THE CHARACTERISTICS OF SOLAR THERMAL COLLECTOR AND STORAGE SYSTEM INCLUDING SEASONAL THERMAL ENERGY STORAGE IN SOUTH KOREA

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Abstract

A renewable hybrid energy system using seasonal thermal energy storage (STES) has been recently constructed in Jincheon, South Korea. The eco-friendly energy town was proposed and constructed in Jincheon to supply the heat from the solar thermal system and new and renewable hybrid energy systems with seasonal thermal energy storage (STES) to six buildings contained in town. In this research, the thermal behavior of the series connected solar thermal systems, which are flat-plate solar collectors and evacuated tube solar collectors, and the STES have been investigated. During the 21 days of trial operation period in January 2017, the ambient air conditions, irradiation, useful thermal energy gain, and internal thermal energy variation in STES were estimated by using measuring data. It was found that the efficiencies of solar thermal systems were 2.4 to 25.4%, and that of the STES were 90%, during the whole test period.

Keywords: solar thermal systems, seasonal thermal energy storage, control logic, experimental results, efficiency

1. Introduction

In South Korea, where the usage ratio of renewable energy among the national energy consumption is still low, the policies have been established to expanding the heat supply from renewable energy facilities including solar thermal systems. As part of these policies, the eco-friendly energy town constructed in Jincheon, South Korea has adopted a centralized heat supply system combined with various new and renewable hybrid energy systems, focusing on the solar thermal systems and seasonal thermal energy storage (STES).

This proposed eco-friendly energy town is the first case in South Korea that uses STES for stable heat supply to the buildings. The eco-friendly energy town contains six buildings with the new and renewable hybrid energy systems which includes a solar thermal system, STES, 3 heat pump systems which have different heat sources, buffer tank, and a district heating loop system. The six buildings are consisted of high school, library, youth center, child care center, public health center. Figure 1. shows the new and renewable energy hybrid system configuration installed in Jincheon. The two types of solar collectors are connected in series, and then the collected heat is stored in the STES through the whole year. The stored heat in the STES is supplied to the building for heating the space and supplying the hot water through the winter season. In the end of heating season, when the stored water temperature in STES is lower than the target supply heating water temperature, the heat pump system increases the supply water temperature with supplying the hot water in the STES to the source side of the heat pump. During the cooling season, two heat pumps which uses the ground heat source and sewage heat source, respectively, are operated to produce cooling water. The produced cooling water is stored during the nighttime in the buffer storage tank, and then the cooling water is sent to the district loop system to cool the buildings during the daytime.

Over the last decades, many researches have been conducted on seasonal heat storage and solar thermal systems focused on European countries. Schmidt et al. (2004) demonstrated the central solar heating plants using seasonal thermal storage. The demonstration plants that had been built up to this point through the government-funded research program, “Solarthermie2000” in Germany were presented in detail. Bauer et al. (2010) showed several central solar heating plants with seasonal storage in Germany while comparing and summarizing the results of

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extensive monitoring programs which were carried out within the framework of "Solarthermie2000". Four different types of thermal energy storage were investigated, such as hot water, gravel-water, borehole, and aquifer. Novo et al. (2010) presented a review of technologies and conducted projects for central solar heating systems which employ seasonal sensible water storage. Different technologies for the storage of heat were available and researched. Xu et al. (2014) reviewed three forms of heat storage, namely sensible, latent and chemical heat storage. It was concluded that in comparison, sensible heat storage is most applicable for practical use whereas latent and chemical heat storage still need to be investigated and developed further.

In this study, we investigated the efficiency of solar thermal system and the thermal storage performance of the STES based on the measured data during the trial operation period.

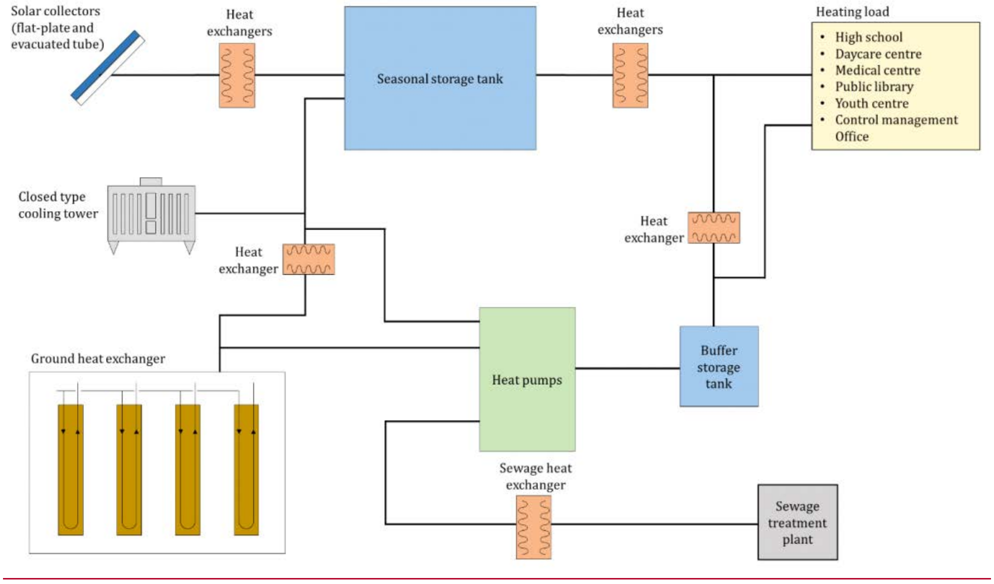


Fig. 1: New and renewable energy hybrid system configuration

2. System overview

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. As shown in Figure 2, the flat-plate type solar collectors and evacuated type solar collectors are connected in series. The solution that passes through the flat-plate type solar collectors is also heated by passing through the evacuated type solar collectors. The aqueous brine solution is used as a heat transfer medium for antifreeze. The collected thermal energy is transferred to the water, and then the water is used as a heat storage medium in STES. Figure 3 shows the installed solar collectors and STES in Jincheon.

The STES is a rectangular-shaped water tank. The STES consisted of concrete walls and a ceiling which are covered with a 700 mm thick insulation on the outside. The inside of the tank has a height of 10.3 m, a width of 16.7 m, and a length of 24.7 m. There is another concrete wall some distance away from the insulation surrounding the STES which creates a space that is filled with ambient air. For observing the stratification performance of the STES, nine temperature sensors are placed at the center of STES with 1 m different heights above the floor of the STES.

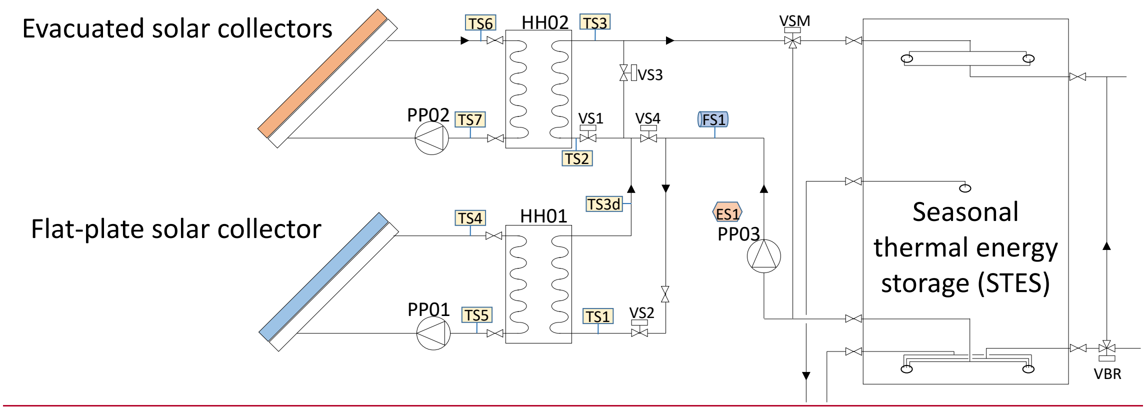


Fig. 2: Configuration of solar thermal collectors and seasonal thermal energy storage (STES)

(a) Solar thermal collectors

(b) STES

Fig. 3: Solar thermal collectors and STES in Jincheon, South Korea

3. Estimation of system performance

3.1 Control logic of solar thermal systems

The hydraulic loop of the proposed system is divided into two parts: the solar thermal system loop and STES loop. The each loop of solar thermal system is closed-circuit with solution, and the water that used to storage heat in STES is firstly passing through the heat exchanger in the circuit of flat-plat type solar collectors, and then the heat exchanger in the circuit of evacuated type solar collectors heats the water. The heated water is distributed into the top of the STES, the water that located in the bottom of STES goes to the solar thermal systems. The each pump of solar thermal system loop is operated when the tilted solar radiation is reached at 400 W/m^2. And then, by comparing the middle or bottom of the water temperature of the STES, the pump of STES is operated. This control logic is primarily for maintaining the temperature stratification of STES. After that, the 3-way valve (VSM) is modulated to maintain the water temperature that higher than the water located in the top of the STES.

3.2 Efficiency of seasonal thermal energy storage (STES)

In order to observe the temperature stratification of STES, the nine temperature sensors were installed in the middle of STES. Each temperature sensor were located from the bottom to top of the tank, and the water inside the tank can be divided into nine sections. For simplifying estimation the efficiency of STES, the volume of the water inside the tank was divided into nine sections according to the nine temperature sensors, and it was assumed that the water temperature within a volume-section is constant and that it only changes with time. Each temperature sensor therefore displays the temperature of one volume-section.

The temperature variation were measured every 30 seconds. Based on the STES, the system can be divided by three circuits, that are the collector circuit, the load circuit, and the auxiliary circuit. For the collector circuit, the added energy is typically positive because heat is delivered from the solar collectors to the tank. When the temperature of STES was increased, the energy is added (i.e., positive) and it also can be mentioned that the more heat was collected from the solar thermal system than the used energy in the load side. On the other hands, when the energy delivered to the load circuit is larger than the energy collected from the solar thermal system, the temperature of STES should be decreased (i.e., negative). The energy added to the tank by the auxiliary circuit can either be positive or negative depending on the application. For the calculations presented in this article however, the auxiliary circuit does not contribute significantly to the results as it has not been activated during the time period from which the measured data was chosen. The energy added to the system through the collector circuit during time step n is calculated as follows.

$$\Delta Q_{\mathrm{C},n} = \dot{V}_{\mathrm{C},n}\left(\rho c_{\mathrm{p}} T_{\mathrm{C,in},n} - \rho c_{\mathrm{p}} T_{\mathrm{C,out},n}\right)\Delta t_n \qquad \text{(eq. 1)}$$

where $\dot{V}_{C,n}$ is the flow rate of the collector circuit in and out of the tank during time step n. $T_{C,\mathrm{in},n}$ and $T_{C,\mathrm{out},n}$ denote inlet and outlet temperature of the water stream, respectively. The length of the time step is denoted with Δt_n. Temperature-dependent values of water density ρ and heat capacity c_{P} have been used for the calculation. The energy added through the load and auxiliary circuits can be calculated in the same way as in Eq. (1):

$$\Delta Q_{\mathrm{L},n} = \dot{V}_{\mathrm{L},n}\left(\rho c_{\mathrm{p}} T_{\mathrm{L,in},n} - \rho c_{\mathrm{p}} T_{\mathrm{L,out},n}\right)\Delta t_n \qquad \text{(eq. 2)}$$

$$\Delta Q_{\mathrm{aux},n} = \dot{V}_{\mathrm{aux},n}\left(\rho c_{\mathrm{p}} T_{\mathrm{aux,in},n} - \rho c_{\mathrm{p}} T_{\mathrm{aux,out},n}\right)\Delta t_n \qquad \text{(eq. 3)}$$

The total energy added by the three circuits is the energy increase of the storage tank under ideal conditions, meaning when there is no heat loss to the environment. This energy increase is calculated as follows for one time step.

$$\Delta Q_{\mathrm{ideal},n} = \Delta Q_{\mathrm{C},n} + \Delta Q_{\mathrm{L},n} + \Delta Q_{\mathrm{aux},n} \qquad \text{(eq. 4)}$$

The change of internal energy in the tank is calculated based on the change in water temperature. For each of the nine sections the change in internal energy is calculated separately before it is added up to yield the change in internal energy for the whole storage tank. The change in internal energy is calculated directly from measurements from the first and last timestamp of the examined time period, which is typically one day. The change in internal energy for volume-section i over this time period is calculated with Eq. (5).

$$\Delta Q_{\mathrm{int},i} = V_i \rho c_{\mathrm{p}} (T_{\mathrm{S},N,i} - T_{\mathrm{S},n1,i}) \quad \text{(eq. 5)}$$

The storage efficiency during charging is calculated by comparing the change of internal energy with the total added energy over the whole charging period:

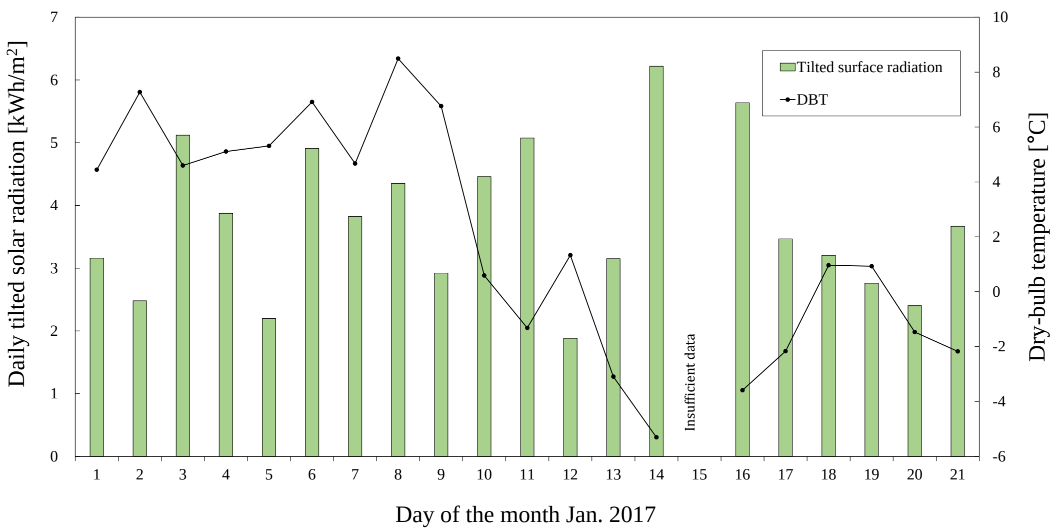
$$\eta_{\mathrm{s,chg}} = \frac{\Delta Q_{\mathrm{int},i}}{\Delta Q_{\mathrm{ideal},n}} \quad \text{(eq. 6)}$$

4. Results

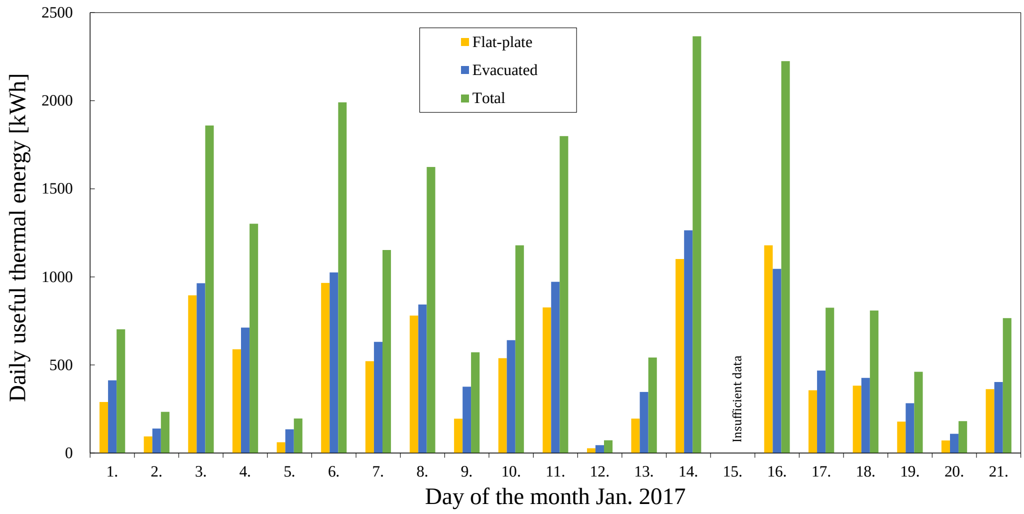
4.1 Efficiency of solar thermal collectors

The produced thermal energy difference from the solar collectors and stored thermal energy into the STES was caused by the operation time difference of the pumps in solar thermal system loop and that in STES loop. Therefore, the useful output thermal energy from the solar collectors was calculated using the water temperature difference between inlet of HH01 (TS1) and outlet of HH02 (TS3).

The trial operation test was conducted during the commissioning period. The tests were done in January 1st to 21th in 2017. As shown in Figure 4(a), during the test period, the average ambient air temperature, relative humidity, and tilted surface irradiation were ranged from -5.4 to 8.6°C, 42.1 to 75.8%, and 1.9 to 6.2 kWh/m^2, respectively. Figure 4(b) shows the produced useful thermal energy from the solar collectors in each day. One can see that the 72.5 to 2365.5 kWh of useful thermal energy could be obtained in each day. It also found that the efficiency of solar thermal collectors based on the useful thermal energy was from 2.4 to 25.4% in each day.



(a) Ambient conditions of test site

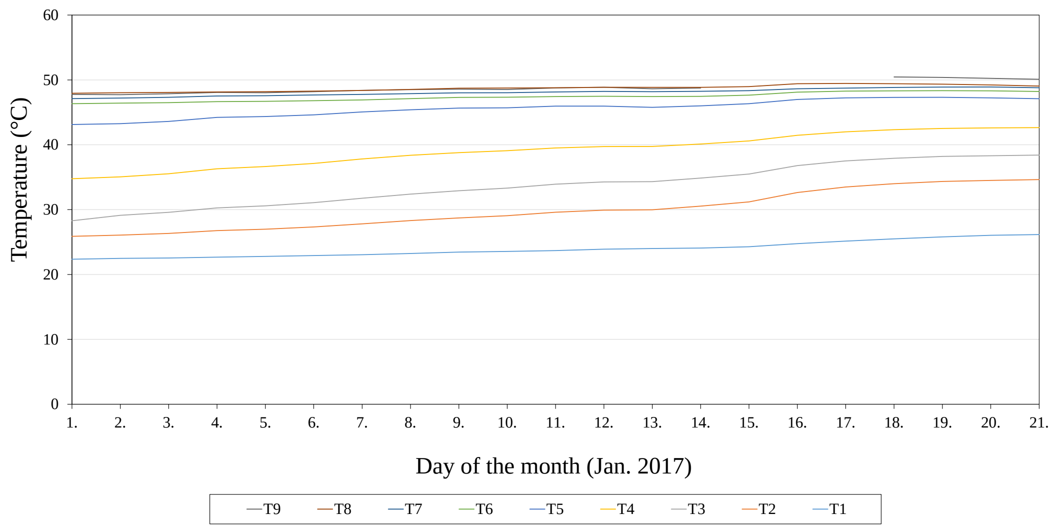


(b) Daily obtained heat energy

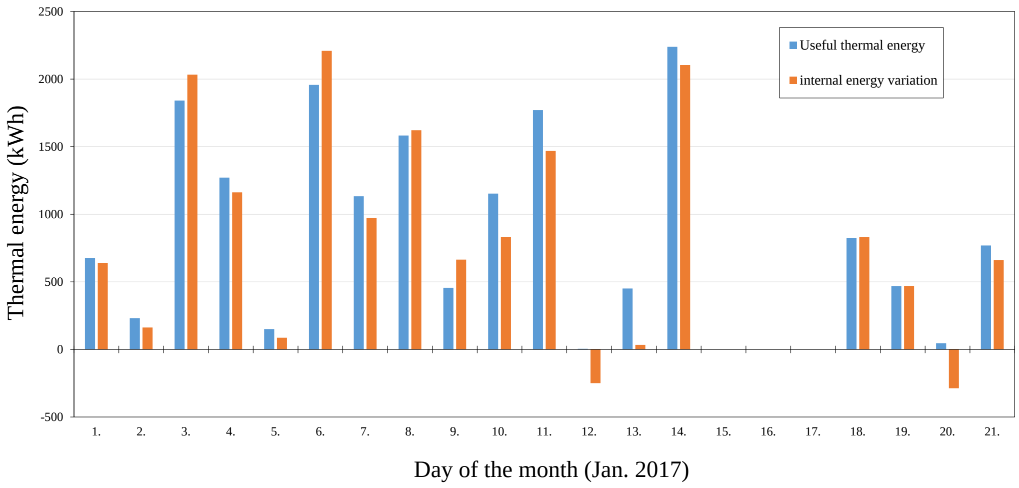
Fig. 4: Test results of solar collectors

4.2 Efficiency of seasonal thermal energy storage (STES)

Based on the produced thermal energy from the solar collectors and the internal energy variations of the STES, the efficiency of the STES was estimated. For estimating the internal energy variation, the installed nine temperature sensors were used, and the STES was divided into nine sections attributed to the nine temperature sensors. It was assumed that the water temperature within a volume-section is constant. The efficiency of STES was calculated by the change of internal energy variation in the STES over the useful thermal energy produced by the solar thermal systems. Figure 5(a) shows the comparison of the useful thermal energy and internal energy change in each day. One can see that the 90% of thermal energy storage efficiency was shown during the whole test period. As shown in Figure 5(b), the stratification of STES was well maintained during the test period.



(a) Daily heat gain compared to daily change in internal energy of the STES



(b) STES water temperatures and load circuit volume flow rate
Fig. 5: Test results of the STES

5. Conclusion

This research investigated the thermal performance of the proposed system, which was tried for the first time to use the STES in South Korea. For observing the thermal performance of the proposed system, the efficiency of solar thermal collectors and STES was estimated based on the experimental data during the commissioning period. It was found that the efficiency of solar thermal collectors based on the useful thermal energy was from 2.4 to 25.4% in each day. One can also see that 90% of thermal energy storage efficiency was shown during the whole test period.

6. Acknowledgement

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