Energy and Buildings 101 (2015) 54–63

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Evaluation of solar hot water heating system applications to high-rise multi-family housing complex based on three years of system operation

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ARTICLE INFO

Article history:
Received 14 October 2014
Received in revised form 4 February 2015
Accepted 20 April 2015
Available online 27 April 2015

Keywords:
High-rise multi-family housing complex
Solar hot water heating system
Hot water use in residential sector

ABSTRACT

This study evaluated three-year operation of solar hot water heating system installed in multi-family housing complex with 1179 households in 14 units. At first, since the size of systems for multi-families are large, position of the building services room and collector installation becomes a significant matter. In order to resolve this, three building services rooms for three or four units of households were planned and the solar collectors were integrated directly on the roof facing South at 22° degrees to the horizontal. The accumulated heat gain from three-year operation was 52% of the design baseline (4069 GJ/year). The reason for this could be a low altitude angle of collectors from the architectural design. Moreover, hot water usage and breakdowns of the system were evaluated using detailed analyses of operation data for three years by considering seasonal factors. These results are expected to give valuable feedback for the future design and wide use of the systems, as well as update the design baseline. Lastly, compared to a conventional boiler($\delta = 85\%$), the system produced a positive environmental effect equivalent to a reduction in oil use of 71,907 L/year, and reduced carbon emissions equivalent to 50.8 TC and 186.3 TCO_2 the pay-back period for the system was expanded 5 years.

1. Introduction

Solar hot water heating systems have been a significant energy conservation measure in buildings, along with improving efficiency of building envelopes and HVAC systems. The systems are expected to play an important role in residential sectors, especially, by improving the efficiency of conventional boilers since the amount of energy used for hot water heaters is responsible for more than 20% of the total energy consumption. According to statistical data from EU, installations of solar hot water heating systems have been increased gradually even though the growth was not rapid like before 2008. Especially in 2013, the total installations were 2.14 GWth (approximately 3.05 million m^2), which was twice the number of installations compared to ten years ago [1,2]. Similar trends were seen from South Korea as well; 96,951 m^2 of installed solar collector areas have decreased after 2009, however, an area of 15,135 m^2 of the areas in 2003 was increased to 63,775 m^2 in 2012, an increase of approximately four times [3]. Currently in South Korea, energy used for hot water heaters is approximately 17% of the total energy consumption, and it has increased even during the summer as the income level increases [4]. Responding to this, the government in South Korea has encouraged the use of high efficiency boilers, but most of them already have near 90% efficiency, consequently, they need to take additional actions. On the other hand, the major targets for the solar hot water heating systems were single-family residences due to the roof systems for such residences being easy to install, and giving enough heating capacity for hot water demands. However, high-rise multi-family housing complexes with larger facilities require a different approach in that additional considerations should be given prior to the installation phase, such as the location of building services rooms, system capacity, etc.

2. Literature review

In order to install solar hot water heating systems, hot water demands used for hot water system sizing should be estimated, and plans for installations and maintenance should be performed. In general, hot water demands can be estimated by two methods;

Abbreviations: TCO_2, tonnes of carbon dioxide; TC, tonnes of carbon; HVAC, heating, ventilation, and air conditioning; EU, European Union; FAR, floor area ratio; KRW, Korean won; LHV, lower heating value.

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http://dx.doi.org/10.1016/j.enbuild.2015.04.037
0378-7788/

the empirical method (i.e., Hunter's Method) that calculates the demand from a number of faucets, and simultaneous uses of hot water [5], and the method studied by Becker and Stogsdill [6] and Aye [7], etc. that calculates the demands from the measured hot water use using estimations from the detailed data of past water use. However, these methods have limitations in that they do not reflect occupant's characteristics, life style changes, etc., and the estimated consumption may not reflect the actual use [8].

In order to resolve these problems, the study by Evartsa and Swan [9] focused on differences of hot water use by hot water heater types, number of family member types and residential types, and estimated hot water use in terms of number of family member types, utility fees and energy usages. In this study, it was shown how the households who over-consumed hot water and hot water use changes by season, resulting in inaccurate statistical data results. In addition, the difference in hot water use by number of family members and their life style changes, was pointed out. For instance, A baseline of 60 L of hot water use per person was not enough for a three-person or less household [10]. Yoo [11] also analyzed the difference in hot water use depending on differences in incomes, number of family members and awareness of energy use. According to the study, the younger generation from high income families tend to use more hot water and corresponding energy. This result implies the sizing of hot water heating systems using the conventional baseline may not be sufficient for hot water demands.

On the other hand, Karteris et al. [12] suggested how solar hot water heating systems should be installed to be more effective through the analysis of locations, directions, etc. of buildings during the design phase. In addition, Hchem et al. [13] contributed to the applicability of solar hot water heating systems in high density buildings by considering building shape and positioning. Chow et al. [14], Colmenar-Santos et al. [15] and Shi et al. [16] analyzed the applications of high-rise buildings in terms of technique and installation methods of the systems, and suggested appropriate position for the systems in high-rise buildings, where hot water demands are high comparing to other residential buildings. These studies expanded the possibilities for the system to be applied to high-rise multi-family and not only single-family residences, as well as provide energy efficient measures for existing buildings. Furthermore, Caglar and Yamalı [17], Baniyounes et al. [18] and Clausse et al. [19] also showed the possibilities to apply the system for cooling using evacuated tube collectors that could transfer the high temperature medium to an absorption chiller. These studies contributed to solar system applications for cooling as well as for heating and hot water heating in buildings.

Even though all these studies pointed out the significance of system capacity estimations through hot water demand estimations, as well as appropriate positions for solar hot water heating systems, there are no application analyses yet for multi-family residential complexes with large numbers of units. In particular, the technical and design plan evaluation of solar hot water heating system application to complexes with large numbers of units would give essential feedback for future introduction of the system. In addition, most system evaluations have been analyzed using simulation programs [20–22]. However, this approach does not consider breakdowns or other troubles in the long-term operation of the systems in terms of economic analysis [23]. Therefore, in this study the application of solar hot water heating systems using flat-plate collectors connected to district heating, in 1179 units in fourteen-building complexes was evaluated. The design planning concept for the buildings and applications of the systems are described, and the result for three-year system operation, including seasonal characteristics and breakdowns of the system would be analyzed in order to find out the problems in the current systems and suggest future improvements. Lastly, pay-back period for the systems was also estimated using the actual historical energy data.

3. Description of solar hot water heating systems

3.1. Solar hot water heating systems for multi-family residences

Fig. 1 shows changes in solar hot water heating systems installed for multi-family residential buildings in South Korea. In the mid 1980s, integrated heating storage systems were installed for hot water and heating for low-rise multi-families residences. However, it was not widely used because there were technical problems such as inefficient solar collectors, damage of evacuated tubes, etc. At the beginning of the 2000s, solar hot water heating systems for hot water and heating were examined to see if they could be applied to the roofs and balconies of high-rise multi-families residences. However, there were problems as well, including not enough free area for solar collectors and hot water storage systems that resulted in a lack of heating capacity. From the mid 2000s, the government in South Korea began to actively support and encourage construction companies to apply renewable energy systems. In these circumstances, solar hot water heating systems were planned with the hot water demands for multi-family complexes in mind from the beginning of the architectural design phase. The building complexes were composed of a large number of household units, so the position of building services rooms and other considerations were reviewed from the design planning phase.

3.2. Description of housing complex

Table 1 shows a description of the housing complex discussed in this study. The complex, located at 37°N longitude and 127°E latitude, was constructed with reinforced concrete in 2010 and comprises of 50,613 m^2 of site area and 7318 m^2 of floor area (i.e., floor area ratio of 14%). The complex consists of 14 units (11F-15F) occupied by 1179 households. 90% of these units face south and have 1.5H of distance between the units to avoid shading which would affect the performance of solar collectors, as demonstrated in the simulation results. The housing complex has a district heating system for space heating which is designed to supply additional heat to raise the hot water temperature in case hot water from the solar collectors fails to provide the sufficient temperature.

3.3. System design

Fig. 2 shows the pipelines for the solar hot water heating systems. The heat obtained from the flat-plate collectors on the roofs is delivered to the building services room assigned to each unit, and stored in the 1st and 2nd storage tanks. If the water temperature is above 55 °C in the tank, the hot water is supplied to each household directly, but if the water temperature is below 55 °C, the heat from the district heating system is added to reheat the hot water, then supplied to the households. The installation of heat storages and heat exchangers for single-family residences is easier than for multi-families. Since the size of the systems for multi-families are large, position of building services room becomes a significant matter.

In order to resolve this problem, three building services rooms (sub #1–sub #3) for three or four units of households were planned as shown in Fig. 3. This strategic planning was expected to shorten the length of pipelines reducing heat loss, and making it easy to maintain the systems (sub #1: units #102–#105·#110/sub #2: units #106–#109/sub #3: units #101·#111–#114). Fig. 4 shows the vertical shaft and utility tunnel that transfers heat medium obtained from solar collectors to underground building services rooms. The shaft was designed to have several inspection spaces at constant intervals to manage unexpected problems such as antifreeze leakage, etc., and the tunnel has a high ceiling so that people can get in for maintenance.