Adaptability of photovoltaic mono-polycrystalline solar panels and photovoltaic roof tiles on dwelling roofs of real estate developments

Adaptabilidad de paneles solares fotovoltaicos mono y policristalinos en techumbres de viviendas de emprendimientos inmobiliarios

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Abstract
The use of photovoltaic (PV) technology in urban areas is an appropriate way to optimize the use of solar energy, since the energy conversion system is located in the same place as the demand. Thus, the losses caused by distribution networks and even technology costs are reduced; in addition, less space is required for energy production in the countryside. Energy can be produced in neighbourhood dwellings located in the periphery in low-density areas that contribute to supplying electricity to high-density urban centres. The performance of a solar system largely depends on the integration capacity of solar panels in building roofs or facades to maximize production. This research has analysed the integration of this type of system in the roofs of new types of housing in developing countries and its adaptability attributable to the geometry of solar panels with regular-sized mono- and polycrystalline cells. This research is based on 32 sloped roof typologies built since 2010. The main results indicate that an average of 36% of the roof surfaces are not useful because of their irregularity; in addition, the small solar panels show more adaptability, although less than expected with respect to large-format PV panels.

Keywords: Solar roofs, solar energy, photovoltaic, monocrystalline cells, polycrystalline cell.

Resumen
La integración de fotovoltaicos en zonas urbanas es una alternativa óptima, el sistema de conversión está en el mismo lugar que el consumo. Se reducen entonces las pérdidas por redes de distribución, así como impacto y ocupación por explotación y producción energética en zonas agrestes. Las viviendas bajas en zonas urbanas periféricas por su geometría pueden contribuir al suministro de electricidad tanto de demandas propias y generar excedentes exportables. En este escenario, el rendimiento de un sistema solar depende en gran medida de la capacidad de integración de placas solares en techos o fachadas. Esta investigación analiza la capacidad de integración de fotovoltaicos en techos de viviendas resientes, acorde a características geométricas de paneles solares de formato regular de células mono y poli-cristalinas y un modelo de teja fotovoltaica. Esta investigación levanta tridimensionalmente 32 tipologías de techo inclinado construidas desde 2012 a través de herramienta BIM. Los principales resultados indican que hay un promedio del 36% de la superficie del techo que no es útil en paneles solares normales y del 12% para tejas fotovoltaicas. Además, paneles solares de formatos menores muestran una mayor adaptabilidad, aunque en menor medida de lo esperado respecto a aquellos de gran formato.

Palabras clave: Techos solares, energía solar, fotovoltaicos, placas de celdas cristalinas, tejas pv.

Introduction

One efficient way to use solar energy is by converting it to thermal or electric energy in urban areas by installing solar collectors and solar panels directly on buildings, roofs and/or façades. This reduces transmission losses and minimizes the space required to install the collectors and panels (Byrne et al., 2016; Carlisle et al., 2009; IEA, 2009; Mikkola & Lund, 2014). According to Mikkola & Lund 2014, in 2040, at least 65% of the world's population will reside in urban areas; thus, the use of solar systems to develop more sustainable urban environments is a good solution to reduce both ambient pollution caused by heating systems and to reduce the autonomy and costs of the people, by developing more sustainable urban environments. The efficiency of solar systems depends strongly on urban configuration. From a solar perspective, a good urban design will promote conditions that maximize solar collection to improve the efficiency of solar thermal and photovoltaic systems (Cárdenas & Uribe, 2012; Freitas et al., 2015). With good urban and architectural planning, it is possible to have buildings that, on balance, make a zero or negative external energy demand annually. This obviously requires more investment to improve building envelopes by using more efficient equipment and by applying passive techniques such as natural ventilation and improved solar gains (Disch, 2010; Lund, 2012; Zalamea & García Alvarado, 2014).

Nevertheless, there are some constraints on solar energy availability. It changes hour to hour, day to day and month to month, which absolutely requires the use of energy storage systems to match building energy demands (Salpakari et al., 2016). In most cases, solar energy is not enough to satisfy a building's thermal and electric demand; thus, an auxiliary system is usually required. Electricity can be sold to the electric grid, which also imposes constraints on the electric distribution network, which must be adapted (sized) for variable conditions because of the injection of electricity produced by solar systems (Wegertseder et al., 2016).

Worldwide, monocrystalline and polycrystalline silicon solar-cell panels are the most commonly used PV technologies: 95% of PV roofs use these technologies (Cerón et al., 2013). Thus, the modular sizing of an individual monocrystalline or polycrystalline cell will dominate the dimensions of commercial PV panels. The shape of the wafers used for the cells results from the manufacturing process, and the most common square shape is 6 inches per side. In the case of monocrystalline cells, the four corners of the square shape are cut off at an angle of 45° because they are obtained from the cylinder of a circular base, whereas polycrystalline cells do not have this cut-off, since their manufacturing process involves crystallization (Luque & Hegedus, 2011). Polycrystalline cells are less expensive to produce than monocrystalline silicon cells, but less efficient.

From an architectural point of view, the use of PV panels creates challenges such as architectural integration, pursuant to which PV must perform additional tasks such as roof coating, shading, providing balustrades, etc. (IEA SHC Task 41, 2012). New products as PV roof tiles are emerging in the market, these are promising alternatives from architectural perspective. Several products for roofing architectural integration have been developed, with different sizes and technologies; thin film solar cells added in regular ceramic roof tiles are becoming popular (Tesla, 2017). These new products are available in different sizes but smaller than regular solar panels, so a better occupancy according to geometric adaptability is expected.

Kaan & Reijenga (2004) provide suggestions to architecturally integrate these systems. In recent years, PV technologies such as amorphous silicon, CdTe, CiGs, and organic compounds have been developed and can also be considered for integration in buildings. However, these technologies do not have the maturity of crystalline silicon-based solar collectors, and suffer from lower efficiency or higher costs. Thus, it is assumed that crystalline silicon-based solar collectors will continue to be manufactured for a long time with the potential to be integrated into buildings (Building Integrated Photovoltaics, BIPV). Products such as small PV roof tiles still lack the confidence of installers because of their installation complexity and maintenance limitations (Cinnamon, 2016a). Therefore, it is very important to evaluate the effect of the configuration of the solar panels and their geometry, taking into account their adaptability in sloped roofs, by considering that this surface is normally the most irradiated by the sun, especially at low and middle latitudes.

State of the art

Some studies have evaluated the potential of solar panels to supply a building's energy demands (Chen and Yin, 2016), along with the possibility of integrating them into the buildings (Cerón et al., 2013; Jelle, 2016).

Several capabilities were proposed for determining the solar potential in urban areas to use it in passive or active systems (Compagnon, 2004). In order to include active systems, some geographic information has been collected, which has been used to evaluate the solar radiation on buildings surfaces (Izquierdo, Rodrigues, & Fueyo, 2008). Some other techniques like the use of radar or lighting levels on the roofs have been also used to evaluate the solar potential on roofs (Lukač & Žalik, 2013). These methodologies allow to determine the solar potential in different kinds of architectonic typologies, by considering the Some years ago, several capabilities were proposed for determining the potential to use passive or active solar systems in urban areas (Compagnon, 2004). For active systems, some geographic information has been collected and has been used to evaluate solar radiation on roofs (Izquierdo et al., 2008). Other techniques such as the use of radar or lighting levels on the roofs have also been used to evaluate roofs' solar potential (Lukač & Žalik, 2013). These methodologies allow determination of the solar potential in different kinds of architectonic typologies by considering total roof availability in urban areas (Izquierdo et al., 2011). The integration of PV systems into the electrical grid has been analysed in various studies that have determined constraints such as the difference between demand and generation, along with some well-known constraints imposed by the size of the local grids (Wegertseder et al., 2016; Jongerden et al., 2016). These studies evaluate solar potential by considering the total available roof surfaces without considering the effect of the geometry of regular-sloped roofs and the restraints related to the adaptability of solar panels. From an architectural point of view, the aspectual expression of photovoltaic technology has been extensively analysed (Munari, 2009; Wall et al., 2012), but aspects related to mono- and polycrystalline cells and the consequences of their adaptability to building roofs have not been considered.

In Chile, the use of renewable energy in buildings has been promoted both to mitigate the high cost of energy and to reduce the pollution associated with the combustion of fossil energies and wood. That notwithstanding, solar accessibility for buildings has not been developed (Cárdenas & Uribe, 2012). Some measurements have been made to evaluate solar potential by using techniques based on aerial roof photographs (Araya-Muñoz et al., 2013), by developing a characterization of urban typologies (García et al., 2014) and by conducting studies to evaluate the solar potential in typologies of urban entrepreneurship by considering some geometrical aspects of integrating solar panels (Zalamea et al., 2016). In a previous study, Zalamea et al. (2014) have pre-dimensioned the shape of the best wing-roof by case according to orientation and size, and the available radiation on these surfaces was identified. They concluded that it is possible to supply up to 75% of a building's total electric demand through PV integration, but with 100% occupancy, full coverage would be impossible because of PV geometry. Additionally, studies have evaluated the shape of the roof with the highest solar potential and the shape of the roof with the lowest solar potential (Zalamea et al., 2016). However, it is impossible to find results to correlate the type and geometry of solar panels with roof shapes, inclinations and specific dimensions. This work's primary contribution is to detect the extent to which it affects the shape and dimension of typical solar panels compared to roof geometry. This simple analysis has not yet been carried out. It is clear that solar panels with lower dimensions are more easily adaptable to any roof shape, particularly to more complex shapes. However, it is not exactly clear which is the best solution and to what extent that is the case. Therefore, this research proposes to evaluate the integration of commercial PVs in sloped roof houses and geometric and dimensional surfaces, considering both mono- and polycrystalline solar panels in regular commercial sizes.

Methodology

In a previous analysis by Zalamea & García (2014), heating and electricity demands on buildings and some characteristics of the geometric roof were determined for different types of single-family housing typologies by identifying the location on the roof with the best solar potential in each case. In this study, all the cases were considered by selecting the roof shape's best characteristics and obtaining the main geometrical indicators.

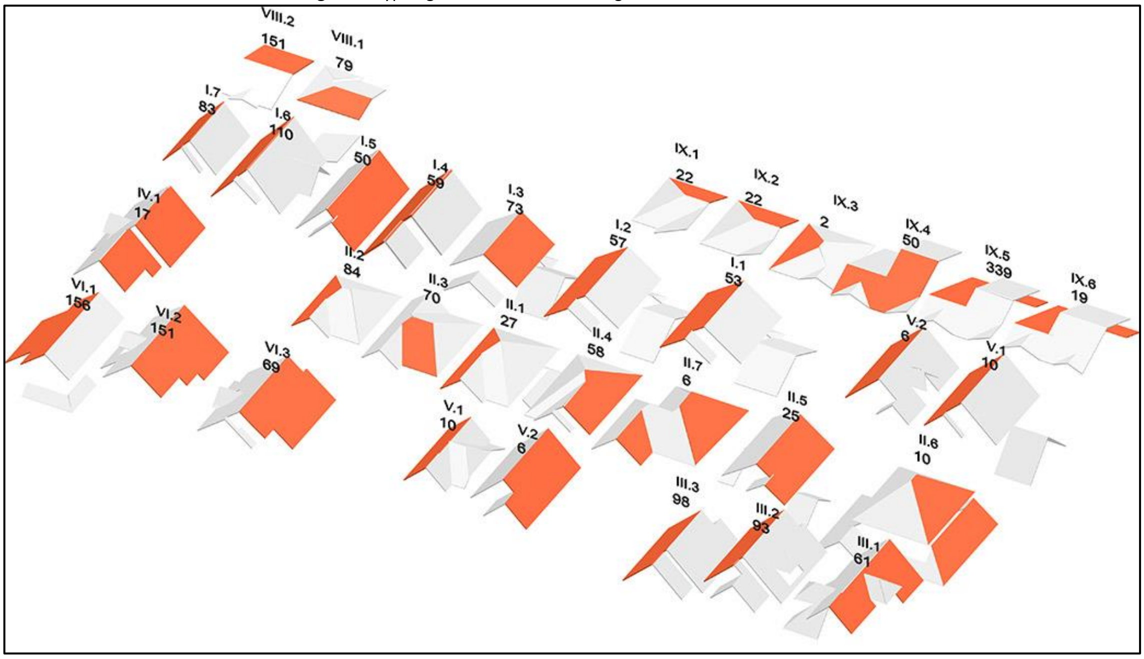
According to the shape and dimensions of the monocrystalline or polycrystalline silicon cell, one can obtain typical dimensions found in the market, with cells grouped in a rectangular shape that has 6 inches on each side. Although these panels are designed to be added to buildings (Building Added Photovoltaics, BAPV), it will be more interesting to construct panels to be integrated into buildings (Building Integrated Photovoltaics, BIPV). However, this research establishes the consequences of forms and panel sizes in both cases: new BIPV products and currently available BAPV products. First, an analysis of the commercial panels is developed to identify the most frequent dimensions and shapes available in the market. Second, an analysis of roof shapes in urban housing developments is performed, superimposing the solar panels on the forms of the roofs to detect tendencies, adaptability and where to receive irradiation, simulating either horizontal or vertical placement. The main output of this analysis is to determine whether the useful area of the roof for PV collection, which provides the maximum energy conversion, is strongly dependent on the panel geometry.

Results and discussion

Identification of building roof shapes located in urban entrepreneurship

To identify the different geometries and shapes of residential building roofs, 2,132 houses were considered. This analysis identifies 33 roof typologies, which are shown in Figure 1.

Figure 1. Typologies of residential housing roofs. Source: The authors.



Characterization of photovoltaic panels geometry

According to commercial PV product analysis, there are three types of solar panels composed of crystalline cells of 6 inches per side. In the panel classification based on the number of PV cells, the bigger panels have 72 cells, the medium-sized panels have 60 cells and the small panels have 36 cells. There are even other solar panel sizes for solar cells and quantities, resulting in many solar-panel formats, but those analysed in this research are the most common. The 72-cell panels have 6 rows of 12 cells each, the 60-cell panels have 6 rows of 10 cells each, and the 36-cell panels have 4 rows of 9 cells each. The dimensions of the solar panels of the same number of cells, are not exactly the same, but they have very similar sizes, as shown in Table 1, with only a few millimetres of difference among them. Thus, for the analysis developed in this study, we take an average dimension of the three typologies for integration into the building roofs. This enables us to determine the capability for integrating the PV panels into roofs.

The average length and width of each type of solar panel was taken as reference. Using this procedure, the reference dimensions for the solar panel of 72 cells have a length of 1,970 mm and a width of 974 mm; the 60-cell solar panel has a length of 1,643 mm and a width of 944 mm, and the 36-cell solar panel has a length of 1,497 mm and a width of 672 mm. Consequently, these dimensions are used in the roof models analysed to determine the availability of the resulting photovoltaic collecting surface. Due to the diversity of existing formats of PV roof tiles, it is not possible to establish a similar relationship between this kind of products. In consequence, the format of the product know as "Smooth" of Tesla inc has been adopted, considering that this typology corresponds to regular size of a roof tile. The size of this tile model is about 356 mm by 220 mm.

Analysis of the integration of solar panels into roofs

By performing a three-dimensional analysis using BIM Archicad@ 19, it was possible to configure the different solar panels' placement or location on building roofs. Using the vector texture software tool, it is possible to superimpose the grid texture representative of the formats of 72-, 60- and 36-cell photovoltaic solar panels on the roofs. Using this as a template, the effective surfaces for collecting solar irradiation are redrawn, and the effective photovoltaic surfaces were obtained using the BIM sizing tool. The panels are located longitudinally and transversally to determine the number of panels for every panel type that can be effectively installed on the roofs. This allows us to identify the ratio among the roof surfaces that are occupied by the solar panels while considering the overall surface available on the roofs. Although the panels used in this analysis are not designed to be architecturally integrated into the building, it is expected that in the near future, technology will be developed to integrate panels into building roofs according to IEA-SHC (Farkas, 2013) and developed from normal-sized silicon solar cells. Consequently, there is a good possibility that they will be built in sizes similar to those proposed here. The solar panel of crystalline silicon cells presents a great potential for integration in buildings because of its technological maturity, its high efficiency (NREL, 2017), and its large format, which requires less installation work and poses less risk of installation mistakes. This last aspect is very closely related to the installation process, because small PV-like photovoltaic tiles require a large amount of interconnections and wiring, making it difficult to detect any connections (Cinnamon, 2016b).

Table 1 shows the results of the best capabilities reached in each case. From the 33 models analysed, in 18 cases the PV panels of 36 cells had the largest capacity, in 13 cases the PV panels of 60 cells had the largest capacity, and in 10 cases the PV panels of 72 cells had the largest capacity. The logical result of a better surface occupation of the smaller formats occurs; however, this situation appears only in 55% of the cases, compared to 30% of the situations, in which the largest area of effective solar capture is achieved by panels of 72 solar cells. But with smaller format of PV roof tiles, in every case, the surface occupancy is always higher. It is verified that although in most situations it is possible to use the surface area better with smaller panels, this does not mean that smaller panels will always have better adaptability, as it might seem logical; in relevant proportion, larger panels provided better occupation. In some cases, the resulting solar capture surface coincides with the deployment of different panel formats, a situation shown in the modular format of the 6-inch solar cell panels analysed in this study.

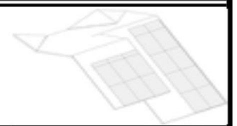
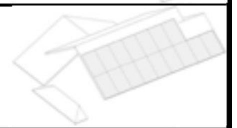
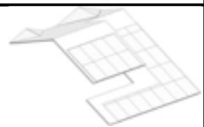
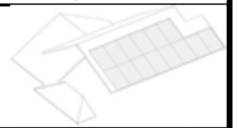
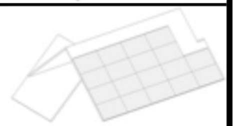
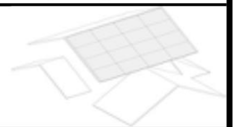
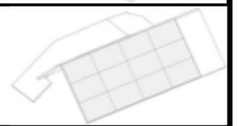
Table 1. Characteristics of the monocrystalline and polycrystalline silicon-cell solar panels.

72-CELL CRYSTAL SILICON PHOTOVOLTAIC PANELS						
	cm	cm	cm	# Cells	Technology	References
Trina Solar	195.6	94.1	4	72	Polycrystalline	http://www.trinasolar.com/HtmlData/downloads/us/US_Datasheet_PD14.pdf
Maxpower Panels	195.4	98.2	4	72	Polycrystalline	http://www.canadiansolar.com/fileadmin/user_upload/downloads/datasheets/v5.5/Canadian_Solar-Datasheet-MaxPower-CS6U-P-v5.52en.pdf
SOLARWORLD 320	199.3	100.1	3.3	72	Monocrystalline	https://www.altestore.com/store/solar-panels/solarworld-320-watt-solar-panel-sunmodule-sw320-mono-v40-frame-p11864/
Sunmodule SW 315-320 MONO	198.5	95.5	4.6	72	Monocrystalline	https://www.solarworld-usa.com/.../sunmodule.../sunmodule-pro-...
YLM 72 CELL	196.0	99	4	72	Monocrystalline	http://d9no22y7yqre8.cloudfront.net/assets/uploads/products/downloads/DS_YLM72Cell-36b_40mm_EU_EN_20160121_V04.pdf
Average Dimensions	197.0	97.4	4.0			

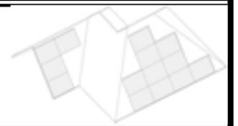
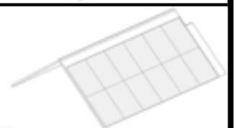
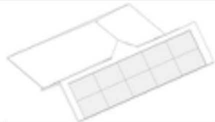
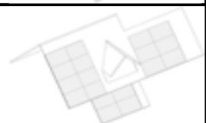
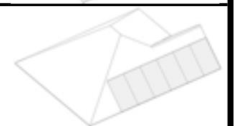
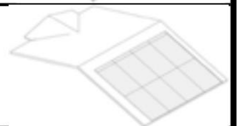
60-CELL CRYSTAL SILICON PHOTOVOLTAIC PANELS						
	cm	cm	cm	# Cells	Technology	References
Solar Brightstar LG	165.1	99.1	4.6	60	Monocrystalline	http://brightstarsolar.net/2014/02/common-sizes-of-solar-panels/
Solar Gaines	165.1	101.6	4.0	60	Monocrystalline	http://blog.solargaines.com/is-there-a-standard-size-of-solar-panels
Sunmetrix	164.0	99.0	4.5	60	Monocrystalline	http://sunmetrix.com/solar-panel-size-for-residential-commercial-and-portable-applications/
The Greenage Suntech	166.5	86.1	5.0	60	Monocrystalline	http://www.thegreenage.co.uk/how-many-solar-panels-can-i-fit-on-my-roof/
The Greenage Sanyo	161.0	86.1	3.5	60	Monocrystalline	http://www.thegreenage.co.uk/how-many-solar-panels-can-i-fit-on-my-roof/
Average Dimensions	164.3	94.4	4.3			

36-CELL CRYSTAL SILICON PHOTOVOLTAIC PANELS						
	cm	cm	cm	# Cells	Technology	References
SYNTHESISPower	148.2	67.4	3.5	36	Polycrystalline	http://www.solarpanelstore.com/assets/SP130-150P-36.pdf
Kyocera	150.0	66.8	4.6	36	Monocrystalline	http://www.solarpanelstore.com/pdf/KD145SX-UFU.pdf
Carmanah	150.0	66.8	4	36	Monocrystalline	http://www.solarpanelstore.com/pdf/Go_Power_SPC_CTI-160-C-vA.pdf
Solartech	150.4	67.4	5	36	Polycrystalline	http://www.solarpanelstore.com/pdf/SPM140P-BP.pdf
Solarland	150.0	67.5	5	36	Polycrystalline	http://www.solarpanelstore.com/pdf/SLP15012_150011234.pdf
Average Dimensions	149.7	67.2	4.4			

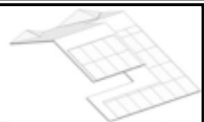
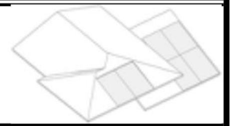
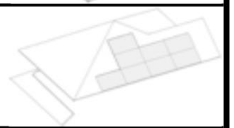
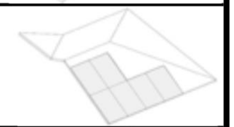
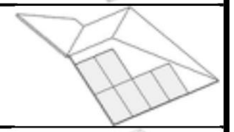
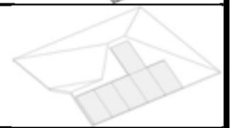
Table 1. Integration of solar panels into building roofs. Source: The authors.

Code	Roof area main wing roof(m2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Tolal solar capture surface PV roof tiles (m^2)	Axonometry	Code	Roof area main wing roof(m^2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Tolal solar capture surface PV roof tiles (m^2)	Axonometry
I.6	44.1	30	60	43.8	42.0		IX.4	49.2	34	36	29.8	44.2	
VI.1	53.1	46	36	40.3	50.6		I.2	35.8	16	72	28.0	34.7	
IX.6	65.0	23	72	40.3	60.4		I.1	32.8	18	60 y 72	26.3	31.9	
VI.3	48.6	27	60	39.4	42.2		V.1	34.8	16	72	26.3	33.5	
II.6	58.3	25	60	36.5	53.8		I.3	27.9	16	60	23.4	26.8	
III.1	52.3	41	36	35.9	46.0		VII.1	27.6	16	60	23.4	25.8	

Continuation of **Table 1.** Integration and geometrical adaptability of solar panels on dwellings roofs. Source: The authors.

Code	Roof area main wing roof(m^2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Tolal solar capture surface PV roof tiles (m^2)	Axonometry	Code	Roof area main wing roof(m^2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Tolal solar capture surface PV roof tiles (m^2)	Axonometry
VII.2	45.8	40 y 20	36 y 72	35.0	43.4		II.7	36.1	24	36	21.0	32.3	
VI.2	47.2	40 y 24	36 y 60	35.0	45.0		II.4	26.6	14	60	20.4	24.4	
I.4	42.8	40	36	35.0	41.2		I.7	24.6	12	60	17.5	23.6	
III.2	40.0	24	60	35.0	37.5		II.3	22.1	18	36 y 72	15.8	20.0	
IV.1	52.7	39	36	34.2	47.7		II.1	23.9	17	36	14.9	21.5	
I.5	43.9	23	60	33.6	40.2		VIII.2	19.3	8	72	14.0	17.3	

Continuation of **Table 1.** Integration and geometrical adaptability of solar panels on dwellings roofs. Source: The authors.

Code	Roof area main wing roof(m^2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Total solar capture surface PV roof tiles (m^2)	Axonometry	Code	Roof area main wing roof(m^2)	# solar panels	Solar Panel (# cells with best adaptability)	Total solar capture surface (m^2)	Total solar capture surface PV roof tiles (m^2)	Axonometry
IX.5	62.7	37	36	32.4	50.9		VIII.1	23.5	15	36	13.1	21.2	
V.2	39.2	36	36	31.5	37.8		II.2	17.2	12, 6 y 6	36, 72 y 72	10.5	15.4	
III.3	44.6	21	60	30.7	35.7		IX.2	15.9	11	36	9.6	14.4	
II.5	36.5	17	72	29.8	35.3		IX.1	15.2	10, 10 y 6	36, 36 y 60	8.8	13.3	
							IX.3	16.4	10, 6, 6, 5, 5	36, 60, 60, 72 y 72	8.8	14.6	
60 CELLS SILICON PV PANELS OCCUPANCY (%)													71.8%
% PV ROOF TILES OCCUPANCY (%)													88.3%

The indicator that is considered the most important finding of this study is the proportion of occupancy of solar cells or effective PV surface against total roof area. Curiously, among the three types of deployment, the indicator shows close results: 72-cell panels need an average of 61.5% of available roof surface, 60-cell panels need an average of 64.3% occupancy and 36-cell panels rarely obtained an occupancy lower than the 60-cell panels, reaching only 63.7%. This last indicator suggests that on average, on existing roofs, the inclusion of large format plates does not show that the solar collecting net surface is penalized. Consequently, the expected energy production will not be affected by this aspect. Regarding the best occupancy considering the longitudinal or transverse layout factor of the panels of the formats analysed, it might be believed that longitudinal deployment is the best option because of the existing longitudinal proportion in most of the roofs. However, when measuring the area of irradiation collection and its relation to the effective area in all the cases studied, longitudinal arrangement prevails in only 52% of cases, compared to the 48% that predominates in transverse deployment. In that event, factors such as orientation, inclination, and even the cost of panels and their installation process are more influential factors than longitudinal or transversal placement.

On average, considering all the cases, a feasible roof occupancy by PV of 64% is obtained; however, in the best regular- and wide wing-roof reaches, 90% of PV occupancy is possible, unlike smaller and irregular wing-roof surfaces, which show occupancy of only 27% (PV surface of 4.38 m^2 against a wing-roof area of 16.22 m^2). With PV solar roof tiles, the best occupancy rate observed is 96% and the lower one reaches an 80% occupancy.

Conclusions

This research analyses the implications of typical PV formats of mono- and polycrystalline solar panels according to their ability to be integrated into sloped housing roofs, both in the case of being superimposed on a roof and in the potential future case of comprising architecturally integrated coating BIPV plates. To arrive at that result, typical commercial formats are considered by detecting three recurrent formats: 60-cell panels, which are the most common, 72-cell panels and 36-cell panels. In this study, only 6-inch panels are considered. Also these conventional products then are compared against recent products for architectural integration for mimicry as a PV roof tile model.

When these 33 panels are virtually installed on the typical Chilean roofs of the entrepreneurship buildings located in Concepción, in 18 cases we observed a better integration of the small-format panels. However, the larger format with 72 cells has 10 cases with a collection area equal to or greater than the smaller format. In contrast, when the average occupation indicator was determined, 60-cell panels have better occupation, with a slight difference compared to 36-cell panels (64.3% against 63.7%), Therefore, in these cases in general, smaller panels do not show better adaptability to roof shapes, as expected. In relation to longitudinal or transverse placement, no prevailing configuration is observed to reach a higher roof occupancy. Thus, there is no recommendation either for the geometric design for future solar panels in terms of incorporation into the building roof or the longitudinal or transversal position, neither of which show an advantage over the other. As a collateral conclusion, it is evident that for solar potential estimations, it is highly necessary to consider that the entire surface area is not usable. A reduction factor should be considered, which in the crystalline silicon technology solar panels could be as low as 38% and that on average exceeds by a little 60%, even in cases of smaller format. A highly variation of occupancy was observed because roofs sizes principally. With BIPV roof tiles, a considerable lower sizing is observed and, in this case, an concise improvement on roofing occupancy of solar capture area. But there exist some restrains in efficiency of thin film solar cell that reduces the energy output.

It is also concluded that roof shape is the most relevant variable in the occupancy of the panels, not their format or dimensions. Rectangular roof shapes are best suited for typical size and geometry silicon solar panels. There are also other relevant variables such as slope and orientation that improve energy production capacity more than the geometric adaptability of solar panels. However, there are other, perhaps more important variables that make large solar panels advantageous, such as a low number of connections among panels, implying minor failure risk, shorter installation time and fewer maintenance requirements.

This research has been carried out in different models of a housing typology, but only in a specific context. A similar analysis must be performed elsewhere to determine whether other conclusions coincide with the results found in this context, confirming that silicon PV regular size and format panels are not the main restraint on their adaptability to roof shapes. However, geometry and amplitude definitely determine the roof capability of incorporated regular silicon PV solar panels.

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