Energy balance investigation of a hybrid renewable energy system using seasonal thermal energy storage for eco-friendly energy town

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Abstract

Among the numerous effort to widespread renewable energy deployment in South Korea, an eco-friendly energy town integrated with a hybrid renewable energy system (HRES) has been constructed in Jincheon city. This real-scale experimental testbed has been operated for supplying a thermal energy as well as electric load to buildings over the course of a year. The town contains six public buildings, and the facilities incorporated with HRES. To configure the net plus energy town, an 850 kWp grid-connected photovoltaic (PV) system produced the electricity and the HRES managed the thermal energy for heating, cooling, and domestic hot water for buildings. This paper mainly describes the field tests and measurement results of annual and monthly source and site energy consumption and generation of the buildings and town. It was mainly found that the proposed town achieved 134.5% net plus energy town in South Korea.

Keywords: PV systems, solar thermal systems, seasonal thermal energy storage, experimental results, zero energy rate

1. Introduction

For boosting the energy transformation to the renewable energy supplement, the government of South Korea have been many effort to widespread of renewable energy system. Until now, policies of South Korea have been focused on the significant increase of the photovoltaic (PV) system and wind generation system. On the other hands, recently the interest in terms of hybrid renewable energy system (HRES) for considering the energy conservation, efficiency, well utilization has been raised. The key of the proposed HRES is covering the electric load by PV system and reducing the load of electricity as well as thermal energy (i.e., cooling, heating and domestic hot water). This research proposed the HRES for serving the electricity and thermal energy to eco-friendly energy town. The town contains the six public buildings, which are a high school, library, youth center, childcare center, public health center, and management center. The major component for generating the electricity is PV system, and that for delivering the thermal energy are solar thermal system, seasonal thermal energy storage (STES), heat pumps, and district thermal network. This paper demonstrates the experimental results of annual and monthly electric and thermal energy performance for net plus energy community via operation of HRES of the Jincheon eco-friendly energy town. Then, the energy balance of the current town are compared with that of the town without solar thermal system and STES.

2. Hybrid renewable energy system overview

In this town, 850 kWp of PV systems were installed in the building, parking lots, and sidewalk. The PV system is on-grid system, the entire generated electricity is delivered to the grid and then the electricity demand of the town is served by the grid. The solar thermal systems in the proposed system consisted of 800 m2 of flat-plate type solar collectors, 800 m2 of evacuated type solar collectors, and 4000 m3 of a STES. Fig. 1 shows the overview of hybrid renewable energy system. The flat-plate type solar collectors and evacuated type solar collectors are

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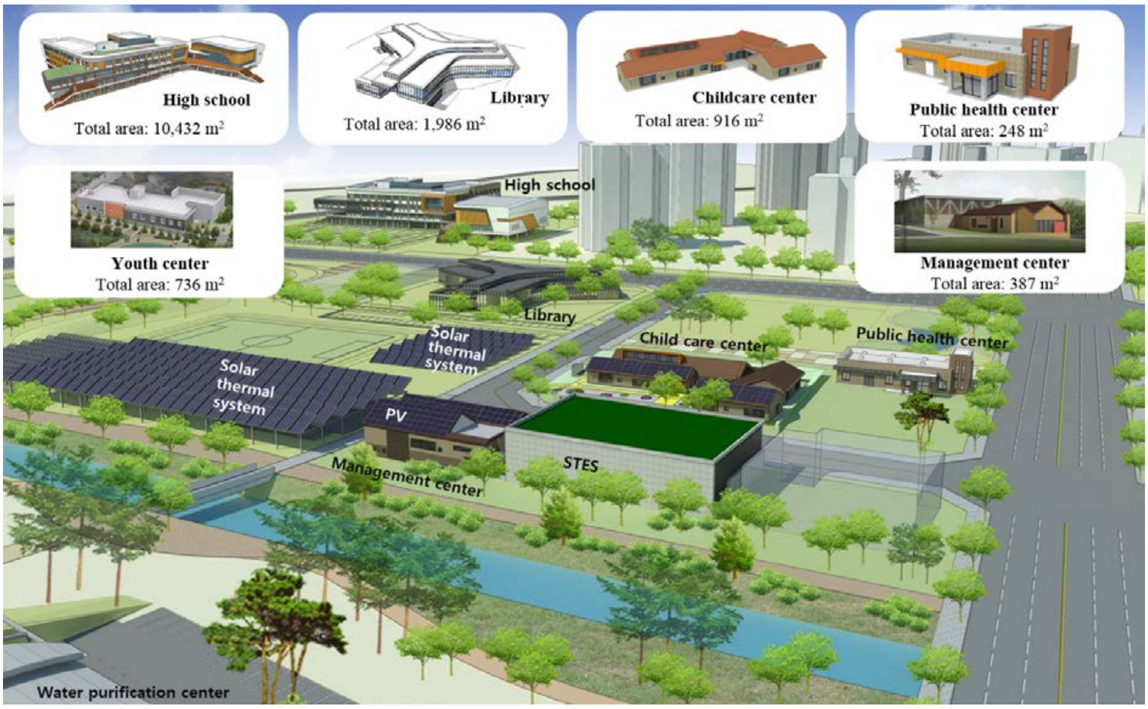
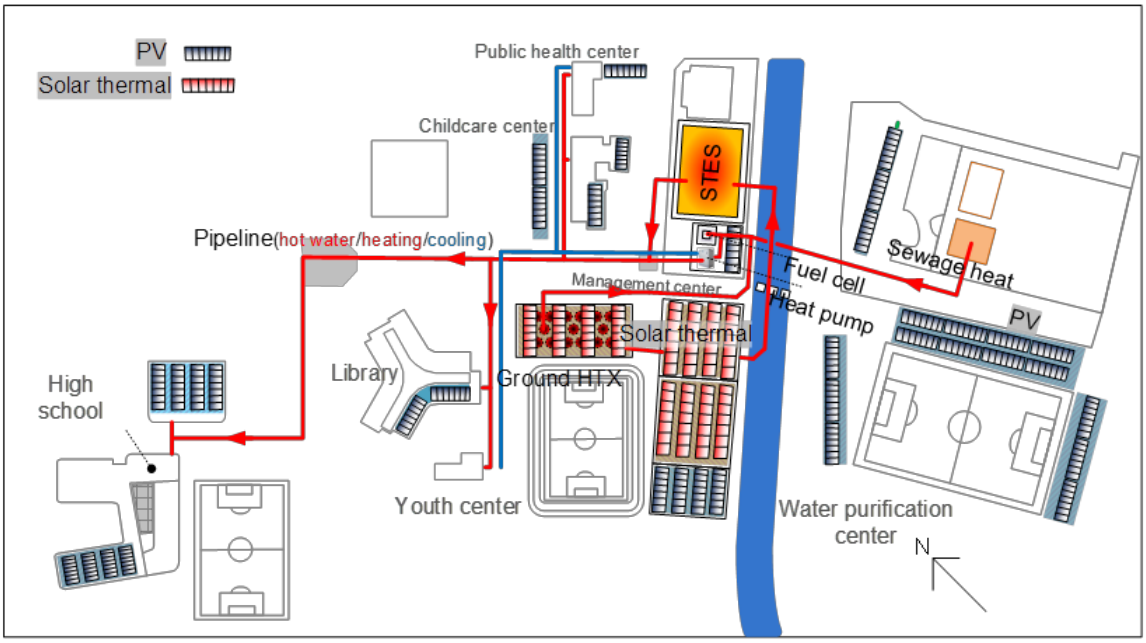
connected in series. The collected thermal energy is stored into the STES. The STES is a rectangular-shaped tank type thermal energy storage. The stored heat is delivered to the buildings using district thermal network for space heating and domestic hot water (DHW) during the heating season. During the cooling season, the chilled water is served to the building and the chilled water is produced by heat pump with ground source heat exchanger and sewage water plant.



(1.a) Overview of buildings

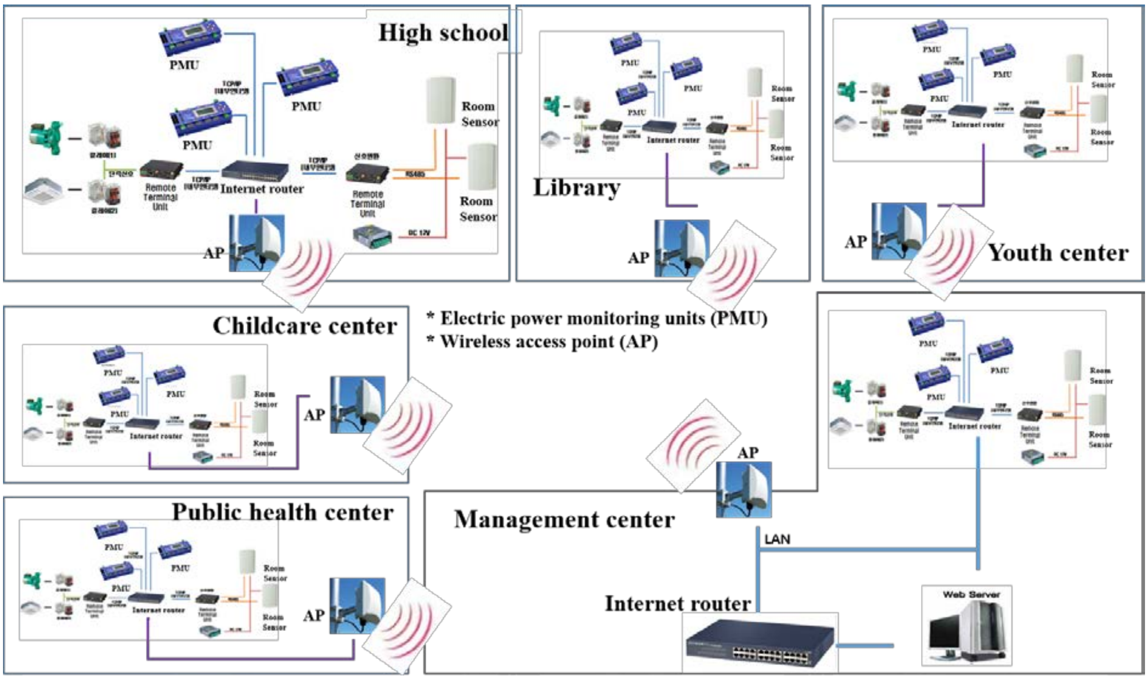


(1.b) Overview of hybrid renewable energy systems

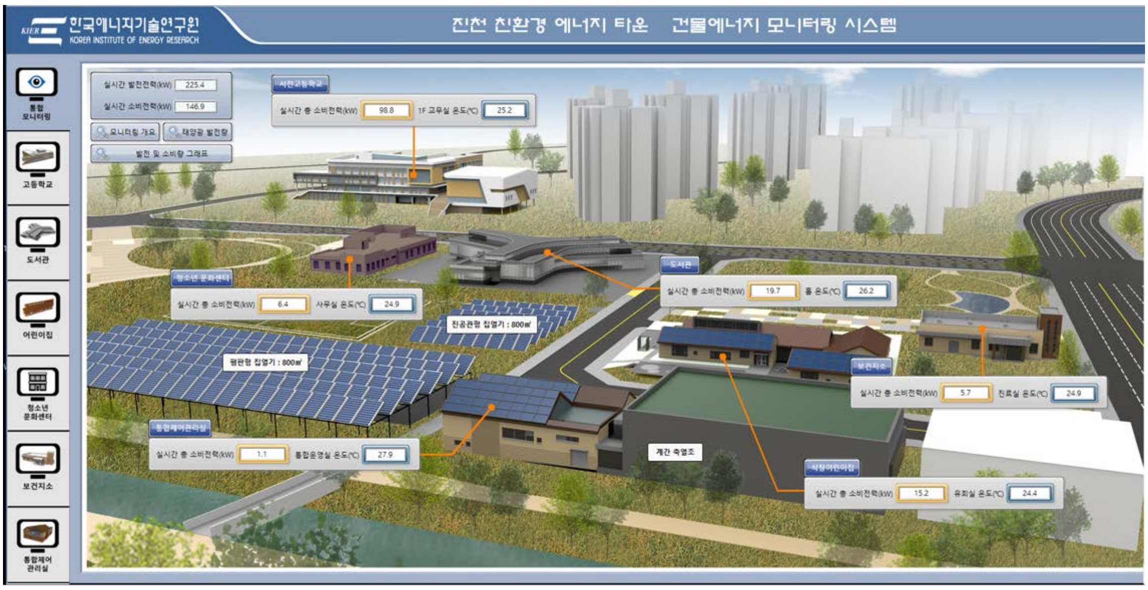
Fig. 1: Overview of Jincheon Eco-friendly Energy Town

3. Overview of monitoring systems

The network pipeline is composed of two lines, the domestic hot water line and the space heating and cooling line. The town's total domestic hot water energy consumption and the total energy for space cooling and heating were measured with the monitoring system. To measure the horizontal and tilted surface solar irradiations, two pyranometers are installed on the top side of the solar thermal collectors. The pyranometer model is ISO 9060:2018 spectrally flat class A. The building electric energy monitoring system comprises electric power monitoring units (PMUs). The measured data for each building are sent through an internet router inside each building and passed through the wireless access point located on the outside of each building. All data are gathered in the management center and collected in a web server computer. The monitoring system logs all real-time electricity generation data for the inverters every 1 min.



(2.a) Configuration of monitoring system



(2.b) View of monitoring system

Fig. 2: Overview of monitoring systems

4. Results

4.1. *Ambient conditions during the test periods*

The ambient air and indoor air conditions of the monitoring periods are presented. During the measurement period, the monthly average ambient air dry-bulb temperature (DBT), relative humidity (RH), and horizontal surface solar irradiation ranged from –1.8 to 31.5 °C, 54.6 to 70.7%, and 83.3 to 189.1 kWh/m^2, respectively. The highest value of tilted surface solar irradiation occurred in July 2018 (180.2 kWh/m2) and the lowest value in October 2017 (108.6 kWh/m2). Fig. 3 shows the comparison of measured weather data and TMY2 weather data that is used to estimate the building thermal load and to size the HRES. The measured ambient air DBT is approximately 13% higher than the design data, and the RH of ambient air showed an approximately 7% difference between measured and design data.

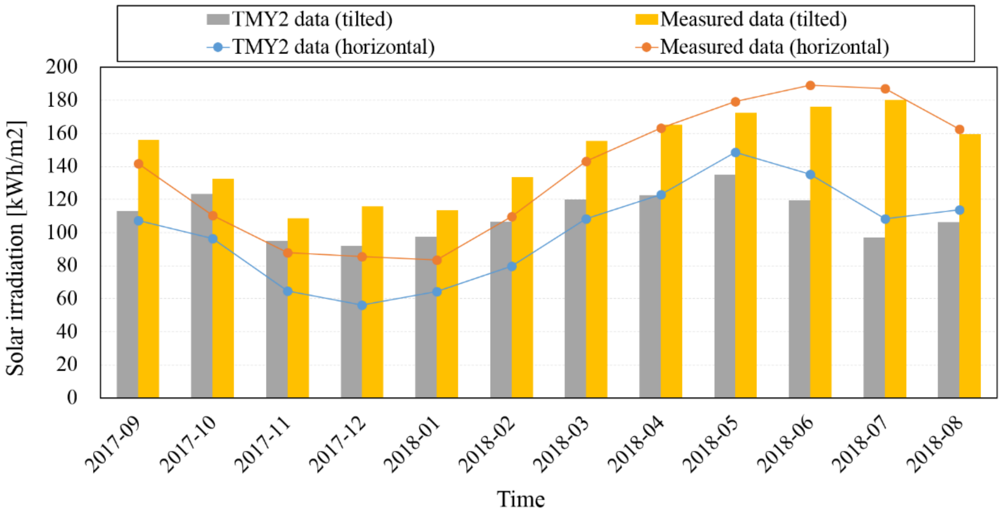
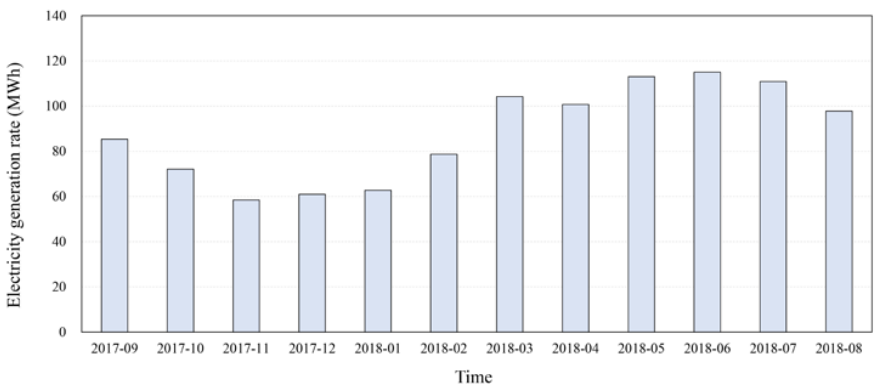


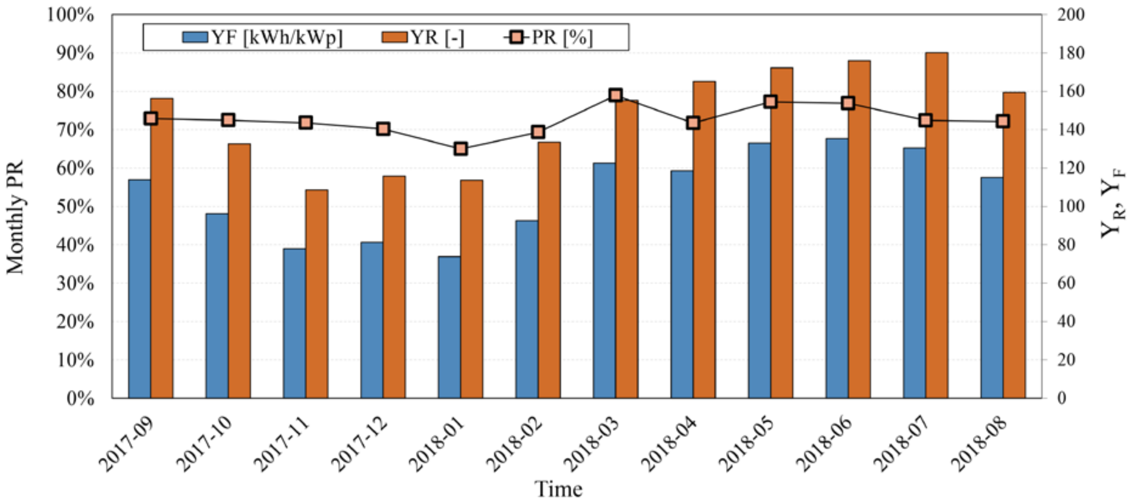
Fig. 3: Test results of the ambient conditions

4.2. *Monthly energy balance of the town*

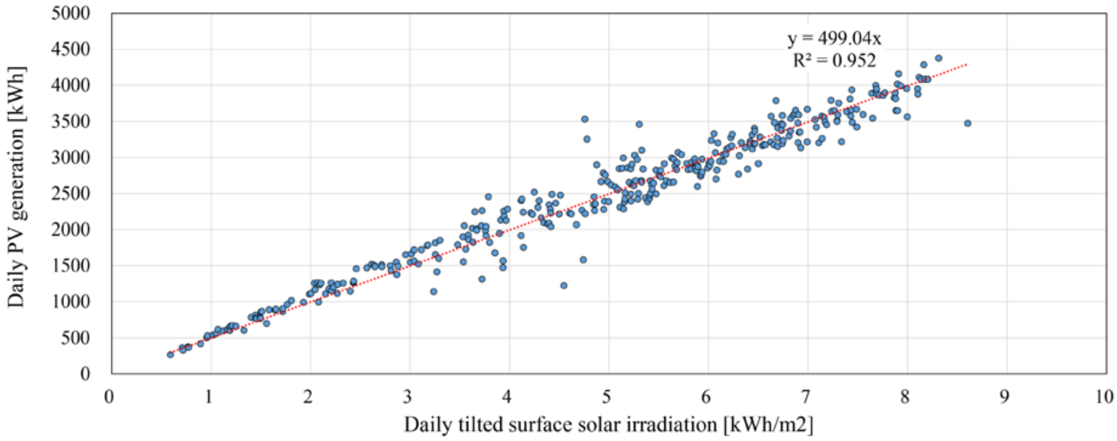
The PVs installed in the town generated 1060.3 MWh over the course of a year. As shown in Fig. 4(a), the monthly electricity generation ranged from 58.5 MWh (October 2017) to 115.0 MWh (June 2018). Fig. 4(b) shows the monthly PR of the PV system installed in the town. The annual average daily final yield in the town was 3.5 kWh/kWp/d, which is high compared to those reported in other countries in previous research: Germany, 1.8 kWh/kWp/d; the Netherlands, 1.8 kWh/kWp/d; Italy, 2.0 kWh/kWp/d; Japan, 2.7 kWh/kWp/d; and Israel, 3.5 kWh/kWp/d. Even though the installed PV system in the town was not optimally oriented on the south side, a sufficient PV generation rate was still acquired. Consequently, the monthly PR value was 65% to 79% during the measured period. Fig. 4(c) shows the variation of daily PV generation rate vs. solar irradiation. The PV generation rate had a linear relationship with solar irradiation with a correlation coefficient R^2 of 0.952.



(4.a) PV generation rates.



(4.b) Overall efficiency based on tilted surface solar radiation.



(4.c) Daily PV generation versus solar irradiation.

Fig. 4. Performance of PV generation rate.

4.3. *Monthly energy balance of the town*

Fig. 5 shows the monthly net source energy generation and consumption balance for the town. This energy balance includes the appliance energy consumption of the buildings. Except for two months during the test period that had the least solar irradiance (Dec. 2017 and Jan. 2018), the energy generation of the PV system was much higher than the source energy consumption of the buildings in the town. It mainly caused a sufficient amount of PV systems installed on the roof, parking lots, and empty places in the town. The annual town source energy generation and consumption were 2915.8 MWh and 1926.8 MWh, respectively. Consequently, it is clear that a 134.5% plus-energy town can be achieved using an HRES with a solar thermal system, STES, and PV systems integrated with low energy buildings.

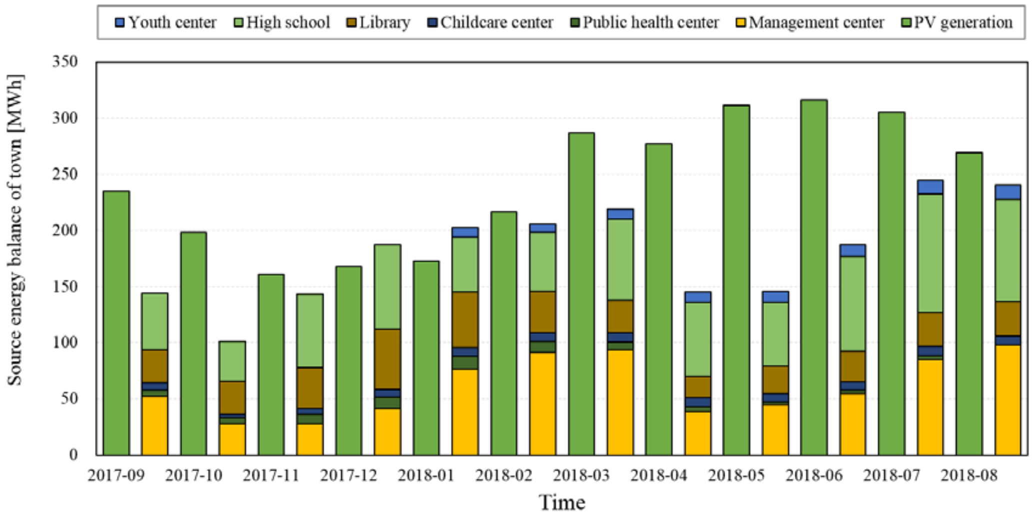


Fig. 5: Monthly source energy balance of the town

5. Conclusion

This research investigated the source energy balance of the Jincheon eco-friendly energy town. From the monitoring data measured during a year operation, it was found that the annual town source energy generation showed 34.5 % much larger than that energy consumption. It mainly caused that the proposed HRES can serve the thermal and electricity with significant low operating energy consumption compared with the conventional system. Through the community scale experimental results indicated that the net plus energy community beyond net zero energy can be realized by HRES integrated with PV systems. However, this high penetration renewable energy system can cause unstable of the national or local grid, the way to improve self-consumption of the PV generation should be considered to widespread of the HRES.

6. Acknowledgement

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7. References

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