' needs (for example, the need for private and communal spaces). Figure 6 shows an example of how the floor plan can be changed in response to a change in the family structure. Figure 6(a) shows a floor plan for when the family has one child; the child's room is in the *en* within eyeshot of the parents. When an additional child is introduced to the family, the children's space can be expanded as shown in Figure 6(b); in this way, the neighbors also can follow the children's growth. After the parents retire, the *en* space can be opened as shown in Figure 6(c) to allow the neighbors to visit, thus facilitating a good relationship between the residents and the community.

4.2. DESIGN TO CONTROL THE ENVIRONMENTAL CONDITIONS

Several features of the traditional Japanese environmental design are adopted in the Kisekae House. For example, the sliding doors and partitions can be changed daily or seasonally to establish comfortable temperature and lighting conditions in the house and

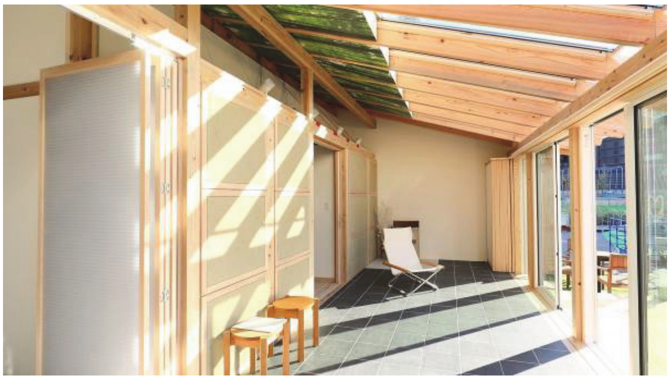
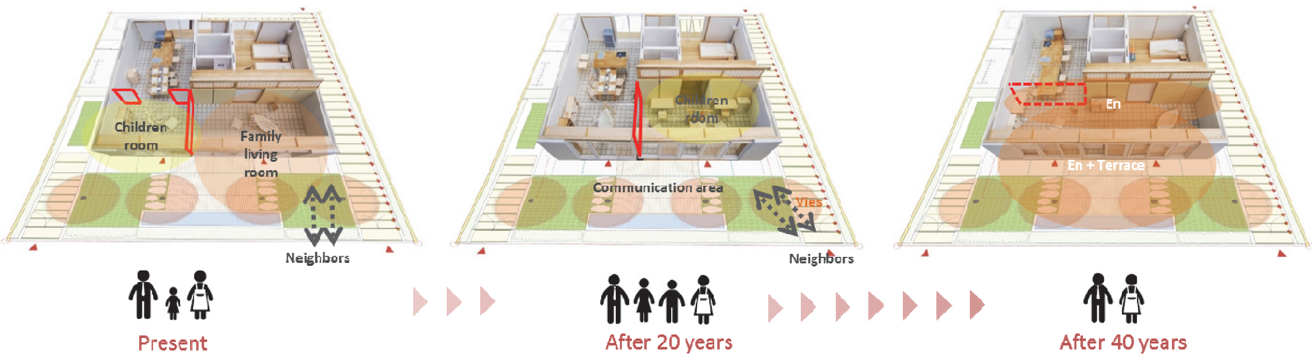


Figure 4 Inside the *en* space: solar energy can be obtained via skylights to create a bright and warm communal living space.

Figure 5 Inside the *kura* space: the space is isolated from the surrounding room by highly insulated partitions to create a private living space with a stable temperature.



(a) When the family has one child; the child's room is in the *en* within eyeshot of the parents.

(b) When an additional child is introduced to the family, the children's space can be expanded; in this way, the neighbors also can follow the children's growth.

(c) After the parents retire, the *en* space can be opened to allow the neighbors to visit, thus facilitating a good relationship between the residents and the community.

Figure 6 Example of how the partitions can be moved depending on the family structure.

control the heat gained from solar radiation. Moreover, the recent technical improvements in thermal insulation enable effective control over the retention of heat gained from solar energy. These features are detailed as follows.

4.2.1. Interior Window Shades

In order to control the environmental conditions, two types of window shades based on the traditional Japanese partition doors are installed: highly insulated interior shades to increase the thermal resistance of the openings in the house (Figure 7) and interior ventilation shades made of bamboo blinds to block sunlight while allowing ventilation during the summer and transition seasons (Figure 8). Although the shades inside the windows are usually changed seasonally in traditional Japanese homes, in the proposed design, they can be opened and closed daily or hourly in response to changing environmental conditions. These shades are placed on the north and south sides of the room (Figures 3 and 11). Because of the limited space, each shade type is on a single slide rail. This further contributes to the airtightness of the house by reducing the air leakage through the gaps between the shades.

4.2.2. Highly Insulated Shades Under Skylights

The energy consumption for heating and lighting can be reduced by utilizing the solar energy and daylight obtained via the skylights. Movable and highly insulated shades comprising 175-mm-thick extruded polystyrene foam (Table 2) are installed under the skylight windows as shown in Figure 9 to mitigate the solar heat gain and prevent heat loss. Roll blinds are also installed to block solar heating and control the lighting (Figure 10). In the winter, the highly insulated shades and rolling blinds can be opened in the daytime to let in light and heat the house and closed at night to prevent heat loss through the windows. In the summer, the insulated shades can be closed during the day to block the solar radiation. In interim period, they are controlled depending on the condition.

The flat rails attached to both sides of the highly insulated shades slide along a flat rail attached to the roof balks. Because there are no spaces between the rails, the air leakage through them can be limited. The highly insulated shades can be controlled by hand. Alternatively, an electrical opening system can be programmed to open and close them depending on the room air temperature, floor surface temperature, or heat flow. The system also connects to the internet to allow the residents to control the shades while away from the house.

4.2.3. Floors and Walls with High Thermal Mass

The solar radiation through the skylights and south-facing windows irradiate the floor in *en* space as well as the interior clay walls (Figure 4). Thus, high-emissivity black tiles are used in the *en* space where the direct solar radiation reaches, and white tiles are used in places that do not receive solar radiation to increase the brightness of the room. In addition, to retain the solar energy, the floor was made of tiles (9mm thick) and mortar (80mm thick and the walls between the *en* and *kura* spaces were made of thick clay (24mm thick) with clay panels (26mm thick)[Note3]. Thus, the total thermal masses of floors and clay walls were 3180 and 360kJ/K, respectively. The clay walls additionally have high moisture capacity to stabilize the air humidity in the connecting rooms when the temperature changes rapidly.

Figure 7 Window shades installed inside windows for insulation.

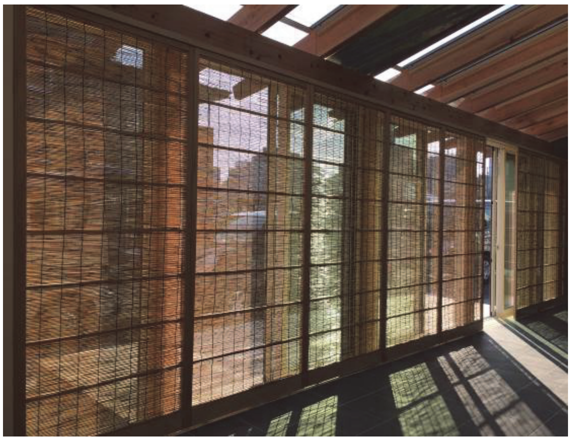


Figure 8 Window shades that allow ventilation and block solar radiation.

Figure 9 Highly insulated shades under skylights that can be moved up and down manually or via electric power.

Figure 10 Roll blinds under skylights.

4.2.4. Highly Insulated Envelope

Table 2 shows the heat transmission coefficient of each element of the house (the components are labeled in Figure 11). The average heat transmission coefficient (U_A [W/m^{2}K]) of the house is 0.45W/m^{2}K. Low-E pair glass is used in the skylight, and polyethylene foam (175mm thick) is used as a highly insulated shade under the skylights. Thus, the total U-value of the glass roof is 0.20W/m^{2}K. Low-E pair glass and highly insulated internal shades of polyethylene foam (40mm), which have a thermal resistance of 0.68m^{2}K/W, are used for the windows on the north and south walls. Thus, the total thermal resistance of these windows is 1.46m^{2}K/W, which is three times higher than that of the low-E pair glass alone; in addition, the U-value of these windows is 0.68W/m^{2}K.

The air exchange rate due to air leakage was calculated from the decrease in the measured CO_2 concentration over time as 0.17 times/hour in the *kura* space and 0.22 times/hour in the *en* space. Fans can be used to circulate air between the *en* and *kura* spaces to control the thermal environment.

4.2.5. Lighting Performance

Solar energy is utilized for lighting during the daylight hours. White floor tiles were used in the living room, where direct solar radiation does not reach, to enhance the daylight factor. The size of the skylights and the interior materials were simulated[Note4], revealing that the daylight factor[Note5] at the backside of the living room exceeded 2%.

Table 2 U-values of building elements.

	U-value [W/m^{2}K]
Wall	0.18
Roof (North side)	0.17
Roof (South side)	0.18
Skylights with highly insulated shade	0.20
Windows	2.2
Highly insulated inner shades	0.20

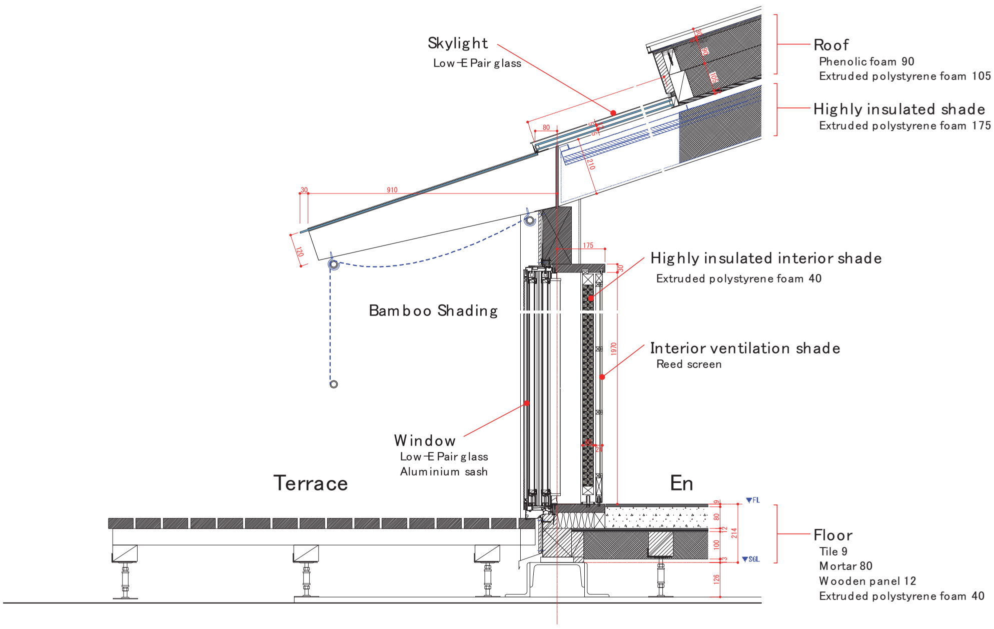
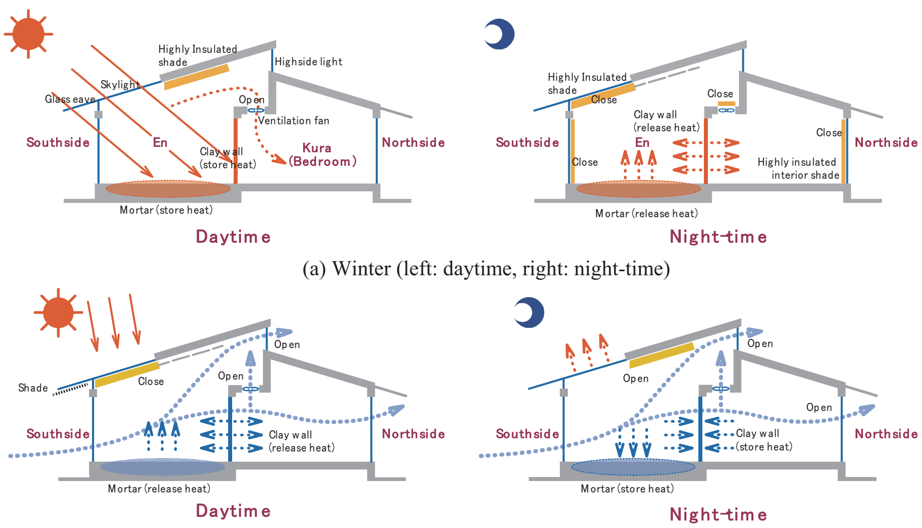


Figure 11 Components of the house design.



(a) Winter (left: daytime, right: night-time)

(b) Summer (left: daytime, right: night-time)

Figure 12 Combination of passive environmental control methods.

4.2.6. Seasonal Control of the Kisekae Elements

Figure 12 shows how the Kisekae elements can be used in different combinations in the summer and winter. In the winter (Figure 12(a)), the open skylights can be opened to allow the sun to irradiate the floor and heat the *en* space. The warm air can be circulated from the *en* space into the *kura* space using an exhaust fan in the daytime. The heat stored in the floor and walls and the use of highly insulated shades can maintain a comfortable room temperature at night. In the summer (Figure 12(b)), the shades can be closed to block the solar radiation from heating the room and keep the room cool. At night, the ventilation through the high side windows can cool the room.

4.3. FACILITY DESIGN FOR ENERGY CONSERVATION

High-efficiency equipment for hot water supply, air conditioning, lighting, etc., is installed in Kisekae House to reduce the energy consumption. In addition, energy is created by photovoltaic (PV) energy generation to meet the energy demand.

4.3.1. Equipment and Appliances

Table 3 and Figure 13 show the equipment and appliances and the energy performance installed in Kisekae House. High-COP air conditioners are installed in the *en* space, living room, and *kura* space to further control the environment when the passive techniques are not sufficient. The *kura* space can be thermally isolated (as explained in Section 4.1) to limit the size of the air-conditioned space that is needed at night. A high-performance heat pump water heater is used to supply hot water. To reduce the heat loss while bathing, a highly insulated bathtub and bathroom floor are used. All of the lights in the house are light-emitting diode (LED) lights. Lights are placed in several points in the room and can be controlled individually depending on which spaces are being used.

4.3.2. Solar Energy Generation

The installed photovoltaic generator (PV) system is capable of generating 3.5kW of electricity per solar radiation (Table 4 and Figure 13). The generated electricity is stored in an electric accumulator. The system includes two power conditioners to reduce the loss of electricity in the conversion from direct current to alternating current, resulting in a 96% conversion efficiency.

4.3.3. VPP System to Heat Water with Solar Energy

Normally, when the electric generation by PV exceeds the electric load, the excess electricity is sold to the public electric grid. However, this strategy results in energy loss due to power transmission and the increased load on the electric power system. Therefore, to minimize the overall environmental load, it is preferable to use the generated energy on-site. In the proposed design, when the excess electricity generated by the PV and stored in the electric accumulator exceeds the storage capacity of the accumulator (such as during sunny weather), any additional electricity generated by the PV beyond the energy demand is utilized by a virtual power plant (VPP) system (ANRE 2014) to heat water. In this way, excess electric energy is efficiently stored on-site as thermal energy.

Table 3 Equipment and appliances used.

Air conditioner	DAIKIN (S22UTAXS-W) APF 6.7
Heat pump for hot water supply	Panasonic (HE-JPU37HQ)
Lighting	LED lights

Table 4 Photovoltaic generator and electric accumulator.

Photovoltaic generator (PV)	Panasonic (VBHN250WJ01) Maximum power output 3.5kW (250W x 14 panels)
Electric accumulator	Panasonic (LJB1156) Capacity 6.5kWh
Power station	Panasonic (LJPB21)

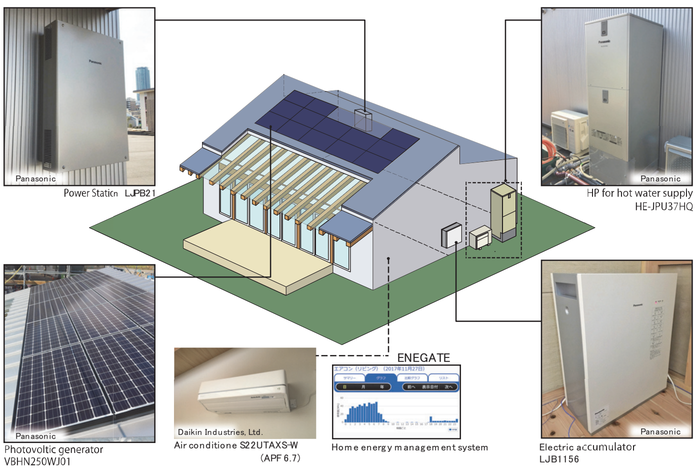


Figure 13: Appliances and equipment.

Figure 15 Flexible washbasin.

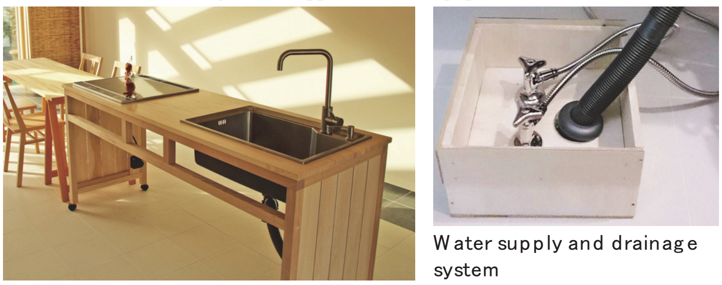


Figure 14 Inside of the kitchen and living room (left) and water supply and drain pipes (right).

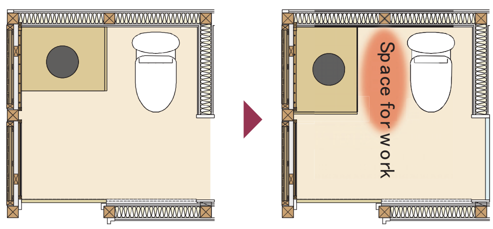


Figure 16 Changeable layout of the washbasin.

The system is controlled according to the amount of solar radiation; operating schedules for the water heater are prepared on the basis of the weather forecast and sent to the system the day before via the internet. Furthermore, the operating hours of the hot water supply can be controlled by the VPP system via the internet according to the predicted energy demand and PV energy generation predicted based on the forecasted solar radiation over the subsequent 2 days.

4.4. VARIABLE DESIGN BASED ON LIFESTYLE

The design can be modified according to the residents' lifestyle by changing the sizes of the *kura* and *en* spaces as shown in Section 4.1. In addition, various items can be arranged according to the residents' lifestyle. Flexible facilities (including water supply, drains, and electricity) are included in the kitchen so that it can be rearranged as needed. Multiple water supplies and drainage systems are installed in several locations in the *en* space, living room, and dining room (Figure 14 right). An electric cooking system is installed because power can be readily supplied via any electric outlet. Because there is no gas exhaust, the electric system does not require exhaust fans and, thus, can be positioned anywhere.

The lavatory washbasin unit can also be moved easily if the residents require space for a wheelchair (Figures 15 and 16).

Table 5 Annual primary energy consumption [GJ/year]. The values are calculated by the program[Note 7].

	Baseline energy consumption	Kisekae House without control of highly insulated shades under skylight	Kisekae House
Heating	10.3	9.0	7.1
Cooling	4.4	3.1	3.1
Ventilation	2.5	1.0	1.0
Hot water supply	16.4	9.2	9.2
Lighting	6.4	1.8	1.8
Other appliances	16.9	16.9	16.9
Total energy consumption [GJ/year]	55.8	40.0	38.1
Total energy consumption excluding other appliances [GJ/year]	40.0	24.1	22.3
PV generation	-	39.6	39.6

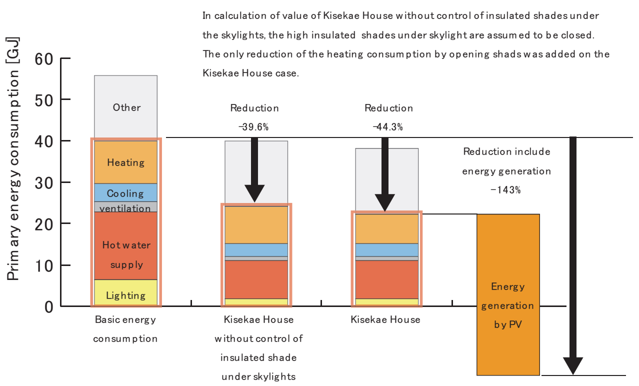


Figure 17 Reduction in the annual energy consumption.

5. Actual Energy Consumption and Thermal Performance

5.1. CALCULATED ANNUAL ENERGY CONSUMPTION

The primary energy consumption, the breakdown of the energy consumption, and energy generation by PV in the Kisekae House is shown in Table 5 and Figure 17. The table shows the results of energy consumption of the baseline [Note 6)] and that of the house which the highly insulated shades under the skylights were kept closed in Kisekae House. The energy required for air conditioning was reduced by 31% and that required to supply hot water was reduced by 43% in the Kisekae House compared with the baseline energy consumption. The total energy consumption was 22.3GJ/year, which is 56% of the baseline energy consumption. The annual electric generation by the PV system was 36.9GJ, which exceeds the primary annual energy consumption (Figure 17). Thus, considering all factors, the basic primary energy consumption was reduced by 143%.

5.2. MEASURED ENERGY CONSUMPTION AND ENVIRONMENTAL CONDITIONS

The Kisekae House was constructed over the period from October 23 to November 10 in 2017. Measurements of energy consumption and environmental conditions were collected over 9days from November 18 to 21 and 24 to 28 in 2017. The room air temperature, outdoor temperature, relative humidity, illuminance, and CO_2 concentration were measured in the *en* space, the living room, and the *kura* space. The solar electric generation and the energy consumption by the appliances were also measured. Three students stayed at the house and controlled the devices from 09:00 to 18:00. In the measurement period, the predetermined loads of the water heater and household appliances were imposed every day.

5.2.1. Measured Energy Generation

The total amount of energy generated by the PV system during the 9day period is shown in Figure 18. The energy generation exceeded the energy consumption on 6 of the 9 days, which were relatively sunny; the 3 days (18^{th}, 20^{th} and 26^{th}) on which the energy consumption exceeded the energy generation

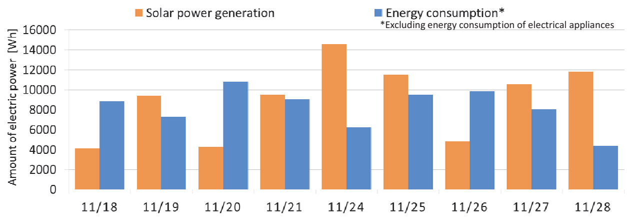


Figure 18 Total PV energy generation and consumption.

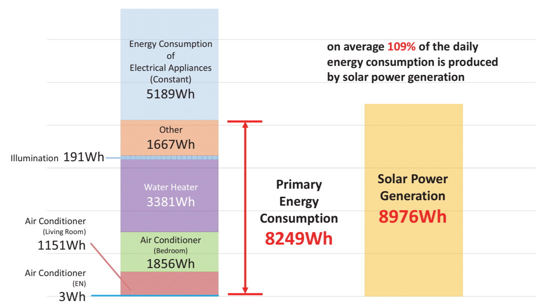


Figure 19 Average solar energy generation and breakdown of the average power consumption.

had poor electricity generation because of cloudy weather and insufficient solar radiation. The self-consumption rate, which express the ratio of the energy consumed in the house to the solar energy generation, of the solar energy (Figure 20) was above 90% except on the 24th and 27th, 28th. The days of 24th and 28th were when the solar energy generation was significantly larger than the energy consumption. Because of technical issues associated with the internet connection, the VPP system did not work properly on the 27th and the hot water supply operated at night, which is an unusual pattern; as a result, the self-consumption ratio was low (52%) on this day (Uehara 2018a,b). Over the entire measurement period, the energy generation by the PV exceeded the energy consumption (it was approximately 109% of the total consumption) (Figure 19). Thus, even though the generation by the PV system was relatively low compared to that in summer or interim period and the energy consumption for heating and hot water supply are relatively large because of the cold winter weather, the Kisekae House achieved net-zero energy balance.

5.2.2. Recorded Environmental Conditions

The residents can control the interior window coverings and shades (see Sections 4.2.1. and 4.2.2.) to achieve their desired conditions and suit their lifestyles. The air conditioners in the living room and bedroom were operated to maintain the room temperature around 23°C at night; during cooler days, the air conditioner in the *en* space was not used.

Figure 21 shows the indoor globe temperatures and outdoor air temperature. Except for the day when the temperature fell below 15°C during the hours of active ventilation, the indoor temperatures remained between 22°C and 23°C. The temperature in the *en* space fluctuated between 28°C and 35°C in the daytime because of the variable effects of direct sunlight from the skylight and south windows. However, because of the heat storage in the floors and walls, the temperature in the *en* space did not fall below 15°C.

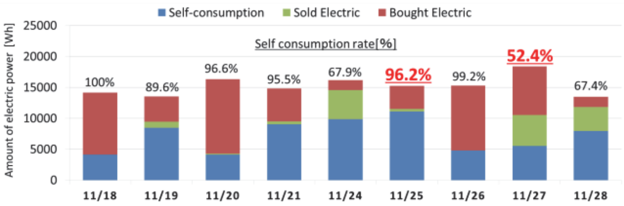


Figure 20 Self-consumption rate of solar energy during the measurement period.

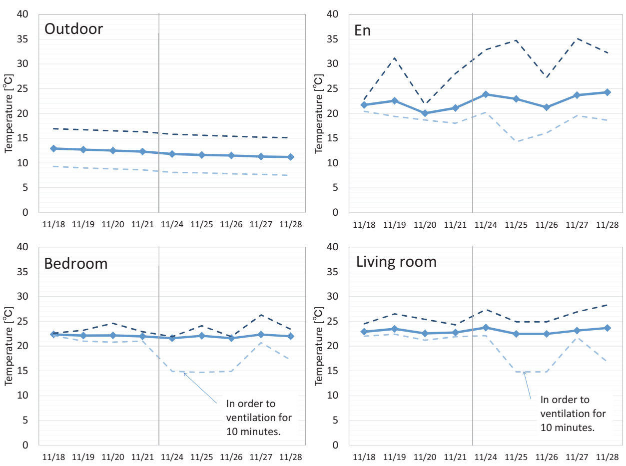


Figure 21 Measured environmental conditions.

When the temperature rose above 30°C in the *en* space during a sunny day, the residents controlled the shades under the skylight to prevent solar heating. Thus, the incorporation of flexible items that can be controlled by the residents and user training in their operation and impact on the indoor environment were considered to be very important.

6. Conclusion

In this paper, we described a facility and system design for the Kisekae House which achieves net-zero energy balance as well as introduced the facilitates communication with neighbors. The basic design of the Kisekae House was developed on the basis of the traditional Japanese environmental design and adapted to a modern lifestyle. It was found that adjusting the interior window coverings, highly insulated window shades, and other devices effectively reduced the energy consumption. Due to the various improvements incorporated in the Kisekae House, the primary energy consumption was only 56% of that in a standard house. When considering the energy generated by the PV system, the basic primary consumption was reduced by 143%, below the ZEH threshold.

An experimental trail with three residents living a normal lifestyle over 9days in November revealed that the temperature in non-air-conditioned *en* space, which collected a significant amount of solar heat through the skylights during the daytime and was highly insulated at night, did not fall below 15°C. The energy generation by the PV system was sufficient to meet the total energy demand, clearing the ZEH threshold despite the cold winter weather.

In addition, a VPP system was implemented to enhance the self-consumption of solar energy. When the system worked properly on a sunny day, the self-consumption of the electricity generated by the PV system was over 90%. We can conclude that the VPP system was an effective tool for using natural energy available on site.

There is more work to be done to quantitatively evaluate the annual energy balance, ensure compatibility with a variety of lifestyles, and verify the effectiveness of each passive design adopted in the Kisekae House by numerical simulation. Although most people control the environment using active equipment even in the houses with high-performance envelope and high efficiency equipment, we aim to demonstrate a new lifestyle of adjusting passive features found in traditional Japanese houses in high-performance houses to achieve a net-zero energy balance.

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Endnotes

1. This Enemane House competition project was hosted by Enemane House 2017. The aim of the project was to popularize ZEH (zero-energy house). It was required to propose advantaged technologies and lifestyle in cooperation with universities and private companies. Five teams passed a preliminary selection by the proposal documents, built a model house of Zero Energy House (ZEH), and evaluated the performance of the house.
2. Students in the 2nd and 1st grades of the master course joined the competition and conducted the primary design, detail design, surveillance, evaluation of thermal performance, measurements of thermal environment, and public exhibition and demolition.
3. Arakabe Panel is a clay panel for foundation layer of clay wall.

4. DIALux simulation program was used.
5. Daylight factor is defined as the ratio of inside illuminance to outside.
6. The calculation program (METI nd) in web site is used.
7. The household energy consumption is not included here.
8. The house was completed in November 2017, and the several environmental factors and energy consumption were measured to evaluate the performance.

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