

Evaluation of Available Solar Thermal Energy in High-rise Apartment Complex Depending on the Installation Types of Solar Thermal Collectors

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ABSTRACT: This study is on the availability of solar thermal energy in Korean high-rise apartment complex depending on the installation type of solar thermal collectors to roof or façade of building. Firstly, solar access evaluation on the roof and the facade of apartment buildings was carried out. The total thermal load of each apartment unit and building was investigated and matched with the energy which was produced by solar thermal systems on the roof or the facade. The considered layout patterns of apartment buildings were ‘— type’, ‘alternative — type’, ‘⊂ type’ and ‘□ type’.

There are 4 types of area option in which the solar thermal systems can be installed in the roof or façade of building. Extensive dynamic hourly building simulations with the solar thermal system were performed with the TRNSYS program of SEL. We assumed that the apartment complex is composed of 9 buildings and located in Daejeon.

Result shows that in the case of area option-R, the available solar thermal energy for the domestic hot water of the site is about 505,215Mcal/yr and the solar saving fraction of total site thermal load is 13%. The best layout type of buildings for solar access reveals a ‘— type’. In the case of façade installation of solar thermal collectors, the produced solar thermal energy with the area option 3 is about 654,870Mcal/yr, and the solar saving fraction is 16%. The best layout pattern was ‘— type’ also.

Keywords: Apartment complex, Solar thermal systems, Solar saving fraction, Apartment layout, Shading effect of adjacent buildings, TRNSYS simulation

1. INTRODUCTION

In case the solar thermal systems are applied to apartment houses among various renewable energy systems, the application of solar thermal systems is fundamentally

restricted by many conditions because apartments have a high density among the adjacent high-rise buildings, unlike detached houses. In other words, in the case of apartment the distances between buildings, layout patterns and direction cause a great

change in shading effects of unit households of the complex, so these conditions may be the very big influential factors during application of solar energy system.

In this study, the comprehensive solar access evaluation for the apartment complex was carried out through the analysis of annually accumulated solar insolation on the envelope of apartment building in accord with building layout patterns and building orientation. And on the basis of the results, this study was aiming at the decision making on the possible maximum supply scale and the selection of applicable parts that are suitable for the installation of solar thermal system, by comparing the total load with the supplied amount through solar hot water heating system.

And the available installation area of solar collectors was evaluated in the front sides of apartment building classifying them into 4 types including conventional roof area. In this study the solar thermal system was designed to be applied the heat load, that is, the hot water and the heating.

2. Model definition and assumption

2.1 Categorization of layout patterns

In order to analyze the available amount of solar energy on the roof and the façade of building in the complex, a categorization of typical building layout patterns should be decided in advance. In this study, the cases of 148 apartment complexes constructed by the 21 major private construction companies across the country were investigated through the preceding study[1], and the 4 types of apartment layout patterns derived from the survey were established as the analysis object of this study, and it is illustrated in Fig. 1 such as ‘— type’, ‘alternative — type’, ‘⌈ type’ and ‘□ type’.

2.2 Solar access grade of façade area

Due to the shading effect of adjacent buildings, insolation distribution of building façade may be quite uneven. If the annual insolation level of each building façade in

the condition of apartment complex is available, it would be very helpful to determine the bottom line of installation area of which solar collector should be placed with a certain cost effectiveness.

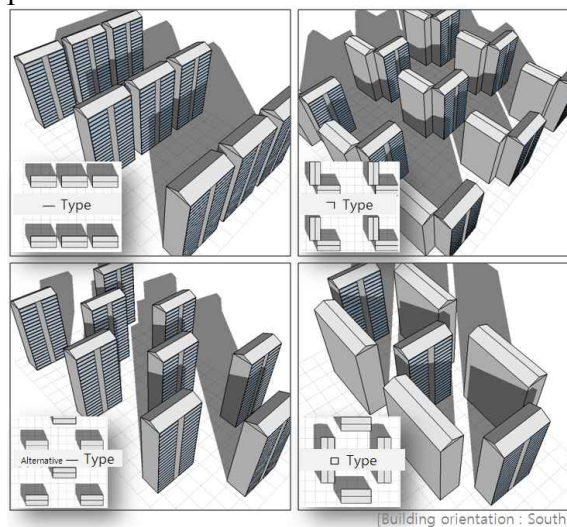


Figure 1: Categorization of layout patterns in apartment buildings.

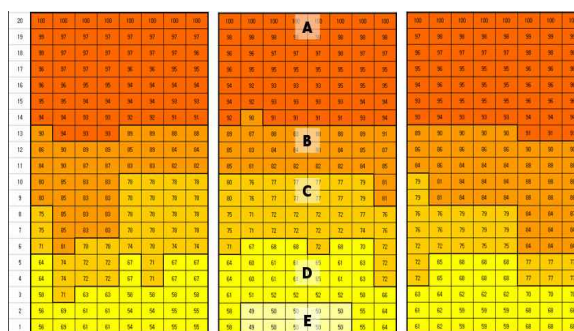


Figure 2: Sample result of solar access grade analysis in the preceding studies

Therefore, detailed insolation analysis of building façade and roof was conducted with hourly based simulation program of Ecotect in the previous study[2]. After a surface of building front façade was subdivided with 168 analysis grid, annual incident solar radiation of each analysis grids was calculated considering shading effect of other buildings. Depending on the amount of annual insolation, the grids were grouped into five sections by 10% of space as shown in Fig. 2 based on the relative ratio of 100% surface grid receiving the biggest insolation. The part with 91~100% of insolation was designated as grade A and

the part with 81~90% was designated as B. We assumed that solar system could be supposed to be applied to the households with A or B grade in this study.

2.3 Estimation of available installation area of solar thermal collectors.

In order to apply the solar thermal system to apartments, it is necessary to decide on which part to install the solar collectors. In this study, it was assumed that the installation areas available were the opaque walls on rooftop and vertical wall surface between households and balcony parts of each household, and they were supposed to be applied as shown in Figure 3.

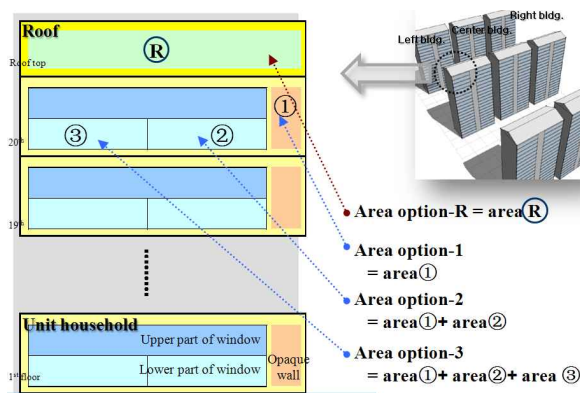


Figure 3: Area options of solar collector installation for apartments.

We assumed that a apartment complex is composed of 9 unit building with 3 row and 3column as shown in Fig. 3. Each building has 20th floors and 40 unit household, therefore the total households of this apartment complex are 360 units. The slope of roof is assumed 30°.

As shown in Table 1, the effective installation area of rooftop in unit building was estimated 121 m² with 65% of available effective area ratio for system installation. And the available area on the vertical wall could be the opaque wall between households and the balcony of each household, so in this study the areas were classified into three ranges named ①, ② and ③ respectively. As shown in Fig. 3, the area option-1 is the opaque wall between

households, and the dimension of it was 4.7 m², so it was calculated to be 187 m² when converted to the sum of a unit building. And the area option-2 is the dimension in which the quarter of balcony chassis is added to the area option-1, so the dimensions are 10.2 m² and 408 m² for each unit household and building respectively, and the area option-3 is the dimension in which the half of balcony chassis is added to the area option 1, so the dimensions are 15.7 m² and 629 m² for each unit household and building respectively.

As mentioned above, at this time the area option 1, 2, and 3, which were the installation range on vertical walls, were applied to the grade A and B of solar access level. Accordingly, the available dimension of installation on vertical walls were applied differently for each layout pattern because the areas occupied by the A and B grade according to each layout pattern as shown in Fig 2.

Table 1: Estimation of available installation area for solar collectors on rooftop and vertical wall(m²)

Area Option	Unit household building			
	No. of households	1	40	360
	Floor area	131	5,223	47,011
Area option-R	Effective roof area	60.6	121	1,091
Area option-1	Opaque wall area ①	4.7	187	1,687
Area option-2	①+②	10.2	408	3,675
Area option-3	①+②+③	15.7	629	5,662

- Façade area of unit household ; 38.7 m²,
- Balcony window area of unit household : 22.1 m²,
- 1/4 of balcony window area (②) : 5.5 m²
- 1/2 of balcony window area (③) : 11 m²

2.4 Load analysis method

The first stage to set up the load matching of solar thermal system in a site scale is to decide the profile and the amount of domestic hot water and heating load in the unit household, building and entire complex. In this study, the data collection

was carried out extensively, centred on the existing data actually measured in complex scale and the results of preceding studies in order to decide the annual load change profile per hour. Though it was desirable to decide the profile through the data actually measured, the heating load change per hour was derived through simulation at the last stage due to the realistic problems, and in case of hot water the annual load change profile of hot water per hour was drawn up based on the results of preceding studies[3][4]. Load profile of heating and hot water in this study is shown in Table 2.

Table 2: Heat load profile in unit household

Month	Hot water load(Mcal)	Heating load(Mcal)	Total load(Mcal)
1	340	1,748	2,088
2	298	1,446	1,744
3	333	1,260	1,593
4	300	782	1,082
5	246	0	246
6	160	0	160
7	132	0	132
8	105	0	105
9	113	0	113
10	149	652	801
11	194	1,135	1,329
12	249	1,580	1,829
Total	2,623	8,604	11,227

As for the solar collector, heat pipe type of vacuum tube solar collector was applied, and the maximum efficiency ($FR\tau\alpha$) and the heat loss coefficients($FRUL$), which was the index dominating the function of heat collector, were 0.535 and 2.5934 kJ/hr m² K respectively.

For the energy simulation of apartment building and solar system, we used the TRNSYS program[5] which is one of the well approved dynamic system simulation program, developed by the SEL of Wisconsin University. And then the load matching interpretation was carried out through the spreadsheet works. Climate data of Daejeon with TRY format was applied

3. Result analysis of solar saving fraction on the basis of apartment complex scale

3.1 Result analysis for each building level

In case a solar thermal system is installed on the rooftop of a unit building, the efficiency of the system varies a lot according to how many households are supplied with the produced heat. It is a kind of central heating system. Accordingly, in this study, the condition was presumed, in which the heat was supplied to 10, 20, 30 and 40 respectively in the pertinent building through a solar thermal system installed on the rooftop, and then the various interpretation results were derived from it, according to each condition. On the other hand, in case of installation on façade vertical walls, it was presumed that the produced energy from the solar collectors of their façade is just used for that household. It's kind of individual system.

Looking into the interpretation result of hot water supply in Table 3, 4 and 5, it is identified that the total hot water load occurring in the 40 households of the unit building is 104,920Mcal/yr. In case the tube-type solar heat collector was installed on the 121 m² of rooftop and 10 households are provided with heat for hot water produced by that device, the annual amount of heat for hot water would be 25,050 Mcal/yr, so solar saving fraction(SSF) appeared to be 20% of the hot water load for 40 households in the entire building.

And it showed that in case of providing 20 households the SSF was 39%, and in case of 30 households the rate was 48% and in case of providing all 40 households 53% of the hot water load could be replaced by solar energy. This implies that in case an associated heat production system is applied like installation on rooftops, the more households are supplied with heat for hot water, the more efficient it is. That is because in case of less households supplied with the heat, most of solar heat may not be used for the load.

Table 3: Solar saving fractions (— type layout, **Left** building location, South site orientation) (Mcal/yr)

			No. of sharing households	Total load	Produced solar heat	Solar saving fraction(SSF)
Hot water	Rooftop		10 households	26,230	25,050	24%
			20 households	52,460	41,076	39%
			30 households	78,690	50,362	48%
			40 households	104,920	56,027	53%
	Vertical Wall(facade)	Area option	Solar access grade	Total load	Produced solar heat	Solar saving fraction(SSF)
		Area option 1	A	104,920	19,643	19%
			B	104,920	10,379	10%
			A+B		30,022	29%
		Area option 2	A	104,920	31,289	30%
			B	104,920	16,533	16%
			A+B		47,822	46%
		Area option 3	A	104,920	36,181	34%
			B	104,920	19,117	18%
			A+B		55,298	53%
Heating + Hot water	Rooftop		10 households	112,270	36,825	8%
			20 households	224,540	45,582	10%
			30 households	336,810	51,869	12%
			40 households	449,080	56,135	13%
	Front side	Area option	Solar access grade	Total load	Produced solar heat	Solar saving fraction(SSF)
		Area option 1	A	449,080	17,945	4%
			B	449,080	9,482	2%
			A+B	449,080	27,427	6%
		Area option 2	A	449,080	33,897	8%
			B	449,080	17,910	4%
			A+B	449,080	51,807	12%
		Area option 3	A	449,080	47,688	11%
			B	449,080	25,197	6%
			A+B	449,080	72,885	16%

The SSFs of the solar thermal system installed on rooftops were the same regardless of the location of buildings (left, middle and right) because the solar radiation heating the rooftops of the 3 buildings were the same.

As mentioned above, in this study the application of solar thermal system was limited to the range of A and B grade only, which are the top part of buildings and have good amount of solar radiation, because the installation on the lower part, where the annual solar heat amount is less than 80%(C~E grade), was considered to be inefficient due to the low level of solar heat.

As for the area option 1, in case the solar thermal system was applied to the scope of A grade at front side of a unit building, the produced solar heat through the 187 m² of total heat collection dimension appeared to be 19,643Mcal/yr annually. According to this result, it seemed that the 19% of total hot water load could be supplied by solar heat, and when the system was installed at the A+B range, the SSF appeared to be 29%. In case the area option 3, with which it was able to maximize the heat collection, was applied to the A+B grade of front side of unit building, the SSF appeared to be 53%.

In case of vertical wall surfaces, the heat supply may be changed depending on the building location due to the shading effect of adjacent buildings. Accordingly, the heat supply from the solar thermal system installed on vertical wall shall be interpreted by each building, unlike the interpretation of rooftops.

As shown in Fig. 4, the hot water supply from the solar thermal installed on the facade of the building in the middle appeared to be 18,050Mcal/yr in case the system was applied to the A grade of area option-1, and the SSF in connection with that appeared to be 17%. As the installation dimension was increasing, the hot water supply also increased, so when the system was applied to the A+B grade of area option-3, which was the biggest dimension under the condition, the SSF was 49%, and the SSF appeared to be 57% when the system was installed on the vertical surface of the building on the right. According to the interpretation of heating + hot water load, the total load of heating + hot water of the entire one building was 449,080Mcal/yr, and in case the system was installed on the rooftop to provide all 40 households with heat, the SSF of solar thermal system appeared to be 13%. And when the A + B range of area option-3, with which the heat collection dimension could be maximized in case it was installed on the vertical surface, was applied the SSF was 16%, and in case of the building facade in the middle the SSF

was 15%, and in case of the front side of the building on the right the SSF appeared to be 17%. In the same manner, the interpretations for the ‘alternative — type’, ‘⊥ type’ and ‘□ type’ layout carried out, and the result was presented in Table 8.

Table 4: Solar saving fractions (— type layout, **Middle** building location, South site orientation) (Mcal/yr)

Hot water	Rooftop	No. of sharing households		Total load	Solar heat amount	Solar saving fraction(SSF)
		10 Households		26,230	25,050	24%
		20 Households		52,460	41,076	39%
		30 Households		78,690	50,362	48%
		40 Households		104,920	56,027	53%
Heating + Hot water	Front side	Area option	Shading grade	Total load	Solar heat amount	Solar saving fraction(SSF)
		Area option 1	A	104,920	18,050	17%
			B	104,920	9,928	9%
			A+B	104,920	27,978	27%
		Area option 2	A	104,920	28,752	27%
			B	104,920	15,814	15%
			A+B	104,920	44,566	42%
		Area option 3	A	104,920	33,247	32%
			B	104,920	18,286	17%
			A+B	104,920	51,533	49%
Heating + Hot water	Rooftop	No. of sharing households		Total load	Solar heat amount	Solar saving fraction(SSF)
		10 Households		112,270	36,825	8%
		20 Households		224,540	45,582	10%
		30 Households		336,810	51,869	12%
		40 Households		449,080	56,135	13%
	Front side	Area option	Shading grade	Total load	Solar heat amount	Solar saving fraction(SSF)
		Area option 1	A	449,080	16,490	4%
			B	449,080	9,070	2%
			A+B	449,080	25,560	6%
		Area option 2	A	449,080	31,148	7%
			B	449,080	17,132	4%
			A+B	449,080	48,280	11%
		Area option 3	A	449,080	43,821	10%
			B	449,080	24,102	5%
			A+B	449,080	67,923	15%

Table 5: Solar saving fractions (— type layout, **Right** building location, South site orientation) (Mcal/yr)

Hot water	Rooftop	No. of sharing households		Total load	Solar heat amount	Solar saving fraction(SSF)
		10 Households		26,230	25,050	24%
		20 Households		52,460	41,076	39%
		30 Households		78,690	50,362	48%
		40 Households		104,920	56,027	53%

	Front side	Area option	Shading grade	Total load	Solar heat amount	Solar saving fraction(SSF)
		Area option 1	A	104,920	19,643	19%
			B	104,920	12,635	12%
			A+B	104,920	32,278	31%
		Area option 2	A	104,920	31,289	30%
			B	104,920	20,127	19%
			A+B	104,920	51,416	49%
		Area option 3	A	104,920	36,181	34%
			B	104,920	23,273	22%
			A+B	104,920	59,454	57%
Heating + Hot water	Rooftop	No. of sharing households		Total load	Solar heat amount	Solar saving fraction(SSF)
		10 Households		112,270	36,825	8%
		20 Households		224,540	45,582	10%
		30 Households		336,810	51,869	12%
		40 Households		449,080	56,135	13%
	Front side	Area option	Shading grade	Total load	Solar heat amount	Solar saving fraction(SSF)
		Area option 1	A	449,080	17,945	4%
			B	449,080	11,543	3%
			A+B	449,080	29,488	7%
		Area option 2	A	449,080	33,897	8%
			B	449,080	21,804	5%
			A+B	449,080	55,700	12%
		Area option 3	A	449,080	47,688	11%
			B	449,080	30,675	7%
			A+B	449,080	78,363	17%

3.2 Result analysis for complex site level

Once the result is derived, it will be possible to predict the total load of apartment complex scale and calculate the SSF of solar thermal system because those values can be obtained by multiplying the number of buildings.

In case of the buildings located at the forefront to the south in the site, which have no other building in front of themselves, the value can be obtained by multiplying the number of buildings at the forefront after interpretation of the case of one building without distinction of location in terms of left, middle and right

Because the layout pattern was ‘— type’ composed of 9 buildings, the adjacent buildings, which were located in front of the buildings on the left, middle and right respectively when the rear side was established as the datum line, were two respectively, and the forefront was composed of three buildings on the left,

middle and right, which were not affected by shading effect.

Accordingly, the total number of households in the complex was 360, and the total hot water load appeared to be 944,280 Mcal/yr, and the total heat load (Heating + Hot water) appeared to be 4,041,720 Mcal/yr.

Table 6: Produced solar energy and SSFs of the case of **rooftop** installation(— type layout, South site orientation) (Mcal/yr)

Hot water	No. of sharing households	Solar heat amount	Solar saving fraction(SSF)
	90 Households	225,447	24%
	180 Households	369,686	39%
	270 Households	453,254	48%
	360 Households	504,246	53%
Heating + Hot water	No. of sharing households	Solar heat amount	Solar saving fraction(SSF)
	90 Households	331,421	8%
	180 Households	410,235	10%
	270 Households	466,819	12%
	360 Households	505,215	13%

Table 7: Produced solar energy and SSFs of the case of **facade** installation(— type layout, South site orientation) (Mcal/yr)

Hot water					
Area option	Solar Access grade	Solar heat amount	Solar heat amount (A+B)	SSF	A+B
Area option-1	A	168,825	269,748	18%	29%
	B	100,923		11%	
Area option-2	A	268,918	429,677	28%	46%
	B	160,759		17%	
Area option-3	A	310,958	496,848	33%	53%
	B	185,890		20%	
Hot water + Heating					
Area option	Solar Access grade	Solar heat amount	Solar heat amount (A+B)	SSF	A+B
Area option-1	A	154,232	246,432	4%	6%
	B	92,200		2%	
Area option-2	A	291,327	465,482	7%	12%
	B	174,155		4%	
Area option-3	A	409,857	654,870	10%	16%
	B	245,012		6%	

As shown in Table 6, in case the tube-type solar collector was installed on rooftop surface alone and the produced heat was supplied to 90 households in the complex, that is, 10 households in each building, the SSF appeared to be 24%. When the heat was

supplied to the 90 households as the ‘Heating + Hot water’ type, the SSF was 8%.

As shown in Table 7, in case the tube-type solar collector was installed on the vertical wall surface of each household and the heat was supplied to the households with A + B range of solar heat grade as to area option-1, the hot water load occupied the 29% of the total hot water load, and it appeared that the 6% of total heat load could be supplied with solar heat in case of ‘Heating + Hot water’. As for the area option-3, the total hot water provided by the solar heat was 496,848 Mcal/yr, so it was identified that the 53% of hot water load was allocated to solar heat and ‘Heating + Hot water’ could be allocated to solar heat.

3.3 Result analysis for the layout patterns of building arrangement in apartment complex

Table 8: SSFs in accord with layout pattern (South site orientation) (Mcal/yr)

Division	Area option	Hot water		Heating+ Hot water	
		Solar heat amount	SSF	Solar heat amount	SSF
— type layout	Option-1	269,748	29%	246,432	6%
	Option-2	429,677	46%	465,482	12%
	Option-3	496,848	53%	654,870	16%
Alternative — type layout	Option-1	231,152	24%	211,172	5%
	Option-2	368,198	39%	398,880	10%
	Option-3	425,758	45%	561,169	14%
⊥ type layout	Option-1	195,794	21%	178,870	4%
	Option-2	311,878	33%	337,866	8%
	Option-3	360,633	38%	475,331	12%
□ type layout	Option-1	72,036	10%	65,809	2%
	Option-2	114,745	16%	124,306	4%
	Option-3	132,683	18%	174,882	6%

According to the result mentioned above, the analysis of vertical wall surface was carried out for each layout pattern(as ‘— type’, ‘alternative — type’, ‘⊥ type’ and ‘□ type’). As shown in Table 8, where the SSF was compared in accord with layout pattern, the SSF of solar thermal system was placed in the order like ‘— type’ > ‘alternative — type’ > ‘⊥ type’ > ‘□ type’,

so it was identified that the '— type' layout provided the optimal supply system of solar energy. In case the solar thermal system was installed in the area option-3 of '— type' layout, the solar heat supply amount increased by 35% in hot water, and by 10% in 'Hot water + Heating', when they were compared to the '□ type' layout which had the lowest SSF.

4. CONCLUSION

When the solar thermal system was installed on rooftops and vertical wall surface of apartments to share the heat load occurring in unit households, the load matching evaluation was as follows. When the solar thermal system was installed, the layout pattern with the biggest solar saving fraction(SSF) occurring in unit building of apartments was the '— type' due south, which had the best solar access, so the annual heat amount for hot water supply by solar heat was 504,246 Mcal/yr, and the SSF appeared to be 53%, and the annual heat amount for 'Heating + Hot water' supply by solar heat was 505,215 Mcal/yr, and the SSF appeared to be 13%.

And when the solar thermal system was installed on vertical wall surface, that is, the system was applied to the area option-3 by which the heat collection could be maximized, the heat amount for hot water supply by solar energy was 496,848 Mcal/yr, and the SSF appeared to be 53%, and the annual heat amount for 'Heating + Hot water' supply by solar heat was 654,870 Mcal/yr, and the SSF appeared to be 16%.

In this study, following the preceding studies in which the solar heat amount on rooftops and vertical wall surfaces of apartments was evaluated, the solar saving fraction of each household and complex was analyzed in case the solar thermal system was installed on certain parts where the solar amount is good enough, so that this study may be used as the basic study for the

suitable scale in application of sunlight and solar thermal system to apartments.

In case the detailed basic design of systems, which is suitable for the domestic conditions, and the system, which is designed through selection of suitable parts among various installation parts on rooftops and vertical wall surfaces in consideration of elevation design of buildings and practicality are applied to the system, it is estimated that the back-up studies shall make progress for the survey of energy yield and the evaluation of system efficiency.

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