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**CONSTRUCTION PATHOLOGY, REHABILITATION TECHNOLOGY AND
HERITAGE MANAGEMENT**

(8th REHABEND Congress)

Granada (Spain), March 24th-27th, 2020

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Civil Engineering School

Department of Structural and Mechanical Engineering

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Avenue Los Castros s/n 39005 SANTANDER (SPAIN)

Tel: +34 942 201 738 (43)

Fax: +34 942 201 747

E-mail: rehabend@unican.es

www.rehabend.unican.es

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220	REGENERATION STRATEGIES ON SOCIAL HOUSING IN CHILE: FROM DEMOLITION TO TRANSFORMATION BETWEEN PAST, PRESENT AND FUTURE <i>Bustamante, Waldo; Bertolini, Enrico; Melano, Mario; Romeo, Emanuele; Schmitt, Cristian; Serra, Valentina</i>	1760
223	TEMPERATURE VALIDATION OF AN ADVANCED HYGROTHERMAL MODEL: STATISTICAL ANALYSIS <i>Barbosa, F.C.; De Freitas, V.P.; Almeida, M.</i>	1771
225	THE INFLUENCE OF INSULATION ON THE PASSIVE DISCOMFORT INDEX OF DWELLINGS LOCATED IN HISTORICAL BUILDINGS WITH INTERMITTENT HEATING PATTERNS <i>Magalhães, Sílvia A.; Freitas, V. P.; Alexandre, J. L.</i>	1778
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283	GREEN DESIGN OF ECO-CEM SYSTEMS AS A PROPOSAL FOR SUSTAINABLE REHABILITATION OF HISTORICAL CEMETERIES. CASE STUDY: LA APACHETA GENERAL CEMETERY - AREQUIPA <i>Roque-Rodríguez, Francisco Javier; Hidalgo-Valdivia, Alejandro Víctor; Montesinos-Tubée, Daniel Bernardo; Alvarez-Tejada, Erik Miguel; Medina Ramos, Robert Joaquín</i>	1797
337	DESIGN AND STUDY OF PREFABRICATED MATERIALS FOR USE IN THE INTERIOR CONSTRUCTION AND ENERGY REHABILITATION OF THE BUILT HERITAGE <i>Rodríguez Saiz, Angel; Santamaría-Vicario, Isabel; Alameda Cuenca-Romero, Lourdes; Gutiérrez-González, Sara; Calderón Carpintero, Verónica</i>	1806
372	ENERGY RENOVATION OF THE BUILT HERITAGE HOUSING BASED ON THE LIVING BUILDING CHALLENGE CERTIFICATION. CASE STUDY IN BRESKA (SPAIN) <i>Aguacil, Sergi; Moreno, Victor; Pauwels, Emmanuel</i>	1814
409	HOSPITAL LIGHTING: FROM VISUAL FUNCTION ASSISTANCE TO THE WELCOMING AND HUMANIZATION TOOL <i>Moura, Mariangela; Lopes, Ricardo G.</i>	1823
423	DESIGN OF SUSTAINABLE SOLUTIONS FOR CONCRETE BLOCK WALLS <i>González-Fontebo, Belén; Seara-Paz, Sindy; Martínez-Abella, Fernando; Pinto-Pérez, Adonay; García-Carrillo, Pablo; Prego-Martínez, Javier; Millán-Pérez, Jose; Díaz-Méndez, Rodrigo</i>	1832
431	A DESIGNING METHODOLOGY FOR OPTIMAL SIZING OF PHOTOVOLTAIC AND ELECTRICAL STORAGE SYSTEMS FOR TERTIARY BUILDINGS <i>Castellà, Marc; Castro, Cristina; Crespo, Eva; Kampouropoulos, Konstantinos</i>	1841
435	A THERMAL COMFORT ASSESSMENT IN A REHABILITATED RESIDENTIAL BUILDING OF THE CITY CENTER OF TEGUCIGALPA, HONDURAS <i>Gamero-Salinas, Juan Carlos; Monge-Barrio, Aurora; Sánchez-Ostiz, Ana</i>	1849
461	ECO-REHABILITATION OF COURTYARD HOUSE <i>Hania, Taib; Aissa, Mahimoud</i>	1857

484	BIM METHODOLOGY IN ENERGETIC REHABILITATION OF BUILDINGS: APPLICATION TO A PUBLIC RESEARCH LABORATORY <i>Silva, Sara; Falcão Silva, Maria João; Couto, Paula; Pinho, Fernando</i>	1865
501	CONSERVATION AND RENOVATION TO NZEB OF SILVIO SPAVENTA FILIPPI ELEMENTARY SCHOOL IN AVIGLIANO, POTENZA, ITALY <i>Lembo, Filiberto; Marino, Francesco Paolo R.; Rinaldi, Carmen</i>	1873
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537	SUSTAINABLE CONSTRUCTION AS A FUTURE HERITAGE: TECHNIQUE, ROOT AND NATURAL CONTRACT <i>Bedoya Montoya, Carlos</i>	1890
543	SUSTAINABILITY THROUGH RECYCLING FOR BUILDING SELF- CONSUMPTION <i>Madrazo, Alfredo; Balbás, Francisco Javier; Aranda, José Ramón; García, Javier; Ceña, Alberto</i>	1897
549	THE THERMAL COMFORT IN BUILDINGS OF VERNACULAR ARCHITECTURE OF THE CITY OF LOJA AND MALACATOS – ECUADOR <i>Tapia, Wilson; Correa, Ramiro</i>	1905
552	DISSEMINATION OF BEST-PRACTICE IN ENERGY RETROFIT OF HISTORIC BUILDINGS. RAINHOF, A CASE STUDY IN THE ITALIAN ALPS <i>Herrera-Avellanosa, Daniel; Exner, Dagmar; Haas, Franziska; Troi, Alexandra</i>	1918
573	IS INFORMATION SYMMETRY SUFFICIENT IN THE PROMOTION OF ENERGY EFFICIENT HOUSING? MAIN RESULTS OF THE ENERVALOR PROJECTS <i>Marmolejo-Duarte, Carlos; Spairani, Silvia; Del Moral, Consuelo; Delgado, Luis; Chen, Ai; Pérez, C.</i>	1927

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70	THE DIRECTOR PLAN FOR THE RECOVERY OF THE LORCA CULTURAL HERITAGE AFTER THE SISM OF 2011. COMPARATIVE ANALYSIS IN THE INTERNATIONAL CONTEXT <i>García Martínez, María del Sagrado Corazón; Martínez Ríos, Carmen</i>	1946
185	MULTI-SCALAR ANALYSIS SYSTEM FOR THE PRIORITIZATION OF INTERVENTIONS IN ARCHITECTURAL HISTORICAL HERITAGE: THE CASE OF SAN AGUSTÍN NEIGHBORHOOD IN PUEBLA CITY, MEXICO <i>Parra, Jaime; Lombillo, Ignacio; Ribalaygua, Cecilia</i>	1955
488	MULTICRITERIA ANALYSIS TO SUPPORT DECISION IN PUBLIC BUILDINGS REHABILITATION INTERVENTIONS <i>Barcelos, João; Falcão Silva, Maria João; Couto, Paula; Pinho, Fernando</i>	1964
489	MULTICRITERIA ANALYSIS APPLIED TO PUBLIC REHABILITATION INVESTMENTS <i>Couto, Paula; Falcão Silva, Maria João; Salvado, Filipa</i>	1972
584	CLASSIFICATION OF ROOF TYPES IN EXISTING RESIDENTIAL BUILDINGS IN MADRID. DATA FOR AN ENERGY REHABILITATION STRATEGY <i>Alonso, Carmen; de Frutos, Fernando; Martín Consuegra, Fernando; Frutos, Borja; Galeano, Javier; Oteiza, Ignacio</i>	1981

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191	SEISMIC ASSESSMENT AND RETROFITTING OF AN OLD MASONRY BARRACK <i>Zucca, Marco; Crespi, Pietro; Mendoza, Russell; Ruggeri, Luca</i>	1997
204	REHABILITATION OF TWO MASONRY BRIDGES IN CUEVA (BURGOS, SPAIN) <i>Martínez Martínez, José Antonio; Aragón Torre, Ángel; García Castillo, Luis María; Aragón Torre, Guillermo</i>	2006
212	CONCRETE SURFACE APPLIED CORROSION INHIBITORS: ON SITE EVALUATION BY NON-DESTRUCTIVE ELECTROCHEMICAL TECHNIQUES <i>Martínez, Isabel; Castillo, Ángel</i>	2015
230	NUMERICAL INVESTIGATION OF THE STRUCTURAL PERFORMANCE OF AGED RC BRIDGE COLUMNS SUBJECTED TO CORROSION AND SERVICE LOADS <i>Dabas, Maha; Zaghian, Sepideh; Martín-Pérez, Beatriz; Almansour, Husham</i>	2023
232	STRUCTURAL RESTORATION OF THE BUILT HERITAGE: CASE STUDY OF TAZI PALACE HOTEL <i>Kaddouri, Hajar; Cherradi, Toufik; Kourdou, Ibtissam</i>	2032
333	EVOLUTION OF PHYSICAL AND MECHANICAL PROPERTIES OF BRICKS TREATED WITH DIFFERENT CONSERVATION PRODUCTS APPLICABLE IN THE REPLACEMENT OF EXPOSED BRICKS IN HERITAGE BUILDINGS <i>Romay Carola; Charbonier, Andrea; Rodríguez de Sensale, Gemma</i>	2042
429	QUANTIFICATION OF WATER TRANSPORT IN FACADES WITH THE USE OF HYGTHERMAL SIMULATION <i>Mota, Larissa; Bauer, Elton</i>	2051
532	STUDY OF THE REHABILITATION PRACTICES IN VILA REAL HISTORIC CENTRE: CASE STUDY <i>Mendonça, Alana; Domínguez, Caroline; Mendes da Silva, José; Paiva, Anabela</i>	2060
538	PROMPT QUALITY ASSESSMENT METHODS FOR REHABILITATION PROJECTS: THE METHOD 'MIMAQ' <i>Mouraz, Catarina P.; Silva, J. Mendes</i>	2068
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505	U-SHAPED FRCM FOR STRENGTH AND DEFORMATION ENHANCEMENT OF REINFORCED CONCRETE BEAMS <i>Ebead, Usama; El-Sherif, Hossameldin</i>	2157
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CODE 195

NZEB SCHOOLS IN ITALY: DEFINITION AND OPTIMIZATION OF SYSTEM USING PHOTOVOLTAIC TECHNOLOGY

Ciacci, Cecilia¹; Bazzocchi, Frida¹; Di Naso, Vincenzo¹; Rocchetti, Andrea²

1: Dipartimento di Ingegneria Civile e Ambientale DICEA
University of Florence

e-mail: cecilia.ciacci@unifi.it,

e-mail: frida.bazzocchi@unifi.it, web: <https://www.dicea.unifi.it/p-doc2-2019-200006-B-3f2a3d303b2c2e-0.html>

e-mail: vincenzo.dinaso@unifi.it, web: <https://www.dicea.unifi.it/p-doc2-2019-200006-D-3f2b3429322831-0.html>

2: Dipartimento di Ingegneria Industriale
University of Florence

e-mail: andrea.rocchetti@unifi.it, web: <https://www.dief.unifi.it/p-doc2-2019-200006-R-3f2a3d323b2e2b-0.html>

ABSTRACT

The realization of a Nearly Zero Energy Building (nZEB) school cannot ignore the proper design of the building distinguishing features (shape, orientation and distribution of functional bands and units, window-to-wall ratio – WWR, structure, technological solution for the external envelope, solar shadings etc.) already during the preliminary phase of the design process in order to minimize the energy needs according to the climate zone of construction. At the same time it is necessary to identify the appropriate relationship between building and plant and consequently the share of energy ensures by renewables. In Italy, since 1st January 2017, for new buildings the 50% of energy needs for service hot water, heating and cooling must be guarantee by renewable energy. This is strictly related to the demands of “2050 low-carbon economy” (2018) that requires a decrease in greenhouse gas emissions equal to 80% by 2050. The paper concerns with the three new typological models for kindergartens, defined in a previous stage of the research, to design Nzeb schools in the Mediterranean area: one with compact shape with internal courtyard and two with a predominant linear shape respectively with three and six classrooms. In this case an electric heat pump (air-water) for heating, ventilation and air conditioning (HVAC) and service hot water powered by an integrated photovoltaic system in the building and lighting systems, plackloads and auxiliary system related to HVAC with high energy efficiency were used. The study aims at investiganting the influence on energy produced by photovoltaic panels of the shape and the geometry of the roof and the orientation of the building, considering three cities belonging to different Italian climate zones. The modeling of the system and the energy simulation in dynamic regime with hourly time step were carried out with Design Builder. To estimate the energy production of photovoltaic panels PVGIS software was used considering the system extendend to the available area of the roof. The goal is to define and to optimize the system in term of electricity production, in order to obtain a positive electricity balance and make the system able to share energy with other users.

KEYWORDS: Sustainable schools; nZEB schools; energy consumption; renewable energy; PV panels.

1. INTRODUCTION

1.1. Literature review

The solar energy is the most widely and freely available in nature among the other renewable resources. The term renewable resource appeared in the scientific literature in the beginning of 20th century as a resource that can be used to prevent the utilisation of fossil fuel [1]. A distinction is immediately identified between a renewable energy source like wood that is not forever available and inexhaustible ones like wind, hydro and solar radiation [1]. Nowadays the International Energy Agency (IEA) gives this definition of renewable energy: “*energy derived from natural processes that are replenished at a faster rate than they are consumed*”. In the context of the Paris Agreement the exploitation of renewable resources is one of the best ways that will ensure the minimisation of gas emissions in the atmosphere and so it will lead to decarbonisation within 2050. In fact, the development of systems to produce clean energy is one of the necessary phases in order to face problems deal with pollutants emissions and climate change in the future [2]. The solar energy that the sun emits is approximately $3.8E^{23}$ kW [3] and the Earth receives a nearly constant solar specific radiation (1360 W/m^2) outside its atmosphere [4]. To reach ground level, traveling through the atmosphere, a variable part of this radiation can be absorbed and partly discarded or reflected. The solar energy, at ground level is strictly linked to the geographic position, the latitude and the climate characteristics that necessarily affect the amount of energy that the earth receives. The development of the solar industry is one of the utmost options to face the energy crisis, to meet the future energy needs and reduce the impacts of the greenhouse gas emissions on Earth's climate due to human activities [5], [6]. Photovoltaic is an enhanced technology to convert directly solar energy in electricity. At first used to produce electricity in aero spatial applications, in the last three decades this technology attained a huge growth in conversion efficiency as much as in reliability, achieving a leadership in small power green electricity production market. There are different types of photovoltaic panels related to the type of material of the photovoltaic cell that catches the solar radiation [7]–[9]. Today photovoltaic systems are frequently used in civil applications, to supply the electricity needs of the users. It is necessary to merge the aleatory availability of the solar energy source with the user energy request profile and it's possible to use storage system and share electricity by the grid with other users. The photovoltaic technology can open new perspectives to spread the solar renewable energy source use when applied in a “smart” integrated system. The impacts of the greenhouse gas emissions on Earth's climate due to human activities are the big deal of this century and climate changes and reduction of greenhouses effects are the most relevant challenges. Renewable energy sources can help mankind to win this dare.

1.2. Aim of the study

The realisation of a neutral carbon school building cannot ignore the use of renewable sources. The legal standards of the most part of the European countries impose that renewable energy sources be the relevant energy production system: in Italy as example, since 1st January 2017 [10], for new buildings the 50% of energy needs for service hot water, heating and cooling must be guarantee by renewable energy. Photovoltaic system offers a simple and smart solution for the integration of renewable source onto a building. It can be easily integrated on the building envelope and typically the roof is its more convenient and obvious positioning. The sizing and designing methods of the PV system are generally guided by an economic optimal cost using building electrical energy needs as load to satisfy. In our work a different point of view is considered, aiming at sizing the PV system to maximize the electric production in order to make the building an energy-plus system, able to share electrical energy with the surrounding building or electric grid. This can be a winning strategy to plan and manage renewable energy production in smart and sustainable cities. Furthermore, the production of electricity with PV system reduces the CO₂ emissions in the atmosphere of about $0.53 \text{ kgCO}_2/\text{kWh}$ [11] and it is important to stress out that the conversion factor for the calculation of the total amount of CO₂ emissions of a building during the operational phase for the use of renewables is obviously equal to $0 \text{ kgCO}_2/\text{kWh}$. This is closely connected with the goals of the Paris Agreement concern with the neutral carbon economy. In fact, this is helpful to decrease the environmental impact of the building with its related

consumptions and to face the climate change. The main aim of the study in the paper is to design a photovoltaic system for the 3 new typological models for kindergarten, determined in a previous phase of the research [12], in order to obtain the maximisation of the electrical production. An extensive analysis has been made to find the configuration of PV panel that, considering different orientation and tilt of the PV panels, considering the requested distance to prevent shading between succeeding rows, maximise the electricity production. The design of this kind of PV system that exploits the entire available surface on roof top leads to an overplus electrical annual energy production intended as the difference between the annual energy produced by PV system and the final annual energy required by the building. As previously hinted in the abstract the analysis presented is a part of a broader work of research aimed at delineating quantitative and qualitative guidelines as a supportive tool for the designers during the early stage of the design process with the aim of realising nZEB schools in the Mediterranean Area. Three different models for kindergarten has been defined from morphological, dimensional and aggregation point of view and they represents the needs required of both current teaching methods and public administration that realize schools. Then the optimisation of the main building features [13], [14] was done. The present stage concerns with minimise the primary energy demand and the CO₂ emissions during the operational phase of the analysed buildings. The main goal is to maximise the production of the electrical energy by PV choosing the optimal configuration, mainly considering the environmental impact in terms of avoided CO₂ and investigating some design parameters.

2. METHOD

First, to evaluate the influence of some design criteria on the PV system performance the analysis was carried out considering 3 different locations belonging to 3 different Italian climate zones [15] which are representative of Mediterranean climate: Milan (climate zone E), Florence (climate zone D) and Palermo (climate zone B). Then different architectural parameters are considered and investigated: the shape of the roof of the building (considering the 3 typological models for kindergarten), the orientation of the PV panels on the roof (south and east/west) and the tilt angle with respect to the horizontal plane of the PV panels for which a parametric analysis was done, varying it within a range between 10° and 80° that influences the area of the PV panels and consequently the producibility. This parametric analysis allows to identify the optimal distribution of the PV panels on the roof with the aim of maximising the annual electricity production (considered in this case as the sum of plus electricity production for each month). The surplus energy production is calculated with the difference between the energy produced by PV panels organised in the whole available area of the roof and the final energy consumption for heating, cooling, service hot water, lighting and equipment. In this study to calculate the maximum available area for PV panels installation, the minimum distance between PV panels rows in order to guarantee no mutual shading was establish, considering an inclination of solar rays at 1:00 p.m. related to the 21th of December for south orientation and an inclination equal to 10° for east/west orientation. Furthermore, the minimum distance is set at least equal to 70 cm in order to guarantee the minimum space for maintenance. The simulation of PV panel was carried out with PVGIS-5 software available online and for this analysis the main dimensions of one panel are equal to $A = 1 \text{ m} \times B = 1.70 \text{ m}$. The crystalline silicon technology for PV panels (monocrystalline panels) was chosen with an installed pick power equal to 0.15 kWp/m² and system losses equivalent to 14%. The price for the PV panel for the economic analysis is equal to 90 €/m² and the electrical energy one is about 0.2 90 €/kWh. These values are chosen because they are the most recurrent in the PV system market. Finally, for each analysed model, a considerable surface equal to 50 m² dedicated to the air handling unit (AHU) for mechanical ventilation and all connected auxiliary systems is removed from the available area of the roof. The energy simulation in dynamic regime with hourly time step of the 3 typological models was performed with Energy Plus using Design Builder as graphical interface. Obviously, it is fundamental to point out that the final energy consumption of the analysed buildings, used to determine the plus electricity produced by PV, is strictly linked to both functional bands and units' distribution, orientation, intended use, occupancy level and the whole set up of Design Builder templates.

3. INPUT DATA

3.1. Climate zones

The study of the PV systems was carried out looking at 3 different cities representative of the Mediterranean area and belonging to 3 different climate zones in line with the national law D.P.R. 412/1993 [15] according to the number of heating degree days (HDD). Table 1 illustrates the following characteristics about chosen cities: altitude alt, latitude lat, longitude long, heating degree days HDD and Köppen Geiger climate classification K-G.

Table 1: Characteristics of the chosen cities

City	alt	lat	long	HDD	K-G	Climate zone
Milan	122	45.62°	8.73°	2404	Cfb	E
Florence	50	41.8°	12.23°	1415	Cfb	D
Palermo	34	38.18°	13.1°	751	Csa	B

For the energy simulation of the 3 typological models for kindergarten performed with the software

Energy Plus, the climate data of a typical year calculated by the Italian Technical Committee (CTI) are used. They are based on the European standards EN ISO 15927-4.

3.2. Basic models

To investigate the shape of the roof and so the different area and the distribution of the PV panels 3 different new typological models for kindergarten have been considered, previously outlined by the research [12] and designed with an internal distribution organised on a single ground floor: one with compact shape and an internal courtyard with 3 sections (model I1) and 2 with predominant linear shape with 3 (model I2) and 6 (model I3) sections respectively. Table 2 illustrates the main geometrical characteristics (volume V, area S, length A, width B, internal height H) and some concern technological solutions for walls and glasses (thickness t, thermal conductivity λ , thermal transmittance U for each climatic zone, thermal transmittance U_g for glass, solar factor g and light transmittance) of the considered models.

Table 2: Geometrical and technological characteristics of typological models for kindergarten

Geometrical characteristics					
Model	V [m ³]	S [m ²]	A [m]	B [m]	H [m]
I1	5154.6	888.7	37.8	29.8	4.4
I2	5534.8	954.3	75.6	14.9	4.4
I3	10764.8	1736.3	100.8	19.5	4.8
Technological solution for the external wall					
Layer	Material	t [m]	λ [W/mK]	U [W/m ² K]	
1	External plaster	0.025	0.9		
2. Zone E-D	Wood fiber	0.14	0.038	0.20	
2. Zone B	Wood fiber	0.04	0.038	0.42	
3	XLAM	0.130	0.12		
4	Acoustic insulation	0.02	0.048		
5	Gypsum bard	0.015	0.21		
Glasses characteristics					
Zone	U _g [W/m ² K]	g [%]	Light transmittance [%]		
E	1.1	52	75		
D	1.2	50	74		
B	2.5	69	78		

The thickness of insulation for walls required to comply with thermal transmittance of the envelope elements has been identified according to Italian law limit [10] in different climate zones (B, D, E). For

the ground floor layer, the solution with plastic formwork for underfloor ventilation was completed with expanded polystyrene (EPS) insulation layer. Finally, related to windows, a thermal break frame was adopted and a double glazing with different properties was used according to the climate zone. On southern façade for each models a shading system has been designed and realized with an overhang of 2 m against each window in the façade.

3.3. Design Builder templates settings

For each different thermal zone, in which buildings have been divided, many parameters were defined in the templates' settings: occupancy (person/m²) according to UNI 10339, minimum air change rate refers to the same legislation and finally internal gains in line with UNI/TS 11300-1. Concerning level of illuminance UNI EN 12464-1 was considered. Regarding simulations, lighting control was used with the maximum index of glare allowed. Systems are simulated through HVAC simple and main design parameters are shown below (they are the same for each climate zone in order to have the similar basic condition to perform parametric analysis concerns with PV panels):

- controlled mechanical ventilation (VMC): free cooling and sensible heat recovery with 90% of efficiency;
- heating/cooling system: heat pump with coefficient of performance COP = 3.6 and efficiency energy ratio EER=3.2;
- heating setpoint: 20°C activity period – 10°C during the rest of the day;
- cooling setpoint: 26°C activity period – 36°C during the rest of the day.

4. RESULTS AND DISCUSSION

In the following paragraph the main results of the analysis of the PV systems are illustrated and discussed. Figure 1 is related to the model I1 and it illustrates the available area measured in m² for each tilt angle considered for the 3 cities analysed for south oriented PV panels (blue columns) and east/west ones (pink columns in the graph). While figure 2 shows the PV output in kWp always referred to the model I1 and the all cities and both orientations for the distribution of the PV panels rows. Only the figures related to the model I1 are reported in the paper for brevity, but all the results obtained are commented.

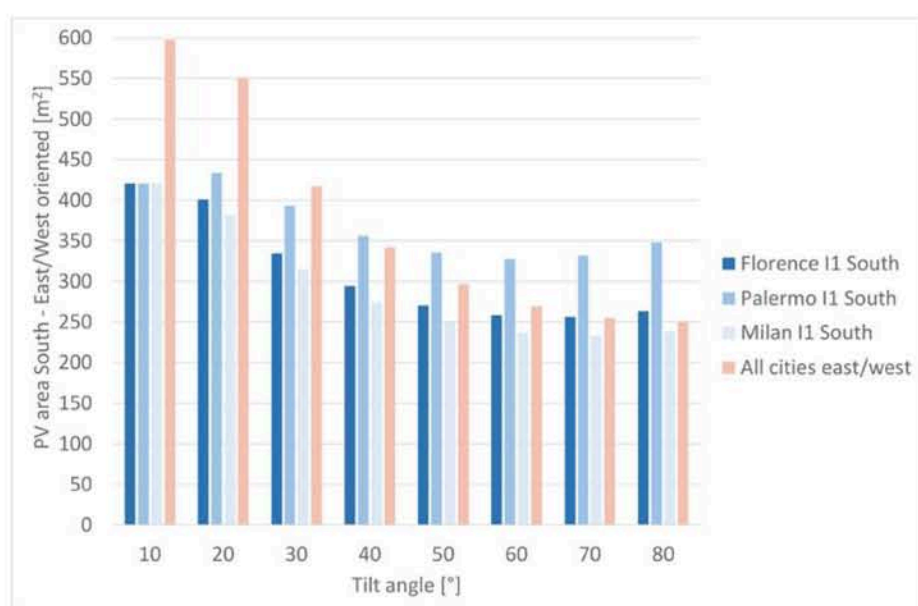


Figure 1: PV panels area for model I1

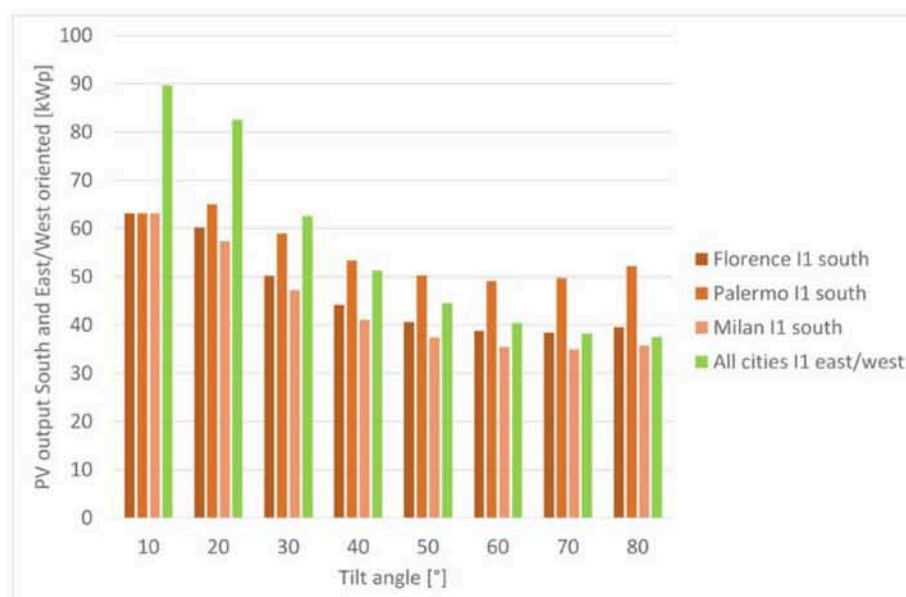


Figure 2: PV output for model I1

As showed in figure 1, obviously, the model I1 situated in the city of Palermo lets to have the major available surface of PV panels with the tilt angle equal to 20° for south orientation. This is strictly linked to the value of the inclination of the solar rays ($\alpha = 28.43^\circ$) that allows to obtain a smaller value of the minimum distance between PV panels rows. For Florence and Milan, the higher available area on the roof for the installation of the PV panels is obtained with a tilt angle equal to 10° with a minimum distance between panels rows equal to 70 cm.

In general, the model I3 permits to obtain the higher surface of PV panels for all the cities and considering both orientation because it presents a superior value of the available surface on the roof (for instance with respect to the model I1 with PV southern oriented there is for a tilt angle equal to 10° an increase in the surface measured in m^2 of about 60%).

The most interesting thing that Figure 2 demonstrated is that the PV panels eastern/western oriented lets to obtain the most electrical energy production with a tilt angle equal to 10° inasmuch the available area for PV panels increases of about 30% with respect to the same tilt angle for south orientation. This is valid for all the analysed city.

Furthermore, figure 2 showed that until a tilt angle equal to 30° the east/west orientation are better than south one for all the cities. For Milan this situation is valid until a tilt angle equal to 80° . With the increasing of the tilt angle the south orientation is advisable in order to obtain the maximisation of the producibility of PV panels for Florence with only 70° and 80° of the tilt angle while for Palermo the south orientation is better from an inclination of 40° .

For all the cities there is a decrease in both the area (figure 1) and the PV output (figure 2), and consequently in the producibility, until the tilt angle equal to 60° and then within 80° a slight increase is happened. This is valid for all the analysed models.

Figure 3 shows the results of the energy produced by PV panels related to the entire area of the 3 considered buildings. For the city of Florence, the trend changes in correspondence of 30° while for model I2 and I3 for 40° of the tilt angle.

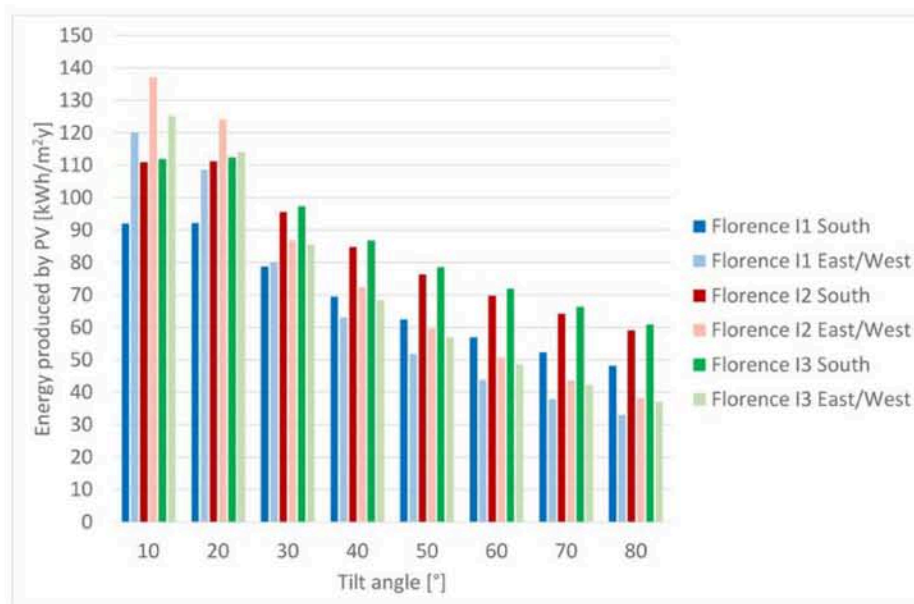


Figure 3: Energy produced by PV system for 3 models situated in the city of Florence

Therefore, it is essential to carefully analyse the plus electrical energy production in order to calculate the total amount of CO₂ emissions avoided with the production of this electricity that can be fed in the public grid and used by other buildings in the context of realizing smart cities in the next future. It is a significant step to evaluate the environmental impact of the construction of a PV system and the related payback period, considering the whole available area on a roof with the aim of maximising the producibility.

Figure 4 exhibits the plus energy production of the Model I1 (for brevity as explained before) examining the all cities and both orientation of the PV panels rows for each tilt angle considered.

The results reported in figure 4 are rigorously linked to the final energy demand of the model I1 in each city and it is important to remind that for the city of Milan the most considerable energy needs is required because of the heating system being in climate zone E.

As showed in figure 4 the uppermost production of plus electrical energy is obtained for all the cities where the models are situated for the energy simulation is obtained for east/west orientation of the PV panels with a tilt angle of 10°. For instance, for the city of Florence, considering a tilt angle equal to 10°, the difference between south and the best orientation in the plus electrical energy production is of about 28 kWh/m²y. For Palermo there is the most noticeable difference between the two examined configurations with a value of about 38 kWh/m²y. This is valid also for the other studied typological models (I2-I3).

Thereafter, it is possible to admit that the first configuration is the one that leads to an increase in plus electrical energy production due to the maximisation of the area of the panels and so it is the most environmental-friendly.

Consequently, considering for instance the city of Florence, for east/west orientation the CO₂ avoided for other buildings connected to the public grid that exploits the plus energy produced by the school PV system is equal to about 52 kgCO₂/m²y versus an amount of about 30 kgCO₂/m²y considering the most recurrent tilt angle (30°) and orientation (south) of the PV panels in the Mediterranean area.

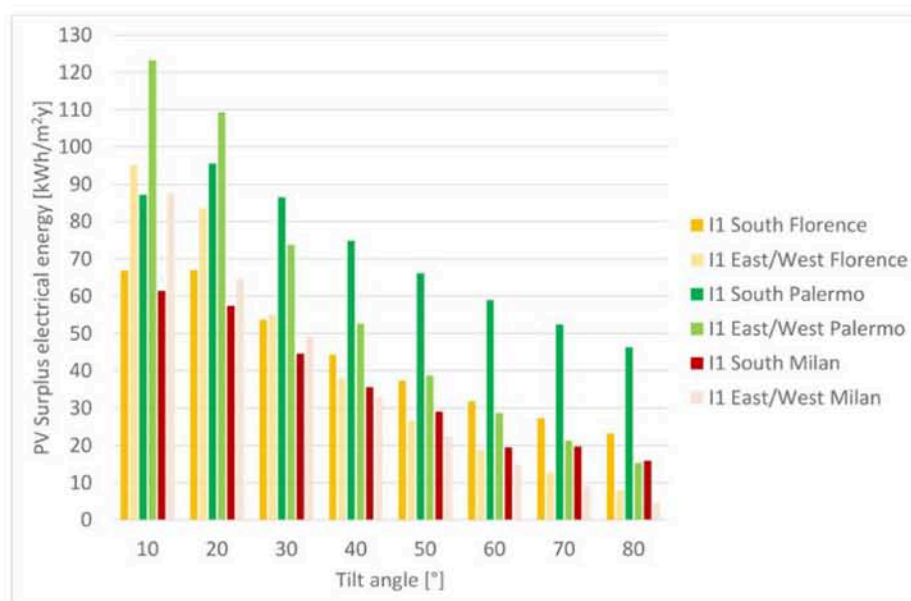


Figure 4: Surplus electricity production for model I1 in all cities

Speaking about these results it is fundamental to remark that between the monthly simulation and the hourly time step simulation there is a difference of about 10% (for instance for Florence for model I1 there is a difference of about 5300 kWh in one year between hourly and monthly simulation for the optimal configuration). The most advantageous simulation is the hourly time step one for the surplus energy production. This is linked to the consideration of the simultaneity of the production of the surplus electrical energy in the hourly time step evaluation, which does not happen in the monthly one. Therefore, with monthly calculation there is an underestimation of both the plus electrical energy production and the electrical energy required from grid when the one powered by PV panels is not available.

If the payback period for Florence city for model I1 is evaluated in terms of CO₂ emissions for the construction of the PV panels, considering an operational life of 30 years, the results stressed out that: for the optimum configuration with a tilt angle of 10° and east/west orientation of the PV panels rows the payback period is equal to about 2 years while for the most recurrent configuration for the Mediterranean area is of about 4 years. The payback period of a PV systems with an angle of 30° and southern oriented can be considered double. Despite if an economical point of view is considered the initial investment cost for the optimal configuration is higher than the most recurrent one of about 30%. The payback period for the construction of the whole PV system is of about 4 years while for the optimal configuration for producibility is 3 years and a half. So, for the public administration that realises the construction of a school where there is a precise budget to spend also this consideration is equally substantial to consider.

5. CONCLUSION

In conclusion, as a matter of fact, in order to maximise the producibility of a PV system installation in the Mediterranean area, considering the 3 new typological models for kindergarten, it is necessary to decrease the inclination of the PV panels from the most recurrent one equal to 30° until 10° and to change the orientation of PV panels rows from south to east/west. This is strictly linked with inclination of solar rays that for this optimal orientation does not cause shade between panels rows during the day. This leads to a reduction of the CO₂ emissions as well (for instance ~ 44500 kgCO₂/y for model I1) because this configuration lets to obtain a higher production of plus electrical energy that can feed the public grid and can be exploited by other buildings in the district. So, it can be considered as the most environmental-friendly installation.

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