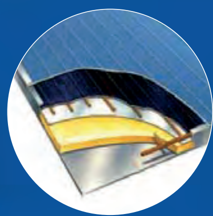
International Solar Energy Society

ISES Solar World Congress 2015

November 8 - 12, 2015
Daegu, Korea



Conference Proceedings

Organized by ISES International Solar Energy Society

Hosted by 사단법인 한국태양에너지학회 THE KOREAN SOLAR ENERGY SOCIETY

Conference Proceedings

Solar World Congress 2015

Daegu, Korea, 08 – 12 November 2015

Solar Constraints and Potential in Urban Residential Buildings

Chul Kim[1], Liliana Beltran[1]

[1] Texas A&M University, College Station (USA)

Abstract

High-rise residential building in Korea is distinctive. Urbanization level and city dwelling ratio are the nearly same even though the national land in Korea is 140 times larger than Singarpore. Above all, three-fourth of the number of total multi-family housing is above ten stories building. This signifies that today a half of Korean lives in high-rise residential building like apartment. Above all, giant residential areas in cities require huge energy to support residents' lifestyle. In this respect, solar systems are one of effective solutions for urban residential buildings. Thus, as a fundamental approach, this paper studies solar potential in high-rise residential buildings in Korea. High-rise residential building is gnerally unfavorable for solar energy. That is because, it is impossible to avoid diverse interferences from other urban factors. Therefore, high-rise residential building is required advanced strategies to maximize solar potential in order to set up renewable system in the near future. This study analyzed typical multi-family housing types and did a case study in the complex level to find the effective ways to solar energy. This result can be utilized for architect and engineers to refer to this study in their design to build low energy building.

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

1. Introduction

1.1. Backgrounds

Buildings are major one of energy consuming sectors in the world, and in Korea, they also account for 21.2 percent of total final energy consumption that consists of 9.3 percent and 13 percent in commercial building and residential building respectively (Energy Census, 2010). This share is still lower than transportation sector and industry sector, but will be expected to become like other cases in developed countries reported by IEA that residential buildings averagely consume about 27 percent of total final energy consumption. In Korea, the Photovoltaic (PV) and Solar thermal (ST) market is consistently growing by government promotion projects after 2008, due to green growth policy. Firstly, Korea Energy Management Corporation (KEMC), a public institution, has operated a supply business for renewable energy system such as PV and ST, especially giving financial packages that are totally about 20 million in 2015, and has carried forward a green villiage project that provides a financial aid to 35~50 percent per total installation cost. However, unlike such support, eight major metropolitan cities in Korea recorded 8.3 percent of the amount of power by region in renewable energy sector, and of that, the amount of power by residential buildings is only 0.4 percent in 2013 (Renewable Energy Dissemination of Statistics, 2013). Consequently, for making a better environment to supply solar systems, it is necessary to evaluate and to understand solar potential in urban residential buildings. However, Korean types of housing are distinguished from other building types. A census on population and housing conducted Korean National Statistical Office (KNSO) in 2010 also informed that multi-family housing, it captured 47 percent of total household, continuously has shown a growth from 53 percent in 2005 to 59 percent in 2010. Above all, over 75 percent of total multi-family housing is above ten stories buildings. Given this context, almost a half of Korean today is closely connected to high-rise residential building like apartment that consumes lots of energy to stay thier urban life. Therefore, to make environmentally-friendly urban space in energy use, successful strategies for urban residential buildings are required such as renewable system.

Also, in today's global society, many countires have energy concerns that fossil fuel will definitely be depleted in near future, but it will be still necessary in all fields of industries and public livlihood. 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 56 percent from 2010 to 2040 by world economic growth and especially, electric power demand will grow by 80 percent between 2012 and 2040 (IEO 2013). Hence, when it comes to energy performance in buildings, future energy requirement should be considered in order to reduce increased energy consumption by growing economy. It is necessary to achieve energy efficiency in many kind of manufacturing industries and all kinds of buildings for reducing excessive energy demand and postpone exhausting fossil fuel resources in near future. As a result of energy saving trends, many nations of the world are planning to go into effect on mandatory building codes to build low and zero energy buildings and to renovate old and existing buildings into high performance buildings. As many european countries will introduce zero energy building (ZEB) policy between 2015 and 2030, also Korean government has driven the movement to phase in ZEB as a mandatory policy from 2008 to 2025.

This means that many multi-family housing like apartment, especially in high-rise residential buildings, will have to be reviewed renewable energy installaiton with energy efficieny because only use of passive design and efficient building systems cannot gaurantee ZEB requirement on site. Therefore, to maximize building energy performance and to design buildings in urban area, urban solar constraints and potential should be understood and settled by designers and engineers. For this, in this research, it studied solar potential in urban high-rise residential building in Korea and, due to their typical forms and arrangement, the study can be gerneralized and utilized in whole country.

1.2. Objective of the study

The objective of this study is to investigate solar potential in urban areas such as Seoul, especially, focused on high-rised multi-family housing which have very dominated in Korean housing market. The study has three major pursposes; At first, multi-family housing in Korea has shown unique characteristics in its forms and arrangements. This is due to the fact that forms of multi-family housing are standardized by governmental institutes and contractors and sometimes, their methods for arrangement are guided in the stage of District Unit Planning by regional governments. As a result, multi-family housing complex in many Korean cities already forms their urban context, which are not particularly good in urban scape, but useful to gneralize to establish a dissemination strategy for renewable energy. On the second idea about this study, in a achitectural perspective, solar potential on building envelop can be easily affected by physical features of buildings themselves such as mass projection. Besides, in urban scale such as a multi-family housing complex, solar potential can be strongly influenced by interaction between building structures. Last but not least, development in very densely urban areas usually requires high energy efficiency and for that, building renewable systems should be optimized and effectively planned, and in this respect, this study as a reference is meaningful in the importance for practical experts. Therefore, this study investigates Korean high-rise residential buildings focused on their forms and arrangement, and diagnoses solar potential in building level. And then, it analyzes solar potential through a case study of urban residential complex. By means of the result of this research, architects, engineers and building owners can more understand solve potential and effectivley design buildings with considering urban solar obstacles.

1.3. Research process

This study analyzed solar potential on building envelope and roof that can be used for PV and ST. With study in building and urban scales, this looked through urban solar limitations and solutions. This research is composed of a three-step procedure:

(a) The first step is to study preceding researches on solar potential. Solar potential is usually used a term as solar applicability or solar radiation that is calculated by a ratio of area on the building envelop. This paper deals with topics and results on solar potential by other authors.

(b) On the second step, the research aims to study solar potential and constraints on the building types' level. For this, this study looked into main residential types in Korea and simulated their solar performance. With analysis, solar limitations and solutions are sought.

(c) Last but not least, case study in building complex level is carried out to predict actual solar potential on the building skin. The next step is to analyze a high-rise multi-family complex in Korea that can explain how direction, building arrangement (interference between buildings) can affect solar potential in urban context. As the final outcome, solar potential and constraints are rated to find solutions.

2. Literature review

First of all, residential buildings in Korea have 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] have explosively grown over 10 times from 6 percent to 63 percent in total residential stock (Housing Census, 2010). Actually, plenty of new cities were constructed since 1980s with multi-family housing constructed in earnest and consequently, housing supply ratio presented from 86 percent in 1995 to 118 percent in 2014 in housing census by KNSO. Moreover, 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). Given this context, this study regarding solar potential in Korean high-rise residential buildings can have power of influence to many apartments to be more energy efficient.

In this respect, this paper looked for ways of optimization methods on solar potential in preceding research. Many studies have already developed possible approaches to improving solar access, but still have a distance to explain urban limitations in residential buildings, most of all, because residential building types in Korea are distinguished from other countries in their residential types and patterns. Also, researches in Korea mainly focused on right of solar access in solar potential related researches (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 envelop of the 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 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 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, in present, availability and limitation on urban solar potential are still in progress. On account of specificity in location, design and analytic condition, more study to be generalized and exploited should be studied for solar energy use in Korean urban areas.

3. Building type analysis

3.1. Korean multi-family housing

In 2007, Ministry of Land, Transport and Maritime Affairs in Korea reported that residential buildings in national cities recorded 68 percent and took up the largest portion in all building types. Among all cities, Seoul and Kyunggi-do form a large metropolitan area where 43 percent of Korean population live and the greatest number of residential buildings are built. However, regardless locations, Korean multi-family housing have typical patterns in their forms. Doosung Choi and Jinseok Do (2009)[3] surveied 74 multi-family

[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 builing as a row house by law and its height is limited below 4 floors. Also, seveal households can live in row houses. (KNSO)

[3] 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 referenc 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.

housing complex and 919 multi-family housing buildings built after 2007 to classfy multi-family housing category. Consequently, it informed that flat-type and tower-type occupied 57 percent and 43 percent resectively among investgated building types. Building size depend on the number of units and is changed due to the building conditions. Claasified types of multi-family housing is as below table.1. Types of multi-family housing has 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, this research, from the building level, studied solar performance.

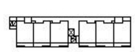
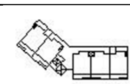
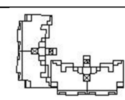
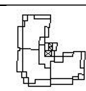
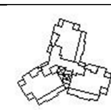
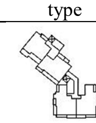
Tab. 1: Leading multi-family housing types in Korea (Doosung Choi 2009)

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

Aims to solar potential in this study are to investigate cause and effect on solar radiation and building shade by building itself. In general, the forms and envelop designs of multi-family housing are primary factors to affect solar radiation on the building surface. Severe building shade can reduce solar potential on the surface in adjacent buildings and its causes are usually its high density or mass projection. Moreover, Korean residentail building has a character that it relatively has broad surface area per volume to get more solar radiation due to general people's preference of sunshine. However, in analysis of an independent building, because 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 affect in complex level. Therfore, assessment in buliding types focuses on the amount of solar radiation, orientation, seasonal changes and restrictions by building design. For this, building height are decided to 16 stories that is one of standards to define tower types, and in a independent building anlysis, building height cannot affect building solar radiation and changes. This study simulated buildings by IES-VE Apache and Sun-cast that can review solar radiation and building shade through their modules to estimate quantitative peroformance on the envelope. Building location is set on Seoul and Seoul weather data is used 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.

Tab. 2: Multi-family residential building information for 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 (㎡)	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

(1) Solar potential

In general, building forms, in solar access, significantly affect solar gain and building shade to itself. Solar potential in every building type is 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 sides on the same direction show different solar potential due to azimuth difference and projection by building forms. As a result of simulation analysis, solar radiation on the roof is the same as 105.2 W/㎡ hr because building roof has no shade 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, almost its units can have an optimal direction in solar access. Values of simulation reports that annual solar radiation on long sides in typical floor by directions is that east, west, south and north are 65.2, 61.3, 81.8, 39.8 W/㎡ hr respectively. 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 two sides are perpendicular crossing which makes two continuing sides have completely dissimilar directions to receive solar energy. At the same time, two perpendicular sides on an opposite side are relatively weak to gain solar energy due to be shaded by building itself. Its directional solar potential is 65.3, 62.0, 78.3, 39.9 W/㎡ hr in a row to east, 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, north on the vertical side are 65.9, 88.4, 96.5, 19.9 W/㎡ hr. Comparing solar potential by building types to average solar radiation 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 weakpoint on less solar potential side. For example, Flat-bending is vulnerable to west and south side.

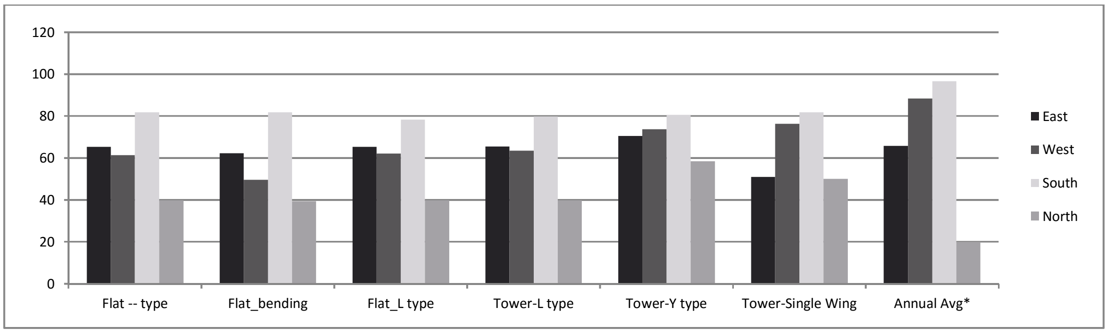


Fig. 1 Annual solar potential on the external walls

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 70.4, 73.7, 80.6 and 58.4 W/㎡ hr. Tower singlewing-type is 50.9, 76.4, 81.7, 50.0 W/㎡ hr. Comparing these data to Seoul's average solar radiation, east side has 77.2~106.8% difference, west, south, north seperately show 71.9~86.4%, 82.7~84.7% and 200.3~293.3% in solar radiation on the surface. One of causes is azimuth difference on the surface at each side and building itself shades its surface due to its roughness and projected mass, such as Tower single-wing type is delicate on east side. Actually, optimal orientation in Seoul is east-south or south (135~210 degree). Nevertheless, Tower types are comparatively exposed to unfavorable directions since their building forms preferentially decide their orientations before their building arrangement. Consequently, even if all building face to the same direction on their placement, surface azimuth and area size on each side can have a large effect on the amount of solar gain.

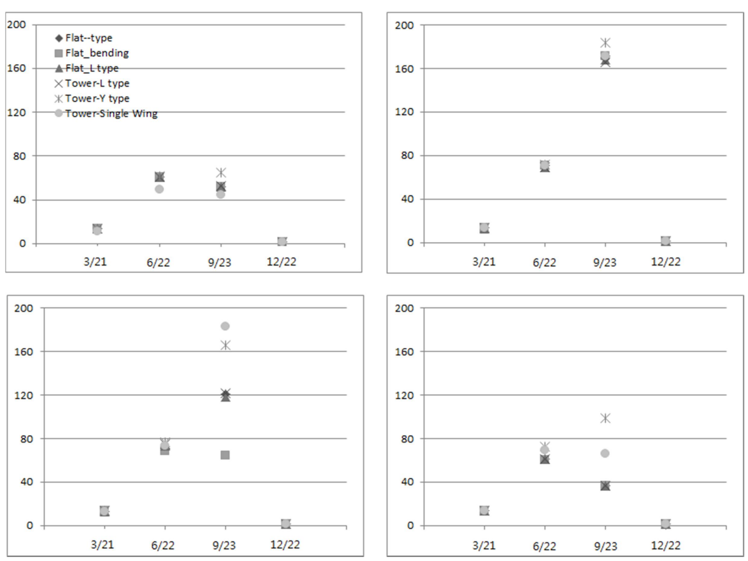
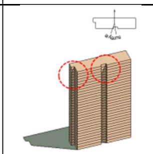
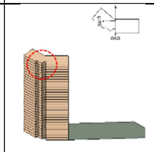
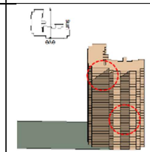
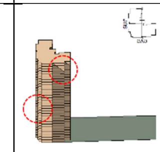
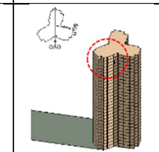
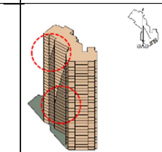
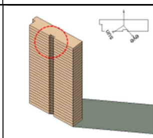
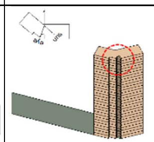
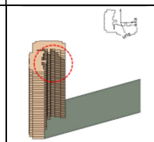
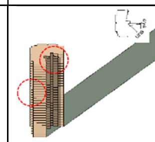
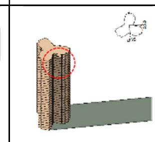
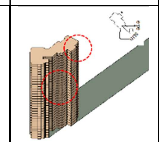


Fig. 2 Seasonal solar radiation on the external walls

(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 ** Case :only one side on a particular direction

(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 gain. West pattern is similar with south in aspect that it takes large solar raditaion on fall equinox. Besides, 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 chnages, influence on solar potential by building types is insignificant.

(3) Building constraints

So far, this study analysed directional and seasonal solar potential by building types of multi-family housing. On the independent building level, solar limitations are as the following; 1) building itself shade, 2) 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 form, 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, 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 weakpoint in building heat gain or loss. This is because low POP ratio indicates that the building has reletively lots of protruded parts on its envelop 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 forms. Given this, preferably, wider building surface on Tower types should be exposed to optimal direction to have better solar potential and reduce building loads.

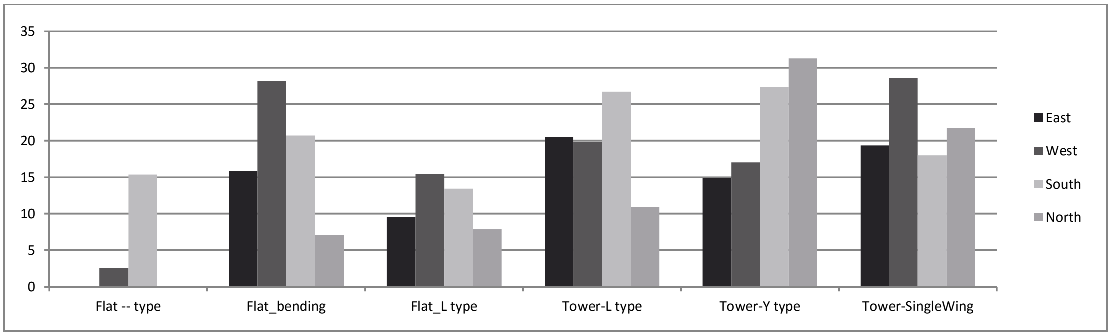


Fig. 3 Solar potential difference between max and min values on the same orientation

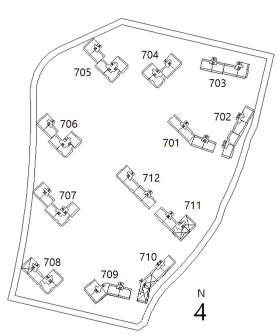
Self-shade presents another limitation. It makes solar potential difference on the same direction. Fig.3 reports how much self-shade by mass projection aggravates solar potential. Flat –type and Flat bending-type are almost same in their forms because it is merely different on 18 degree mass bending. 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 low solar availability due to their structural problems. Accordingly, in order to solve these limitations in urban space, simplification on sun-exposed envelop and optimal arrangement to direction should be far outweighed.

4. Residential complex analysis

4.1. Arrangement of residential complex

Arrangement methods have been developing following building codes and the demands of the times. Primary features of arrangement as follows: Since 1941, practice in fields of construction and design by governmental institutes and construction contractors has generally used typical building drawings, which have affected present 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 a 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). All Korean residential buildings should meet a standard for solar access right in accordance with the provision of Article 53 in the Building Code and Article 86 of the its Enforcement Ordinance. Thus every building that faces other buildings has to have a 0.8 times distance between buildings based on due south (Yoonbok Seong et al., 2004). In this context, the solar limitation of a case residential complex can be a 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 that interference by building shade affects solar potential on the surface. Case complex is a design planning of a prize winner in 47 Block in Dongtan-2 District, Hwasung and it is currently under construction. This project is a governmental project to distribute affordable houses to general people and the number of unit is around 930 households. Number of stories is from 9 floors to 23 floors and east-southern buildings are comparatively lower than west-northern 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, it is very different in vertical solar potential on 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 become main one of urban limitations for renewable use. In the table 5, buildings in the middle location of residential complex (702, 712) are Flat-bending-type (701) and Flat – type (712) that their forms are generally better performance to get solar energy than tower-types. However, in this complex, they are easily influenced by surrounding buildings which affects solar potential on their different stories, especially difference between 1F and 20F is obvious. For example, in 701 building, east-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, buildings can cause severe influence on solar potential and give rise to reduce solar potential for use of renewable system.

On the east side 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 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 difference 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 buildings. Therefore, in order to improve urban solar potential, the number of building in the middle 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). Approach to improve solar potential in arragement level is two way; (1) building desity planning, (2) distance and angle between buildings. Building desity can be decided on the basis of approach of solar access. In this case study, residential building pattern, in density aspect, is that east and south-east buildings are relatively lower than west and north-west 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 buildings can have an advantage to reduce building interference to adjacent other buildings. Therefore, building desity planning based on optimal arrangement is one of better ways to settle urban solar limitation.

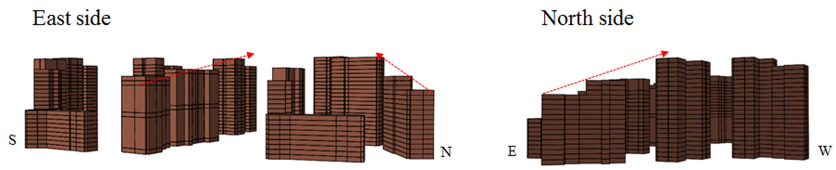


Fig. 4 Density and arrangement in a case high-residential complex

Another obstruction to solar potential is distance and angle between buildings. Below Fig.5 is an example of triangle interference. In general, residential complex is designed within short distances between buildings to maximize using the floor area ratio. In Fig.5, the back building of two front buildings is easily shaded by front buildings, especially, in 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 front buildings or wider angle among 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.

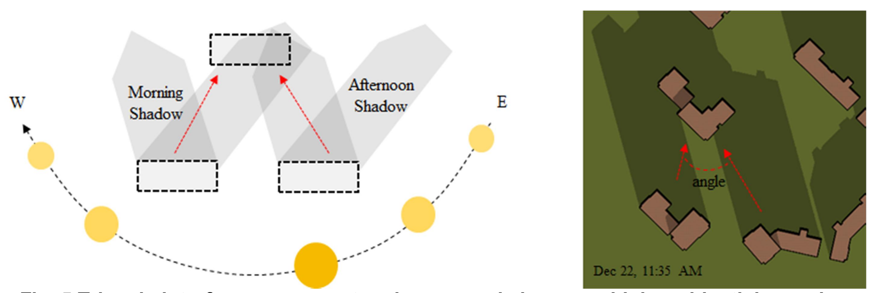


Fig. 5 Triangle interference concept and an example in a case high-residential complex

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 building level, surface azimuth and area size on each side can have a large effect on the amount of solar gain. Also, building forms can significantly affect solar potential because they can make self-shade on their surface which worsen 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 solar potential than Flat types which means Tower types in urban area are unfavorable on solar potential and inevitable to show low 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 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 front buildings or larger angle among buildings is required. This study that investigated building types and a case study can be valuable to understand urban solar potential in Korea. This result is expected to contribute, as a fundamental, 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 photovoltaics. 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