Energy performance investigation of Energy-Plus Solar House integrated renewable energy systems

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Abstract

In order to realize the climate agenda in terms of reducing CO2 emission in the buildings, beyond the zero energy house concept is necessary. This paper investigates and proposes the energy-plus solar house. The house has many advantages to add the renewable energy system. For reducing the cooling and heating load of the house, parametric analysis for the building passive design was conducted and optimum passive design was found for minimize the energy consumption. Using the PV and solar thermal system, the optimum renewable energy system design integrated with the HVAC system was investigated. Consequently, the results showed that the proposed house can produce over 40% more electric energy via the entire energy usage of the house integrating the PV and solar assisted air source heat pump system.

Keywords: Energy-plus solar house, air source heat pump, photovoltaic system, solar thermal system

1. Introduction

Recently, various efforts has been made in the building sector of each country in order to increase the supplement of energy through the renewable energy sources and reduction of global carbon emissions. (AlAjmi et al., 2016; IEA, 2010). South Korea aims to 20 percent of electricity with renewable energy systems by 2030 for shifting the energy from nuclear to renewable energy. In a circumstance of relatively high land price in South Korea, the buildings are good alternative place rather than the land to place the renewable energy systems. The renewable energy systems, such as photovoltaic (PV), solar thermal system, and fuel cell, can be placed in roof, north side wall, and underground mechanical room of buildings. In order to realize the climate agenda in terms of reducing CO2 emission in the buildings, beyond the zero energy house concept is necessary to increase the renewable energy portion in Korea's national energy supply. In order to realize the beyond zero energy house, we proposed the Korea Institute of Energy Research (KIER) energy-plus solar house (KePSH). The PV system can be placed at the roof, lover, and windows of the building, and the solar thermal system can be located at the north side wall for the load match as well as roof to collect thermal energy. The loss for transferring the energy from power plant or other sources to the load can be minimize to place the thermal and electricity generation systems, such as fuel cell, located in buildings. If the house produce surplus energy, and it can move to the near load, and house get incomes.

This paper suggested KePSH and energy performance of that was investigated. Using the PV and solar thermal system, the optimum renewable energy system design integrated with the HVAC system was investigated. The basement operating energy of the house is included the cooling and heating energy, ventilation, domestic hot water, lighting and miscellaneous electric load.

2. Design of KIER energy-plus solar house (KePSH)

2.1. Plus Energy House

In South Korea and EPBD (Energy Performance of Building Directive) in Europe have defined the range of energy usage in the zero energy house as five energies (cooling, heating, hot water supply, ventilation, lighting), and the

doi:10.18086/eurosun2018.06.02 Available at http://proceedings.ises.org

zero energy level is judged based on the primary energy requirement based on the primary energy difference between the produced energy from the renewable energy sources and energy consumption of the house. Meanwhile, the US DOE extends the scope of zero energy houses including the entire energy usage and generation of buildings and land. Plus Zero Energy Building (+ ZEB) is a term that is officially used by the French government. That building produces more energy by the renewable energy system compared with the entire building energy consumption, and the surplus energy can be provided to other sectors, such as other buildings or automobiles.

As shown in Fig. 1, this study defines the positive energy rate in the plus energy house. The zero energy house means that minimizes the thermal load of the house as well as minimizes the energy consumption by utilizing renewable energy systems. Plus energy house extends the concept of the zero energy house to minimize the energy load of buildings as well as maximize the utilization of renewable energy system.

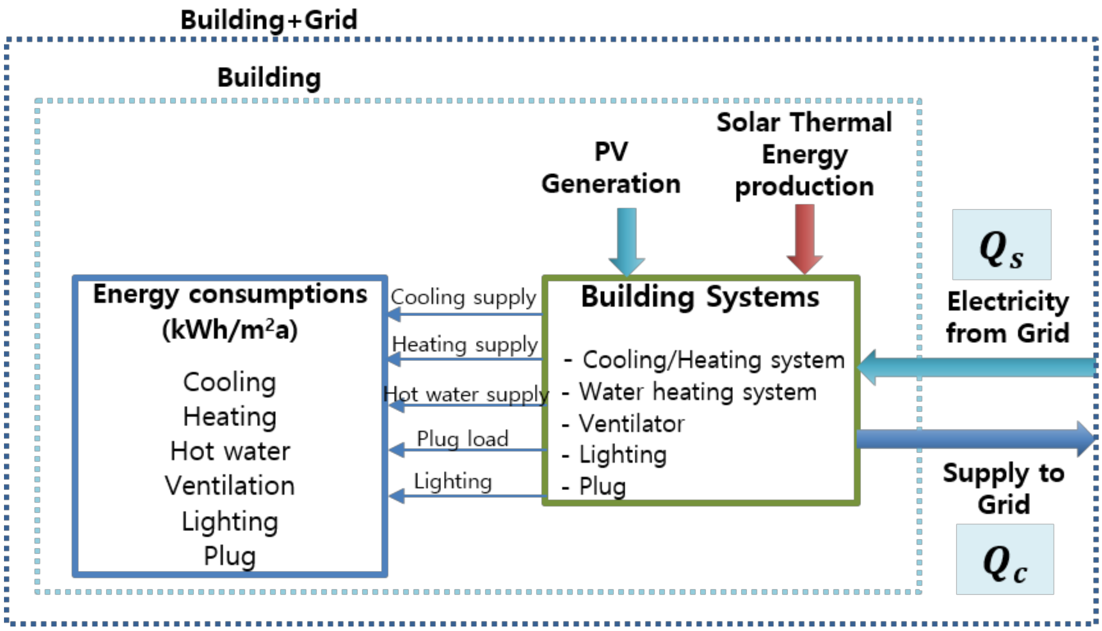


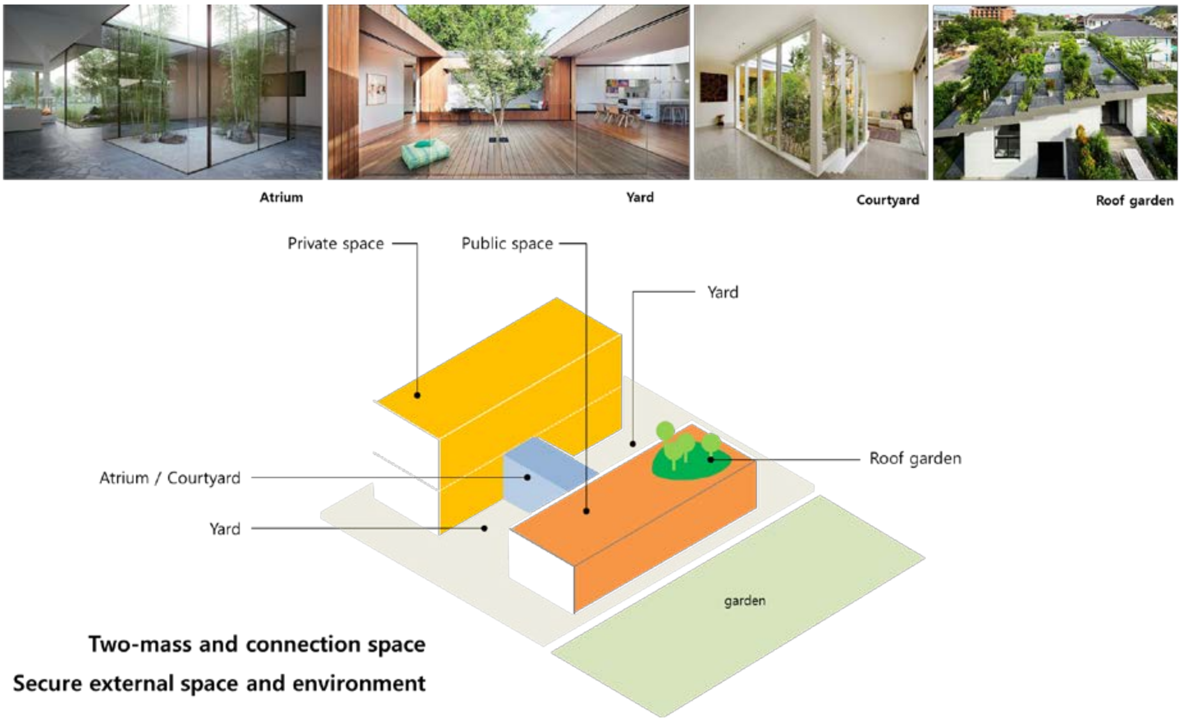
Fig. 1: Definition of Plus Energy Rate (PER)

2.2. Overview of KePSH

For the formative approach of the architectural plan, we proposed a mass segment type that separates the public space and the private space with separating the two masses (Figure 2). That mass type can improve the connectivity with the external environment. The public area including the living room and the dining room is formed on the south facing façade, and the private area such as the bedroom, the study room and the toilet, is arranged on the mass form to clearly distinguish the activity line of the family members and ensure the independence of the private space. In addition, the space created between the two masses is composed of a courtyard that provides a contact with stable external environment and atrium that introduce natural conditions such as light and wind. Based on the mass type and floor plan, the plan for new and renewable energy source was established.

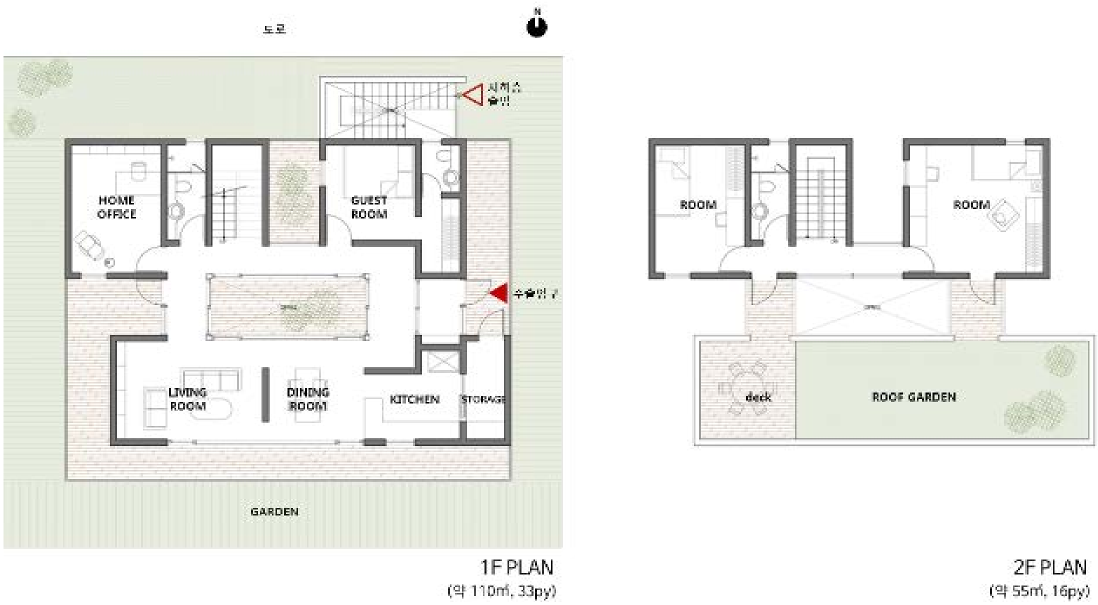
2.3. Overview of Hybrid renewable energy HVAC system

Among the renewable energy systems, the BIPV and BIST systems were selected for the Plus Energy House. The BIPV and BIST systems were integrated with the heating, ventilation, and air-conditioning (HVAC) system and hot water system. The major HVAC system is composed of the air-source heat pump, and independent dedicated outdoor air system (IDOAS). The space cooling and heating water is served to the fan coil unit (FCU) and radiant heating floor, respectively. In order to maximize the power generation and to secure sufficient roof area, building integrated photovoltaic (BIPV) is planned to have a slope of 32 °. Building integrated solar thermal (BIST) has installed a solar collector on the vertical surface of the south faced wall of the first floor as an integral part of the exterior material. In this paper, the two system cases were evaluated (i.e., Case 1 and Case 2). As shown in Figure 3, Case 1 is the major HVAC system integrated with BIPV system and Case 2 is the major HVAC system integrated with BIPV and BIST system.



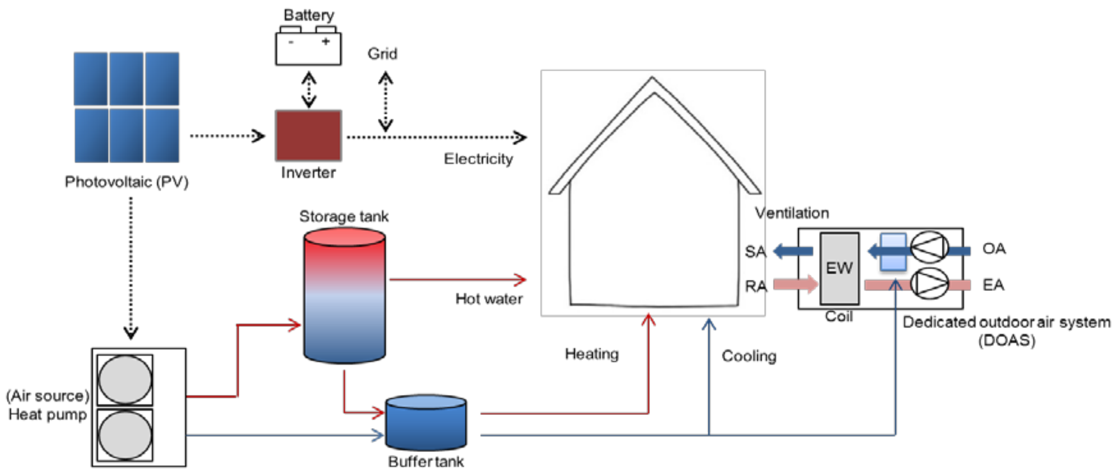
(a) Concept of house

(b) Design overview

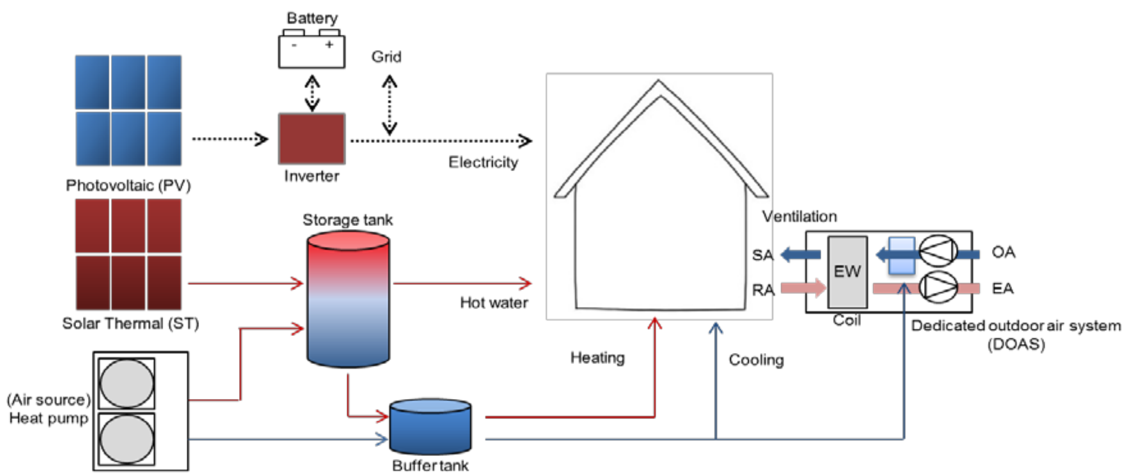


(c) Floor plan

Fig. 2: KIER energy-plus solar house (KePSH)



(a) Case 1



(b) Case 2

Fig. 3: Hybrid renewable energy HVAC system

3. Simulation Overview

To estimate the heating and cooling load of the Plus Energy Solar House, the following input data were used. The meteorological data was obtained from the Daejeon area TMY3 provided by the Korea Research Institute of Standards and Science and the simulation was performed using the TRNSYS 17 program. The building load was estimated using Type 56 and the floor heating was simulated through the Active Layer of TRNBuild. In addition, the cooling and heating set temperature was created by referring to the actual data of the previous paper.

The simulation thermal load profile was obtained the experimental data of the net zero-energy residential house (Lim et al. 2016). The thermal loads of the house was estimated using the TRNSYS 17 program. The floor area of the house was 150 m^2, and the floor height was 2.7 m. Table 1 shows the detailed building parameters of the energy-plus solar house. As results of the simulation, the peak sensible and latent cooling load were estimated at 4.0 kW and 0.7 kW, respectively.

As following the ANSI/ASHRAE Standard 62.2-2016 (2016), the ventilation rates for the residential house was estimated. ASHRAE Standard 62.2 states that the total required ventilation rate is set by depending on the dwelling-unit floor area and number of bedrooms. The energy-plus solar house has six rooms and that rooms were conditioned by the mechanical systems. The dwelling-unit floor area of the house is 172.2 m^2 that volume is 644.2 m^3, and there are four bedrooms. The required ventilation rates were estimated by 43.3 Liter per second and that indicates 0.24 air change per hour. The detailed simulation parameters of the plus-energy solar house is presented in Table 1.

Tab. 1: Simulation parameters overview

Location		Daejeon
Orientation		South
Occupancy (People/m2)		0.047
Equipment Density (W/m^2)		32.2
Lighting Density (W/m^2)		4.7
U-value (W/m^2·K)	**External Wall**	0.10
	Roof	0.09
	External Floor	0.09
	Ground Floor	0.25
	Window	0.65
SHGC		0.40
Window-wall-ratio		14.6%
Infiltration (1/h)		0.137
Setpoint temperature (°C)	**Heating**	22
	Cooling	26

4. Results

Table 2 compares the annual plus energy rate (PER) for houses with CASE 1 (i.e., 6 kWp of BIPV system) and CASE 2 (i.e., 5 m2 of BIST and 5 kWp of BIPV systems). In CASE 1, annual heat pump energy consumption showed 3,490 kWh, entire house energy consumption also showed 7,283 kWh, and 6 kWp of PV generated 10,320 kWh per year. Consequently, the PER showed 142%. On the other hand, in Case 2, the 5m2 of BIST reduced 591 kWh of hot water supply energy consumption of the heat pump. However, the 5 kWp of BIPV generated 8,600 kWh, the total energy consumption of the house showed 6,686 kWh with 122% of PER. In CASE 1, the entire house energy consumed 7,283 kWh and 6 kWp of BIPV generated 10,320 kWh per year, and the PER showed 142%. On the other hand, in Case 2, the 5m2 of BIST reduced 591 kWh of hot water supply energy consumption of the heat pump. However, the 5 kWp of BIPV generated 8,600 kWh, the PER showed 122%. Consequently, CASE 1 generated 37% more surplus electricity than CASE 2.

Tab. 2: Plus energy rate of system cases

System cases	Heat pump energy consumption*				Plug load*	Total consumption*	BIPV generation rate*	Plus energy rate (%)
	Heating	Cooling	Hot water	Total				
CASE 1 (BIPV)	1,270	1,267	953	3,490	3,793	7,283	10,320	142
CASE 2 (BIPV+ BIST)	1,266	1,265	362	2,893	3,793	6,686	8,600	122

* [Unit: kWh/y]

5. Conclusion

In this study, the concept for the KePSH was established and the design for that was conducted. The applicability of hybrid HVAC and renewable energy system to the designed KePSH was analyzed through simulation. This research also investigated two simulation cases, which are BIPV system (CASE 1) and BIPV + BIST system (CASE 2) with same installation area. It was found that the 6 kW of BIPV integrated HVAC system can produce over 40% of surplus electricity than the entire energy consumption of the KePSH. The CASE 1 generated 3,037 kWh of surplus energy but the CASE 2 generated 1,914 kWh of surplus energy. It leads that the CASE 1 generated about 37% more electricity rather than CASE 2.

6. Acknowledgement

This work was conducted under framework of the research and development program of the Korea Institute of Energy Research (B8-2424-03).

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