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Solar Constraints and Potential in Urban Residential Buildings

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Abstract

Today, Asian cities have been full of high-rise and compact buildings with large population. In Seoul, Korean capital city where millions of people have lived, over 20 or 30 floors residential buildings are common sight. As a result, half of the Korean population is living in high-rise residential buildings like apartments. However, large residential buildings in cities have consumed huge energy provided from fossil fuels to support occupants' environmental convenience, and they are currently a major energy-consuming sector. To resolve this environmental and energy issues, solar systems are promising one of effective solutions to supplement energy demand for urban residential buildings. Therefore as fundamental approach this paper studies solar potential and constraints in high-rise residential buildings to understand unfavorable urban environment for solar energy based on diverse interferences from other urban factors. To maximize solar potential and to utilize effective renewable systems on the surface of buildings, this study analyses Korean typical multi-family housing buildings and also includes a case study to deal with an apartment complex to figure out the effective ways for solar energy. This result can be expected to be utilized for architects and engineers in their design process to plan low energy buildings.

Keywords: *Solar potential, High-rise buildings, Solar constraints, Building forms and arrangement*

1. Introduction

1.1. Backgrounds

Buildings, as a major energy consuming sector in the world, accounted for 21.2percent of total final energy consumption, consisting of 9.3percent and 13percent in commercial building and residential building respectively (Korean Energy Census, 2010). Building sector's share is still lower than transportation and industry sectors, but it will be expected to increase like other developed countries reported by IEA. They reported their residential buildings have averagely consumed about 27percent of total final energy consumption. In Korea, the Photovoltaic (PV) and Solar thermal (ST) market is consistently growing by government promotion projects since 2008, due to their green growth policy. Firstly, Korea Energy Management Corporation (KEMC), a public institution, has operated supply business projects for renewable energy systems such as PV and ST with financial packages. The budget are totally about 20 million won in 2015, and they have pursued green-village project that provides financial aid for owners to receive 35~50percent per total installation cost. However, unlike governmental support, major eight metropolitan cities in Korea just showed 8.3percent of renewable power production by region, and of that, the power portion by residential buildings is only 0.4percent in 2013 (Renewable Energy Dissemination of Statistics, 2013). Consequently, in Korea, to encourage solar system use is important strategy to improve energy efficiency of urban buildings. However, in the respect of building shape and arrangement, Korean high-rise residential buildings are unique and standardized unlike other countries' residential buildings. In a census on population and housing conducted Korean National Statistical Office (KNSO) in 2010, they also found that multi-family housing continuously has shown a growth from 53percent in 2005 to 59percent in 2010. Above all, over 75percent of total multi-family housing buildings is over ten stories buildings. Given this context, half of Korean today is closely connected to the life in high-rise residential buildings consuming lots of

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energy to stay their urban life. Therefore, to make environmentally-friendly urban space, successful energy efficient strategies for urban residential buildings are required such as renewable systems.

Also, in today's global society, many countries are worrying energy matters that fossil fuels will definitely be depleted in near future even though fossil fuels are still necessary in all fields of industries and public livelihood. According to a new UN Department of Economic and Social Affairs (DESA) report in 2015, the world population will reach 9.6 billions people until 2050 (UN database, 2015) and International Energy Outlook 2013 by IEA reported that world energy consumption will increase 56percent from 2010 to 2040 by world economic growth and specially, electric power demand will grow by 80percent between 2012 and 2040 (IEO 2013). Hence, as mass energy consuming sectors, future buildings should be considered to increased energy consumption by growing economy. For that, it is required to achieve better design and energy efficiency in all kinds of manufacturing industries and in all kinds of buildings. As the result of this movement for energy saving, many world nations are planning to go into effect on mandatory building codes to design low and zero energy buildings and to renovate existing buildings into high performance buildings. Along many European countries' plan which will reach zero energy building (ZEB) between 2015 and 2030, Korean government has also driven the policy to phase in ZEB as mandatory policy from 2008 to 2025. This means that many multi-family housing, so called apartments in Korea, will have to consider renewable energy systems to satisfy mandatory zero-energy efficiency because only plan for passive design and efficient HVAC systems cannot guarantee ZEB performance on site. Therefore, in order to maximize building energy performance and to design better green buildings in urban area, urban solar constraints and potential should be properly understood and settled by designers and engineers. For this, this research studies urban solar potential based on high-rise residential buildings in Korea and, depending on the features of their typical forms and arrangement, the study can be generalized and utilized for whole country.

1.2. Objective of the study

The research goal is to study solar potential in urban areas and to focus on high-rise multi-family buildings which have been very dominating in Korean housing market. The study has three major purposes; At first, multi-family housing in Korea has shown standardized forms and arrangements. This is due to the fact that forms of multi-family housing have been affected by governmental institutes and contractors for decades and sometimes, their principles for building arrangement have been guided by District Unit Planning by regional governments. As a result, multi-family housing complex have shaped the urban context in Korean cities. While they are not particularly good in urban scape design, it can be useful to generalize and to establish dissemination strategy for renewable energy. On the second purpose of this study, in architectural viewpoint, solar potential on building envelope can be easily affected by building physical features such as mass projection and curved mass design. Besides, in large multi-family housing complex, solar potential may be strongly influenced by adjacent building structures. Last but not least, the development in very densely urban areas usually requires high energy efficiency and performance following their enhanced building energy codes and for that, renewable systems should be optimized and effectively planned in the buildings. Given this, this study will be meaningful in the importance for practical experts. Therefore, this study investigates Korean high-rise residential buildings focusing on their forms and arrangement, and diagnoses solar potential in single building level. And then, the study analyses solar potential through case study of urban residential complex. By means of the result of this research, architects, engineers and building owners can more understand solar potential and effectively design green buildings reflected urban solar strategies.

1.3. Research process

This study analyses solar potential on residential building envelope and roof where can be used for PV and ST. In single building and urban scale, this study looks at urban solar limitations and solutions. This research is composed of three-step procedure:

(a) The first step is to do literature review on solar potential. Solar potential is usually used to explain a term for solar applicability or solar radiation that is calculated by a ratio of area on the building envelope. This paper deals with some research and their result of solar potential studied by other authors.

(b) On the second step, the research is to study solar potential and constraints in single building types. For this, this study looks into main residential types in Korea and simulates their solar performance by doing simulation tools. With this analysis, solar limitations and solutions are drawn.

(c) At the last step, case study in the single building complex is carried out to estimate actual solar potential on the building surface. Then, analyzing high-rise multi-family complex is done because this can explain how building direction and arrangement in the complex can affect solar potential in urban context. As the final outcome, solar potential and constraints are analyzed to draw solutions.

2. Literature review

Housing market in Korea has greatly changed for last several decades in their types and forms. In 1975, detached house occupied over 92 percent of total housing by total ground area. However, multi-family housing [1] and row house[2] had explosively grown over 10 times from 6 percent to 63 percent in total residential stock (Housing Census, 2010). Actually, plenty of new cities had been constructed since 1980s with multi-family housing buildings and consequently, housing supply ratio recorded from 86 percent in 1995 to 118 percent in 2014 in housing census by KNSO. In 2013, over 71 percent of existing multi-family housing has over 15th stories, which means most of multi-family housing is high-rise buildings (Apartment Housing Statistics, 2013). Therefore this study regarding solar potential in Korean high-rise residential buildings can have powerful influence for many apartments to become better energy efficient.

There are many ways to optimize building solar potential in preceding research. Many studies have already showed possible approaches to improve solar access on the surface, but still have a distance to explain urban solar limitations in residential buildings. Because residential building types in Korea are different from other countries in their residential types, density and patterns. Also, research in Korea mainly focused on the right of solar access (Changho Choi, 2007, Dosung choi 2009). Building's major design parameters (i.e. building aspect ratio, azimuth, site coverage, density and arrangement) are generally considered to assess solar potential in urban area because these are largely able to affect solar potential on the envelope of buildings. According to a study by Dapeng Li et al (2015), the research reported solar potential in urban residential buildings that can be raised when building aspect ratio increases, and thus they studied increased site coverage. Also, this study revealed that photovoltaic(PV) and solar thermal(ST) yield decreased up to 50% and 26% respectively by mutual shade in high-density scenario. However, it explained solar systems to be able to satisfy yearly electrical and thermal demands of residential buildings. Min-Hee Lee et al (2009) conducted a feasibility study to review business value on solar systems and assessed solar potential depended on urban structure. For applicability to urban buildings, the research describes that roughness affects solar potential. Such result is especially remarkable in high-rise and high-density buildings. Similarly, while high-rise buildings has lower solar potential than low-rise buildings, it is possible that solar systems harvest stable solar energy since probable areas for solar system installation are generally converged to particular upper floors in special buildings. However, M. Karteris et al (2013) reported that PVs in the urban environment may not be efficient than suppositions. This is due to the fact that urban obstacles, such as density, heights and shafts, often significantly lower valid surface areas above 50% on the roofs. This research reviewed the actual solar potential as developing a model for roof-top surfaces through a statistical analysis by using existing multifamily buildings in a general Greek city, Thessaloniki. Like above studies, at present, availability and limitation on urban solar potential are still in progress. On account of specificity in location, design and analytic condition, more research to be generalized and exploited should be studied for more solar energy use in Korean urban areas.

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[1] The definition of apartment is an over 5floors permanent building to include many households, and each household can independently live in their apartment. (KNSO, www.kostat.go.kr)

[2] Row house is a permitted building as a row house by law and its height is limited below 4 floors. Also, several households can live in row houses. (KNSO)

3. Single building analysis

3.1. Korean multi-family housing

In 2007, Ministry of Land, Transport and Maritime Affairs in Korea reported that residential buildings took up the largest portion in national cities and were occupying 68percent of all building stock. Among all cities, Seoul and Kyunggi-do have formed the largest metropolitan area where 43percent of Korean population has lived and the greatest number of residential buildings have been built. However, regardless locations, Korean multi-family apartment have typical patterns in their forms. Doosung Choi and Jinseok Do (2009)[1] surveyed 74 multi-family housing complex and 919 multi-family housing buildings built after 2007 to classify multi-family housing category. Consequently, it informed that flat-type and tower-type occupied 57percent and 43percent respectively among investigated building types. Building size depends on the number of units and it can be changed following building conditions. Classified single building types of multi-family housing are as below table.1. Types of multi-family housing have significance on analysis of solar potential because their building forms restrict surface areas that can get solar energy and be installed for renewable energy. Hence, as first step this research studied solar performance in single buildings.

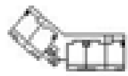
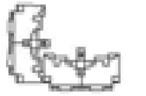
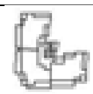
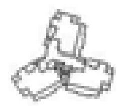
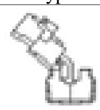
Tab. 1: Dominative Multi-family Housing Types in Korea (Doosung Choi 2009)

Flat-type			Tower-type		
— type	Bending-type	L-type	L-type	Y-type	Single-wing type
68.1%	17.6%	14.3	30.9%	22.1%	21.5%

3.2. Solar potential analysis

The aims to solar potential in this study are to understand cause and effect of urban solar limitations in the scale of single building and urban complex. In general, the forms and envelope designs of multi-family housing are primary factors to affect solar potential on the building surface. Severe building shade can also reduce solar potential on the surface by adjacent buildings that usually causes shading through its high density or mass projection. Moreover, Korean residential building has an unique character that it relatively has broad surface area per volume to get more solar radiation due to general Korean resident's preference of sunshine. However, in the analysis of an independent building, there is no interference from adjacent urban environment and buildings. This being so, there is no solar influence caused by density or height that these factors can be possible in complex level. Therefore, assessment in building types focuses on the amount of solar radiation, orientation, seasonal changes and restrictions by building design.

Tab. 2: Multi-Family Residential Buildings for Single Building Analysis

	Flat-type			Tower-type		
	— type	Bending-type	L-type	L-type	Y-type	Single-wing type
Floor plan						
Units	6	5	4	3	3	4
Floor height (m)	2.8	2.8	2.8	2.8	2.8	2.8
Area (m^2)	571	404	827	569	523	694
Tilt (deg. E/W/S/N)*	90/90/0/0	90/50/0/0	90/90/0/0	90/90/0/0	76/120/166/76	90/141/0/51

* Horizon is 0 degree and counterclockwise rotation

For this, building height are decided to 16 stories that is one of standards to define Korean tower types, and also in single building analysis, building height don't affect building solar radiation and changes. This study simulated single buildings by utilizing IES-VE Apache and Sun-cast that can have ability to review solar radiation and building shade through their modules to estimate quantitative performance on the envelope.

[1] Doosung Choi (2009) defined a term of tower-type that ratio between long and short sides doesn't exceed 4:1 and by using one elevator and stairs, people can directly enter into their apartment units, and it is 16 and more stories with reference to Article 29.3.1 in Seoul Architecture Regulation. Also, Euntae Park (2007) gave tower-type a definition that ratio between long and short sides is under 4:1 on the authority of Article 86 for solar access right in the Building Code.

Building location is set on Seoul and Seoul weather data is extracted from ASHRAE design weather database v5.0, and the location is latitude 37.57N°, longitude 126.97E°, Altitude 86m and standard meridian 135.0E. Analysis duration is from January 1st to December 31th and their daylighting hours are based on monthly solar altitudes in Seoul calculated by VE-SunCast.

(1) Solar potential

In general, building forms in solar access, significantly affect solar gain and building shading to itself. Solar potential in each building type considered in aspect of annual average value, directional and seasonal effect to solar radiation. The longest, max and min solar gain sides on each direction side are reviewed of solar potential because diverse and tilted sides on the same direction show different solar potential due to different azimuth and projection by building designs. As a result of simulation analysis, solar radiation on the roof is the same as 105.2 W/㎡ hr because building roof has no shading by building itself. According to types, Flat-types basically have an advantage that long sides are commonly arranged to face south and can thus get more solar radiation in the amount of total solar potential. Hence, if Flat — type can face south, its most units can have an optimal direction for solar access. Values of simulation reported that annual solar radiation on long sides in typical floor by directions is that east, west, south and north are sequentially 65.2, 61.3, 81.8, 39.8 W/㎡ hr. Although Flat bending-type has partial refraction on the building mass, generally it can be exposed to originally arranged, because even though a bending side takes different azimuth, bending angle is less than 45 degree. Its each directional solar potential represents that east, west, south and north are 62.3, 49.6, 81.7, 39.3 W/㎡ hr in a row. Flat L-type has a form that its mass is perpendicular crossing which makes two continuing sides have completely dissimilar directions when they receive solar energy. At the same time, two perpendicular inner sides are relatively weak to gain solar energy due to be shaded by building mass itself. Its directional solar potential is 65.3, 62.0, 78.3, 39.9 W/㎡ hr in a row from east to west south and north. According to solar radiation data in passive design guideline (PCAP, 2012), average solar radiation* by directions in Seoul is that east, west, south and north on the vertical side are 65.9, 88.4, 96.5, 19.9 W/㎡ hr. Comparing solar potential to average solar radiation by building types in Seoul, there are some different ranges; on the east side, 94.5~99.0%, on the south side, 81.1~84.7%, on the west side, 56.1~70.2%, on the north side, 197.5~200.3%. Some values under average show that each type can have a weak-point on less solar potential sides. For example, Flat-bending is vulnerable to west and south sides.

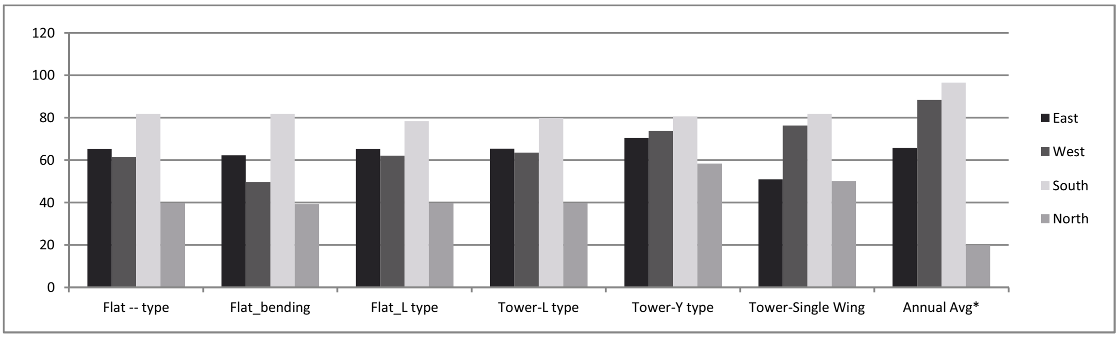


Fig. 1 Annual solar potential on the external walls (unit : W/㎡ hr)

Also, solar potential on long side by Tower L-type is that east, west, south and north are 64.5, 63.6, 79.8, 39.9 W/㎡ hr in a row, and solar potential in Tower Y-type is also 70.4, 73.7, 80.6 and 58.4 W/㎡ hr. Tower single-wing-type is 50.9, 76.4, 81.7 and 50.0 W/㎡ hr. On comparing these data to Seoul's average solar radiation, east side has 77.2~106.8% difference, west, south and north separately show 71.9~86.4%, 82.7~84.7% and 200.3~293.3% difference in solar radiation on the surface. One of causes is azimuth difference at each side on the building envelope and building itself shades its surfaces due to its roughness and projected mass, such as Tower single-wing type is delicate on east side. Actually, while optimal orientation in Seoul is east-south or south (135~210 degree), Tower types are comparatively exposed to unfavorable directions since their building forms preferentially decide their orientations before their building arrangement. Consequently, even if all buildings face to the same direction on their placement, surface azimuth and area size on each side can be different owing to their types and forms have large effects on the amount of solar gain.

(2) Seasonal changes

On the other side, seasonal changes in Korea make considerable influence on solar potential by altering solar altitude, azimuth and daytime hours. Seoul's solar altitude is that spring and fall equinox are 52.4°, summer solstice is 75.9°, and winter solstice is 28.9° depended on Latitude 37° 34′. According to seasonal changes in Fig.2, east and north sides get the annual highest solar radiation on summer solstice and fall equinox. West pattern is similar with south in aspect that it takes large solar radiation on fall equinox. Besides, single building types and seasonal changes have a little correlation on their solar gain per the unit area even though they have azimuth difference on external surface. Hence, in respect of seasonal changes, influence on solar potential by single building types is insignificant.

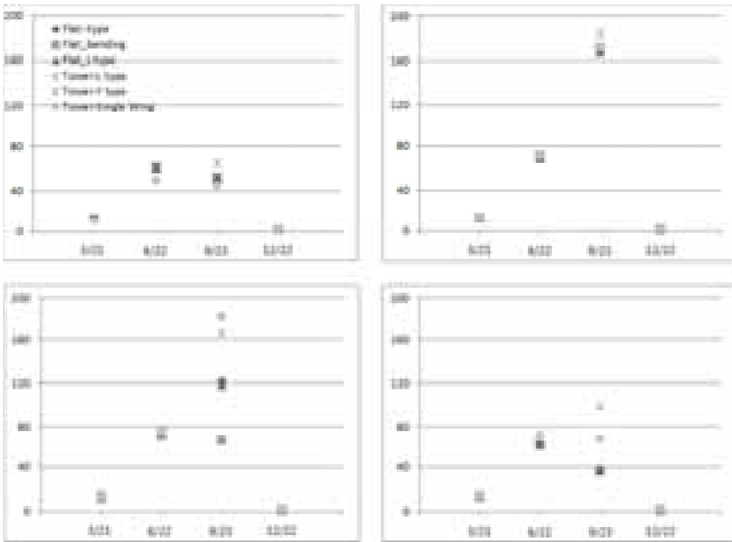
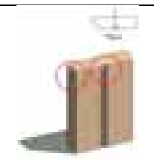
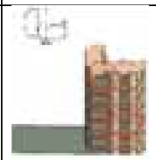
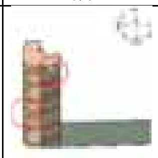
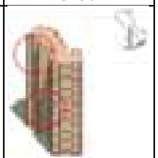
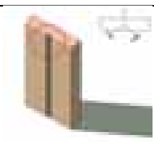
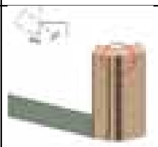
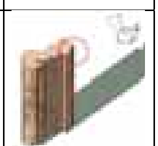


Fig. 2 Seasonal solar radiation on the external walls
(L-top: east, L-down: west, R-top: south, R-down: north, unit : W/㎡ hr)

Tab. 3: Building Mass Information

		Flat-type			Tower-type		
		— type	Bending-type	L-type	L-type	Y-type	Single-wing type
POP (%)		67	69	49	66	63	63
L/W *		4.12	1.87	1.47	0.95	1.10	0.91
Tilt (Max/ Min deg.)	E	90**	90/142	90/90	90/90	76/76	51/90
	W	90/90	142/50	90/90	90/90	120/120	141/90
	S	0/0	0/172	0/0	0/0	166/166	0/0
	N	0	142/0	0/0	0/0	76/165	51/0
Weak point	Sum-mer	 22 Jun 17:00	 22 Jun 16:00	 22 Jun 16:00	 22 Jun 16:00	 22 Jun 10:00	 22 Jun 12:00
	Win -ter	 22 Dec 17:00	 22 Dec 09:00	 22 Dec 11:00	 22 Dec 09:00	 22 Dec 12:00	 22 Dec 09:00

* Length/Width (L/W) ratio on a typical plan, ** Existing only one side on a particular direction

(3) Building constraints
So far, this study analysed directional and seasonal solar potential by single building types of multi-family housing. On the independent building level, solar limitations are as the following; 1) building itself shade, 2) solar potential changes on surface affected by seasonal changes on solar azimuth and altitude. On account of seasonal solar changes are natural, solar potential and limitations by building forms are studied in this part. Generally, building shape, which is able to alter building exposure to external environment, is reviewed in the design stage to reduce energy consumption and to increase energy efficiency. On the design planning, to examine building mass, some indicators such as Surface/Volume (S/V) ratio, Length/Width (L/W) ratio and POP ratio can be used. Therefore, to find limitations in the independent building level, building types are diagnosed through such indicators. Table 3 demonstrates POP and L/W in case building types. Applied POP equation is like this;

$$POP = 2\frac{\sqrt{\pi \times A_b}}{P_b} \times 100(\%) \qquad \text{(eq.1)}$$

In the equation from Passive Design Guideline (2012), A_b = building area, P_b = perimeter length. High POP building commonly has a benefit in building heat gain or loss, whereas low POP ratio building has a weak-point in building heat gain or loss. This is because low POP ratio indicates that the building has relatively lots of protruded parts on its envelope, and if its weak-point is not revised on building arrangement, self-shade can largely reduce solar potential. Among building types, Flat L-type has the lowest POP value and other buildings are almost alike. In the table.3, weak point of Flat L-type shows a probable problem in low POP ratio buildings. To improve solar potential, low POP ratio building should consider dented parts on the surface and have an optimal placement to avoid perpetual shade. L/W ratio is also normally optimized on 1.5:1 which can affect annual heating and cooling loads by changing heat gain area by solar radiation and shaded heat loss area. Flat-types have L/W ratio that is almost 1:5 or more. However, Tower-types take around 1:0 in L/W ratio, which means that they have a weak spot on the surface by their shapes. Given this, preferably, wider building surface on Tower types should be more exposed to optimal direction to have better solar potential and reduce building loads.

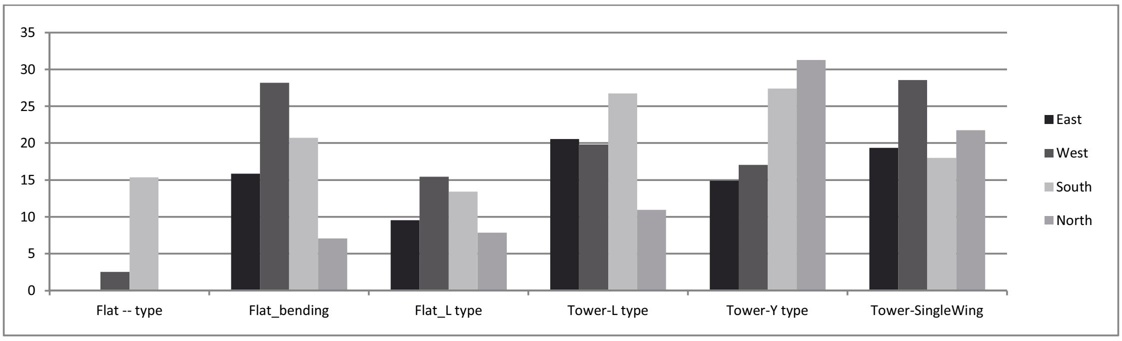


Fig. 3 Solar potential difference between max and min values on the same orientation (unit : W/㎡ hr)

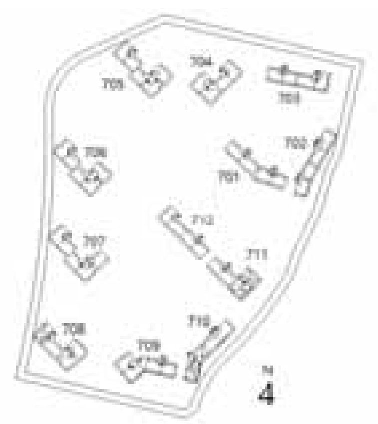
Single buildings' self-shade presents another limitation. It makes solar potential difference and degradation on the same direction. Fig.3 reports how much self-shade by mass projection aggravates solar potential. Flat –type and Flat bending-type are almost even in their forms because it is merely 18 degree different on mass bending. On the contrary, in solar radiation on the same orientation, the bending makes large solar performance difference between the max and min values. Furthermore, Tower types reveal larger dynamic dispersion range than Flat types, which indicates Tower types in urban area are disadvantageous on solar potential and inevitable to have lower solar availability due to their structural problems. Accordingly, in order to solve these limitations in urban space, simplification on sun-exposed envelope and optimal arrangement to direction should be far outweighed.

4. Residential complex analysis

4.1. Arrangement of residential complex

Building arrangement methods have been developed following national building codes and the demands of social trends. Primary features of arrangement as follows: Since 1941, practice in fields of construction and design dominated by governmental institutes and construction contractors has generally used typical building drawings, which have affected current residential complex forms and urban context (Booseong Kang et al., 1999). After 1998, residential complex planning in Korea has a new trend that is remarkable changes of building forms. Some residential complex is consisted by only tower-type buildings, but most complexes of them have combination of flat-type and tower-type buildings. Also, the frequency of residential complex applied by diagonal line was increasing. The background of this is the result of chronological changes by preference of diversity, views and direction of urban scape planning. Moreover, wall area in flat-type-dominant residential complex is mainly larger than that in tower-type-dominant residential complex (Byeongho Lee et al., 2010). Also, all Korean residential buildings should meet governmental standard for solar access right in accordance with the provision of Article 53 in the National Building Code and Article 86 of the its Enforcement Ordinance. Thus every building that faces other buildings has to have 0.8 times distance between buildings based on due south (Yoonbok Seong et al., 2004). In this context, the solar limitation of case residential complex can have direct implication to improve solar potential in residential complex planning.

Tab. 4: Residential Complex (47BL) Information

	Project : 47BL Dontan-2 District, Hwasung Type : National sales and rental housing Location : the whole region around Seoku-dong, Bansong-dong and Dongtan-myeon, Hwaseong-si, Gyeonggi-do located to 40km South from Seoul Lot area (㎡) : 56,353 Floor area ratio (%) : 180 or less Units : 930 households Number of stories : 9F~23F Building types : total 12 buildings (Flat – type, Flat-bending-type, Flat-L-type, Tower single-wing-type)

4.2. Solar performance

(1) Case information

This case study is to analyze solar performance of a residential complex in order to figure out the influence of building shade on the solar potential. The case complex is a design planning of a prize winner in 47 Block in Dongtan-2 District, Hwasung and it is currently under construction following this design. Above all, this project is a governmental project to distribute affordable houses to general people and the number of unit is around 930 households. Building size is diverse from 9 floors to 23 floors and east-southern located buildings are comparatively lower than west-northern located buildings due to satisfy a solar access code and get more sun shine that is preferred by many Koreans. IES-VE Apache and Sun-cast modules are used to analyze changes of solar potential and building shade on building surface. Weather data is Suwon, a neighboring city nearby Hwasung, of ASHRAE design weather database v5.0.

(2) Solar potential analysis

On the result of analysis, due to adjacent building's shades, gradation of solar potential is very different in vertical building surface. Solar potential on the surface in 20F is maximum value reflected by little influence of other buildings, and solar potential difference from 1F to 20F is the extent of building intervention that worsen urban solar potential and mainly become one of urban limitations for renewable use. In the table 5, the middle part located buildings in residential complex (702, 712) are Flat-bending-type (701) and Flat – type (712) that their forms are generally favorable performance to get solar energy than tower-types. However, in this complex, they are easily exposed by surrounding buildings which deteriorate solar potential on their different vertical stories, especially difference between 1F and 20F is obvious. For example, in 701 building, east side-solar potential shows about 3 times gap between 1F and 20F and if there is no interference from other buildings, solar potential in each story by floor is the same as already confirmed in chapter 3. This means that in urban area, neighboring buildings can cause severe influence on solar potential and give rise to lower solar potential for use of renewable system.

On the east part in the complex, buildings (702, 710, 711) are Flat-bending-type (702, 710) and Flat-L-type (711) buildings. They represent that these buildings obtain almost same solar potential regardless their different stories and it signifies that the effect of adjacent buildings is small because the buildings are exposed to open space on the east side and there are only a few buildings along solar path. On the south side, buildings (708, 709) are Flat-L-type (708) and Tower single-wing-type (709). 708 building has a pattern that regardless of their floors, they show good efficiency due to open space in front of the buildings. Whereas east side of 709 building is influenced by 710 Buildings and its 1F solar potential is nearly one-third of 20F. On the west side are Flat-L-type (706, 707). Their solar potential gap by height is from 8.5 to 24.9 W/㎡ hr. Buildings located on the north are Flat – type (703) and Flat-L-type (704, 705). Their solar potential gap by height is from 0 to 25.1 W/㎡ hr. Also, comparing differences on the 1st floor, east, south, west and north side gap (max-min) are 48.8 W/㎡ hr, 26.2 W/㎡ hr, 52.1 W/㎡ hr and 14.2 W/㎡ hr respectively. East and west sides are relatively heavily affected by neighboring buildings. Therefore, in order to improve urban solar potential, the number of building in the middle part of complex should be relatively reduced or secure long distance from adjacent east and south buildings to make better solar potential.

Tab. 5 Solar Potential by Height and Direction (Unit: W/㎡ hr)

Bldg No.	EAST			SOUTH			WEST			NORTH			Note
	1F	10F	20F	1F	10F	20F	1F	10F	20F	1F	10F	20F	
701	28.4	72.1	78.7*	56.4	67.3	75.5*	56.4	67.3	75.5*	29.0	34.9	40.6*	*19F Value
702	74.8	75.0*	N/V	68.6	75.5*	N/V	24.8	34.7*	N/V	39.2*	40.8	N/V	*9F Value
703	68.9	69.9	N/V	61.7	74.4	N/V	34.0	37.9	N/V	35.9	36.1	N/V	
704	53.6	64.4	78.7	53.6	64.4	78.7	34.3	37.1	45.1	34.3	37.1	34.3	
705	52.0	58.6	73.9	63.0	62.2	76.2	63.0	69.2	76.2	26.9	45.9	32.0	
706	53.6	65.1	77.3	61.8	67.6	75.5	61.8	67.6	75.5	23.3	24.0	31.8	
707	53.1	66.6	78.1	62.6	68.8	75.7	62.6	68.8	75.7	26.9	33.9	46.3	
708	60.4	62.6	73.4	76.9	76.9	76.9	76.9	76.9	76.9	21.7	23.1	30.3	
709	27.2	69.6	79.6	78.9	74.9	74.2	69.6	69.9	76.9	25.4	31.0	50.1	
710	77.2	78.6	N/V	79.8	79.8	N/V	30.7	31.8	N/V	30.7	35.8	N/V	
711	75.7	77.2*	N/V	57.1	69.0*	N/V	57.1	69.0*	N/V	22.2	24.0*	N/V	*9F Value
712	39.3	43.6	78.7*	57.8	67.2	74.6*	57.8	67.2	74.6*	33.3	39.9	47.6*	*19F Value

(3) Urban solar limitations

Urban solar limitation in the complex is mainly building shades between adjacent buildings. Building interference significantly deteriorates solar potential on middle and lower floors (Tab.5). The approach to improve solar potential in arrangement level is two way; (1) building density planning, (2) distance and angle between adjacent buildings. Building density can be decided on the basis of principles of solar access. In this case study, residential building pattern, in density aspect, is that east and south-east located buildings are relatively lower than west and north-west located buildings. This is due to the fact that optimal direction for solar potential in Korea is south or south-east, and with optimal arrangement, lower front located buildings can have an advantage to reduce building interference to adjacent the back or the left other buildings. Therefore, building density planning based on optimal arrangement is one of better ways to settle urban solar limitation.

Fig. 4 Density and arrangement in a case high-residential complex

Another obstruction to solar potential is distance and angle between the front and the rear adjacent buildings. Below Fig.5 is an example of triangle interference. In general, residential complex is designed to have short distances between buildings to maximize using the floor area ratio. In Fig.5, the back building of the two front buildings is easily shaded by the front buildings, especially, in the middle and lower floors which is crucial one of urban limitations. Hence, to minimize building shaded area on the surface, suitable distance is secured from the front buildings or wider angle among two front located buildings is needed. Given this context, high-rise residential housing in Korea has particular points in parts of building forms and arrangement. Therefore, in order to maximize solar potential in urban area and to exploit it for renewable energy system, above-mentioned points should be considered in the design stages.

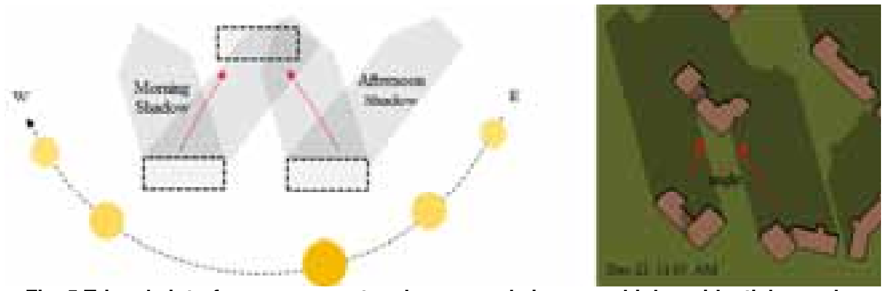


Fig. 5 Triangle interference concept and an example in a case high-residential complex

5. Conclusions

This study reviewed urban solar potential in high-rise residential buildings which are the most universal housing type in Korea. This study can be summarized as follows. In the single building level, surface azimuth and area size on each side can have large effect on the amount of solar gain. Also, building shapes can significantly affect solar potential because they can make self-shade on their surface which worsen vertical solar potential in urban areas. For instance, Flat-bending is weak to west and south side, and Tower single-wing type is feeble on east side when they face due south. Also, Tower types report larger dispersion range on the vertical solar potential than Flat types, which means Tower types in urban area are unfavorable on solar potential and inevitable to show lower solar availability because of such structural problems. On the other hand, high-rise residential building is disadvantageous for solar energy use. However, in urban environment, it is inevitable to avoid interference on solar potential between neighboring buildings due to high density. Therefore, high-rise residential building cannot help but consider effective mass design and arrangement to maximize solar potential and to use solar systems on upper floors or specific orientation. In triangle interference, in order to improve solar performance in lower and middle floors, proper distance is secured from the front buildings or larger angle among buildings is required. This study regarding building types and complex case can be valuable to understand urban solar potential in Korea. This result is expected to contribute, as a fundamental, for architect and engineers to create designs for low energy building.

6. References

Dapeng Li et al. (2015) Solar potential in urban residential buildings. Solar Energy 111, 225–235

M. Karteris et al. (2013) Urban solar potential in Greece: A statistical calculation model of suitable built roof areas for photovoltaic. Energy and Buildings 62, 459-468

Byeongho Lee et al. (2010) Comparative study of environmental sustainability in basic community planning for multiple stock housing based on lay-out types. Journal of Architectural Institute of Korea 26, 10. 271-282

Min-Hee Lee et al. (2009) An study on the application method of solar systems based on urban characteristics. Conference Journal of Architectural Institute of Korea 53. 693-696

Seonghwan Yoon and Seonyeong Jeong. (2009) Predictive Evaluation of Outdoor Thermal Environment in Summer of Apartment Housing According to Building Types and Site Planning Types, Journal of

Architectural Institute of Korea 25, 9. 321-328

Doosung Choi and Jinseok Do. (2009) A Study on the evaluation of the Residential Environment Efficiency by Arrangement of Multi-Family Residential Buildings - focused on the evaluation of daylight and view environment, Journal of Korea Institute of Ecological Architecture and Environment 9, 6. 57-64

Changho Choi et al. (2007) The possibility of PV application in Domestic Apartment and analysis of shade. Journal of Korean Institute of Architectural Sustainable Environment and Building Systems 1, 2. 1-7

Yoonbok Seong et al. (2004) A study on the variation of solar access right of apartment buildings according to site planning. Journal of Korea Institute of Ecological Architecture and Environment 4, 4. 35-45

Booseong Kang et al. (1999) A study on the spread of attitude to arrange standard housing buildings repeatedly at Korean housing estates. Journal of Architectural Institute of Korea 15, 9. 91-101

Passive design guideline (2012) Presidential Commission on Architecture Policy. available at www.greentogether.go.kr/fcs002004/actionFcs002004R01.do

Energy Census, Housing Census (2010), Apartment Housing Statistics(2013) Korea National Statistical Office. available at www.kostat.go.kr

Renewable energy dissemination of statistics (2013) Korea Energy Management Corporation. available at www.energy.or.kr