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Energy Earnings and Carbon Dioxin Reduction Achieved by the Application of Photovoltaic Cells, Case Study of Shopping Light Mall in Sao Paulo

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Abstract: Being the shopping mall a typology of building tending to have high rates of energy consumption and greenhouse emissions, the current study focuses in the analysis of a theoretical case of ecological refurbishment applied on the shopping light mall, placed in Sao Paulo. This analysis has as main objective the demonstration that energy savings and reductions in carbon dioxin emissions can be achieved by the application of solar cells on the roof of the studied mall. Within this analysis, the benefits that this operation can have towards the environmental objectives of Kyoto protocol and Europe 20-20-20 were considered. It was established as conclusion that the application of solar cells in the roof is enough to comply with Kyoto protocol but not enough to comply with the energetic and greenhouse gases requirements established by 20-20-20 initiative.

Key words: Photovoltaic, environment, mall, Sao Paulo, greenhouse gases, Spain

INTRODUCTION

In the last decades and because of the increase in carbon footprint, different international and national authorities have encourage to establish a new model of energy management in this new model a correct technological management is required. In 1987, Bruntland established the concept of sustainability and it consists in the continuation of the development of the societies, without harming the environment or the life conditions of its people. Encouraging the reduction of greenhouse emissions, the Kyoto protocol established as objective the reduction of these emissions in a 5% in the period going from 2008-2012, currently, this protocol has a second phase up to year 2020, establishing a reduction of a 15% (UNO., 2012). In the frame of EU, the report of the European Commission 20-20-20 makes buildings responsible of approximately the 40% of energy consumption and the 36 % of European Union carbon dioxin emissions (EU Commission, 2007). The current paper was aimed in the analysis of the efficiency of the application of solar cells with the objective of evaluating the usage of renewable energies and the decrease of carbon dioxin emissions generated by shopping light mall. Related to solar irradiance on buildings and the energy can be generated by the sun, the city of New York in the PlaNYC. established that the best buildings to install solar energy devices are the ones with large surfaces placed on the outskirts of the city. Higueras and Neila (2012) performed a study of the best criteria to project eco friendly buildings in the Spanish town of Vitoria Gasteiz, Wilsona *et al.* (2003) considered that different urban planning typologies carry on different surface temperature and sun irradiation indexes within, making later a report of these indexes in the city of Indianapolis. Marques (2008) studied the possibilities of the different urban tissues in the city of Sao Paulo to catch solar energy, also, considering the relevance of both, shape and volume of buildings (Marques, 2008). Escorcia *et al.* (2012) a research with the objective of establishing a criteria of sustainable and healthy design for housing developments. Two scenarios of energetic efficiency are considered including both the constructive composition and the energy savings (Escorcia *et al.*, 2012).

For the current study, a theoretical retrofitting by the application of photovoltaic cells was studied on the roof of Predio do light (light company building). This building is considered in the city of Sao Paulo as a representative one and located in the dense urban area of the center of Sao Paulo is the house of shopping light mall, a large commercial business whose visitors in 2014 were estimated in about 75,000 per week. The surface of the building is about 36,000 m^2. The importance of considering an energetic retrofitting in a shopping mall as a good example of energetic management is justified because this building typology tend to imply a high rate of energy consumption and carbon dioxin emissions when working its functions.

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MATERIALS AND METHODS

Methodology applied on the case study: The first step in the study was the making of an analysis of sun exposed hours on the roof of shopping light. This analysis was done by the usage of shadow simulation being the result the number of sun exposed hours per year.

The second step in the analysis was to convert the sun exposed hours formerly calculated in energy units concerning solar irradiation. To achieve this, a spreadsheet of sun irradiation calculus done by Neila (2004) was used inserting on it the data concerning the features of the areas to be studied, the climatic conditions of the city of Sao Paulo and the sun exposed hours.

The third step was to estimate what amount of the energy irradiated by the sun can be used to cover the shopping light energy needs. To achieve this aim, different statistics about the performance of photovoltaic cells were studied interpolating the solar irradiation obtained before. The data concerning solar cells performance in generating energy for consumption was provided by the Intemper technical service.

The fourth step was to establish a theoretical scenario of retrofitting by the application of photovoltaic tiles in the areas of the roof. The result of this step was the generation of clean energy by the application of the solar cells in kW/h. this data is important facing the conclusive analysis.

The fifth and last step was conceived as a previous step towards the conclusions. In this step, the energy consumption of shopping light was estimated, obtaining by this way the necessary information to establish a minimum of relevance. To obtain these data, the CE3X 2.1 computer program (2015) was used, considering its current state without applying any retrofitting.

Finally, the positive results obtained from the analysis of retrofitting scenarios were compared with the energy consumption of shopping light. The results obtained from this comparative analysis headed towards the final conclusions. Furthermore, a minimum of relevance was established that in this case study were to approach toward the objectives of Kyoto protocol related to emissions and the 20-20-20 directive related to both emissions and usage of renewable energies.

Calculation of the efficiency of solar cells: For this research, the case study chosen was the building of the shopping light mall placed in the city of Sao Paulo. Before starting any analysis, the area for the study of the photovoltaic cells application was established on the upper roof areas of the building. This area has a surface

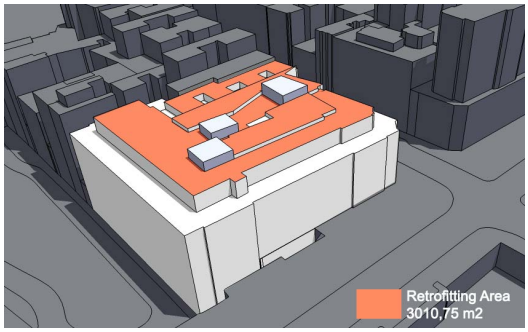

Fig. 1: Areas to be considered for shopping light

of 3010.75 m^2. Lower roof areas were not selected because they are terraces used by the shopping mall customers (Fig. 1).

As a starting point for the study, a solar exposure analysis was performed. Furthermore, a shadow simulation with a tridimensional model of shopping light and urban environment was done, establishing by this way the yearly percentage of sun exposed hours on the roof. The percentage of the time shopping light upper roof is exposed to sun irradiation (without being shaded) was estimated in a 77% approximately of the yearly daytime hours (Fig. 2).

The next step was to calculate the energy irradiated by the sun. By this way a spreadsheet done by Neila (2004) was used inserting on it the climatic data of Sao Paulo. The amount of yearly energy obtained irradiated by the sun is about 207,875 kJ/m^2 on a flat surface. Once solar irradiation was calculated it was necessary to apply a criteria of sun exposure related to the roof of shopping light. Because, Neila (2004) spreadsheet does not considers obstacles facing sun exposure, data obtained from formerly done shadow simulation was considered with the aim of establishing a reference to calculate energy generated by photovoltaic tiles.

Facing the retrofitting by the application of photovoltaic cells it is important to calculate the amount of energy that can be generated considering the solar irradiation on shopping light mall roof. The calculation of the energy generated by the usage of photovoltaic panels was based on the data provided by Intemper company technical service. This data was related to the amount of energy for consumption that can be converted from sun irradiance. Based on a formerly done research about an environmental retrofitting for a public building placed in the Spanish town of Vitoria Gasteiz (Higueras and Carretero, 2015) intemper technical service estimated approximately 44,984.36 kW/h generated for the electrical supply of that building analyzed, considering an area of

PERCENTAGE OF THE ROOF SURFACE EXPOSED TO SUN, DURING A TYPOLOGIAL DAY IN THE DIFFERENT MONTHS OF THE YEAR																MONTHLY AVERAGE
	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	
January	0%	0%	0%	50%	50%	80%	90%	90%	90%	90%	50%	20%	0%	0%	0%	68%
February	0%	0%	60%	80%	90%	90%	90%	100%	90%	90%	90%	50%	20%	0%	0%	77%
March	0%	0%	60%	80%	90%	90%	100%	100%	100%	100%	90%	80%	70%	20%	0%	82%
April	20%	50%	80%	90%	90%	100%	100%	100%	100%	100%	80%	80%	60%	20%	0%	76%
May	50%	70%	90%	90%	100%	100%	100%	100%	100%	100%	100%	90%	50%	50%	0%	85%
June	70%	90%	90%	100%	100%	100%	100%	100%	100%	100%	100%	90%	80%	50%	20%	86%
July	50%	70%	90%	90%	100%	100%	100%	100%	100%	100%	100%	90%	50%	50%	0%	85%
August	20%	50%	80%	90%	90%	100%	100%	100%	100%	100%	80%	80%	60%	20%	0%	76%
September	0%	0%	60%	80%	90%	90%	100%	100%	100%	100%	90%	80%	70%	20%	0%	82%
October	0%	0%	60%	80%	90%	90%	90%	100%	90%	90%	90%	50%	20%	0%	0%	77%
November	0%	0%	0%	50%	50%	80%	90%	90%	90%	90%	50%	20%	0%	0%	0%	68%
December	0%	0%	0%	40%	50%	70%	90%	90%	90%	60%	40%	0%	0%	0%	0%	66%

Fig. 2: Sun exposure and shadow analysis

500 m^2 without obstacles. This study was done, considering the photovoltaic slab model Filtron I, 40 according to the total amount of energy irradiated by the sun in Vitoria (a yearly sun irradiation of 191,026 kJ/m^2) (Higueras and Carretero, 2015). But nonetheless to conduct the analysis in a more specific way it was necessary to perform an interpolation between the data provided by the technical service of Intemper for Vitoria and the data obtained in the formerly done solar analysis for Sao Paulo in addition to the one related to shadows.

In order to overcome this, the first operation was to put the values of energy generated by the Filtron I 40 in kW/h per square meter. This was done by dividing the monthly totals given by Intemper between the standard surface considered (500 m^2), obtaining by this way a rate of 89,97 $kW/h/m^2$ generated for the building necessities. To obtain this rate for the climate of Sao Paulo, this data was interpolated.

According to, the data given by the spreadsheet done by Neila (2004), the yearly sun irradiation that Sao Paulo receives wasestimated in 207,875 kJ/m^2. By comparing this irradiation rate with the one related to the town of Vitoria, the rate of energy generated by the Filtron Slab I 40 for the climate of Sao Paulo was established for this study in 98 $kW/h/m^2$.

For this research, the solar panels were of application for the roof of Shopping Light mall, only on selected areas (Fig. 1). To obtain the yearly energy can be generated, this surface (3010,75 m^2) was multiplied by the rate established before obtaining a total amount of 295,053.5 kW/h.

However, the value formerly obtained was calculated considering a surface with no shadows. By this way, this obtained value was multiplied by the percentage of total sun hours obtaining in the shadow analysis (0,77%). To sum up with these calculus, the roof of shopping light mall can generate about 227,191.195 kW/h. per year.

RESUTLS AND DISCUSSION

Results of the application of photovoltaic cells: Once the energetic retrofitting by the application of photovoltaic tiles were analyzed, next step was to establish the criteria towards the conclusions. This criteria was be based on the energy consumption of the center and lately the carbon dioxin emissions generated by it. Related to both energy consumption and carbon dioxin emissions, an estimative analysis of the shopping light mall building was done with CE3X 2.1 program. Obtaining the data concerning carbon dioxin emissions derived from energy usage. It also, may to be considered that the application of the photovoltaic tiles will produce a reduction in carbon dioxin emissions rate because this will suppose a minor dependence in pollutant energy sources. In order to see these reductions, the methodology of application was the insertion of the architectural features and installations of the shopping light mall building within CE3X. This analysis was going to be estimative because the characteristics of the installations of shopping light mall were not known. Because CE3X does not have data of the climate of Sao Paulo, the climate of Santa Cruz de Tenerife was considered because of the similarities in temperatures (Fig. 3).

In this program an estimation of the features of the facades of shopping light mall were inserted, The orientations of the facades of shopping light mall were readapted to the requirements of the program (Northern orientation facades in real shopping light mall building were considered as south in the virtual model of CE3X). Related to facades, the detail of massive wall built of stone and concrete was considered, being hollow chambers in both roof and floor. Windows were considered made of steel with single glass. Because there were no data concerning installations for this analysis was supposed shopping light mall to have air conditioning facilities, ventilations systems and heat

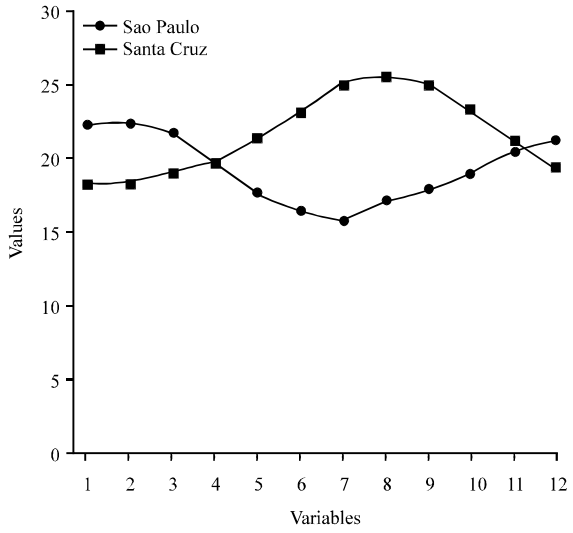

Fig. 3: Climate comparison of Sao Paulo and Santa Cruz

water by heat pump, the three with an estimated performance of a 250%. The results of the CE3X simulation for shopping light mall were the following ones:

- Energy consumption: 356.4 kWh/m^2 per year (C)
- Yearly CO_2 emissions: 0.095 T/m^2 per year (C)

Related to the analysis of energy consumption and the reduction achieved by the application wasconsidered necessary to compare the energy generated by the usage of photovoltaic cells with the energy consumption of the shopping light mall. The program CE3X established an energy consumption of 356.4 kWh/m^2 being the useful surface of shopping light mall 30,000 m^2 approximately. By this way the yearly energy consumption of shopping light was estimated to be 10,692,000 kW/h per year. The estimated emissions of shopping light, according to the formerly mentioned installations were approximately of 0.131 T/m^2. Considering the same surface (30,000 m^2) the total emissions are about 2850 tons of carbon dioxin per year.

Having the consumption and carbon dioxin emissions data, a comparative analysis was done towards the conclusions, next step was to see if a relevant rate of the shopping light mall energy demand could be supplied by the usage of solar tiles. Related to energy generation, the coverage of the shopping light mall roof with solar tiles can generate 295,053.5 kW/h per year that is a 2,1% of the yearly energy consumption. (10,692,000 kW/h.) this improvement is scarce and solutions concerning reduction of energy consumption by the increase of isolation or the usage of low consumption installations would be also required.

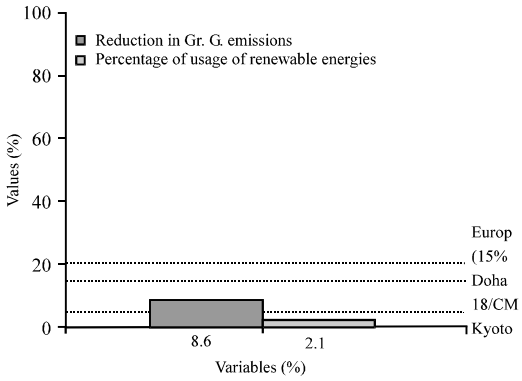

Fig. 4: Comparative analysis with thresholds established

Other issue to be considered on this paper is carbon dioxin reduction by this way a new energetic simulation of the building of shopping light mall was done in CE3X once again inserting the amount of energy generated by solar tiles studied formerly. The result was that carbon dioxin emissions were lowered from 0.095-0.082 T/m^2/year (a balance of 0.012 T/m^2/year) being the final total emissions of shopping light mall after the application of photovoltaic tiles of 2460 tons of carbon dioxin emitted per year. As consequence of this a reduction of about an 8.6% is done related to carbon dioxin emissions.

Threshold analysis: Once data related to conclusions was obtained, a comparative analysis was done. To carry out with this, a minimum of relevance was established being established two thresholds. The first one was the reduction of the 5% established in the Kyoto protocol, despite the rate of greenhouse gasses emissions of shopping light mall in 1990 is not known. The second threshold established is the reduction expected in the current phase of Kyoto protocol established in Doha (15%) and the third is the Europe 20-20-20 directive, considering for this case the assimilation of the 20% of the emissions generated by the building and a coverage of the 20% of energy demand using renewable sources. To sum up, the reductions achieved were put in the following graph establishing the two thresholds established (Fig. 4).

As shown in Fig. 4 with the application of photovoltaic cells in the roof, the most relevant achievement is the reduction of carbon dioxin emissions. This retrofitting would allow shopping light mall to comply with the requirements of primitive Kyoto protocol, (focused only in greenhouse gas emissions). However, the achievements in the emissions are still far from other initiatives with most ambitious environmental objectives in greenhouse gasses emissions as the current phase of Kyoto protocol or the Europe 20-20-20 Initiative. Is important to consider that Brazil is not included in these two directives.

Therfore, related to the usage of clean energies, the application of solar cells on the roof of shopping light mall is not enough to make the building to comply with Europe 20-20-20 objectives, achieving only a scarce percentage of a 2,1%. In contrast to this is important to consider that according to ICLEI, the 90% of the energy used by the city of Sao Paulo, comes from renewable sources (ICLEI., 2012). Furthermore, considering this statement as true, shopping light mall can supply the 92% of its energetic demand by renewable sources, enough to comply with Europe 20-20-20 requirements on usage of renewable energies. The challenge shopping light mall must achieve though is the energetic self dependence on energetic sources in addition to the reduction of greenhouse gas emissions. Objectives that are still far to comply considering only the application of photovoltaic cells in the roof.

CONCLUSION

As a conclusion it becomes evident that buildings of relevance in the city, owned by influent private landlords or local authorities must be an example of correct energy management, resulting this in solutions that can be exemplar for the rest of the city. According to Trevilcock (2011). "In Chile, the public sector have pointed its policies of buildings towards the energetic efficiency and the usage of non conventional renewable energies" (introduction chapter). The studio done on the shopping light mall in Sao Paulo, demonstrates both the opportunity and the benefits of photovoltaic roofs. Being achieved by this way, a following reduction of energy consumption generated from environmentally harmful sources and a reduction of carbon dioxin emissions. In addition, it is important to consider the retrofitting in energy consumption and carbon dioxin emissions because shopping mall are buildings that tend to have high rates of energy consumption in addition to emit a large amount of greenhouse gases due to their large surface and intense activity.

To sum up, the application of solar cells in the roof only is not enough to comply with the directives and initiatives having these initiatives, ambitious goals in environmental requirements in spite of being not related to concrete cases. With this research, it has been demonstrated that still there is much to do towards the challenge of sustainability. The shopping malls are an opportunity facing energy savings and reduction in carbon dioxin emissions, despite not being included in these environmental directives.

By this way, to comply with the environmental requirements these directives have established, mixed solutions are going to be required being also, necessary an accessible register of consumption and carbon dioxin emissions data, related to shopping malls. The aim of these proposals are to guarantee any future operation of environmental retrofitting on a shopping mall to be truly effective.

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