Potential Application of Solar Power Systems for Residential Buildings in High-Density Urban Pattern: The Case of the Eixample District, City of the Barcelona, in Spain

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Abstract: The Importance of energy saving is one of the highlights of buildings environment during recent years. In order to improve the energy performance in residential dwellings, in countries with remarkable solar irradiation resource as a key issue for sustainable urban development, the usage of solar water-heating and photovoltaic systems are inevitable. The city of Barcelona with available an average solar radiation of about 1500 kWh/m^2/year has a potential to produce significant amount of energy. This paper deals with collecting and analyzing the energy consumption data of four different blocks with approximately 640 inhabitants each in Eixample area-Barcelona and employing of a solar power as a water-heating and photovoltaic system instead of natural gas and electricity. The paper concludes with a discussion and suggestion of possible substitution energy resource scenarios to illustrate how the system may be improved at level of economics and energy saving to assist targeting of urban environment, in limited availability of fossil energy resources, climate change problems and economic crisis worldwide.

Key-words: Energy saving; Buildings environment; Sustainable urban development; Solar water-heating system; Photovoltaic system.

1. Introduction

The building sector represents 40% of the total primary energy demand in European Union countries and it is responsible for one third of the GHG emissions [1], while this amount would be approximately 23% in Spain which consists of two sectors: residential and commercial by 15% and 8% respectively [2].

In 2008, Barcelona energy consumption represents 1.38% of all the energy consumption of Spain and is distributed as follows: tertiary sector 29.9%, residential 27.9%, transports 24.1%, industry 17.2% and in other sectors such as primary sector, energy, building and public works 0.8%. Electricity consists the primary energy consumption source and represents 44.3% of total; natural gas represents 31.8% and the remainder diesel 15.4%, petrol 7% and liquefied petroleum gases (LPG) 1.4%. The consumption ratio per inhabitant was 10.52 MWh/inhab with an average annual growth rate of 0.91% from 1999 to 2008, less than half the energy consumption by inhabitant of Spain (25.47 MWh/inhab).

The energy consumption of a specific building depends mainly on the building type, climatological conditions, building construction, annual hours of use, installations for heating, cooling, production of domestic hot water and lighting. Moreover, The policy making process in the urban scale, always deals with a variety of parameters in different urban fabrics and it is not reliable to make a decision based on a specific case study. In 2008, the residential sector in Barcelona consumes 4,794 GWh, 28% of final energy, which distributed equally between electricity and natural gas (approximately 48% each) while the remaining consumption was of LPG that progressively declining year after year [3].

The limited availability of fossil energy resources at affordable prices and the related problems in terms of climate change necessitate the use of regenerative energies such as solar energy [4]. Solar energy has been advocated for building applications for many years. The solar intensity on surfaces varies with geographical and environmental conditions. The availability is limited to the daytime, and may not be in line with the energy demands in buildings, such as for water heating or space heating [5]. Solar radiation resource availability in Barcelona is one of the highest in the EU region, ranging from 3.2 to 5.2 kWh/m^2/day [6]. In this regards, renewable energy production in Barcelona significantly increased up to 96.53 GWh in 2008. The energy sources used for this production were photovoltaic energy, solar thermal, small-scale hydraulics and biogas.

Photovoltaic (PV) systems, originally developed for outer space applications, are currently used in many remote applications providing electricity to remote areas for any grid in a manner that uses significantly less primary energy than conventional systems with savings of natural resources and reductions of pollutant emission [7].

There are two common types of solar thermal collectors for water heating: flat-plate collectors and evacuated-tubes. A water-in-glass evacuated-tube consists of a two-layered glass tube and a central feeder tube. A vacuum space is created between the cover (outer) glass layer and the absorber (inner) glass layer. From a storage tank, that serves an array of evacuated tubes, water flows through each feeder tube into the end of the absorber tube and through the absorber tube back to the tank. With a low emissivity of the absorber surface and the presence of the vacuum space, the collector allows a better capture of the beam radiation and avoids the cold winter water-freezing problem. The equipment cost is, however, higher than the flat-plate collector [8].

The economics, technical performance and optimization [9-14], as well as the modeling and sizing [15-26] of a number of different solar water heating technologies deployed in different climates, has been extensively investigated and reported in the literature. In this work we have looked into the efficiency of methodologies for evaluating the potential of solar energy utilization in the neighborhood scale of sustainable urban environment. We have presented a methodology in which benefits are accounted for from both the residential energy consumption, as well as from the environment friendly technologies perspectives.

2. Methodology

The methodology presented in this work involves selecting a small stochastic community to reach a solution and proposal of specific block due to set of design and recovery. In this proposal the amount of renewable energy production consists of PV panels and solar collectors. Despite the fact that residential blocks (6 floors, 130×130 m^2 and courtyard in the center) were chosen randomly among the potentially recoverable blocks in the area of the Eixample, the output design mean values will be reliable data of decision making and urban policy making processes. Details are presented in Table 1 and Figure 1.

By obtaining the number of inhabitants in each block, an estimation of the total energy consumption was gained. Total energy consumption per each person is 2.96 MWh/year in residential sector, while the portion of the electricity is 1.43 MWh/year.

Table 1. Breakdown of residential population

	Eixample District	Stochastic Community	Single Block
Number of Blocks	415	4	1
Number of Inhabitants	266,874	2570	640

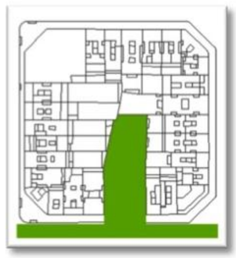
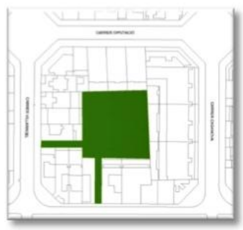
	**Maria Matilde Almendros** The existing buildings occupy the courtyard but more free spaces are available for rooftops occupation.
	**Paula Montal** Courtyard is almost free which is suitable for solar trees. But less rooftop spaces.
	**Cesar Martinel** This courtyard is suitable for both solar trees and occupation of rooftops.
	**Merce Vilaret** Small portions of the courtyard but more space for rooftops are available.

Fig.1. Randomly selected blocks schematic plans and details.

This means that every year almost 50% of total energy consumption is spent on electricity for each individual. Therefore, installations of PVs are well-advised and also contain a financial justification.

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In these case studies, the possible installation location of solar collectors and PV panels are: on the rooftop, facades and courtyard. The choice and the number of the solar power systems depend on:

1- Energy production capacity of the PV panels and solar collectors
2- The desired efficiency to achieve as a goal for electricity and hot water production
3- Spatial and installation parameters
4- The willingness of the blocks inhabitants due to new power systems installation.

2.1. Energy Production Capacity

A typical residential solar water heating system (SWHS) for a family of four, delivers 4 kilowatts of electrical equivalent thermal power under intense sun beam when the temperature of the water in the storage tank is about the same as the air temperature. As a mean value 1.5 KWh/m^2 per day would be chosen for Barcelona climatic situation. On the other hand, PV panels would produce 0.5 KWh/m^2 per day under the same climatic situation of Barcelona. However, the energy production will be different depending on the apparatus type but it will not affect our purpose.

2.2. Desired Efficiency

The overall energy consumption of a block was calculated by multiplying the energy consumption of a person in the region per year to the number of inhabitants living in a block. Therefore, for the selected case studies, the annual value of 1900 MWh for each block was obtained which is around 50% of this annual value, is related to the electricity and the rest is necessary heating energy. The potential for reduction of energy consumption in residential buildings by using appropriate insulations is high, comparing to energy efficient houses but this topic is out of the scope of our subject in this section [27].

This research focuses more on the implementation of a methodology to estimate the potential of renewable energy production in the cities, which are characterized by repeatable urban pattern like the district of Eixample.

In Eixample district, it is worthwhile to mention that more than half of the cities electricity supply is provided by the nuclear plants. In addition, in the last decade about 50% of the residential energy consumption was due to water heating process for domestic purposes. This leads to the fact that the solar collector systems are more beneficial than PV panels in term of using solar renewable energy. This consideration along with other factors affected the proposals.

2.3. Spatial and Installation Parameters

Solar collectors are equipped with a storage tank for water to use the hot water for periods in which the solar radiation is off or not sufficient. Application of the solar collectors in a huge scale means that the load of the water tanks and the necessary equipment should be considered, especially, when the subjected buildings are not newly built or there are some doubts about their stability under extra loading. Another important factor would be the consideration of the area occupied by the installations; For example, the PV panels are required to be installed in a large scale to produce a considerable amount of energy. This consideration is especially important for buildings, which already have some equipment, installed on rooftop. Therefore, the amount of installations would be limited to the available area.

2.4. Installation Investigation Based on Inhabitants

According to our random investigation and poll among blocks' Inhabitants to understand their opinions and demands toward possible renewable energy options, there were few differences in consumer attitudes across each block that were considered in installation of solar power systems.

Respondents were briefly explained about the renewable energy description and related options, and they were presented by simplified choices. In the case of rooftops, they were asked to offer us available area to install solar power systems and as a result we found the specified percentage of each area to installation. In the case of facades, since the appropriate area for installation was limited, the concentration of the survey was on the willingness of the consumers and engineering regulations to put or not to put PV panels on facades. The same approach was taken for the solar trees.

3. Results and Discussion

In this work, the total energy production due to installation area for all of the four blocks, namely Maria Matilde, Paula Montal, Cesar Martinell and Merce Vilaret, were obtained and shown in Table 2.

On the other hand Table 3 illustrates total energy generation and efficiency of the blocks in respect to its total consumption. Furthermore while we wish to use courtyard as an installation base for PV panels in the shape of solar trees, absorbed solar energy should be considered. Our analysis by Ecotech software indicates that the courtyards receive considerable amount of solar radiation and the shading effects of surrounding buildings in the center of the courtyard are negligible. The schematic solar energy absorption is shown in Figure 2.

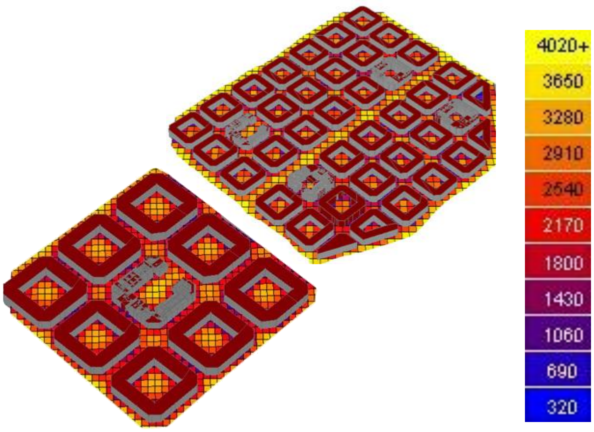

Fig.2. Solar access for grid line on the ground level showing intensity of the incident solar radiation

Our results show that Maria Matilde and Merce Vilarte blocks with approximately same facade area for installation of PV panels, which is giving almost same total energy production and about 29 MWh/year that is the minimum amount among all four blocks. However, Cesar Martinell block by using both rooftop and solar trees in courtyard area reached to the maximum amount of 334.65 MWh/year energy productions compare to other blocks. In comparison to PV panels, solar collectors are used only on rooftops regarding to its installation problems for all of the cases. Due to wide area occupation for installation of solar collectors in Maria Matilde and Merce Vilaret (exactly twice of the area used in two other blocks), the total energy consumption in former blocks are twice the latters and equal to 843.15 MWh/year. It is clear that the main role of these differences played by area amount.

By summing up all total energy productions obtained from all four cases, we received to three different efficiency percentages of blocks, 30% and 40% for Paula Montal and Cesar Martinell respectively and 46% for both Maria Matilde and Merce Vilaret blocks. Eventually it is apparent that solar power energy generation is more useful in case of Maria Matilde and Merce Vilaret blocks.

Table 2. Energy production and Area of PV panels and solar collector systems of four selected blocks

		Maria Matilde	Paula Montal	Cesar Martinell	Merce Vilaret
PV Panels Area(m^2) and Energy Production(MWh/year)					
Rooftop	m^2	-	1100	2200	-
Rooftop	MWh/year	-	140.52	281.51	-
Façade	m^2	222	-	-	230
Façade	MWh/year	28.35	-	-	29.38
Solar tree	m^2	-	-	103.12	-
Solar tree	MWh/year	-	-	26.57	-
Total energy production (MWh/year)		28.35	140.52	334.65	29.38
Solar Collectors Area(m^2) and Energy Production(MWh/year)					
Rooftop	m^2	2200	1100	1100	2200
Rooftop	MWh/year	843.15	421.57	421.57	843.15
Façade	m^2	-	-	-	-
Façade	MWh/year	-	-	-	-
Solar tree	m^2	-	-	-	-
Solar tree	MWh/year	-	-	-	-
Total energy production (MWh/year)		843.15	421.57	421.57	843.15

Table 3. Total energy production and efficiency related to each selected block.

Case study	Total energy production MWh/year	Efficiency of the block in respect to its total consumption
Maria Matilde	871.50	46%
Paula Montal	562.09	30%
Cesar Martinell	756.22	40%
Merce Vilaret	872.53	46%

These results are clearer in Figure 3. In this bar chart, vertical axis shows energy consumption and energy production (MWh/year) while horizontal axis shows four different blocks situation. Actual energy consumption, solar collectors energy production and PV panels energy production are being represented by standing red, green and purple lines respectively. Our calculation demonstrate that the renewable energy generated by solar power,

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effectively reduce energy consumption of our stochastic community urban pattern in the range of 30% to 50%. This case study will be extensible as a suggesting pattern for other cities.

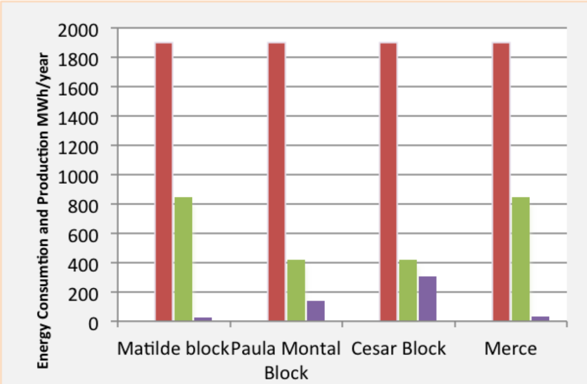

Fig.3. Actual energy consumption (red bar), solar collectors energy production (green bar) and PV panels energy production (purple bar) for each block

4. Conclusions

Cities are playing a critical role in the reliability, affordability and environmental sustainability of its' energy supply. While potential areas include improving building efficiency in existing construction and promoting energy efficiency in new buildings. For instance after the Barcelona bylaw became active in August 2000, within one year the total amount of square meters of solar thermal applications quadrupled. The ordinance has shown that a clarified attitude towards the natural renewable energy resources of a region can achieve the goals of sustainable development.

This paper was developed as a pattern for cities with same situations. It gives an attitude of the challenges and approaches for implementing sustainable energy programs in urban fabric. In case of Eixample district, by randomly choosing 4 out of 415 blocks, energy production capacity, efficiency of devices, analyzing possible solutions to installing solar power devices and investigation of inhabitants opinion due to project processing was considered.

Current studies indicate that the 30% up to 50% of energy consumption is covered by means of solar collectors and PV Panels. These results emphasize on further usage of renewable energy gained by solar power devices in residential buildings with the benefits of energy saving, financial justification and reduction of emissions. Learning from existing case studies and understanding of local government role will certainly help cities to become leaders in energy efficient sustainable urbanism.

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