Organic photovoltaic panels for bus rapid transit stations in Curitiba – a viability study

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Abstract

Curitiba is the capital city of Parana State in Brazil. The city is famous for its urban plan and Bus Rapid Transit (BRT) system. The cylindric design of the bus stations, known as tubelike stations, in Curitiba's BRT system, is unique and considered a symbol of the city. Recently these bus stations have been criticized for lacking thermal comfort and for their high-power consumption (around 18 kWh/day). Organic Photovoltaic (OPV) solar panels printed on flexible polyethylene terephthalate (PET) substrate can be a solution to locally generate power without altering the unique design of the stations. The energy provided by OPV panels should cover at least 60% of that demand to be economically viable. In this work we analyzed efficiency, reliability and resilience of OPV panels installed on the top of a tubelike station for 11 months. Performance related parameters (JxV curves, J_{SC}, V_{OC}, irradiance) were measured and a methodology to test soiling effects on the OPV panels was designed. Because there are not many publications on soiling effects on OPV panels the methodology used in this work was adapted from methodologies described in works on soiling effects on Si based PV modules.

Keywords: OPV, urban furniture, flexible solar panels, efficiency analysis, soiling effects on PV modules.

1. Introduction

Bus rapid transit (BRT) is the main public transportation system in Curitiba. BRT stations in Curitiba were revamped back in 1991 and since then became a symbol of the city (Leitman and Rabinovich, 1996). On more than one occasion interventions to the iconic tubelike bus stations were proposed and were not accepted because they added major changes to the original design of the stations.

The average energy consumption of a standard tubelike station is, according to the Urban Administration Office (URBS) of Curitiba, 180 kWh per month. URBS will only consider installing OPV panels on BRT stations if the panels can generate at least 60% of the power demand of each station. Analysis of energy efficiency, environmental cost and adaptation of solar cells to a standard tubelike station will help local administration to decide on the use of OPV panels for BRT stations and other urban furniture.

In this work we report the performance of Organic Photovoltaic (OPV) panels that were installed in a test tubelike station. URBS donated the station that was installed inside Universidade Federal do Parana (UFPR) campus that is destined to research and development of technologies that might be later reproduced in other tubelike stations in Curitiba.

Although OPV based cells have been studied for over 30 years (Inganas, 2018), the industrial production of the panels only happened a few years ago. OPV panels enable better architectural integration and also have the advantage of having a production with less environmental impact than the production of Si based solar panels (Hengevoss et al, 2016). Production of OPV panels should soon have even less environmental impact with the use of green solvents that have been recently researched (Wouk de Menezes et. al, 2018).

The lack of viability studies on market ready OPV panels in climate conditions similar to those in Curitiba motivated us to design a comprehensive set of measurements that evaluate efficiency, reliability and

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resilience of the panels in Curitiba. As OPV panels can be printed on flexible substrates like PET they have potential to be used on windows and urban furniture.

The OPV panels studied in this work were produced by CSEM Brasil using roll to roll technique (Hosel et al, 2012) and are available to the market. The panels were installed on the top of the test tubelike station (Figure 1).

Figure 1: Test tubelike station at UFPR campus. CSEM OPV panels are installed on the top of the station.

The main difference between organic and Si-based solar cells is in the semiconductor layer. In organic cells, this layer uses organic compounds (usually C60 and derivatives) as electron receptors and an electron donor polymer, such as P3HT. The organic solar panels installed on the top of the test tubelike station were produced by CSEM / SUNEW.

In this viability study we periodically measured open circuit potential (V_{OC}) and short circuit current (I_{SC}) *of* 14 sets of 2 solar panels to evaluate their efficiency in different seasons. Efficiency measurements usually done in a lab environment on 10 *cm* x 10 *cm* cells as described by Canestraro 2007 and Cava 2013 were adapted to measure the efficiency of the OPV panels. The measurements made by Krebs, F.C. et al in 2014 were also a reference for our measurement protocol.

Figure 2 shows how the panels are disposed on the top of the test tubelike station. We also present an experimental setup to test how soilingt affects efficiency of OPV panels and to characterize the dust that adheres to the panels in Curitiba. Previous works on soiling that guided our choice of experimental setup were reviewed in Kazmerski et al, 2013. Although none of the soiling studies presented by this review were done for OPV panels it was possible to adapt the protocols to our setup.

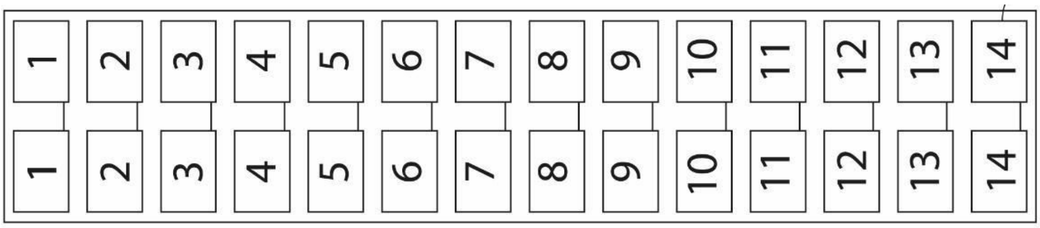


Figure 2: Arrangement of panels on top of the bus shelter.

2. Materials and Methods

2.1 Solar Panels

The test tubelike bus shelter was installed inside the university campus between a parking lot and a campus road. 28 OPV solar panels printed on polyethylene terephthalate (PET) were installed over the top of a cylindrical bus shelter, see Figure 2. The panels were connected in series in sets of 2. The 14 sets of panels were then connected in parallel. 2 sets of panels are under a tree shadow part of the day. The panels are connected to an energy monitoring system that allows voltage readings of the 14 sets of panels separately.

2.2 Sample preparation for microscopy and transmittance measurements

PET samples measuring 10 cm x 30 cm were taped on the top of the bus shelter between OPV panels. Part of the samples received a film of a hydrophobic solution (NT70) and part of the samples didn't receive any treatment. Prior to transmittance measurements and microscopy, part of the samples were cleaned with common neutral detergent. This procedure was done to check if standard hygienization is effective to restore light transmittance. The detergent used for cleaning was common neutral detergent used for cleaning dishes. Transmittance measurements were performed on PET samples after 1 week, 2 weeks and 3 weeks. Confocal microscopy, SEM and EDS were also performed on the samples. SEM was performed with a magnification of 1.39 kX and the potential was 15 kV.

2.3 JxV measurements

JxV measurements: For measurements an HP benchtop was connected to the energy monitoring system. The connection was done for each of the 14 sets and an HP benchtop multimeter used with the ammeter function to measure the forward and reverse current. In this work we report measurements relative to one set of panels that was not under a shadow throughout the 10 months when the measurements took place.

3. Results and Discussion

3.1 Efficiency of the OPV panels

In the period between August/2018 and July/2019 several J xV measurements were done. The panels were connected two by two in series. Every set of 2 panels was then connected in parallel with the others. Measurements in dark and under different conditions of illumination and temperature were also done.

On Figure 3, measurements of the current density (*J*) versus the voltage (*V*) are presented. These measurements were done in daylight. Chart 3 is a plot of measurements done on August 31/2018 and November 30/2018 under illumination.

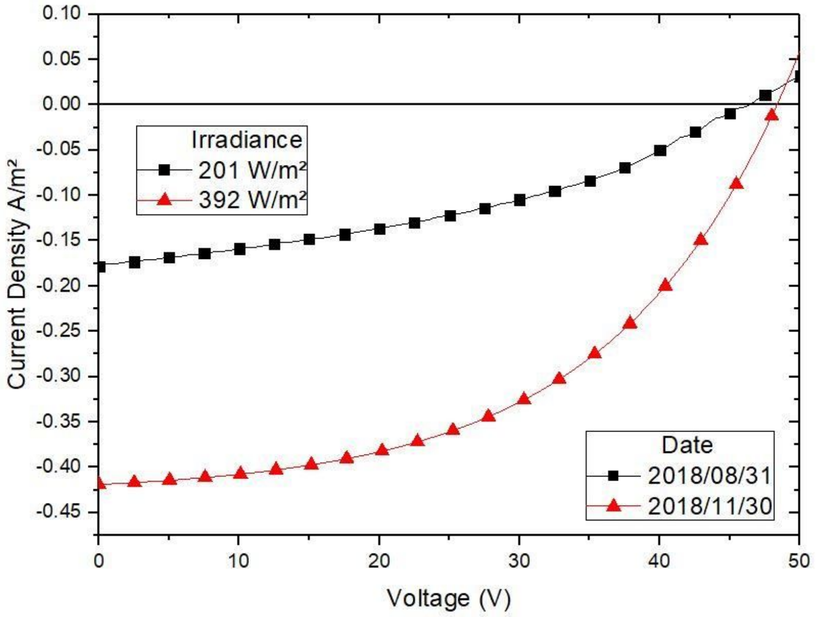


Figure 3: **J x V curve. Measurements of one set OPV panels placed on top of the bus shelter made under illumination.**

Performance of OPV panels varies according to the climatic conditions. Solar irradiation was 51% higher in November 30/2018 compared to August 31/2018. This difference indicates that a higher efficiency of the panels should be expected from the November measurements due to greater accumulation of solar radiation[1].

To calculate the efficiency of the solar panels we took the measurements done on August 31/2018 and November 30/2018 in one of the sets of panels and used equation (1).

$$\eta = \frac{J_{sc}V_{oc}FF}{P_{in}} \quad (1)$$

Where η is the efficiency, V_{OC} is the open circuit voltage, J_{SC} is the short circuit current density, FF is the fill factor and P_{in} is the input power density. In table 1 measured quantities and calculated values are presented.

Table 1 Measured and calculated values

Date	V_{oc} (V)	J_{SC} (A/m^2)	FF	P_{in}(W/m^2)	η (%)
2018/08/31	46.34	0.18	0.38	201	3.16
2018/11/30	48.38	0.41	0.51	392	3.27

The efficiency calculated for both dates is around 3% and is considered satisfactory for OPV based panels. It is not possible to affirm to what extent soiling affected influenced the efficiency of the panels in the 3 months period between measurements. In order to better understand the performance of the OPV panels, measurements of J x V and J_{sc} and V_{oc} will continue in the next few months and will be then compared to measurements from 2018. Measurements in dark will also be made to study degradation of the solar panels.

In table 2 measurements of short circuit current density (J_{SC}) and open circuit voltage (V_{OC}) at different dates for different illuminances are shown. As expected V_{OC} and J_{SC} values increase for higher temperatures and with higher solar irradiance.

Table 2 I_{sc} and V_{oc} measurements

Measurement count	Date	V_{oc} (V)	J_{sc}(A/m^2)	T (ºC)	Irradiance (W/m^2)
1	Aug 29/2018	49.48	0.343	15	570.38
2	Sep 12/2018	44.42	0.111	14	110.76
3	Sep 19/2018	50.39	0.423	19	617.00
4	Sep 24/2018	50.44	0.415	20	613.04
5	Oct 22/2018	50.19	0.287	19	231.87
6	May 03/2019	44.91	0.228	18	587.05
7	June 13/2019	38.1	0.072	16	112.73

3.2 Transmittance and Microscopy

Although Curitiba dust levels are not high, light transmittance on PET is affected when samples are exposed to the open environment. After 7 days exposed, samples that were not submitted to any cleaning treatment had a 5% loss in light transmittance while samples cleaned with detergent or samples that received a hydrophobic film (NT70) showed no loss in transmittance. After 2 weeks the loss in transmittance was 7% for samples with no treatment, 3% for samples treated with hydrophobic film and under 1% for samples exposed for 2 weeks and then cleaned with detergent .

The final light transmittance measurements were done on samples exposed to the open environment for 3 weeks. Light transmittance of PET samples that were not cleaned had a 20% loss in the light transmittance while the samples treated with hydrophobic film had a loss of 15% in light transmittance and samples that were cleaned with detergent after exposure had a loss of 4% in light transmittance.

Confocal microscopy on PET samples shows progressive soiling accumulation after 1 week, 2 weeks and 3 weeks of exposure (Figure 5). SEM of the samples after 3weeks (Figure 6) reveals soiling accumulation on a sample exposed without any treatment. In samples treated with hydrophobic film, soiling accumulation was concentrated on punctual spots. Samples exposed and then cleaned prior to SEM showed a clear surface with no soiling spots.

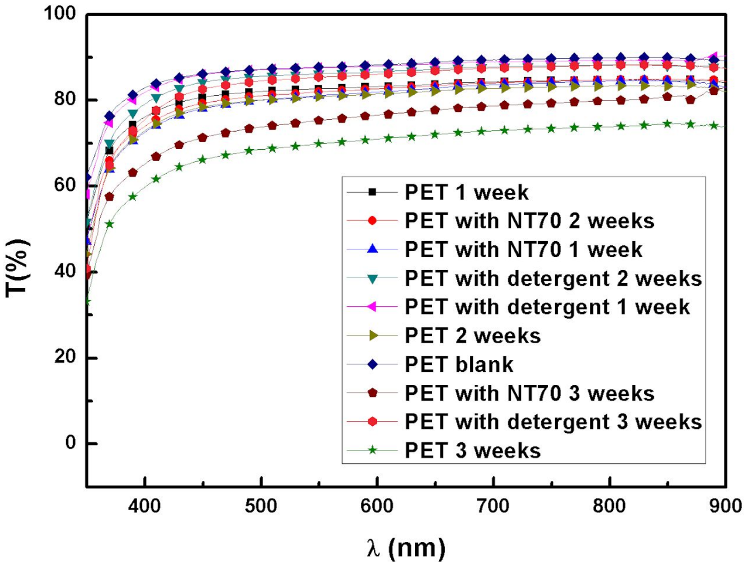


Figure 4: Transmittance measurements on PET samples. The blank is PET with no treatment and no exposure. Treated and untreated samples were exposed on the top of the bus shelter for periods of 1-3 weeks.

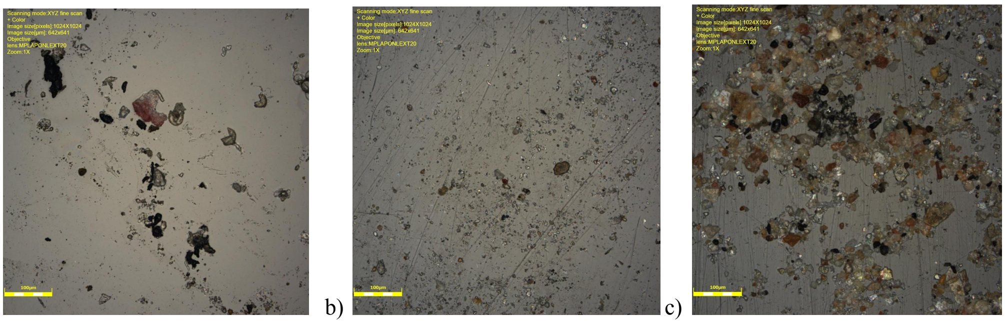
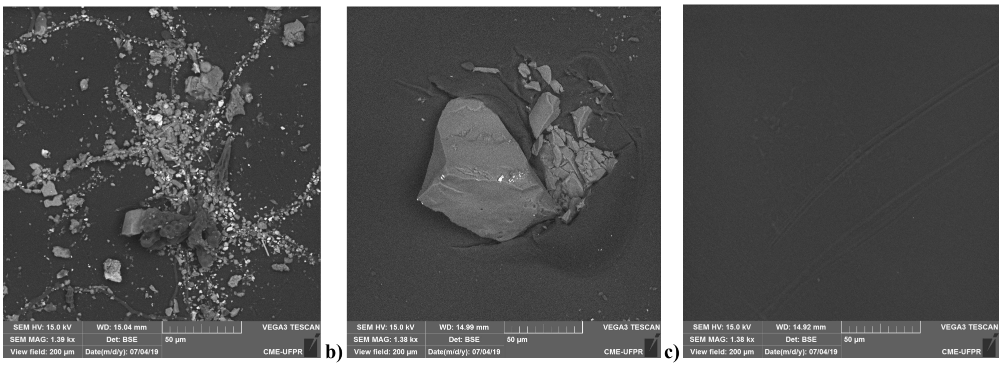

a) b) c)

Figure 5: Confocal microscopy of the samples after a) 1 week, b) 2 weeks and c) 3 weeks of exposure.



a) b) c)

Figure 6: SEM on a view field of 200 µm a) sample with 3 weeks of exposure b) sample cleaned NT70 cleaning, c) sample cleaned with detergent.

4. Conclusions

Soiling affects light transmittance and cleaning with common detergent restores light transmittance. Application of hydrophobic film delays the need for cleaning. Although Curitiba is not in a region with moderate amount of dust (Ghazi, 2014) soiling affects the performance of solar panels.

During the 10 months of this work the setup of the panels and energy monitoring system proved to be reliable. In the next two years we will continue to measure IxV, V_{oc} and I_{SC} to compare the efficiency of the panels with the values measured in the first months of use.

It is important to follow the efficiency of an OPV panels setup under real use conditions. Degradation studies of the panels under real use conditions should be done as they are critical to evaluate the reliability of this kind of system for the use in urban furniture.

5. Acknowledgements

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