PROMOTING GRID-CONNECTED PHOTOVOLTAICS IN BRAZIL THROUGH HIGH VISIBILITY SHOWCASE BIPV PROJECTS

Ricardo Rüther[1,2,3], Priscila Braun[1], Alexandre A. Montenegro[1], Lucas R. Nascimento[1] and Clarissa D. Zomer[1]

[1]Universidade Federal de Santa Catarina / UFSC

Caixa Postal 476, Florianópolis – SC, 88040-900, Brazil

[2]IDEAL – Instituto para o Desenvolvimento das Energias Alternativas na América Latina

R. Lauro Linhares 2123, 5º andar, Florianópolis – SC, 88036-003, Brazil

[3]Visiting Academic at The School of Electrical, Electronic & Computer Engineering, The University of Western Australia

Stirling Highway, Crawley 6009, Australia (ruther@mbox1.ufsc.br)

Abstract

In most of the large countries of the developing world grid-connected, building-integrated photovoltaic (BIPV) systems in the urban environment can have an important role to play, especially in sunny areas, where high annual energy yields make PV generation more competitive. In Brazil, high and rising electricity tariffs, high solar irradiation levels, and the declining costs of PV will lead to the cost-effectiveness of solar electricity (*i.e.* grid-parity) sometime soon in the present decade. In this context, this paper presents technical aspects on the potential of BIPV in Brazil, and an overview of a number of high visibility BIPV projects, namely the *Eletrosul Megawatt Solar*, the *Solar Soccer Stadia for the 2014 World Cup*, and the *Solar Airports* projects currently under way in the country. These projects aim at the same time to promote large-scale photovoltaic generation in Brazil to energy planners, and to attract the attention of architects and builders to the aesthetic potential of PV as a building element. Two major worldwide events to take place in Brazil are the Soccer World Cup in 2014, and the Olympic Games in 2016. These events will attract considerable media attention worldwide, and are a perfect opportunity to showcase the PV technology in Brazil and globally. In the case of the *Solar Airports* project, the leitmotiv includes CO_2 abatement of the emissions related to the aviation industry, since air flight is currently responsible for some 5% of total greenhouse gas emissions worldwide and is expected to double until 2015.

1. Introduction

The major challenge of this century is to discover what energy sources will be moving humanity in the future. With the forthcoming end of the era of oil and gas due to both growing environmental concerns and the depletion of world reserves, the more developed countries are investing vast resources in researching alternative energy sources. Although everyone acknowledges the huge renewable energy resources present in all Latin American countries, there is a need for initiatives that promote a fast and widespread uptake of these technologies in these countries. It is in this scenario that we created IDEAL – Instituto para o Desenvolvimento de Energias Alternativas na América Latina (Institute for the Development of Alternative Energy in Latin America). IDEAL was born with the purpose of promoting renewable energy together with governments, parliaments, academia and business, allowing the establishment of an energetic integration policy and regional development. While IDEAL promotes all forms of renewable energies, it has concentrated efforts in promoting solar photovoltaics (PV), as this is the least developed, but currently the fastest growing segment of energy technology worldwide, and the ultimate renewable energy source in terms of geographical distribution and availability. Solar energy might be the only renewable energy source that presents the potential of sustainably and economically supply all the energy needs of mankind, and with the continuously declining costs of the PV generation, efforts should be devoted to promoting this benign technology, especially in the sunny areas of the developing world. IDEAL has strong links with Universidade Federal de Santa Catarina, and since 2007 has been promoting a number of high visibility initiatives, including workshops, seminars and PV showcase projects designed to foster the uptake of solar PV in Brazil. Many of these initiatives were supported by the German Development Bank (KfW) and the German Technical Cooperation (GIZ).

Grid-connected PV is usually perceived as an energy technology for developed countries, whereas isolated, stand-alone PV is seen as more suited for applications in developing nations, where so many individuals still lack access to the public grid. However, the traditional utility concept relies on a relatively small number of considerably large power plants, which are not necessarily close to the urban centers where energy is consumed. Centralized, large hydropower generation plays a fundamental role in Brazil in spite of the large distances from urban areas. The present installed capacity of some 75 GW in hydropower generation corresponds to over 75% of the national electricity supply, which grows at some 4 to 5% per year. Growing environmental restrictions, and the larger distances from urban centers to the remaining potential, however, are considerably increasing the costs of new hydropower plants. As a consequence, conventional electricity prices are increasing. The Brazilian interconnected electricity system is one of the largest and most complex in the world, with an installed capacity of over 110 GW in 2010. In a large country like Brazil (8.5 million km^2), transmission and distribution infrastructure and associated losses are not negligible, and utilities could benefit from PV distributed generation. Political barriers and costs, however, still restrain diffusion of grid-connected PV systems in developing countries. In this scenario, this paper presents some showcase PV projects, where technical aspects, together with public and stakeholder awareness campaigns are presented to make the case for a more widespread uptake of the solar PV technology in Brazil and in the whole of Latin America.

2. Showcase project ELETROSUL MEGAWATT SOLAR

Eletrosul is a daughter company of Eletrobras, the Brazilian largest utility, serving the southern states of the country. Eletrosul has been investing in small hydro and wind generation for a number of years, and more recently it has become interested in the potential of solar photovoltaics in assisting urban distribution grids. It has been previously shown how BIPV can assist distribution utility daytime peaking feeders in peak shaving under different environments (Al-Hasan *et al.* 2004; Rüther *et al.* 2008; Hernández *et al.* 2008). Jimenez *et al.* (2006) used transformer operating temperatures as an indicator of the stress on the feeder transformer, and have shown that temperatures were at its lowest when solar PV systems were providing the maximum output. We have also previously shown that a PV locating strategy can successfully be applied in siting PV installations in urban environments in order to maximize benefits. When strategically sited, PV generators integrated to building façades and rooftops in urban areas at limited penetration levels can benefit local feeders with these distributed "negative loads" (Jardim *et al*. 2008).

In this showcase project we presented results on the potential of integrating a 1MWp BIPV system onto an existing large-area commercial building in a metropolitan environment in Brazil (Braun & Rüther, 2010). We carried out one-hour resolution simulation studies on the integration of this PV generator on the ELETROSUL headquarters building in Florianópolis – Brazil, and have compared the potential solar energy generation with real electricity demands of that building complex for the year 2007. In order to be able to simulate the performance of the proposed 1MWp PV installation, real and simultaneous solar irradiation data were used. The most relevant technical aspect presented in this work was the quantification, and demonstration that a BIPV solar generator can offer peak shaving opportunities for the commercial building operator, which come in addition to the displaced energy benefits of on-site generation. Additionally, benefits for the local utility were also identified, with demand peak-shaving in summer taking place at the corresponding feeder. The methodology presented in this work can be used in any situation where PV generation profiles match the corresponding building energy demand profiles, and is maximized in buildings where air-conditioning cooling loads are predominant.

The medium voltage (13.8kV) utility feeder #TDE-07 supplying energy to the ELETROSUL headquarters covers a mixed residential and commercial area in the heart of the city. Figure 1 shows the geometry and layout of feeder #TDE-07, with the main (red) line, and a number of ramification nodes (blue) and transformers (dark dots). Solar irradiation and PV generator performance data were obtained from the first grid-connected BIPV installation in Brazil, a 2kWp BIPV system that operates continuously since 1997 in our laboratory at UFSC (Rüther 1998, Rüther & Dacoregio 2000). With the simulated output of the proposed 1MWp solar generator, based on the real 2kWp installation performance data, and the building's electricity demand data sets, information on energy and power demands and costs was produced for the 12 months period analysed.

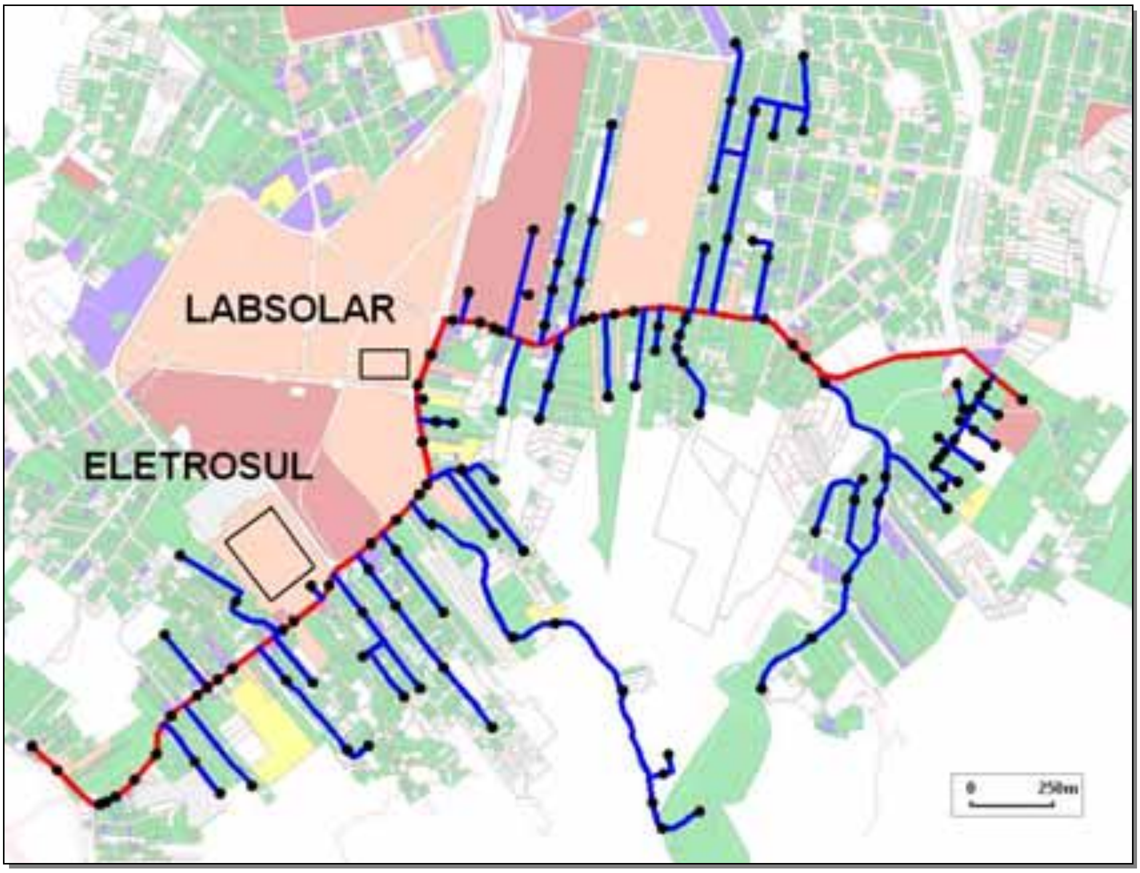

Figure 1: Layout of the distribution feeder TDE-07, which supplies the ELETROSUL building in Florianópolis, Brazil (27ºS, 48ºW), showing the main (red) line, a number of ramification nodes (blue) and transformers (dark dots). The BIPV solar generator from which the performance data used in this work was obtained is in close proximity, operating at the LABSOLAR building at Universidade Federal de Santa Catarina since 1997.

Figure 2 shows the effect of the solar contribution to the ELETROSUL's building load curve with typical examples of a sunny workday and a sunny weekend day. The light-blue dotted line shows the real building's load curve on 30th and 31st March 2007, typical late summer, consecutive sunny days in Florianópolis; the orange dashed line shows the 1MWp solar generator output on that same sunny day; and the blue squares line represents the resulting load curve, as seen by the distribution utility feeder. The workday load curve is representative of a public/commercial office building with predominantly air-conditioning loads, with a strong ramp up in demand when HVAC systems start operating in the early morning, peaking in the mid-afternoon and ramping down strongly towards the early evening. In the evening and overnight, there is a lower and fairly constant base load. On a weekend day, the demand is also lower throughout the whole day, with a fairly constant load, which is at a similar level as the workday baseload. On the sunny weekday, the 1MWp solar generator has a peak-shaving effect on the resulting load curve, reducing the maximum load perceived by the distribution utility feeder, and shifting it to the early to mid-morning, when feeder loads are not critical as we will further show. On weekends, on the other hand, there is a considerable amount of energy that is fed back to the utility grid as a consequence of the reduced load in the ELETROSUL building. The peak reduction potential of the 1MWp solar generator shown here, will be further explored as a tool for renegotiating the ELETROSUL building's demand contract with the local distribution utility.

Strategically sited PV systems can contribute to alleviate urban distribution networks, shifting demand peaks when there is a good match between loads and the solar radiation resource. We have shown how a building-integrated solar PV generator in the 1MWp range can contribute to both the commercial building operator and the local distribution utility in a metropolitan environment in a warm and sunny climate. Since a considerable fraction of the local distribution feeder load is due to the large commercial building under analysis, the BIPV generator can contribute in reducing the feeder's peak. Furthermore, this project is the first Megawatt-scale PV generator installation in an urban environment in Brazil, and it will attract considerable attention as a showcase project. A public call for tenders has been announced, and installation is planned for late 2011/early 2012.

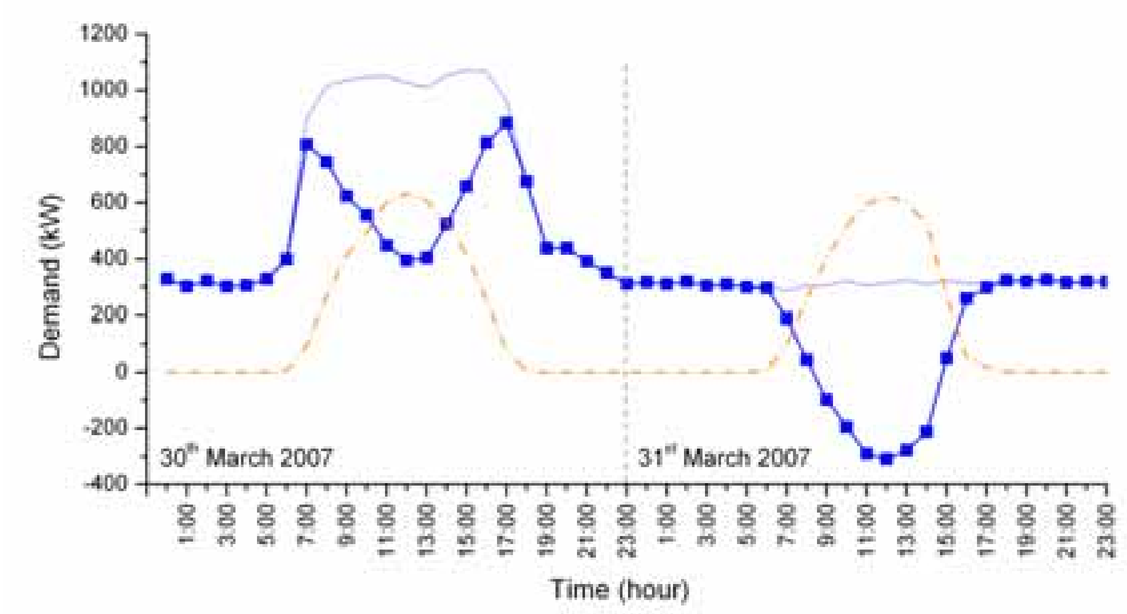

Figure 2: Effect of the solar contribution to the ELETROSUL's building load curve with typical examples of a sunny workday and a sunny weekend day. The light-blue dotted line shows the real building's load curve on 30th and 31st March 2007, typical late summer, consecutive sunny days in Florianópolis; the orange dashed line shows the 1MWp solar generator output on that same sunny day; and the blue squares line represents the resulting load curve, as seen by the distribution utility feeder.

The typical assessments of PV benefits for investors usually take into consideration only the energy (kWh) component of the PV contribution, disregarding the potential contribution of the power (kW) component in renegotiating the building's demand contract with the local distribution utility. We have demonstrated that there is an additional benefit of on-site PV generation, which is related to the demand (kW) component of a building's energy bill. For the building operator, we have quantified the individual cost reduction contributions of the PV generator both in terms of energy (kWh) and demand (kW) costs. We have shown that the peak shaving attribute of the on-site PV generator should not be disregarded, as it can represent an additional 15% to the potential cost reduction. This additional financial benefit can influence the decision of installing PV, bringing payback times closer to more attractive levels.

3. Showcase project SOLAR SOCCER STADIA FOR THE WORLD CUP 2014

In Europe, some countries have adopted what are called "solar stadia", as was the case during the FIFA World Cup 2006 in Germany, and during the UEFA Cup 2008 in Switzerland, as a method of using the space on the rooftops of these stadia to generate electricity. The World Cup in 2014 brings a remarkable and timely opportunity for Brazil, as PV costs continue to undergo considerable reductions and the technology starts to attract attention of energy decision-makers in the country. In this context, IDEAL, together with the German Development Bank (KfW) and the German Technical Cooperation (GIZ) promoted a series of awareness initiatives with energy company and soccer stadia stakeholders in Brazil, in order to demonstrate the potential of soccer stadia in generating solar electricity and becoming a major showcase for the PV technology in Brazil and elsewhere.

A field trip to Europe was organized by the GIZ, and a number of soccer stadia with PV generators were visited. A feasibility study was also carried out to demonstrate the solar potential of all soccer stadia in Brazil that might host the 2014 Soccer World Cup matches (Rüther *et al.* 2009). The outcome of this campaign is that a number of soccer stadia in Brazil are carrying out technical and economic feasibility studies, and some have already decided to "go solar". Figure 3 shows one of these examples, where the utility CEMIG, one of the most progressive companies in Brazil, has decided to install a solar generator on top of the Mineirão Stadium in Belo Horizonte-MG. Since soccer stadia are usually in the urban environment, local utilities will also experience the benefits of having these large PV plants connected to their distribution networks, and will accumulate experience in dealing with these distributed generators. Additionally, they will be able to use these projects as a public relations tool with their consumers.

Figure 3: The Mineirão Stadium in Belo Horizonte and the proposed PV generator to be installed by the local utility CEMIG on the existing concrete roof cover.

Some of the existing stadia will not be able to accommodate PV on their rooftops due to structural aspects, but it is expected that most of the Brazilian soccer stadia that will host matches during World Cup 2014 will have PV generators either on their rooftops, parking lots or other adjacent areas.

4. Showcase project SOLAR AIRPORTS

Over the last three decades world energy demands have shown a consistently growing trend, with primary energy growing by 89.5% and CO_2 emissions by 79% in the 1973-2006 period (IEA, 2008). It is forecasted that this trend will continue, with emerging economies energy use growing at an average annual rate of 3.2%, and developed countries growing at a rate of 1.1% (IEA, 2008; Pérez-Lombard et al., 2008). At these rates, by 2020 emerging economies energy use will exceed that of developed nations (Pérez-Lombard et al., 2008). Buildings are responsible for a considerable share of energy consumption, and will play a growing role in the energy demands of emerging economies in the next decades. The concept of zero energy buildings (ZEBs), or net zero energy buildings is a general term applied to a building with a net energy consumption of zero over a typical year under normal operation and use. Buildings are typically responsible for 40% of the total primary energy consumption in the US, the European Union and also in developing countries like Brazil (Baden et al., 2006; Geller, 2002). ZEBs are gaining in importance and popularity, mostly in the developed world. In developing countries the ZEB concept is starting to attract interest, mostly as a public relations or marketing strategy of companies that can profit from the image of environmental responsibility and forward-thinking behaviour.

In countries like Brazil, public buildings in urban areas often present considerably high air conditioning loads, with electricity demands that can hardly be generated on site with renewable energy generating systems. The typical prestige building is a tall, glass envelope, with a electricity demand curve that is usually in good synchronicity with the solar irradiation profile, but which often lacks the necessary (and conveniently oriented and tilted) areas to accommodate enough active solar generator systems that could produce enough power on site. Airport buildings in particular, especially in warm and sunny climates, present even higher energy demands due to air conditioning units. These loads typically present a very good match with the local solar radiation resource availability, both on a seasonal and daily basis, and there is also a good correlation between ambient temperatures and energy demands. On the other hand, airport buildings are typically large and horizontal, free of shading and ideal for the integration of solar photovoltaic generators. On-site BIPV generation avoids the need of voltage step-up and step-down typical of centralised generation and transmission and distribution systems, as well as all the associated hardware and losses. The building's electrical installation itself can be used as the interface between the PV generator and the public distribution grid. With near-future prospects of cost reduction to levels where it might compete with conventional grid electricity prices (van der Zwaan and Rabl, 2003), a more widespread use of BIPV generators can be expected, triggered by national incentive programs carried out in many countries (BMU, 2001; Erge et al., 2001; Kurokawa and Ikki, 2001; Schoen, 2001; Castro et al., 2005).

Energy demands in buildings can be either reduced by the implementation of energy efficiency strategies, or met by on-site generation. Hamza presented a study on the use of double versus single skin façades in hot arid areas, pointing out that the single skin configuration in warm climates is a major contributor towards influencing the cooling loads of office buildings. Façade configurations are predicted to be responsible for up to 45% of the building's cooling loads (Hamza, 2008). Double skin façades are an architectural concept composed of two façade layers separated by a cavity. Transparent glazing is often used on the exterior leaf to maintain a distinct transparent appearance to buildings. Yum and Steemers (2009) have recently demonstrated the effectiveness and implications of applying PV to façades, and Infield *et al.* (2004) have analysed the thermal performance of PV façades. Charron and Athienitis (2006) have optimised the performance of double façades with integrated PV and motorized blinds. We have recently shown that BIPV systems in residential buildings in Brazil can assist in reducing their energy demands (Ordenes et al., 2007), and have also demonstrated that in a typical office building over 50% of the energy demands can be supplied by solar energy (Marinoski et al., 2004). Another recent study carried out in less sunny Tokyo-Japan, concluded that with the use of semi-transparent, BIPV modules, energy consumption was reduced by 54% (Miyazaki et al., 2005). Due to the distinct characteristics of the building envelope of airport buildings, BIPV systems can represent an interesting alternative to assist in meeting their energy demands. Because airport grounds often present large open areas used as sound buffer zones, there is considerable potential for airport complexes to accommodate PV installations that could generate more power than necessary to run the airport, exporting excess energy to the grid, and assisting daytime peaking utility distribution feeders in urban areas (Jardim et al., 2008; Rüther et al., 2008). Furthermore, BIPV can be also used as a Distributed Generation (DG) strategy, adding capacity and power quality to the distribution grid and shaving demand peaks. Caamanõ et al. (2008) have recently performed an extensive revision of the state-of-the-art of the mutual impacts between PV-DG and electricity networks, with a main focus on power quality and safety. They have raised the technical issues, indicating potential problems and solutions, and showing that PV systems offer good options to improve grid supply quality and provide grid services.

In this project we have assessed the potential impact in energy demand reduction of a number of public airports in Brazil. We present here some selected results for the Florianopolis International Airport in the south of the country (27^{o}S, 48^{o}W), with the use of building-integrated photovoltaic systems. We have analysed the building's hourly energy consumption and solar irradiation data, to assess the match between energy demand and potential generation, and we have estimated the PV power necessary to supply the complete airport energy demands. Our results show that the integration of PV systems on airport buildings in warm climates can supply the entire electric power consumption of an airport complex, in line with the general concept of a zero-energy building (ZEB). We have also assessed the potential contribution of solar PV in matching the load curve and the potential of peak shaving, and our results demonstrate that airport buildings are ideal applications of PV due to the close match between the air-conditioning driven electricity demands and the solar irradiation availability profile.

Figure 4 shows an artist's impression of the new Florianópolis International Airport passenger terminal, where PV can be incorporated in very good harmony on the building's envelope using both the brise-soleil and roof cover structures. This passenger terminal will start construction in 2012, and the incorporation of PV is proposed for both the building and as the roofing of the large-area car park lot behind the terminal. As a showcase project it is expected to attract considerable attention to a public including decision makers in both public and private business, as well as government officials.

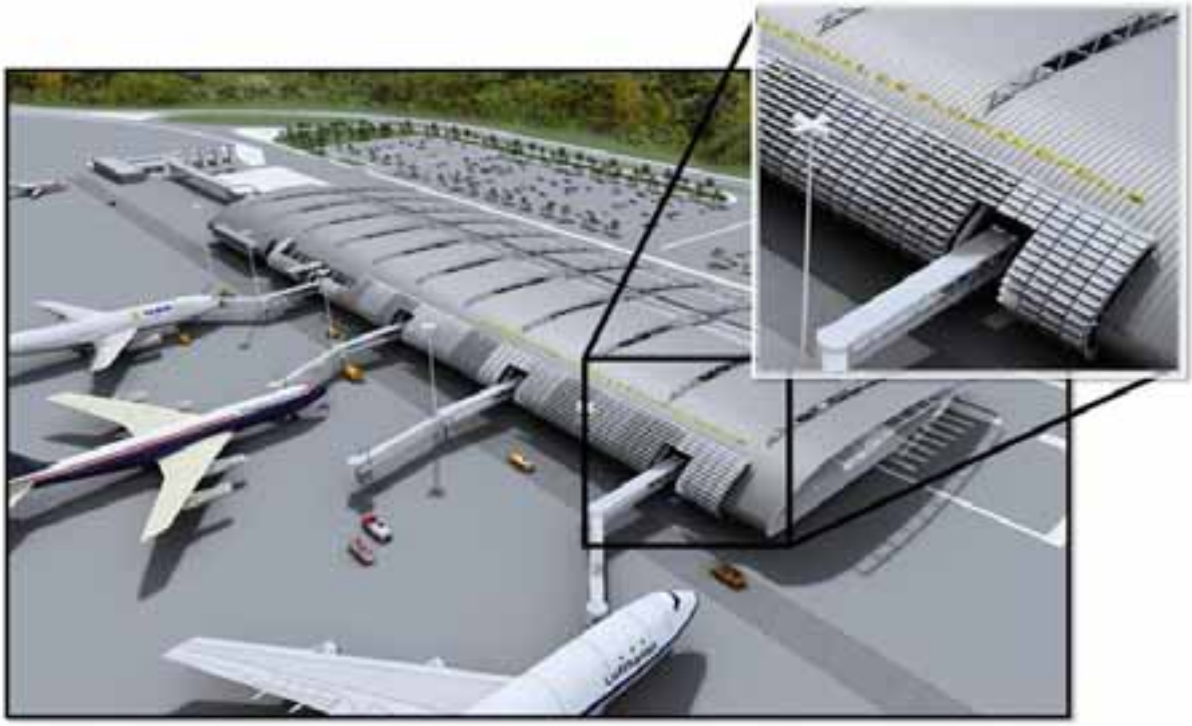

Figure 4. Artist's impression of the new Florianópolis International Airport, where PV can be incorporated as rigid modules on brise-soleil structures, and flexible, metal roof-bonded PV laminates. Source: INFRAERO.

Figure 5 (left) shows the profile of the monthly energy consumption at the Florianópolis International Airport, where a very good match can be observed between the energy demands and the sunnier summer months, where more solar electricity can be produced. Both the energy demand and the solar availability at the airport double in summer months. Furthermore, as figure 5 (right) shows, hourly energy demands at the airport are also in good synchronism with solar radiation availability, with electricity demand peaking at noon, when solar generation is also at its peak.

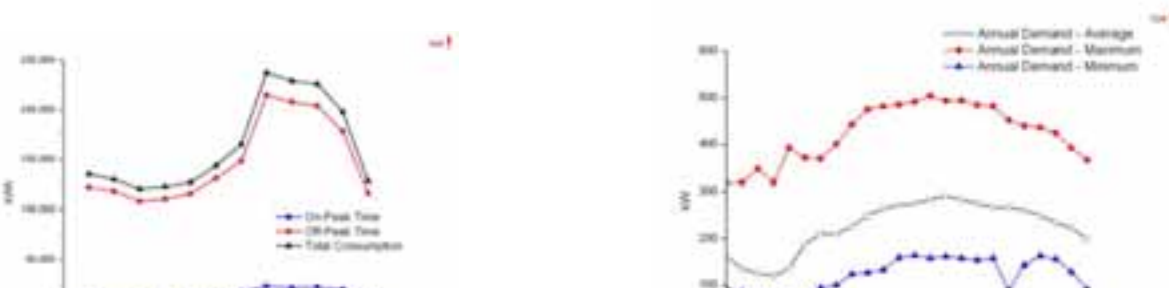

Figure 5. Monthly (left) and hourly (right) energy consumption of the Florianópolis International Airport between June 2005 and May 2006.

In figure 6 we show the good correlation that the airport's energy demand has with local ambient temperature, to demonstrate that airport electricity loads are driven by air-conditioning energy demands. Each graph shows, for a particular month from June 2005 to May 2006, the hourly electricity demand (kW) over the 24 hours for all days. Each and all hourly-demand point for which the ambient temperature was above 25^{o}C is represented by red full circles. Especially in summer months, demand always peaks when temperatures are highest, and peaks are centred around noon, when solar irradiation levels are also highest. Airport buildings are thus not only ideal candidates to accommodate solar PV generators from a public relations perspective; they are also technically well suited to incorporate these distributed generators with perfect match of solar generation and electricity consumption.

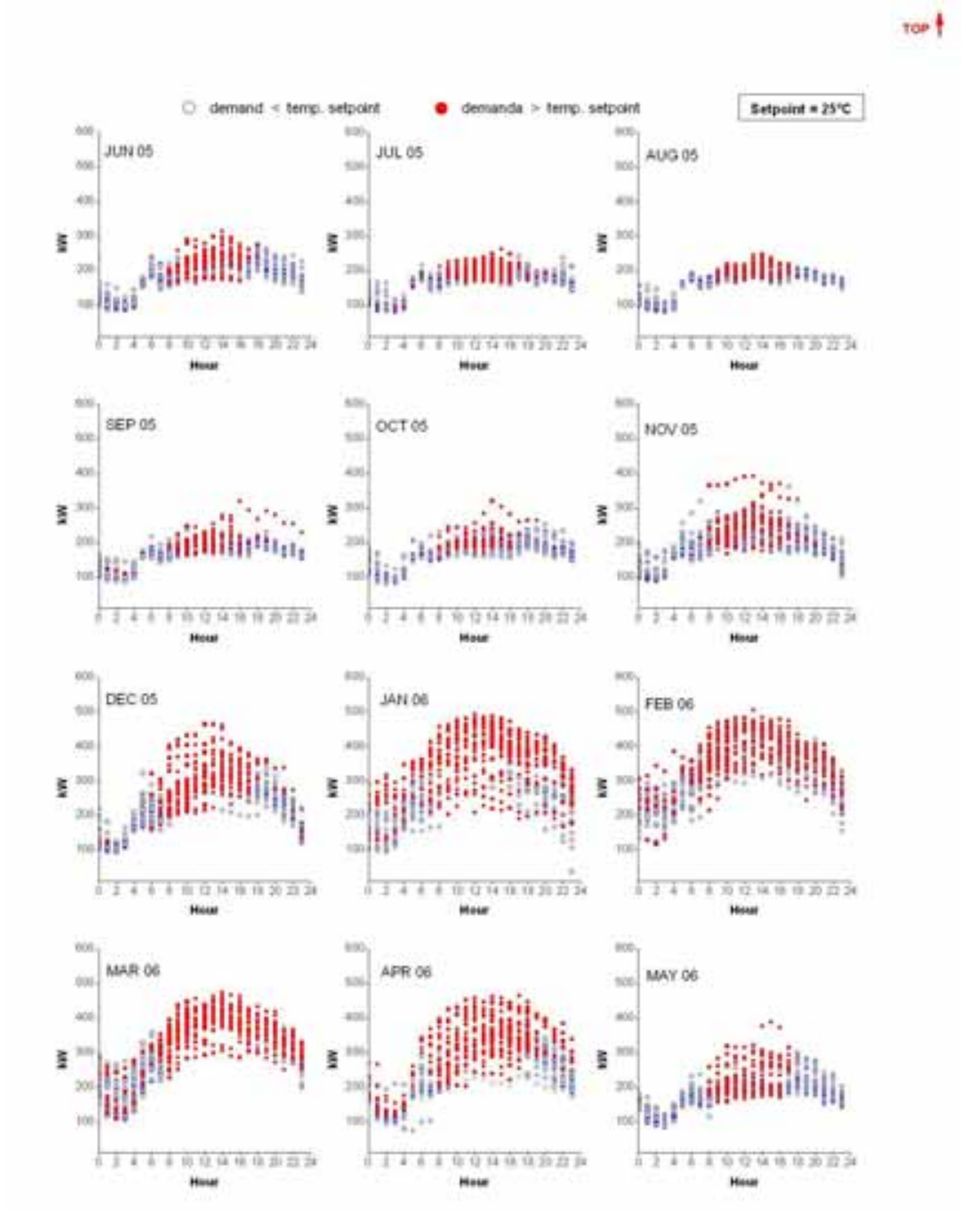

Figure 6. Temperature influence on the electric energy consumption at the Florianopolis International Airport. Hourly demand averages taking place at ambient temperatures above 25ºC are closed (red) symbols, with open (blue) symbols representing hourly demand averages with ambient temperatures below 25ºC.

The civil aviation industry is responsible for over 5% of the global GHG emissions, and that contribution expected to double in the next 15 years (Schiermeier 2006). Airport buildings are also large electricity consumers. The integration of solar PV generators on airport facilities thus presents an excellent technical and public relations opportunity.

5. CONCLUSIONS

We have presented technical and public relations aspects of a number of high visibility, showcase solar PV projects currently under way in Brazil. These projects are part of Universidade Federal de Santa Catarina and Instituto IDEAL's strategies in promoting a more widespread uptake of solar energy generation technologies in Brazil.

While not all of the PV generator's nominal capacity can be regarded as despatchable energy, due to the solar resource intermittency, a considerable fraction of the installed PV power can be relied on for peak shaving. Careful analysis of the historical demand curves is essential in order to maximize the potential of on-site PV generators. The role of grid-connected BIPV generation in commercial building electricity loads in a warm and sunny climate is evident and demonstrated. In a context where the declining costs of PV generation compete against traditional and lower-cost energy generation alternatives, quantifying and maximizing the full benefits of BIPV is of considerable financial and technological interest.

Due to their large, free of shade and typically horizontal construction, airport buildings represent an ideal application of building-integrated photovoltaics. Airport buildings in warm and sunny climates present high energy demands, due to the extensive use of air-conditioning units in large open areas. There is a very strong correlation between ambient temperatures, solar radiation availability and electricity demands. Our studies have also shown that large building envelopes like airport buildings, can host considerably large on-site PV generators that can represent important contributions to the local distribution utilities as sites for DG in urban areas. The building envelope can accommodate the PV generator, and the building's electrical installation can provide the interface between the solar generator and the utility's distribution network, resulting in a strategically sited, virtually zero-area, clean and renewable power plant that is at the same time an excellent public relations tool and strategy for one of the largest GHG emission single contributors.

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