Optimal Thermal Load Sharing Ratio of Solar Thermal Systems Based On the Application of Buildings

Doo-Sung Choi, Hung-Chan Jeon, Jin-Seok Do

Abstract ***This study presented a method of estimating optimal thermal load sharing ratio of solar-powered hot water supply systems through a case study of multi-unit dwellings and accommodations, of which the proportion of hot water usage was large among buildings actually applying solar-powered hot water supply systems. The result of a comparative analysis of actual usage characteristics of hot water by applying the existing criteria of estimating capacity of solar-powered hot water supply systems, when the per-year sharing ratio of solar-powered hot water supply was 60%, the quantity of solar-powered heat production was about 1.1 – 1.5 times the monthly load in a certain period of time such as summer; and when the annual sharing ratio of solar-powered hot water supply was 80%, the quantity of solar-powered heat production was about 1.2 – 1.7 times, which was analyzed that the system efficiency became deteriorated. The study presented a method of applying the optimal sharing ratio of solar-powered hot water supply by taking into account economic feasibility based on the result; and if the sharing ratio of solar-powered hot water supply of an existing solar-powered hot water supply system were increasing from 10% up to 21%, payback period of facility investment cost would be shortened by one to three years. In addition, when changing solar collector area of a solar-powered hot water supply system by taking into account the optimal sharing ratio of solar-powered hot water supply as proposed by this study, the proportion of solar-powered hot water production was increasing from 17 ℓ/person·day to 47 ℓ/person·day, which would increase the proportion of solar-powered hot water production to 49%, a 15% increase on average. Thus, it was analyzed that when the solar-powered hot water production was increased, it would secure the economic feasibility and enhance the energy savings effect.***

Keywords: Solar-powered Hot Water Supply System, Hot Water Load fraction, Optimum Distribution Ratio, Usage Characteristics, Payback Period

I. INTRODUCTION

1.1. Background and Purpose of the Study

Recently, mankind confronts severe environmental problems caused by exhaustion of natural resources and global warming owing to indiscreet use of fossil fuel, which threaten our sustainable survival. Accordingly, the global community is promoting continuous research and development to replace the fossil fuel with environment-friendly new and renewable energy.

To keep pace with such trend, the Korean government announced recently that it would introduce a new energy policy system to improve the penetration rate of renewable energy. At present, the penetration of renewable energy in Korea was 4.62% against primary energy and 6.61% against total energy production as of 2015, which placed Korea at the 34th place among 34 OECD countries in terms of new and renewable energy production. To improve such a low proportion of new and renewable energy and to vitalize the industry, the Korean government set a goal of increasing the penetration rate of renewable energy to 11% or higher compared to the primary energy by 2025.

The category of new and renewable energy resources currently applied in Korea was based on the 'Act on the Promotion of the Development and Use of New and Renewable Sources of Energy', which classified new energy resources into three (hydrogen, fuel cell and liquefied coal gas), and renewable energy resources into eight (solar heat, solar photovoltaic, bioenergy, wind power, hydroelectric power, geothermal power, tidal power, and waste).

Among them, solar thermal systems applied to buildings are facilities used to produce heat by using solar energy for heating and hot water supply, and they have good efficiency and usability, as well as relatively high economic feasibility among renewable energy systems. Thus, this system has been spread steadily thanks to financial support of the government.

However, there have been a few researches related to installation criteria of solar heat facilities such as installed capacity of hot water production for which the facilities are mostly used. In addition, although there are criteria on hot water usage such as the scope of daily hot water quantity per person based on building application as stipulated in some guidebooks of equipment planning and the Handbook of Air-conditioning and Refrigerating Engineering, there have been no researches or data on hot water quantity which would be used when installing a solar-powered hot water supply system.

Accordingly, when conducting capacity design of solar-powered hot water supply systems in Korea at present, a certain percentage of average thermal load has been simply applied to estimate the capacity of a solar-powered hot water supply system in general.

Since such simple application of a certain percentage of hot water usage or hot water usage ratio in summer compared to winter without taking into account scale of hot water usage round the year or usage pattern by season would cause some economical difference compared to the actual usage of hot water, it would be necessary to conduct researches which would present thermal load sharing ratios for economical optimal-sized solar-powered hot water supply systems taking into account the hot water usage by actual building type.

In this context, this study would present a method of estimating optimal thermal load sharing ratios for solar-powered hot water supply systems by considering economical scale and efficiency of facilities when applying solar-powered hot water supply systems based on the analysis of usage pattern of hot water facilities by building type through case study of hot water usage and solar-powered hot water system installation taking into account the variability of seasonal thermal load distribution against buildings such as multi-unit dwellings or accommodations, of which proportion of hot water usage is large.

1.2. Scope and Methods of the Study

To present a method of estimating the capacity of a solar-powered hot water supply system considering its economic feasibility in this research, it was determined that it would be necessary to verify appropriateness and efficiency of the size of solar collector area based on sharing ratio of solar-powered hot water supply to build an economical and effective solar-powered hot water supply system by taking into account the usage pattern of hot water and the size of the system for an actual building with such a solar-powered system.

To do so, the scope of research was limited to solar-powered hot water supply systems installed recently (since 2010) and in operation in a building. The solar collector area which is the most closely related component to the sharing ratio of solar-powered hot water supply among components consisting the system was selected as the target for analysis. Since various other internal components, such as thermal storage tank, heat exchanger, control system, and so forth, may influence the economic feasibility and efficiency, they were excluded from the scope of research.
The method applied in this study was as follows fig.1:

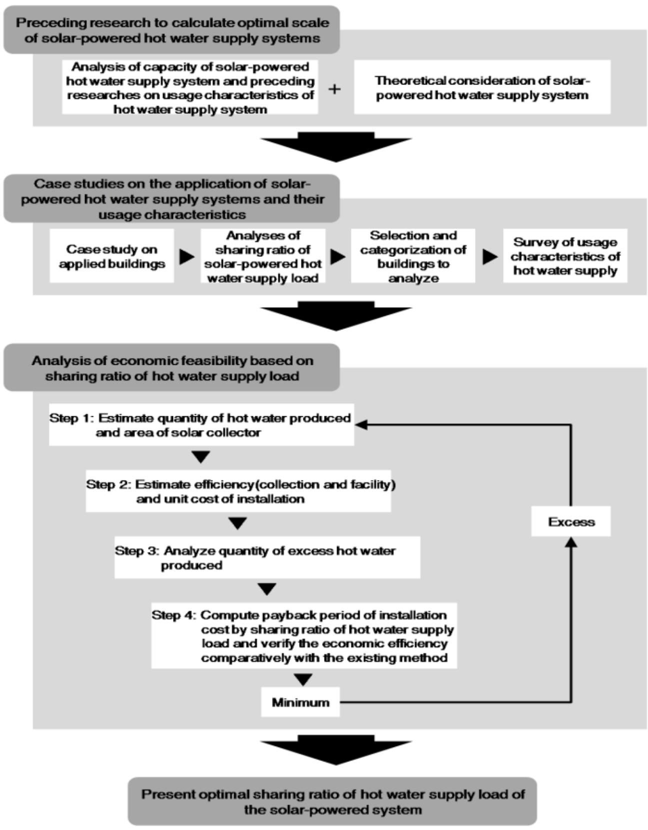

Fig. 1: Method of research

II. CONSIDERATION OF PRECEDING RESEARCHES

The representative preceding researches on solar-powered hot water supply systems, conducted in Korea, can be taken a look at as follows.
M.J. Ko and 3 others(2010) conducted LCC simulations for the corresponding systems considering the scale of solar-powered hot water supply systems, and reviewed the change of various design variables and the change of economic efficiencies according to it. As a result, they investigated that solar collector area, solar collector slope angle, thermal storage tank capacity and solar collector circulation flow rate change as design variables for the LCC optimization system, and studied that initial investment costs and system operation costs change according to it. However, this is a research based on the premise that the corresponding building operates a solar energy system and based on a virtual hot water supply load not considering the actual hot water use pattern, and is a research based on the premise that the solar energy dependence rate is 60%, not considering proper solar energy dependence rates and collector efficiencies. H.W. Oh(2012) presents a capacity calculation method based on the summer hot water supply load, the lowest among the annual hot water supply loads, considering the solar hot water supply system efficiency, but this is a method using only the system efficiency according to the summer solar energy production output as a criterion for the hot water supply system capacity, not considering the economic aspects such as installation costs and maintenance costs for the hot water supply system. T.J. Um(2013) calculated the energy performance and economic efficiency optimization capacity by reviewing proper equipment capacity and installation conditions in introducing a solar heating and hot water supply system as a research for calculation of proper capacity of hot water supply systems through calculation of hot water supply loads for military facilities. However, this has a limit of being a research for calculation of system capacity only for military facilities and being a research not reflecting the actual use patterns. W.S. Kim and 2 others(2015) analyzed hot water supply energy amounts actually used for large apartment houses, and calculated the optimized solar collector area considering the actual capacity patterns. The calculation of solar collector area was based on the actually used hot water supply amount in summer, aiming to supply 50% of the annual hot water supply energy use amount with a solar hot water supply system. N.C. Baek and 3 others(2015) investigated and analyzed the solar thermal behavior and the related equipment performance for solar and geothermal-combined hot water systems for actual single-family houses, and provided basic data for performance improvement and system supplementation of solar hot water supply systems for single-family houses in the future based on this.
M.C. Seo and another(2016) considered the efficacy, economic efficiency and installation problem when constructing a solar hot water supply system at existing buildings such as high usability of heat energy for buildings such as accommodations and silver towns, and investigated the economic feasibility considering the investment cost recovery period when constructing a solar hot water system for 3 existing buildings currently under operation. However, this is a research only considering the recovery period

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according to the investment costs, not reflecting the hot water supply use characteristics.

The following Table 1 shows details of major researches related to the capacity estimation of solar-powered hot water supply systems performed in Korea up to now.

Table 1: Consideration of preceding researches (solar-powered hot water supply system)

Author	Details of Research	Threshold
M.J. Ko	Perform LCC simulations taking into account the size of solar-powered hot water supply systems and review the change of various design variables and economic feasibility.	Need to conduct researches on influence to performance pursuant to the change of system design variables based on studies estimating the capacity of solar-powered hot water supply system to meet the solar hot water fraction of 60%.
H.W. Oh	Conduct researches on estimating the capacity of solar-powered hot water supply systems based on thermal load in summer among the year-round thermal loads.	Analysis performed by applying only the system efficiency for solar-powered hot water production. Need to conduct researches considering interrelationship with economic feasibility.
T.J. Um	Compute the optimal capacity of hot water supply system based on the thermal load estimation for military barracks. Present a method of estimating optimized energy performance and economically feasible capacity based on the review of installed capacity and installation condition when installing a solar-powered hot water supply system in an existing building.	It is for military facilities only and researches on general building were not performed. It has its limit in analysis taking into account the actual usage based on case study on solar-powered hot water supply system.
W.S. Kim	Conduct research on estimation of the optimized solar collector area based on analysis of hot water energy of multi-unit dwellings applying solar-powered hot water supply systems and that of actual usage.	Need to conduct research taking into account characteristics of hot water usage and economic feasibility of solar thermal systems by using design criteria for summer only, a season of the least usage, in lieu of winter, a season of the maximum usage.
N.C. Baek	Provide basic data to upgrade systems and improve performance through survey and analysis of thermal behavior and efficiency related to solar thermal systems.	Need to conduct research considering the interrelationship with performance upgrade and economic feasibility of solar thermal facilities.
M.C. Seo	Present an economically feasible plan by analyzing efficacy, economic feasibility or installation problems of a solar-powered hot water supply system, when installing the system in an existing building.	This research simply considers payback period of the investment cost when taking into account economic feasibility of the solar-powered hot water supply system, so it has its limit for analysis considering usage characteristics of hot water.

The result of analysis on preceding researches showed that the preceding researches on solar-powered hot water supply systems were mostly cases considering the expanded distribution of solar heat facilities, as well as those presenting criteria for selection; optimal criteria and scale of optimal solar heat facilities were not taken into account; when reviewing the economic feasibility, only those for corresponding sizes were considered; and also the economic feasibility analysis for the scale of overall facilities were not performed. In addition, most preceding researches on capacity estimation of solar-powered hot water systems were performed against military facilities, which were restricted to the system capacity of specific buildings rather than that of general buildings; when calculating loads of heating and hot water, only the TRNSYS program was used, which did not take into account the actual usage pattern of hot water. And in case of capacity criteria for hot water supply systems, only system efficiency based on solar-power production in summer was applied simply, while an economical aspect of installation cost of the hot water supply systems was not considered.

There were no preceding researches analyzing the scale of usage by taking into account the quantity of hot water produced by applying and using actual solar-powered hot water supply systems. Most researches were reviews of appropriateness of solar-powered hot water supply systems based on hot water load; it appeared that there were no researches which reviewed and analyzed the economic feasibility of system capacity considering the produced quantity of hot water and the size of corresponding systems. Although criteria of estimating hot water quantity required for general planning of equipment for building were presented in the literature, there were no criteria for hot water quantity to be applied in planning of solar-powered hot water facilities.

III. Case Study and Analysis of Solar Thermal load Sharing Ratio

3.1. Cases of Buildings Applied Solar-powered Hot Water Supply Systems by Year

This research conducted a fact-finding survey against buildings introduced and applied solar-powered hot water supply systems across the nation since 2010 as a basis to investigate actual status of hot water energy usage and scale of usage of the buildings. The buildings were categorized based on application into multi-unit dwellings, accommodations, commercial facilities, manufacturing facilities, public facilities, and miscellaneous facilities including business facilities; and among the total of 141 buildings, multi-unit dwellings and accommodations (such as dormitories, hotels, etc.) of which the proportion of hot water usage was high were targeted.

Table 2 shows the status of installing solar-powered hot water supply systems by building application.

Table 2: Status of applying solar-powered hot water supply systems to buildings by application and by year (from 2010 to 2016)

Year	Multi-unit dwelling	Accommodation	Manufacturing facility	Commercial facility	Public facility	Misc. (Business facility, etc.)	Total
2010	1	7	5	-	5	5	23
2011	-	13	11	1	4	-	29
2012	3	17	10	3	7	-	40
2013	3	3	2	9	-	2	19
2014	-	8	2	5	-	-	15
2015	-	6	-	3	-	1	10
2016	-	-	3	-	1	1	5
total	7	54	33	21	17	9	141

3.2. Selection of Solar-powered Hot Water Supply Systems to Analyze

As described in Section 3.1, the solar-powered hot water supply systems have been applied and in operation in various buildings; this research limited the scope of analysis to multi-unit dwellings and accommodations of which the proportion of hot water usage was high, and the criteria for selection were as follows:

First, Buildings applying solar-powered hot water supply systems after 2010

Second, Buildings of which area of solar collectors is larger than a certain size (Multi-unit dwelling: 1,000㎡ or larger; Accommodation: 100 ㎡ or larger)
Third, Buildings of which variability range of thermal load between winter and summer can be taken into consideration
By taking into account the difference of load criteria for capacity and scale of solar-powered hot water supply systems, targets for analysis were selected by classifying them into five types as shown in Table 3 to analyze the seasonal thermal load distribution of general targets. The reason of classifying the target into five types was because if the capacity was estimated by setting the sharing ratio of solar-powered hot water supply at 60 – 80% of the year-round thermal load, then the consideration of seasonal thermal load distribution would not be reflected properly.

Table 3: Status of buildings to analyze based on classification

Classification		Buildings subject to the case study
Case_1	When the summer thermal load is around 30% of the winter thermal load	Accommodation (Training Center)
Case_2	When the summer thermal load is around 60% of the winter thermal load	Multi-unit dwelling (Apartment)
Case_3	When the summer thermal load is around 80% of the winter thermal load	Accommodation (Dormitory)
Case_4	When the summer thermal load is around 100% of the winter thermal load	Accommodation (Sivertown)
Case_5	When the thermal load is similar round the year	Accommodation (Hotel)

3.3. Result of Sharing Ratio of Solar-powered Hot Water Supply Load Analysis

The following Table 4 shows summary of the solar heat systems installed at each target building to be analyzed as well as usage and production of hot water.

Table 4: Summary of solar heat systems

Case	Building name	Number of Floor	Gross area (㎡)	Solar collector area (㎡)	Solar collector efficiency (%)	Hot water usage (ton)	Quantity of hot water produced by solar heat system (ton)
1	Training Center	5F / B1	16,156	128	49	7,641	2,475
2	Apartment	15F / B2	97,627	1,705	46	67,151	22,685
3	Dormitory	15F / B2	19,114	168	48	12,659	3,053
4	Sivertown	15F / B1	39,260	441	49	15,392	6,122
5	Hotel	9F / B1	8,922	534	50	11,655	6,804

As shown in the above Table 4, it was analyzed that in case of hotels the hot water quantity used round the year was 11,655 tons, while that produced by using solar heat in there 6,804 tons, which made the sharing ratio of solar-powered hot water supply 58%, the highest; while in case of dormitories the hot water quantity used round the year was 12,659 tons and that produced by using solar heat in there 3,053 tons, which made the sharing ratio of solar-powered hot water supply 24%, the lowest.
The following Table 5 shows per-person usage pattern of hot water obtained through direct survey of users by type.

Table 5: Usage pattern of hot water per person

Classification		Winter (Nov. to Feb.)	Summer (Jun. to Sep.)	The Spring and Autumn seasons (Mar. to May, Oct.)	Total	Average
Case_1	Hot water usage	17,190 ℓ	5,852 ℓ	13,343 ℓ	36,386 ℓ	12,129 ℓ
	Quantity of solar-powered hot water	3,086 ℓ	5,205 ℓ	3,495 ℓ	11,786 ℓ	3,929 ℓ
	Usage ratio	18%	89%	26%	-	32%
Case_2	Hot water usage	9,098 ℓ	5,075 ℓ	8,211 ℓ	22,384 ℓ	7,461 ℓ
	Quantity of solar-powered hot water	1,039 ℓ	3,234 ℓ	3,288 ℓ	7,562 ℓ	2,521 ℓ
	Usage ratio	12%	63%	39%	-	34%
Case_3	Hot water usage	8,267 ℓ	6,232 ℓ	11,075 ℓ	25,574 ℓ	8,525 ℓ
	Quantity of solar-powered hot water	1,383 ℓ	2,373 ℓ	2,895 ℓ	6,651 ℓ	2,217 ℓ
	Usage ratio	17%	38%	26%	-	24%
Case_4	Hot water usage	16,827 ℓ	15,808 ℓ	17,337 ℓ	49,972 ℓ	16,657 ℓ
	Quantity of solar-powered hot water	6,263 ℓ	6,519 ℓ	7,094 ℓ	19,877 ℓ	6,626 ℓ
	Usage ratio	40%	38%	41%	-	40%
Case_5	Hot water usage	11,517 ℓ	10,820 ℓ	11,866 ℓ	34,203 ℓ	11,401 ℓ
	Quantity of solar-powered hot water	4,287 ℓ	4,462 ℓ	4,856 ℓ	13,604 ℓ	4,535 ℓ
	Usage ratio	40%	38%	40%	-	40%

In case of the distribution ratio of seasonal thermal load by type, training institutes of which hot water usage ratio was lowest in summer compared to winter showed the lowest ratio at 16%; and in case of hotels which showed the constant usage round the year, the ratio was the highest at 34%. Accordingly, it was analyzed that the usage ratio of hot water quantity produced by solar heat in summer was the highest at 89% in training institutes; on the other hand, dormitories and retirement villages which had higher usage ratio in summer than in winter showed the lowest value at 38%.
In case of daily hot water usage per person by season by type, training institutes in summer showed the lowest value at 29 ℓ/person·day, and retirement villages in spring and fall showed the highest

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value at 99 ℓ/person·day. In these cases, daily hot water usage per person showed the distribution of about 40 – 100 ℓ/person·day on average, which showed a big difference with the criteria of hot water quantity, 75 – 150 ℓ/person·day, in the existing literature.

In a comparative analysis of the above results with actual usage characteristics of hot water by applying 60% and 80% of the year-round sharing ratio of solar-powered hot water supply which is the existing criteria of estimating capacity, it was analyzed that when the ratio of load in summer compared to that in winter is less than 80%, if the year-round sharing ratio of solar-powered hot water supply was set at 60%, then about 1.1 times to 1.5 times more the monthly load would be produced in some periods such as summer by solar heat; and if year-round sharing ratio was set at 80%, then about 1.2 times to 1.7 times more the monthly load would be produced, which would deteriorate the system efficiency. If the ratio of load in summer compared to that in winter was higher than 100%, or the ratio was constant round the year, the quantity of heat produced by solar heat would be larger than the load of hot water usage, so it would not be related to the deterioration of system efficiency.

IV. Page style Computation of Sharing Ratio of Optimal Thermal Load

4.1. Conditions and Methods of Economic Feasibility Analysis

To analyze solar collector area based on hot water load factor and sharing ratio of solar-powered hot water supply by taking into account the hot water usage of actual buildings installing solar-powered hot water supply systems and to present economical sharing ratio of hot water supply load of solar-powered hot water supply systems, the following conditions and methods for economic feasibility analysis by building type were selected:

①Set the scope and criteria for sharing ratio of solar-powered hot water supply closely related to capacity of solar-powered hot water supply systems. The range of year-round sharing ratio of solar-powered hot water supply was limited to 20 – 80% by considering actual conditions of installation of solar collectors, and then the analysis was performed by 5% to distinguish trends of change in detail for each year-round sharing ratio of solar-powered hot water supply

②Set the criteria for efficiency of solar collectors related to installation cost and hot water production based on the scale of system installation. The range of collector efficiency applied in this research was selected for each case based on the amount of solar radiation by inclination of solar collectors by region, tap water temperature, supplied water temperature, and so forth, by taking into account the preceding literature which presented the range of 40 – 45%.

③Conduct analysis for excess quantity of hot water produced from the solar-powered hot water supply system, which was related to the efficiency of hot water production required for the year-round operations of the system. Among economic factors of a solar-powered hot water supply system, it was necessary to consider the portion of hot water produced and discarded when the usage load of hot water was the least. The time period in which the excessive hot water discarded out of the quantity produced in the solar collector area was set to summer (June to September), and the status of excessive quantity of hot water versus hot water usage was analyzed.

④Select criteria of impact analysis for distribution of seasonal thermal load, hot water usage, and so forth.

⑤Perform analysis for estimation of payback period for installation cost of solar collectors by sharing ratio of solar-powered hot water supply related to economic feasibility for facility investment cost. To analyze economic feasibility of the facility investment cost based on optimal year-round sharing ratio of solar-powered hot water supply, a payback period method was applied to calculate the cost of solar collector area for each sharing ratio of solar-powered hot water supply. In addition, the quantity of heat obtained from the solar-powered hot water supply system was converted based on the heating value of light oil, and the boiler efficiency was set to 82% to calculate the quantity of light oil, while the unit price of light oil (KRW 1,277) was quoted from the 2017 Domestic Oil Price Data (April) listed on the web site of the Korea National Oil Corporation to estimate annual cost savings.

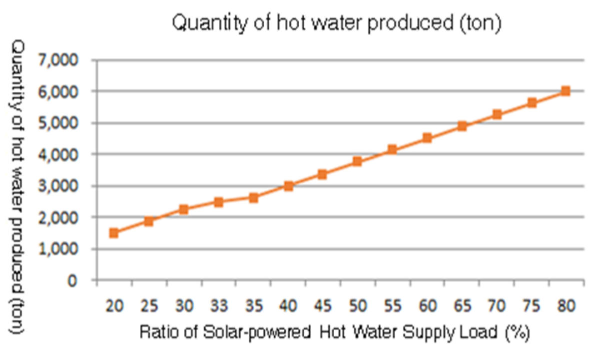
⑥Conduct analysis of impact of thermal load pattern and the scale of usage based on thermal load distribution by season. Interrelationship with the economic feasibility following the change of thermal load distribution by season was analyzed by taking into account the distribution of thermal loads in summer vs. winter (30%, 60%, 80%, 100%, constant round the year, etc.)

⑦Conduct analysis of the quantity of hot water required per person per day and the appropriateness of the size of solar-powered hot water supply system to present direction to the improvement of existing criteria related to estimation of hot water quantity applied in construction facility planning by building type.

4.2. Estimation of Optimal Sharing Ratio of Thermal Load Based on Analysis of Economic Feasibility

The following Fig. 2 shows payback period based on hot water production by type, estimation of solar collector area and installation cost.

CASE 1



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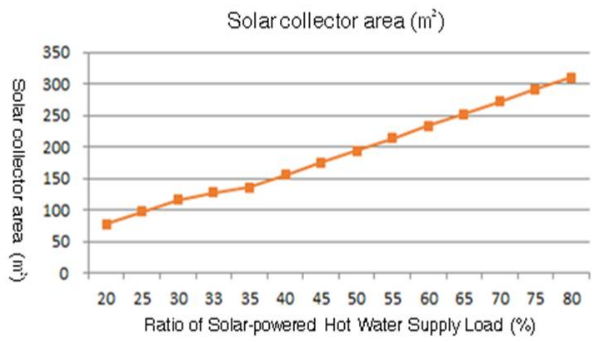
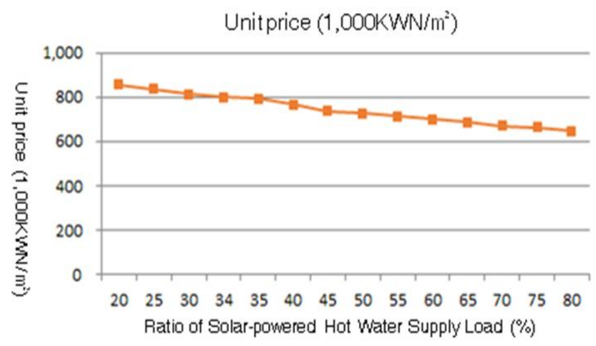
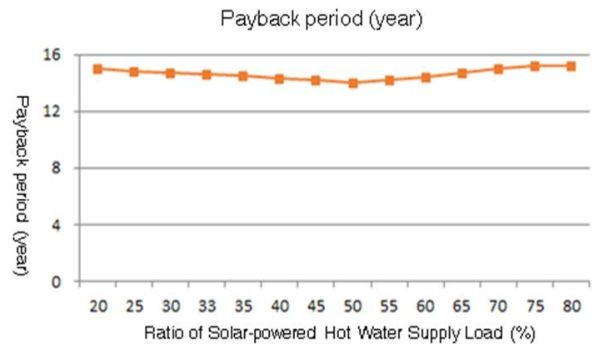
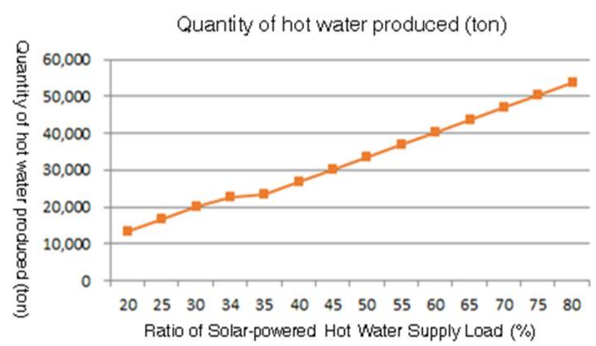
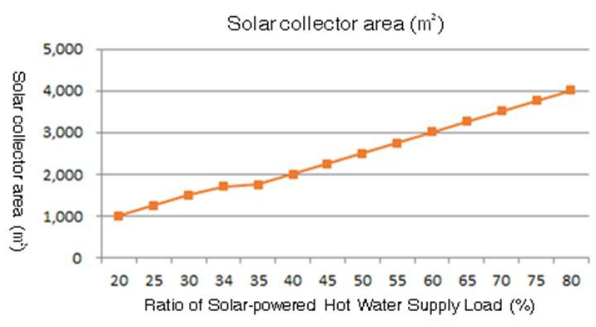

Solar collector area (m²)
Solar collector area (m²)
350
300
250
200
150
100
50
0
20 25 30 33 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

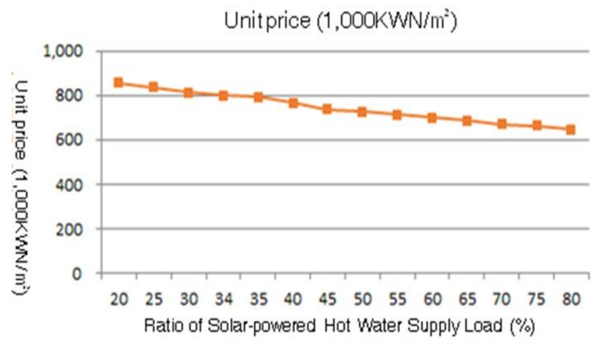

Unit price (1,000KWN/m²)
Unit price (1,000KWN/m²)
1,000
800
600
400
200
0
20 25 30 34 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)


Payback period (year)
Payback period (year)
16
12
8
4
0
20 25 30 33 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

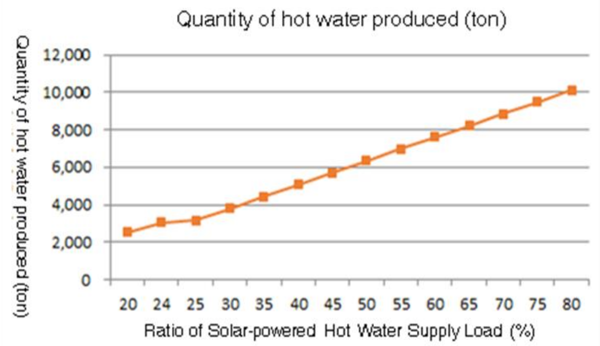
CASE 2

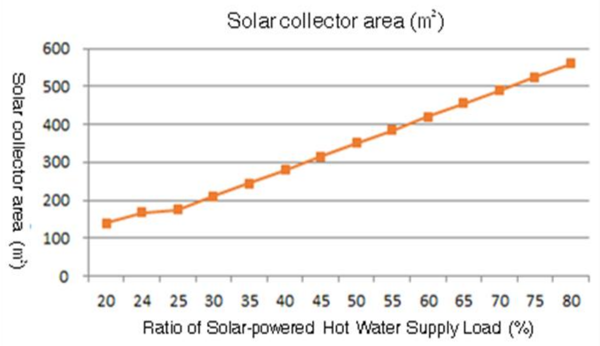

Quantity of hot water produced (ton)
Quantity of hot water produced (ton)
60,000
50,000
40,000
30,000
20,000
10,000
0
20 25 30 34 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

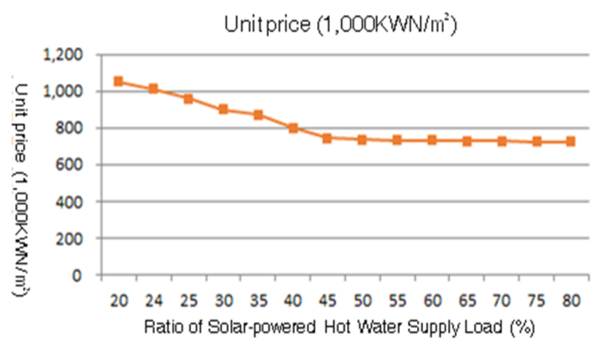

Solar collector area (m²)
Solar collector area (m²)
5,000
4,000
3,000
2,000
1,000
0
20 25 30 34 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

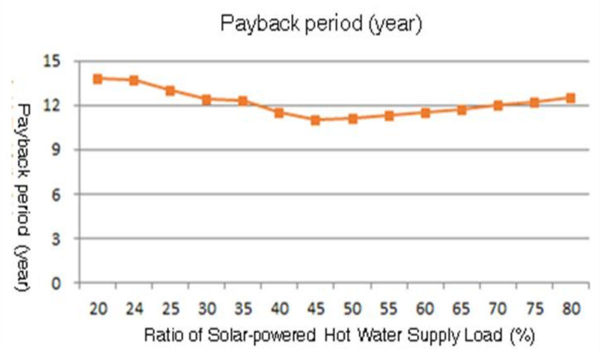

Unit price (1,000KWN/m²)
Unit price (1,000KWN/m²)
1,000
800
600
400
200
0
20 25 30 34 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

CASE 3

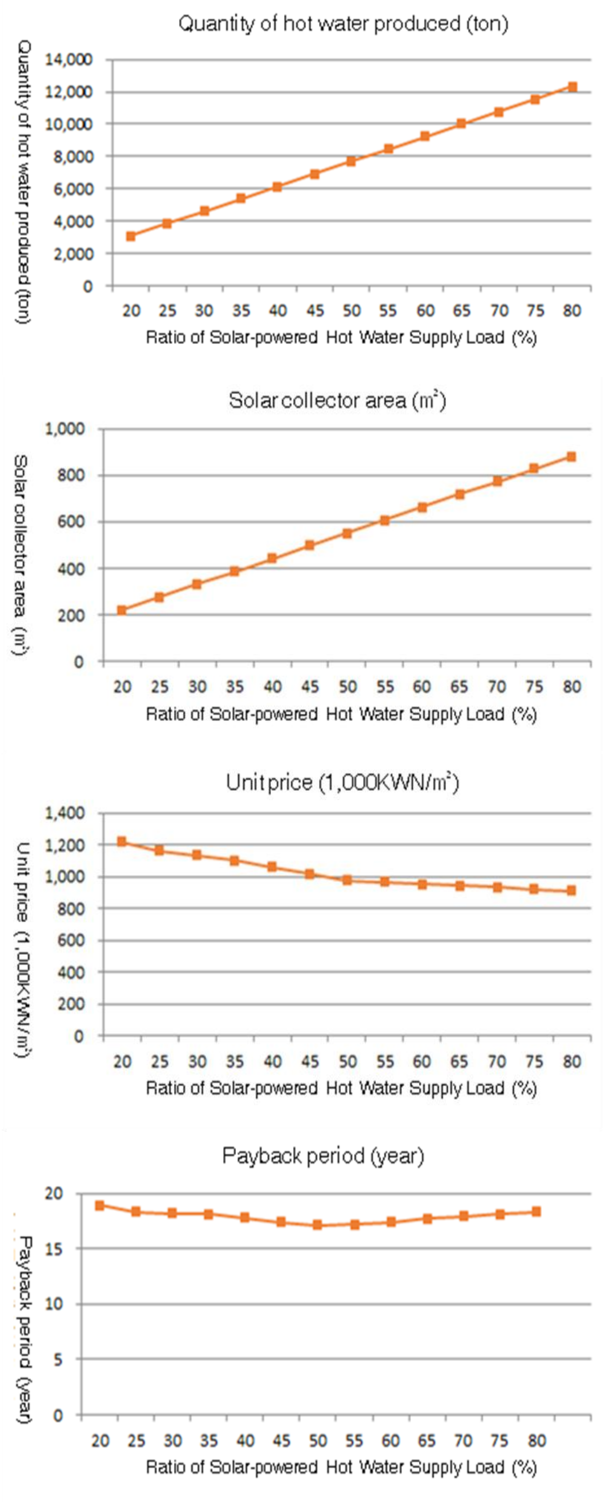

Quantity of hot water produced (ton)
Quantity of hot water produced (ton)
12,000
10,000
8,000
6,000
4,000
2,000
0
20 24 25 30 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)


Solar collector area (m²)
Solar collector area (m²)
600
500
400
300
200
100
0
20 24 25 30 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

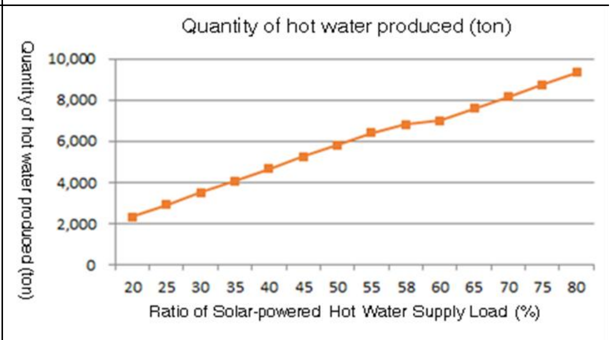

Unit price (1,000KWN/m²)
Unit price (1,000KWN/m²)
1,200
1,000
800
600
400
200
0
20 24 25 30 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)


Payback period (year)
Payback period (year)
15
12
9
6
3
0
20 24 25 30 35 40 45 50 55 60 65 70 75 80
Ratio of Solar-powered Hot Water Supply Load (%)

CASE 4



CASE 5



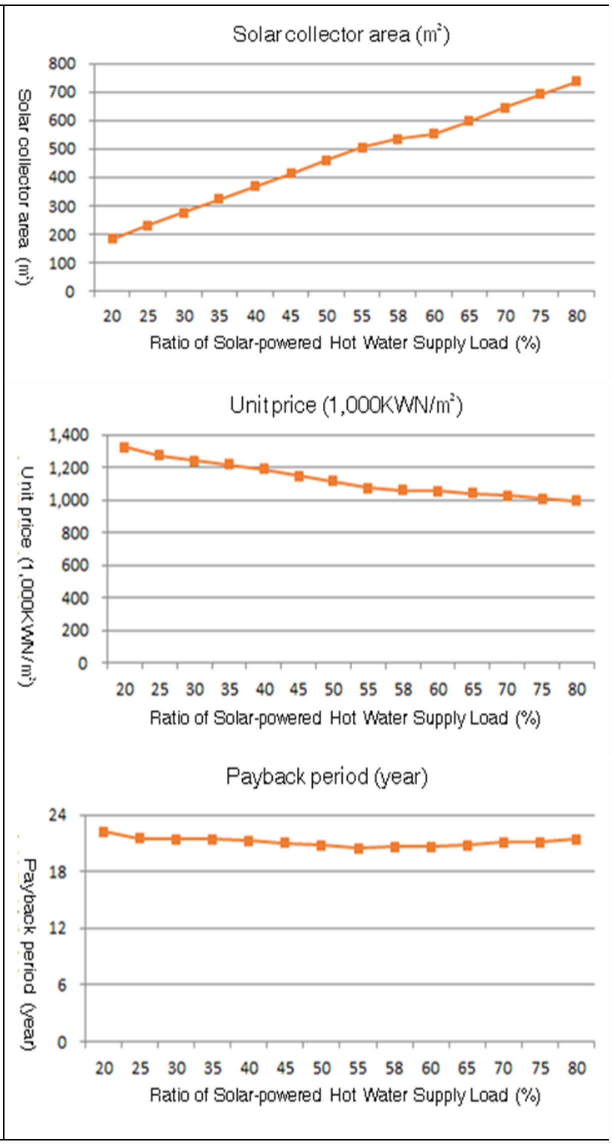


Fig. 2: Payback period by type

Based on the sharing ratio of solar-powered hot water supply by type, their economic feasibility was analyzed by estimating the payback period from the quantity of heat produced in solar collectors of solar-powered hot water supply systems.

For Case_1, it appeared that the sharing ratio of solar-powered hot water supply was 33% from 128 ㎡ of solar collector area, and when the solar heat production was converted to light oil equivalent, the saved amount of money was about KRW 10 million per year, and the payback period of installation cost would be 14.6 years. If the area of solar collector were widened by 66 ㎡ to 194 ㎡ and the sharing ratio of solar-powered hot water supply were 50%, then the saved amount of money would be about KRW 13 million per year, and the payback period would be shortened by 0.6 year to 14.0 years, so it was analyzed that it would reveal the best economic feasibility.

For Case_2, it appeared that the sharing ratio of solar-powered hot water supply was 34% from 1,705 ㎡ of solar collector area, and the saved amount of money was about KRW 89 million per year, and the payback period of installation cost would be 15.3 years. If the area of solar collector were widened by 552 ㎡ to 2,257 ㎡ and the sharing ratio of solar-powered hot water supply were 45%, then the saved amount of money would be about KRW 110 million per year, and the payback period would be shortened by 0.5 year to 14.8 years which was the shortest period among the entire sharing ratios, so it was analyzed that it would reveal the best economic feasibility.

For Case_3, it appeared that the sharing ratio of solar-powered hot water supply was 24% from 168 ㎡ of solar collector area, and the saved amount of money was about KRW 10 million per year, and the payback period of installation cost would be 13.7 years. If the area of solar collector were widened by 147 ㎡ to 315 ㎡ and the sharing ratio of solar-powered hot water supply were 45%, then the payback period would be shortened by about 4 years to 11 years which was the shortest period among the entire sharing ratios, so it was analyzed that it would reveal the best economic feasibility.

For Case_4, it appeared that the sharing ratio of solar-powered hot water supply was 40% from 441 ㎡ of solar collector area, and the saved amount of money was about KRW 26 million per year, and the payback period of installation cost would be 17.8 years. If the area of solar collector were widened by 110 ㎡ to 551 ㎡ and the sharing ratio of solar-powered hot water supply were 50%, then the payback period would be shortened by about a year which was the shortest period among the entire sharing ratios, so it was analyzed that it would reveal the best economic feasibility.

For Case_5, it appeared that the sharing ratio of solar-powered hot water supply was 58% from 534㎡ of solar collector area, and the saved amount of money was about KRW 31 million per year, and the payback period of installation cost would be 20.6 years. If the area of solar collector were reduced by 28 ㎡ to 506 ㎡ and the sharing ratio of solar-powered hot water supply were 55%, then the payback period would be 20.5 years which was similar to the current one, but it was the shortest period among the entire sharing ratios, so it was analyzed that it would reveal the best economic feasibility.

V. Conclusion

Major result of the research was as follows:

From 2010 to 2016, several cases applying solar-powered hot water supply systems with collecting area of 100 ㎡ or larger were surveyed, and the scope of survey was limited to multi-unit dwellings and accommodations among them, which have rather larger thermal load. To analyze the status of seasonal thermal loads of five types, the usage characteristics of hot water including features and current status of scale of usage were studied.

Comparative analysis on the actual usage characteristics of hot water was conducted by applying year-round sharing ratios of solar-powered hot water supply, 60% and 80%, which were used as criteria in estimating the capacity of existing solar-powered hot water supply systems, and it was analyzed that when the load in summer is less than 80% compared to that in winter, if the year-round sharing ratio of solar-powered hot water supply was set at 60%, then about 1.1 times to 1.5 times more the monthly load would be produced in some periods such as summer by solar heat; and if year-round sharing ratio was set at 80%, then about 1.2 times to 1.7 times more the monthly load would be produced, which would deteriorate the system efficiency.

After that, the usage characteristics of hot water of target buildings by type was analyzed, and a method to apply an optimal sharing ratio of solar-powered hot water supply was presented based on the payback period of minimum facility investment cost by taking into account installation cost depending on heat collection, facility efficiency and size of solar-powered hot water supply systems. When the sharing ratio of solar-powered hot water supply systems currently installed was increased from 10% up to 21%, it was analyzed that the payback period of facility investment cost would be shortened by about one to three years.

From the analysis of excessively produced hot water quantity in summer owing to the usage characteristics of hot water, when the hot water usage in summer was in the range of less than 80% compared to that in winter,

it was confirmed that in a certain range the excessively produced quantity of hot water by solar heat would occur as the sharing ratio of solar-powered hot water supply was increased, and that if the hot water usage in summer was similar in the range of 100% across the year, then there would be no excessively produced hot water by solar heat in summer. When taking into account this result, it was analyzed that it would be required to minimize the quantity of hot water produced excessively by solar heat in summer when estimating the size of a solar-powered hot water supply system.

In addition, when changing the solar collector area of a solar-powered hot water supply system by taking into account the optimal sharing ratios of solar-powered hot water supply as proposed by this research, it was analyzed that 30 ℓ/person·day of hot water would be produced by solar heat in average from 17 ℓ/person·day to 47 ℓ/person·day, it was analyzed that if the proportion of hot water produced by the currently installed solar-powered hot water supply system was increased by 15% on average to 49% and the quantity of hot water produced by solar heat was increased, then the economic feasibility would be ensured and the energy savings effect would be improved.

This research presented a method of estimating the optimal sharing ratio of solar-powered hot water supply by taking into account the sage characteristics of hot water when applying to solar-powered hot water supply systems, in this regard, it would be evaluated importantly as a contribution to energy savings based on efficient usage of solar thermal energy.

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