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Energy Saving Performance of Detached House with Hydrogen Co-generation System

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Abstract

Energy consumption is increasing every year in building sector, utilization and development of alternative energy sources and technologies to support the requirements of every house. The hydrogen fuel cell is one of the latest technologies for distributed energy systems. This research is aim to grasp the energy saving performance of the hydrogen co-generation system in the detached house. First, it investigated on the demand-side energy consumption including electricity, cooling, heating and hot water. Second, it introduced a distributed energy resources (DER) system and set six cases to analyze the energy utilization. Different options for changing the heating, cooling, electricity and hot water systems were compared for this type of detached house, assuming basic-case as a reference. Changes in the fuel used, energy operation machines and also demand side and supply side were analyzed. Except past case, every case will be operated under the electricity-tracking mode and heat-tracking mode. The comparisons and evaluations of the energy consumption between cases can suggest the environmental performance of the hydrogen co-generation system.

Keywords

DER System, Hydrogen Fuel Cell, Simulation, Detached House

1. Introduction

The world energy consumption has increased fiercely year by year that we should focus more on the energy using efficiency and energy conservation. As the fossil fuel gradually dried up, it also caused problems of the global warming. In order to control the pollution and make sustainable development, renewable energy and untapped technologies should be taken further attention. The energy generating for power grid makes a big loss. The distributed energy system, using the bottom-up energy system design strategies, together with the onsite re-

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newable energy use can meet the energy consumption of the demand side and make good use of the characteristics of the energy as well as smooth the grid fluctuate. It will cut down the need of fossil fuel and get a more environmental energy generation. In general, distributed energy system is a comprehensive energy utilization system. It includes power generation facilities and at the time, provides the need of heating or cooling with making use of waste heat from the generation system. The distributed energy system has a wider choice and has a potential to offer consumers a lower cost, higher service reliability, high power quality and energy independence. The renewable energy resources are can also be introduced to the distributed energy system, like wind, photovoltaic, geothermal, biomass and hydroelectric power.

The growing worldwide demand for less polluting forms of energy has led to a renewed interest in the use of micro combined heat and power (CHP) technologies in the residential sector [1]. The operation of micro CHP system results in simultaneous production of heat and power in a detached house as small energy conversion units. The heat may be used for space and water heating and possibly for cooling use if combined with an absorption chiller and the electricity is used within the house [2] [3]. For each building type, the energy demands for electricity and heat are dynamically determined. Using these load profiles, several CHP systems are designed for each building type [4] [5].

Primary energy and electricity consumption, associated greenhouse gas emissions and tolerable capital cost are used as indicators [6]. A whole building simulation model was used to simulate the performance of a commonly used cogeneration system with thermal storage in typical single detached houses located in Japan. A high efficiency gas boiler is included to supply heat when cogeneration unit capacity is not sufficient to meet the heating load. The effect of thermal storage capacity, interest rate and acceptable payback period on the overall performance was evaluated through a sensitivity analysis.

The maximum exploitation of local renewable energy sources is a key feature of DER systems: to this aim, Hybrid Power Systems, integrating renewable and non-renewable power sources with local energy storage may represent an effective solution, although they may require an optimum utilization of the different sub-systems, for example if including fuel cell [7]-[9]. Setting new applicable sustainable design guidelines for detached houses [10], the basic assumption is that heating and cooling has play an important role in future sustainable energy systems [11]-[16].

The DER system in the detached house as micro-cogeneration, also termed micro combined heat and power or residential cogeneration, is an emerging technology with the potential to provide energy efficiency and environmental benefits by reducing primary energy consumption and associated greenhouse gas emissions. The distributed generation nature of the technology also has the potential to reduce losses due to electrical transmission and distribution inefficiencies and to alleviate utility peak demand problems [17] [18].

This research investigated the demand-side energy consumption including electricity, cooling, heating and hot water in the detached house with co-generation system including gas-burned fuel cell and hydrogen-based fuel cell. Then introduced a distributed energy resources system and set six cases to analyze the energy utilization. Lastly, the comparisons and evaluations have been carrying out in order to understand the environmental performance of the hydrogen co-generation system.

2. Study Objective and Its Load Performance

From **Figure 1** we will separate three parts to explain the research flow. Firstly we calculated the load of detached house, including electricity, heating & cooling and hot water. Then we set six cases for different distributed energy system, and for each case, we calculated power generation and heat production according to energy supply and demand to analysis [19]. At last we evaluated the results about energy saving and environmental protection.

An illustrate example of the model usage is presented below. It is a two-floor residential building in Kitakyushu Japan, having a total floor area of 250 m^2. A residential hydrogen CHP system is considered for adoption. The Yearly, monthly and hourly energy consumption are estimated according to the energy consumption unit and the building area. From **Figure 2**, we can know that the electricity load in each month stable at around 1000 kW, do not change so much. But in the May, the value is higher than other month, reaches 1175 kW. The maximum value of cooling and heating load is 1592 kW in January. In May, June and October, do not need to consume the cooling and heating load. The hot water load in January has the maximum value, which reaches 784 kW.

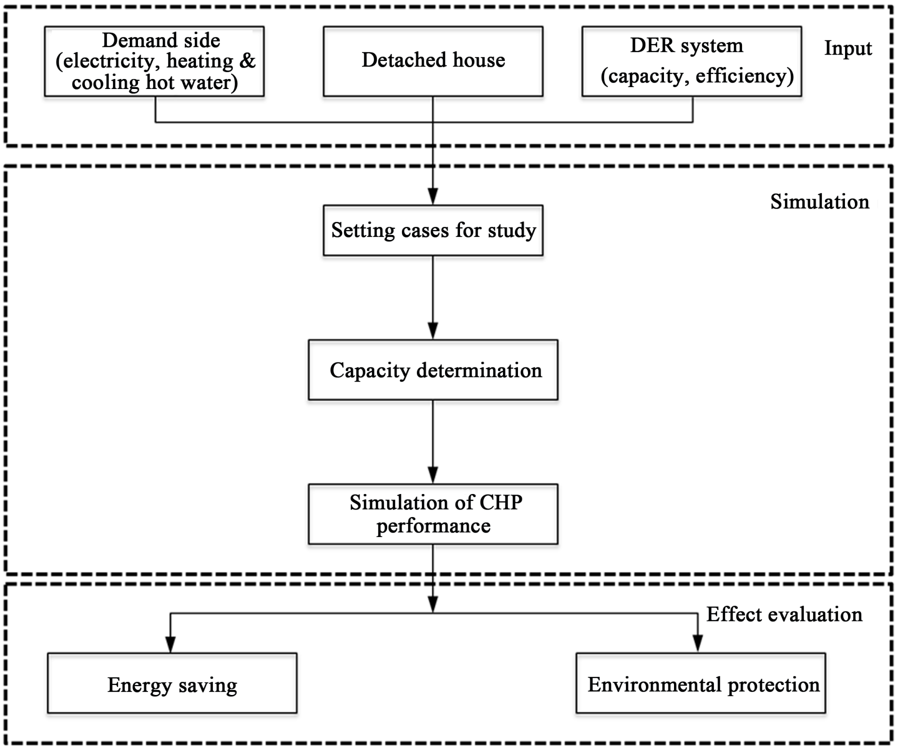

Figure 1. Research flow.

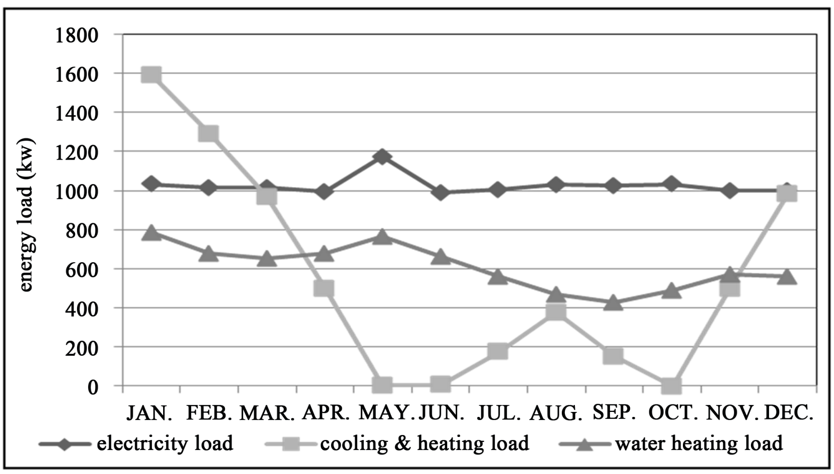

Figure 2. Energy load of detached house.

We select January, August and October as the representative months to indicate characteristics of winter period, summer period and interim period. **Figure 3** represents the hourly average value of detached house energy load in winter period. The heating load in winter has two peaks during a day: one is from 7 o'clock to 9 o'clock in the morning; another is from 17 o'clock to 22 o'clock in the evening. Hot water load has a low peak in the morning and the period between 20 o'clock and 23 o'clock.

Figure 4 represents the energy consumption in summer period. For detached houses, the electricity load is higher than other energy consumption. The peak of cooling load in summer is from 19 o'clock to 21 o'clock in the evening. The hot water load reaches the maximum value at 20 o'clock.

Figure 5 represents the detached house energy consumption in interim period. There is no cooling and heating load in October and electricity load is higher than hot water load. The peak period of electricity load is be-

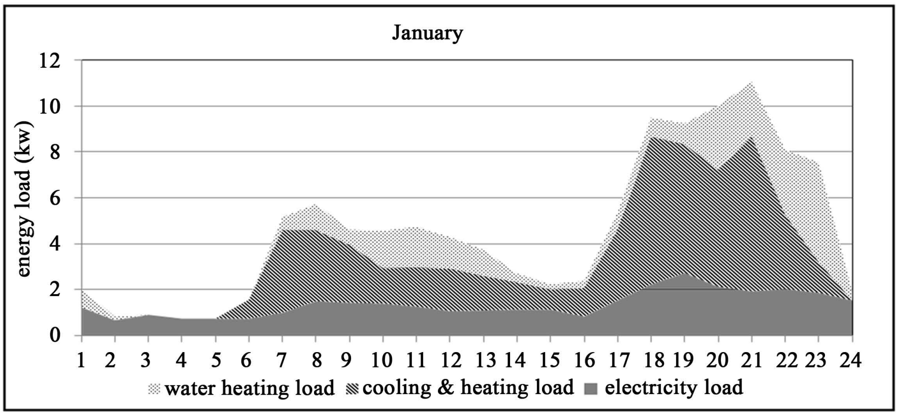

Figure 3. Energy load in January.

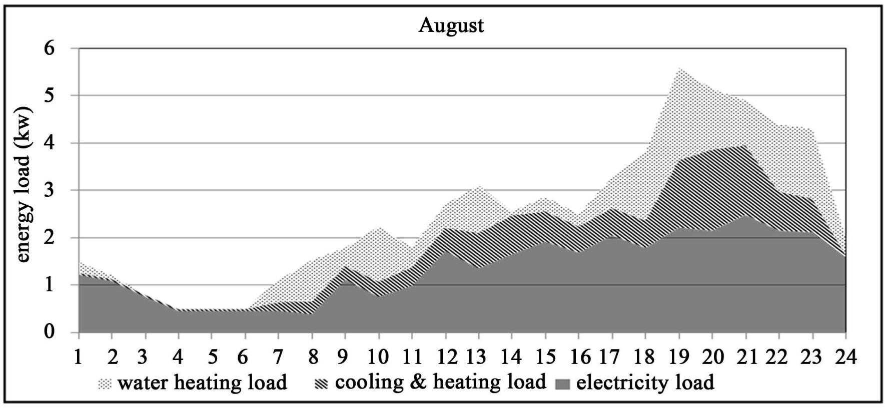

Figure 4. Energy load in August.

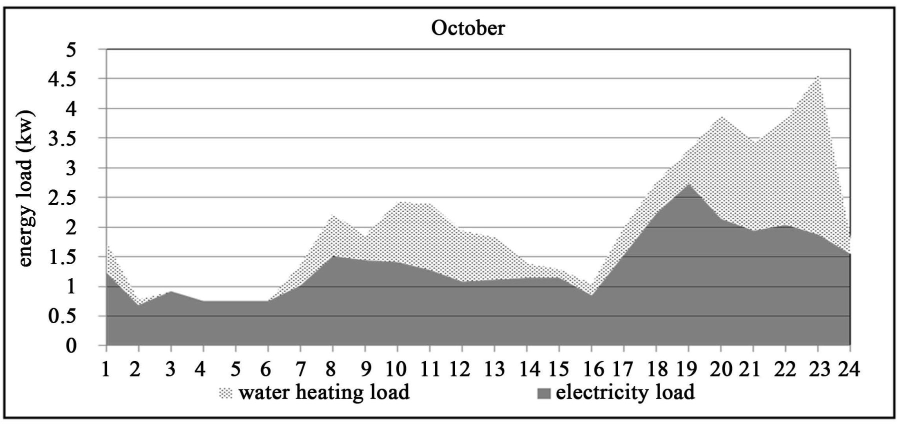

Figure 5. Energy load in October.

tween 18 o'clock and 23 o'clock. The hot water load has two peaks during a day: one is between 10 o'clock and 11 o'clock in the morning and another is between 20 o'clock and 23 o'clock in the evening.

3. Energy SystemDecision

3.1. System Setting

According to the basic survey about this detached house, this research set up 6 cases to analyze energy utilization conditions. Different equipment will provide electricity load, cooling load, heating load and water heating load for the detached house. **Figure 6** represents the conventional energy system of detached house. The system uses grid for the electricity supply, the air conditioner for cooling and heating, and gas boiler for hot water supply.

Figure 7 represents the case 2 that use gas fuel cell co-generation system to supply energy to the detached house. The overall efficiency is much higher than the power generation efficiency from power plant. Part of the electricity load is from the fuel cell power generation, the other is from grid power generation.

From **Figure 8**, we use hydrogen fuel cell to replace gas fuel cell as the energy resource. This hydrogen fuel cell can be set in compact community, detached house and apartment.

Figure 9 is the system considered both hydrogen fuel cell and the PV system. The PV system can generate electricity during the daytime. But the efficiency is affected by the weather condition.

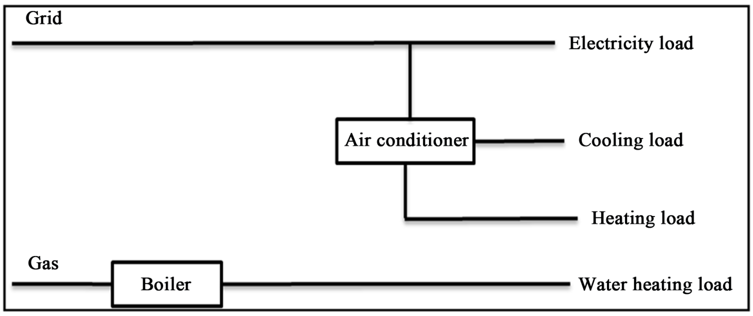

Figure 6. Case 1 (conventional case).

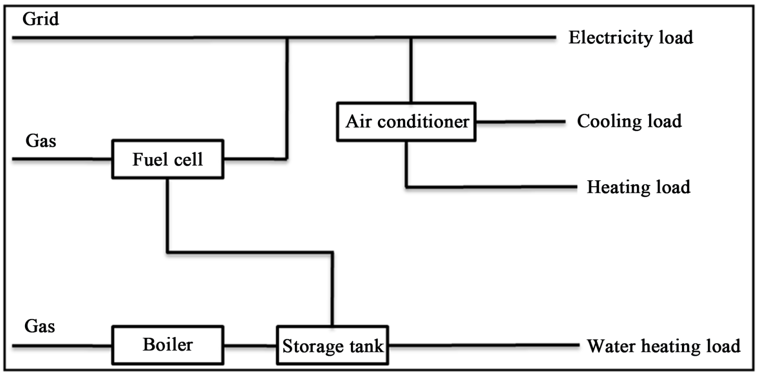

Figure 7. Case 2 (FC by gas).

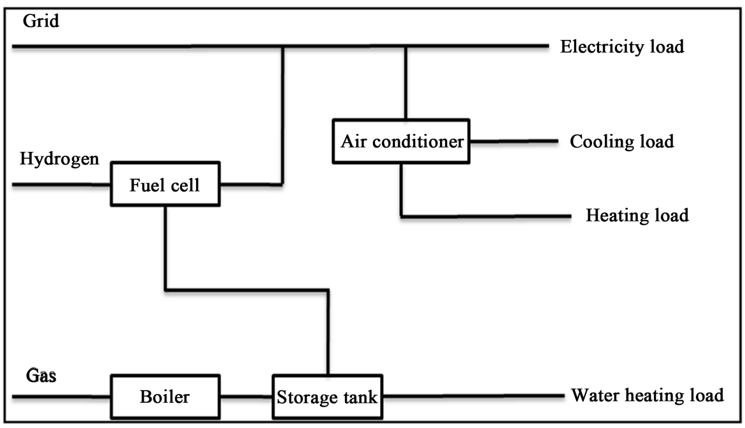

Figure 8. Case 3 (FC by hydrogen).

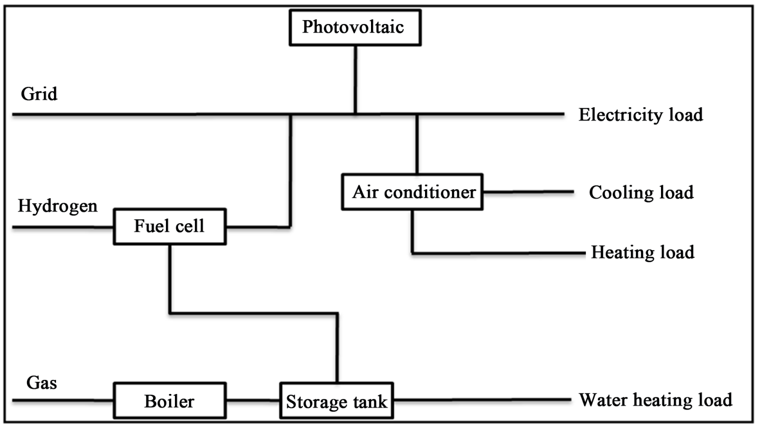

Figure 9. Case 4 (FC + PV).

In case 5 and case6 (**Figure 10** and **Figure 11**), the research introduced storage batteries in the detached house. The charging time and discharging time are stationary in case 5 but floating in case 6. In case 5, the battery is only charged by the grid but in case6, the battery charged by power grid, solar panel and fuel cell. So the electricity of the storage batteries will been regulated in case 6. In heat-tracking mode, storage batteries can utilize more residual electricity to save energy.

3.2. Operation Condition and Machine Selection

When we finished the cases setting, we need to judge operating conditions of each case and set parameters of each equipment.

From case 2 to case 6, the systems are operated in two modes, the electricity-tracking mode and the heat-tracking mode. The electricity-tracking mode means the electricity produced by the distributed energy system meet the electricity demand. At the same time, the recovery heat is used for heating, cooling and hot water. In this mode, there is no left electricity. The storage batteries in this mode will be filled firstly by the residual electricity from the solar system. The fuel cell will not charge the battery. Sometimes the recovery heat cannot be fully utilized.

The heat-tracking mode means the recovery heat can meet the heat demand in the detached house. The recovery heat can fully utilized and the residual electricity will be stored in the battery. The battery will prior charged by the fuel cell and then by solar power generation and the grid.

Figure 12 represents the priority selection of electricity load. When the detached house needs electricity, the first choice is solar panel, second is power generation from fuel cell. If it is still not enough to supply electricity load, use storage batteries to regulate. At last, we will use electricity from power grid to supply electricity load. **Figure 13** represents the priority selection of heat, which firstly from fuel cell and then supplement by the auxiliary boiler.

The CO_2 emissions are estimated by the CO_2 emissions rate of grid and city gas. The efficiency of the facilities is set as **Table 1**.

Calculate the equipment use electricity or gas that how much the energy can be generated. It is the basic thing to simulate the energy operating conditions of the detached house.

4. Simulation Results

4.1. Power Utilization and Heat Utilization

The analysis in this part took the case 6 as the example. **Figures 14-20** are the simulation results.

Figure 14 is the monthly electricity consumption under the electricity-tracking mode. In case 6, the charging time and the storage batteries follow the electricity load. The residual electricity produced by PV can be stored. The hydrogen fuel cell power generations table at around 400 kW in each month. October has the largest solar power generation which reaches 442 kW. January has the least solar power generation which reaches 210 kW.

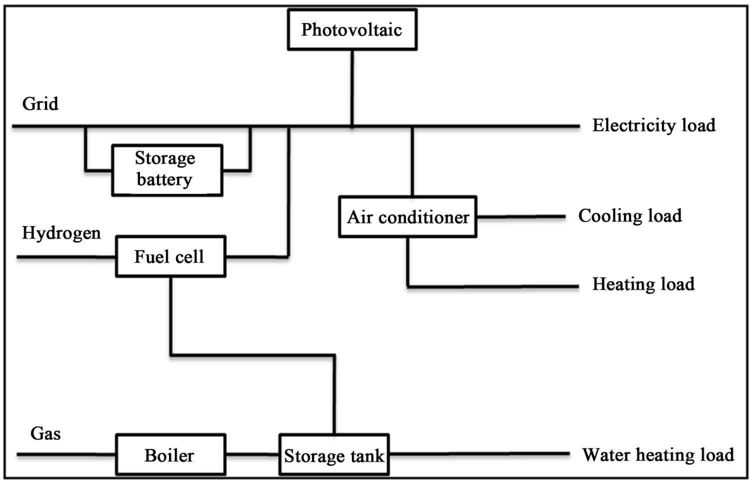

Figure 10. Case 5 (FC + PV + SB).

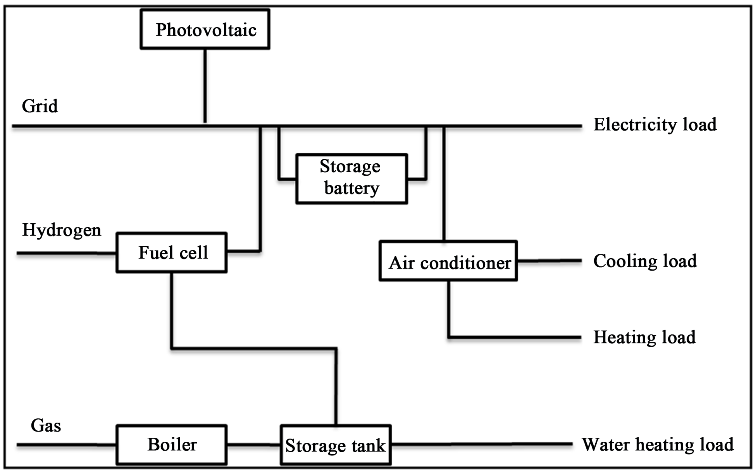

Figure 11. Case 6 (FC + PV + SB).

Table 1. Parameter of each facility.

	Fuel cell specifications		
	Power generation efficiency	Waste heat utilization	Rated output
FC (gas)	0.36	0.5	0.7 kw
FC (H_2)	0.48	0.42	0.7 kw
	Conversion factor of calorific value	Conversion factor of CO_2 emissions	
Power	9.97 MJ/kwh	0.369 kg/kwh	
	46.06 MJ/m^3	2.26 kg/m^3	
	Efficiency of each facility		
Boiler	0.9		
PV	0.145		
SB	0.92		
Air conditioner	4		

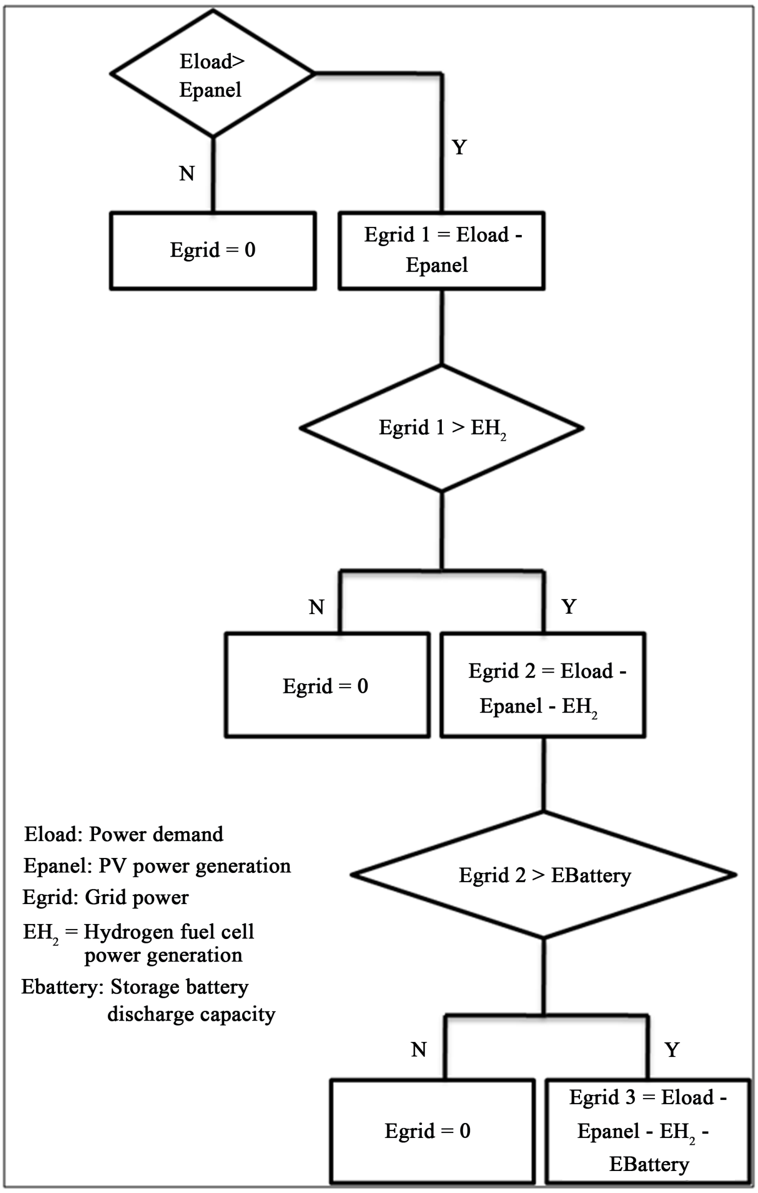

Figure 12. The condition of electricity use.

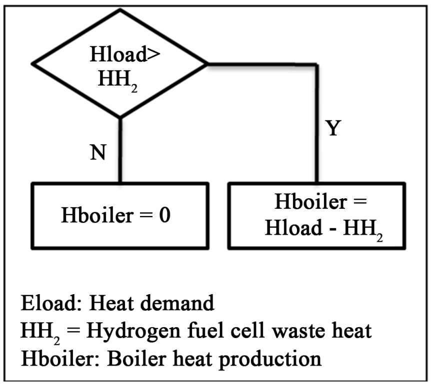

Figure 13. The condition of heat use.

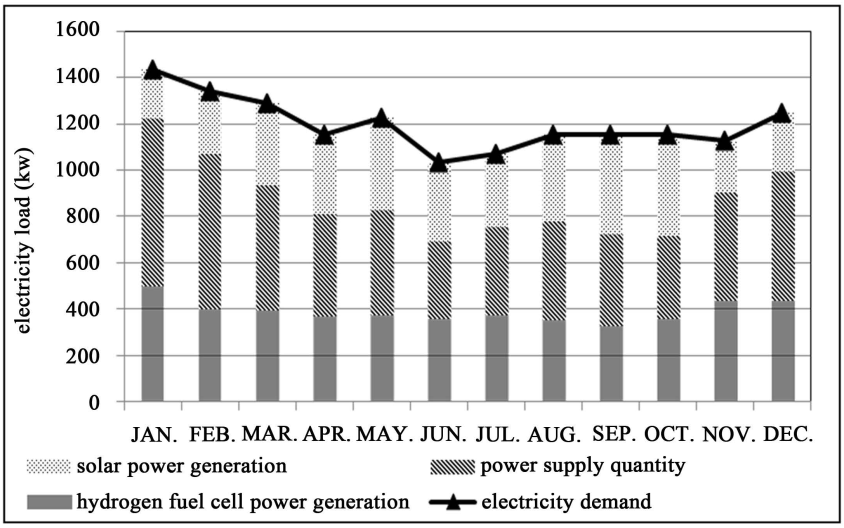

Figure 14. Electricity consumption structure (case 6 mode 1).

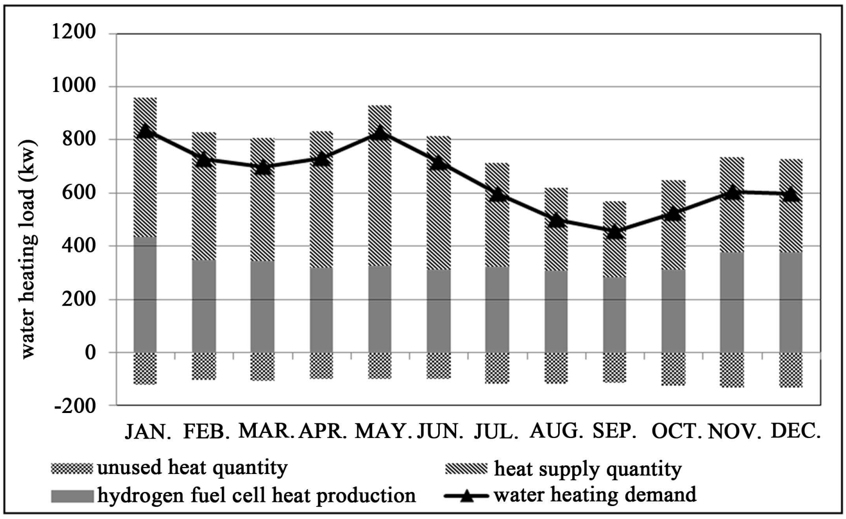

Figure 15. Heat consumption structure (case 6 mode 1).

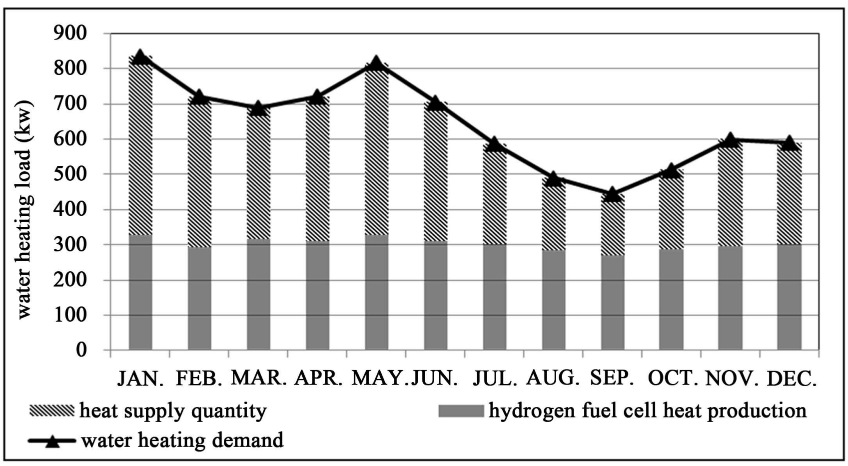

Figure 16. Heat consumption structure (case 6 mode 2).

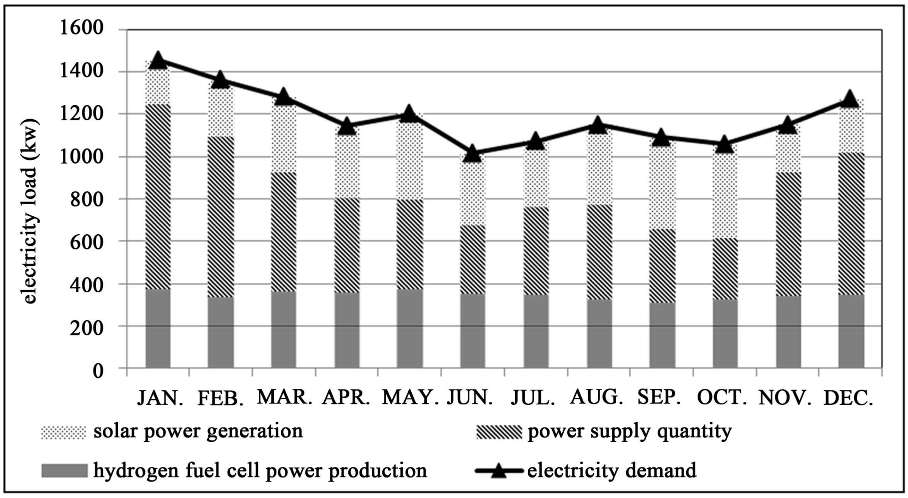

Figure 17. Electricity consumption structure (case 6 mode 2).

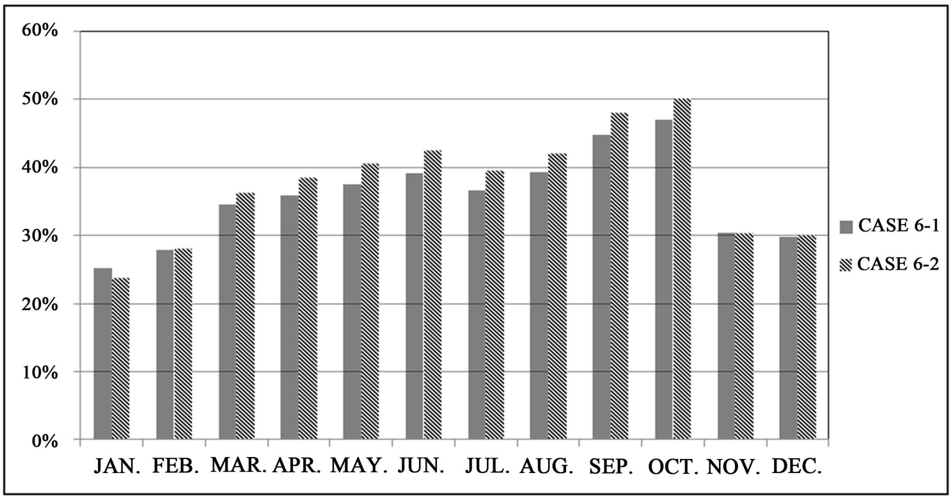

Figure 18. Energy reduction rate per month.

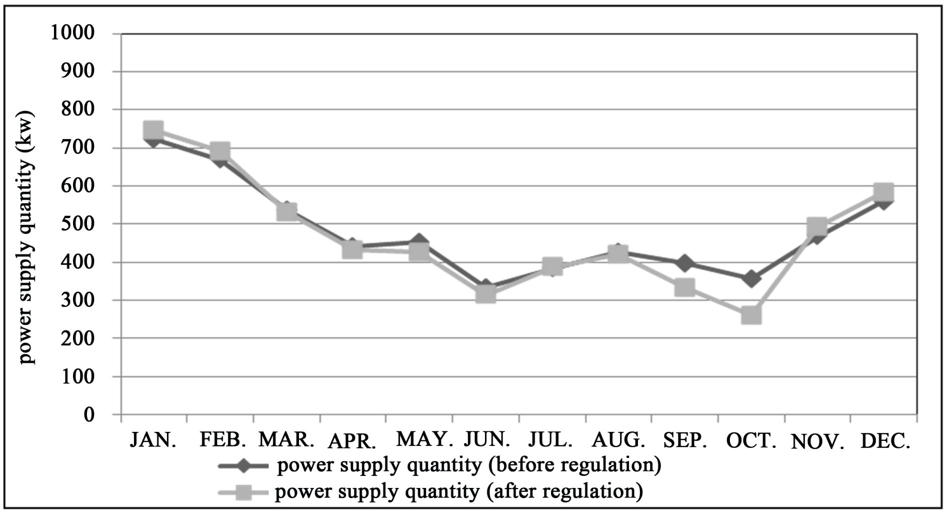

Figure 19. Regulation of storage batteries per year (mode 1).

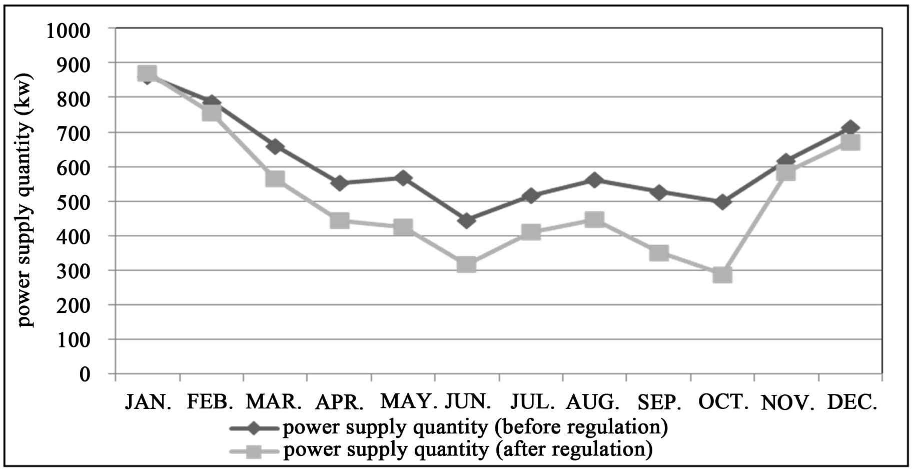

Figure 20. Regulation of storage batteries per year (mode 2).

Figure 15 is the heat consumption structure. The heat produced by fuel cell is determined by hydrogen fuel cell power generation. It is suggested that the unused heat quantity is from the fuel cell heat production. In each month unused heat quantity has around 100 kW losses.

Figure 16 is the heat consumption structure under the heat-tracking mode and there is no residual heat. Hydrogen fuel cell heat production is only about 300 kW in each month.

Figure 17 is the electricity consumption structure under heat-tracking mode. Power supply quantity in January reaches 871 kW which is the maximum value and in October reaches 289 kW which is the minimum value.

4.2. Energy Conservation Regulation

There is no doubt that the primary energy consumption of past case has the maximum value. When we introduced the fuel cell, solar panel and storage batteries in this system, the primary energy consumption is less than previous case. When we set up the PV system in the detached house, the energy reduction rate can reach more than 15% and also have waste. From **Figure 18**, we can clearly know that energy reduction of heat-tracking mode is greater than electricity-tracking mode in most of the time.

From **Figure 19** and **Figure 20**, unused electricity from solar panel and fuel cell is greater than the energy loss of conversion efficiency under heat-tracking mode. But under electricity-tracking mode, there is no unused electricity from fuel cell. Power quantity depends on the solar generation, so the solar radiation rate of some months caused the low power supply quantity.

5. Conclusions

As the energy shortage has become the focus on a global scale. On the other hand, the residential building is a big part of energy consumption. So the energy conservation has become more and more important for the society.

General generating efficiency of power grid makes a big loss where it is generating in plants. Distributed energy resources system enhances the efficiency, and also is faster than before. Offer consumers the potential for lower cost, higher service reliability, high power quality and energy independence. Use renewable energy to supply the distributed energy resources system extra electricity. Like wind, photovoltaic, geothermal, biomass and hydroelectric power.

In the detached house, we set up storage batteries and fuel cell in the system. For the storage batteries, discharge cycle and charge cycle characteristics are excellent, batteries can be put through 500 or more cycles. Self-discharge is minimal, at fewer than 10% per month. Remaining capacity can easily be indicated using the discharge curve. Fuel cells combine hydrogen and oxygen without combustion to generate electricity. Water and heat are the only byproducts of this reaction. The fuel is converted to hydrogen by a series of chemical reactions in a processor. The resulting hydrogen is then combined with oxygen from the air in the fuel cell to generate electrical power in a single step.

Case 6 in heat tracking mode has the maximum value which reaches 37%. Also the time of storage batteries is fixed and does not store the residual energy, so the case 4 is greater than the case in the same mode, caused the energy loss more than 2%. Because of using hydrogen fuel cell, comparing with conventional case, the CO_2 emissions reduction rate increase obviously. Case 6 in heat tracking mode has the maximum value which reaches 55%. Distributed energy resources system can enhance the operation efficiency more than 30%. When we set up the PV system in the detached house, the energy reduction rate reaches more than 15% but also has waste. From case 3 to case 6, using hydrogen fuel cell, can cut down more than 30% CO_2 emissions.

In the future we will further improve the system in the detached house. Make full use of the energy consumption, enhance the operation efficiency. According to the price of gas and electricity; the subsidies of renewable energy application, we can discuss the economy energy usage and equipment cost. Fuel cell also generates heat in the detached house, but it will make energy loss in the system. We can talk about the heat accumulation in the detached house.

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