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Prospects of photovoltaic rooftops, walls and windows at a city to building scale

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Abstract

The building sector is accountable for more than 35% of the global energy demand and almost 40% of the GHG emissions[1]. The pathway to energy mitigation presupposes the improvement of buildings' energy efficiency and the on-site renewable energy generation. Regarding the latter one, there are two building types: those located in low density areas that can meet their energy demand easier, through the installation of renewable energy technologies and those located in highly urbanised environments that struggle due to the limited ground and rooftop space. To address that problem, efforts are being dedicated to increase the utilization of the building envelope for solar-harvesting purposes, through the deployment of building-integrated photovoltaics (BIPV). While opaque photovoltaic (PV) systems are more mature and their performance well-studied[2–4], semi-transparent PV technologies are new but promising[5] although, so far, their commercial representation is limited to amorphous silicon (a-Si) products.

This study aims to estimate the potential of solar windows for buildings located in urban areas, through the case study of the City of Melbourne (CoM). The objectives are threefold: (i) to investigate the relationship between the form of existing urban areas and the PV potential of building envelope elements, (ii) to compare the energy potential of fully deployed roof-applied PV, wall BIPV and solar windows, and (iii) to identify the urban areas and their characteristics that demonstrate high potential for solar windows.

The study method was developed in four stages: i) the morphological analysis of the selected 21 urban areas of the CoM, through the calculation of a set of 7 urban form variables, ii) the simulation of the PV potential of buildings' roof, wall and window areas, iii) the correlation and regression analysis of stage 1 and 2 results, and iv) the estimation of the PV potential of the CoM, based on the identified regression functions. The information of buildings' geometry was obtained by the online open data platform of the CoM[6]. The glazed area of building was calculated based on the window to wall ratio (WWR) of each building archetype[7]. The urban form variables were calculated in Matlab, using the building height and WWR raster datasets, previously created in and exported by ArcGIS PRO. The 3D model of the selected urban areas was used for the calculation of the PV potential, employing Daysim/Radiance[8] and PVWatts[9] software.

To estimate the city-wide annual PV potential (MWh a^{-1}), the CoM was divided in blocks of 500 X 500 m (Fig. 1a) and results were plotted for the same spatial resolution, based on the developed regression functions. While areas of high roof PV (Fig. 1c) and wall BIPV (Fig. 1d) potential are scattered across the city, areas of high solar window potential are concentrated in central urban areas (Fig. 1e). The latter are characterised by high mean and standard deviation of building height, as well as high density, complexity and WWR. It would be expected that medium and high-rise buildings, located most of the times in central urban areas, would demonstrate equal potential for the deployment of wall BIPV and solar windows, given the increased facade areas compared to low-rise buildings. However, according to the employed archetype classification, those buildings have a high WWR, which is determined by the construction year, the building height and the space use, that gives solar windows the competitive advantage over wall BIPV. For central urban areas, that accommodate a large number of medium and high-rise buildings, it is estimated that solar windows

can contribute up to 20% of the total PV potential (Fig. 1f). To identify the turning point of solar window dominance over wall BIPV, we clustered all urban blocks in bins of 5 m and plotted their average against the most readable of the urban indicators, the mean building height. We noticed that areas of more than 20 m mean building height demonstrate higher solar window potential compared to wall BIPV. Regarding the seasonal performance of solar windows, the analysis shows that while the PV potential of roof PV dramatically decreases during winter months, the potential of wall BIPV and solar windows remains steady, having small variations between winter and summer months. The steady supply during the period of low PV power output is what gives added value to solar windows. Finally, the comparison between the annual electricity consumption (year 2018[10]) and production, in case of full deployment of PV in the CoM, shows that PV electricity production can cover up to 60% of consumption and solar windows can supply 5% of that amount.

Therefore, on a large scale, roof PV maintain a dominant role in electrical production, while solar windows' contribution becomes significant in urban areas characterised by high mean and standard deviation of building height, high density, complexity and WWR. Those areas, occupied by clusters of high-rise buildings, which are usually covered by highly-glazed curtainwalls, have been developed all around the world, from Seoul to New York city and from Moscow to Sao Paulo. In the near future, market penetration and deployment of high-efficient solar windows in those urban areas can make a substantive contribution towards the mitigation of their carbon footprint.

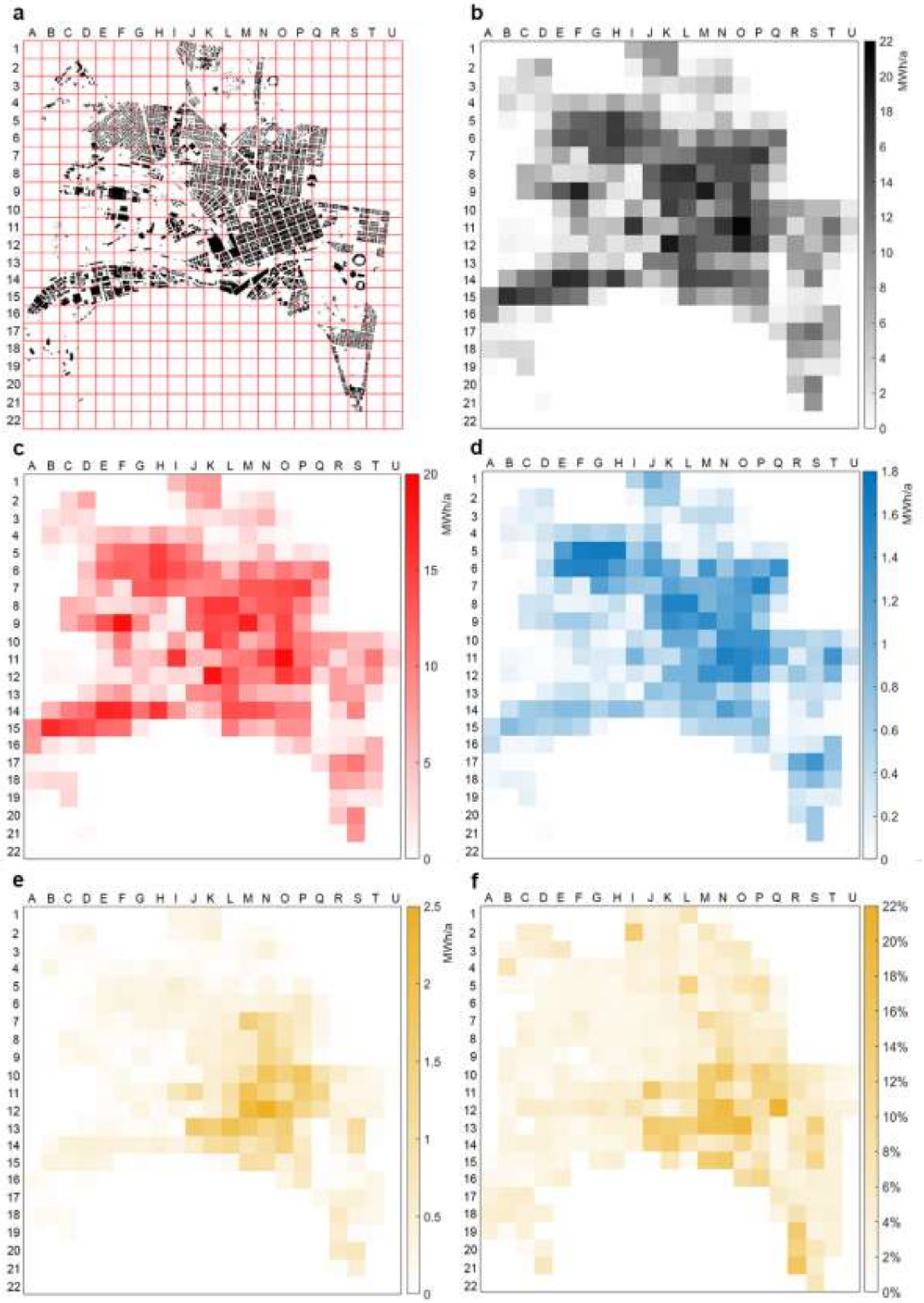

Figure 1. Annual PV potential of the City of Melbourne. a, The City of Melbourne divided in 500 X 500 m blocks. b, Total estimated PV potential. c, Roof PV potential. d, Wall BIPV potential. e, Solar window potential. f, Percentage of the estimated solar window potential over the total

References

1. UN Environment and IEA. Towards a zero-emission, efficient, and resilient buildings and construction sector. Global status report 2017. (2017).
2. Compagnon, R. Solar and daylight availability in the urban fabric. Energy Build. 36, 321–328 (2004).
3. Brito, M. C., Freitas, S., Guimarães, S., Catita, C. & Redweik, P. The importance of facades for the solar PV potential of a Mediterranean city using LiDAR data. Renew. Energy 111, 85–94 (2017).
4. Saretta, E., Bonomo, P. & Frontini, F. A calculation method for the BIPV potential of Swiss façades at LOD2.5 in urban areas: A case from Ticino region. Sol. Energy 195, 150–165 (2020).
5. Lee, K. et al. The Development of Transparent Photovoltaics. Cell Reports Phys. Sci. 1, 100143 (2020).
6. City of Melbourne. 2018 Building Footprints | Open Data. https://data.melbourne.vic.gov.au/Property/2018-Building-Footprints/pq2z-35fu (2019).
7. Stephan, A. & Athanassiadis, A. Quantifying and mapping embodied environmental requirements of urban building stocks. Build. Environ. 114, 187–202 (2017).
8. Reinhart, C. F. & Walkenhorst, O. Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. Energy Build. 33, 683–697 (2001).
9. NREL. PVWatts Version 1 Technical Reference. www.nrel.gov/publications. (2013).
10. C4NET. City of Melbourne Electricity data usage – C4NET observations. (2018).