A STUDY ON THE ECONOMIC EFFICIENCY OF ZERO ENERGY HOUSE AND REGIONAL CHARACTERISTICS

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Abstract. Currently, global warming is a growing problem around the world. As one of the solutions to this problem, the realization of a decarbonized society has been set as a goal. In the field of architecture, the spread of ZEH (Zero Energy Heating) is required to reduce the primary energy consumption to practically zero. Therefore, in this study, we clarified the efficiency of the reduction rate for each exterior skin performance, including lifestyle and regional climate characteristics. It also clarified the economic efficiency of photovoltaic power generation. In the comparison for window glazing, one of the results was that there was a pattern of performance improvements having a negative impact. Various results were obtained in which some areas were able to recover the cost of solar power even in severe climates and some areas were unable to recover the cost even in mild climates.

1 Introduction

In recent years, climate change has become an issue around the world. [1]. In Japan, the movement toward decarbonization is gaining momentum in various fields. In the field of residential construction, in order to realize a decarbonized society, the "Zero Energy House (ZEH)" is being promoted to reduce the total energy consumption of a house to zero by saving energy and using renewable energy. [2]. In order to realize ZEH, it is essential to improve the outer skin performance and install solar power generation. However, in addition to the cost of purchasing a house, additional costs are required, which is a huge burden. The purpose of this study is to examine the primary energy consumption of a model house due to changes in its envelope performance, and to examine the efficiency of ZEH's envelope performance and the economic efficiency of photovoltaic power generation in different regions.

2 Outline of the subject house

The floor plan of the building is shown in Figure 1 and Figure 2, the equipment outlines in Table1, and the heat insulation specification in Table 2. The research subject is a detached house with 4LDK. A photovoltaic power generation system (5.5kw) is installed on the south-facing roof at an inclination of 23 degrees. One heat pump water heater with a hot water capacity of 370L is installed as the hot water supply system. As air conditioning equipment, three air conditioners with cooling capacity of 2.2kw and heating capacity of 2.5kw and one air conditioner with cooling capacity of 5.6kw and heating capacity of 6.7kw are installed.

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3 Simulation Overview

3.1 Simulation Tool

For this study, we used BEST-H (residential version) developed by the Institute for Building Environment and Energy Conservation (IBEC). BEST-H is a residential version of a comprehensive tool for calculating energy consumption of buildings and facilities for the consideration of smart wellness housing. It is possible to perform a variety of simulations, such as calculating energy consumption by time of day in a house, evaluating the thermal environment by heat insulation and solar shielding performance, studying the introduction of optimal housing equipment, studying ZEH by introducing renewable energy, and understanding energy consumption characteristics by lifestyle patterns.

3.2 Calculation types

In this study, 16 types of comparison types were set up by combining four types of window glass, two types of sashes, and two types of insulating materials. Comparisons are made for five types of climatic types: Miyazaki City and Shimonoseki City in Region 7, Tokyo in Region 6, Niigata City in Region 5, and Sendai City in Region 4. The calculation types are shown in Table 3. The primary energy consumption and annual electricity bill were estimated for each type. In addition, the electricity sales method is the surplus electricity sales method. For the electricity rate form, we adopted the all-electric plan of the major power company in each region. The electricity consumption of Type 6 of the subject house is about 57% of that of a typical household in Tokyo, or 94% of that of a slightly more energy-efficient house.

4 Simulation Results

4.1 Overview

The primary energy production by photovoltaic power generation was set as the ZEH standard, and the comparison with the primary energy consumption is shown in Tables 4 and 5. Among 80 types, the ZEH standard was achieved in all types in Miyazaki and Shimonoseki cities and 7 types in Tokyo, and the standard was not achieved in all types in Niigata and Sendai cities.

4.2 Primary Energy Consumption

(1) Miyazaki City

In all types, the ZEH standard was achieved. The primary energy consumption in each type was reduced by 11.9% to 15.17% compared to the standard value.

### Table 1. Equipment Overview

| Item                  | Kind       | Performance | Quantity |
|-----------------------|------------|-------------|----------|
| Solar power generation system | Photovoltaic module | Conversion efficiency 19.90% | Nominal maximum 250W | 21 |
|                        | power conditioner | Electrical conversion efficiency | 96.50% | 1 |
| Hot water supply system | Heat pump water heaters | AF | Capacity | 1 |
|                        | Cooling capacity | Heating capacity | 2.3kW | 2.5kW | 3 |
|                        |              |              | 5.6kW | 6.7kW | 1 |

### Table 2. Thermal insulation performance

| Item                  | Kind       | Heat-insulating material | Type  | Glass wool insulation material 16K | Thermal transmittance | 96k | High-performance 48k | 90 | 0.48 |
|-----------------------|------------|--------------------------|-------|-----------------------------------|-----------------------|-----|---------------------|----|------|
| Windscreen            | Single-pane glass | Aluminum | 5.08 | 2.34 | 1.46 | 0.48 |
| Low-E double-glazing | air layer 6 mm   | Resin | 2.43 | 2.43 | 2.43 | 0.48 |
| Low-E double-glazing | air layer 12 mm  | Resin | 2.43 | 2.43 | 2.43 | 0.48 |
| Low-E triple layer   | double-glazing  | Aluminum | 2.43 | 2.43 | 2.43 | 0.48 |
| Glass type            | Sash        | Type of insulation       | 16K   | Glass wool insulation material 96k | Thermal transmittance | 90 | 0.48 |

### Table 3. Description of type

| Glass Type | Sash       | Type of insulation |
|------------|------------|--------------------|
| Type1      | single-pane glass | Aluminum | 70.00 |
| Type2      | Low-E double-glazing | air layer 6 mm | 64.98 |
| Type3      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type4      | Low-E triple layer double-glazing | air layer 12 mm | 64.72 |
| Type5      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type6      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type7      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type8      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type9      | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type10     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type11     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type12     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type13     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type14     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type15     | Low-E double-glazing | air layer 12 mm | 64.85 |
| Type16     | Low-E double-glazing | air layer 12 mm | 64.85 |

### Table 4. Primary energy consumption (Type 1-8)

| ZEH standard | Primary energy consumption (GJ/year) |
|--------------|-------------------------------------|
| Miyazaki City | 44.74                               |
| Shimonoseki City | 65.17                            |
| Tokyo        | 58.59                               |
| Niigata City | 58.81                               |
| Sendai City  | 57.84                               |
| Unsatisfied  | 63.57                               |

### Table 5. Primary energy consumption (Type 9-16)

| ZEH standard | Primary energy consumption (GJ/year) |
|--------------|-------------------------------------|
| Miyazaki City | 44.74                               |
| Shimonoseki City | 65.17                            |
| Tokyo        | 58.59                               |
| Niigata City | 58.81                               |
| Sendai City  | 57.84                               |
| Unsatisfied  | 63.57                               |

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(2) Shimonoseki City
In all types, the ZEH standard was achieved. The primary energy consumption in each type was reduced by 1.79% to 5.66% compared to the standard value.

(3) Tokyo
Types 1 to 8 met the ZEH standard in two types with Ua values better than 0.58 [W/(m² · K)]. Types 9-18 were able to achieve the ZEH standard under five types, where the Ua value was better than 0.59 [W/(m² · K)]. The primary energy consumption of each type ranges from -1.72% to 2.54% of the standard value.

(4) Niigata City
In all 16 types, the primary energy consumption did not achieve the ZEH standard. The primary energy consumption of each type is higher than the standard value by 12.25% to 17.00%.

(5) Sendai City
In all 16 types, the primary energy consumption did not achieve the ZEH standard. The primary energy consumption in each type is higher than the standard value by 8.52% to 12.71%.

4.3 Suppression Rate by Improving Exterior Skin Performance
A comparison was made to see how much reduction in primary energy consumption could be achieved by improving the performance of window glass, sashes, and insulation materials.

4.3.1 Improvement of window glass performance
The comparison types were fixed with the insulation material being glass wool insulation 90mm 16K, and the comparison with Type 1 set as the standard is shown in Figure 3.
In Shimonoseki City, it was confirmed that the reduction rate when window glass performance was improved was 0.5% higher than in Miyazaki City, which is also in Region 7. In Niigata City, the highest reduction rate of 1.5% to 2.3% was confirmed among the regions covered in this study. However, the growth rate of the reduction rate for each performance improvement was inferior to that of other regions, confirming that the efficiency of the system becomes lower with a certain level of performance. In Sendai City, it was confirmed that the reduction rate decreased when performance was improved. It was confirmed that halfway performance improvement increased the heat load by blocking the outside air in the comfortable season.
4.3.2 Improvement of sash performance

Figure 4 shows a comparison of the reduction rate when the insulation material is glass wool insulation 90mm 16K and the comparison types are fixed, and the sash is changed from aluminum to resin sash.

Overall, high reduction rates were observed, confirming the effectiveness of the resin sashes. When analyzed individually, differences were observed in the four regions other than Sendai City when the performance was improved to Type 4. In Miyazaki City and Tokyo, a 1% improvement in the reduction rate was confirmed. In Shimonoseki City and Niigata City, a 1.5% improvement in the reduction rate was confirmed. However, Shimonoseki City was found to have poor growth in reduction rate after Type 4. Sendai City showed an unsteady reduction rate at low performance. However, the improvement of the reduction rate can be confirmed when the performance is increased, and therefore, facilities with high performance are required.

4.3.3 Improvement of insulation performance

A comparison of the improved performance of the insulation is shown in Figure 5. Stable effects were shown in all regions. By region, similar reduction effects were seen in Miyazaki City and Tokyo. Similar reduction effects were seen in Shimonoseki City and Niigata City. In Sendai City, unlike window glass and sash, the reduction effect was stable for all performance. It was found that insulation was a high priority for maintenance.

5 Consideration of economic efficiency

Since photovoltaic power generation is affected by climate, the amount of electricity generated varies greatly by region. Therefore, we compared the electricity costs by region when the outer skin performance was set to Type6 (Ua value 0.56). The amount of electricity generated by region is shown in Figure 5. The payback period for the PV installation cost was assumed to be 30 years in total, with four people living in the house for the first 10 years and two people living in the house for the next 20 years.

5.1 Solar power installation cost recovery period

The electricity sales price for the first 10 years of the feed-in tariff period is 19 yen/kwh, and the electricity sales price after the feed-in tariff period ends is calculated using the price set by each company. The trial calculation results are shown in Table 6. Only in Tokyo, it was confirmed that the cost recovery would not be completed within 25 years, which is the minimum guarantee period set by the solar panel manufacturers. This confirms that solar power generation is capable of recovering the installation cost and reducing the electricity bill.

6 Summary

In this study, the target houses were set in several regions, and by comparing primary energy consumption and electricity bills, the efficiency of improving the outer skin performance and the effectiveness of photovoltaic power generation were clarified for each region.

In the seventh region, Miyazaki City and Shimonoseki City, it was relatively easy to meet the ZEH standard because of their mild climatic types, and the effectiveness of photovoltaic power generation was confirmed because of the sufficient amount of power generated. In the fourth region, Sendai City, and the fifth region, Niigata City, the climatic types are poor and the cost of electricity is high, but solar power generation is very effective because it can reduce the cost of electricity. From these results, it was confirmed that solar power generation is effective in areas where it is not easy to meet the ZEH standard, as it is possible to recover the installation cost.

In the simulation for the sixth region, Tokyo, it was confirmed that even if the climatic types are favourable, the cost of PV installation cannot be recovered depending on the electricity price. The above shows that PV installation is effective in many cases. However, there are exceptions to this rule, so it is important to study the electricity cost.

References

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| Years elapsed | Cost of Solar Power | Income from power sales ($) |
|---------------|---------------------|----------------------------|
| 1 year        | 13,043              | 723                        |
| 5 year        | 12,652              | 3,617                      |
| 10 year       | 14,261              | 7,234                      |
| 15 year       | 14,870              | 8,044                      |
| 20 year       | 15,478              | 9,060                      |
| 25 year       | 16,087              | 9,226                      |
| 30 year       | 16,696              | 9,193                      |
| Cost recovery period | 22 year | 24 | 14 year | 14 year |