

Energy performance of PV modules as adaptive building shading systems

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Abstract

Shading systems improve building energy performance by controlling solar gains and natural lighting. Integrating photovoltaics opens new opportunities for building integrated photovoltaics by combining the benefits of adaptive shading with facade integrated solar tracking. This in turn reduces the building energy demand and simultaneously generates electricity on-site. This paper presents a methodology for simulating the photovoltaic electricity production of a dynamic facade mounted PV system in combination with the energy consumption of a building through shading. The simulation is conducted within the Rhino / Grasshopper environment using the Ladybug for the Photovoltaic Analysis and HoneyBee / EnergyPlus for the building energy analysis. From this simulation we can determine the optimum position and orientation of the PV panels, not only for optimal energy harvest, but also for the overall balance of the room.

Keywords: Dynamic Photovoltaics, Multi Functional Envelope, BIPV, Adaptive Shading

1. Introduction

Buildings are at the heart of society and currently account for 32% of global final energy consumption and 19% of energy related greenhouse gas emissions [1]. Nevertheless the building sector has a 50-90% emission reduction potential using existing technologies [1]. Within this strategy, building integrated photovoltaics (BIPV) has the potential of providing a substantial segment of a building's energy needs [2]. Even the photovoltaic (PV) industry has identified BIPV as one of the four key factors for the future success of PV [3].

Dynamic building envelopes have gained interest in recent years because they can save energy by controlling direct and indirect radiation into the building, while still responding to the desires of the user [4]. This mediation of solar insolation offers a reduction in heating / cooling loads and an improvement of daylight distribution [5]. Interestingly the mechanics that actuate dynamic envelopes couples seamlessly with the mechanics required for facade integrated PV solar tracking.

Previous BIPV research analyses electricity production and building energy demand for static BIPV shading systems [6] [7] [8]. This paper expands on this work by analysing dynamic PV shading systems, while also taking into account mutual shading amongst modules. This is particularly important for BIPV systems [9].

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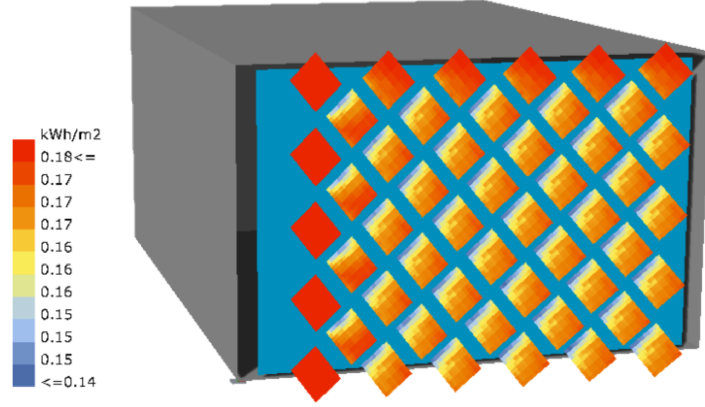


Figure 1: A simulation result from a single configuration at 11:00-12:00 on the 1st January

The work presented in this paper is applied in the context of the Adaptive Solar Facade (ASF) project [10]. The ASF is a lightweight PV shading system that can be easily installed on any surface of new or existing buildings. This paper will present a methodology of simulating an ASF while simultaneously calculating the energy demand of the office space behind the facade.

2. Methodology

To study the electricity generation and building energy consumption, a 3D geometry of the room and solar facade is built using the Rhinoceros [11], and its parametric modelling plugin Grasshopper [12]. The solar facade consists of 400mm CIGS square panels that can rotate in two degrees of freedom. On the horizontal axis the panels can move from 0° (closed) to 90° (open) position in steps of 22.5° , in the vertical axis it can move from 45° to -45° in 22.5° steps. Existing ASF systems [10] have independently actuated panels, however for simplicity we group all panels into one cluster that moves in unison. This leaves us with 25 possible dynamic configurations of the facade system.

The building energy simulation is conducted using Energy Plus [13] through the DIVA [14] interface. The geometric solar facade is interpreted in energyplus as an external shading system. A solar radiance simulation is run in parallel using ladybug [15] /RADIANCE [16] to determine the incident insolation on the solar facade. The approach enables us to calculate solar irradiance on the modules with high spatial resolution including the effect of module mutual shading as seen in Figure 1. The results are coupled to an electrical circuit simulation of thin-film PV modules with sub-cell level representation [9].

A simulation of each possible dynamic configuration of the facade is run for each hourly timestep of the year using the Geneva weather file [17]. The results are then post processed in Python [18] to extract the configurations that minimized building energy consumption while maximising PV electricity production. A corresponding workflow can be seen in Figure 2.

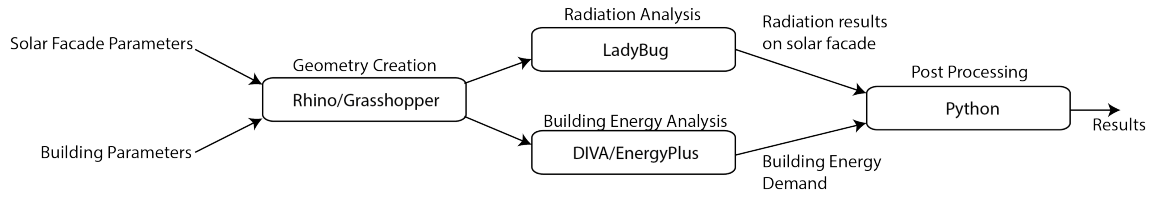


Figure 2: Simulation Workflow

3. Results

The optimal configurations of the ASF can be visualised using carpet-plots. Figure 3 details carpet-plots of the facade optimised to maximise PV generation, and minimise heating, cooling and lighting demands independently. We can see how open configurations (light coloured) are chosen to minimise the building heating demands during the winter months and early mornings of spring and autumn. Likewise closed configurations (dark colours) are the preferred solution to minimise the cooling demand during the summer months. Lighting control is only apparent during the twilight hours where the facade prefers an open position to avoid the use of artificial lighting. The PV optimisation [write as data comes in]...

When the four optimisation cases are combined to achieve the configurations for total energy minimisation we get some interesting results. There is a conflict in the summer evenings between minimising lighting and cooling demands. Likewise, we also see a conflict between heating and PV production during the winter months....

4. Discussion and Conclusion

In this paper we present a simulation methodology to evaluate a dynamic photovoltaic shading system, combining both electricity generation, and the energy demand on the building. The methodology can be applied to evaluate different PV systems, building systems, building typologies and climates. It is then coupled with a post processing python script to determine the optimum system configuration for control.

The dynamic PV integrated shading system has clear advantages to a static system as it can adapt itself to the external environmental. This enables it to orientate itself to the most energy efficient position. The choice of an open or closed configuration are sensitive to the building system and location. The use of LED lights, for example, reduces the weighting of the lighting energy demand. This would result in closed configurations optimised for cooling to over-ride the open positions.

This work ultimately presents a methodology for the planning and optimisation of sophisticated adaptive BIPV systems. Future work will use this methodology to determine the environments and building typologies that could benefit from adaptive BIPV systems.

References

- [1] Fifth assessment report, mitigation of climate change, Intergovernmental Panel on Climate Change 674–738.
- [2] P. Defaix, W. van Sark, E. Worrell, E. de Visser, Technical potential for photovoltaics on buildings in the eu-27, Solar Energy 86 (9) (2012) 2644–2653.

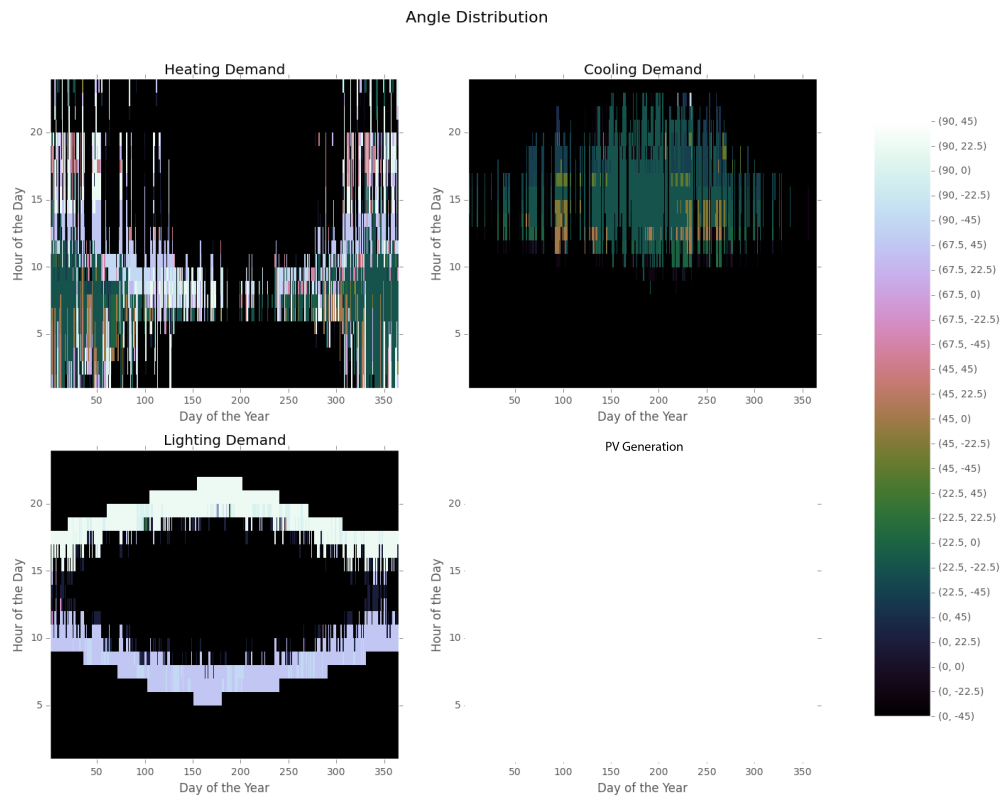


Figure 3: A carpet plot detailing the optimal configuration to minimise the heating demand, cooling demand, lighting demand and maximise PV generation

- [3] M. Raugei, P. Frankl, Life cycle impacts and costs of photovoltaic systems: current state of the art and future outlooks, *Energy* 34 (3) (2009) 392–399.
- [4] R. Loonen, M. Trčka, D. Cóstola, J. Hensen, Climate adaptive building shells: State-of-the-art and future challenges, *Renewable and Sustainable Energy Reviews* 25 (2013) 483–493.
- [5] D. Rossi, Z. Nagy, A. Schlueter, Adaptive distributed robotics for environmental performance, occupant comfort and architectural expression, *International Journal of Architectural Computing* 10 (3) (2012) 341–360.
- [6] M. Mandalaki, K. Zervas, T. Tsoutsos, A. Vazakas, Assessment of fixed shading devices with integrated pv for efficient energy use, *Solar Energy* 86 (9) (2012) 2561–2575.
- [7] S.-H. Yoo, H. Manz, Available remodeling simulation for a bipv as a shading device, *Solar Energy Materials and Solar Cells* 95 (1) (2011) 394–397.
- [8] S. F. et al, Maximizing the solar photovoltaic yield in different building facade layouts, EU PVSEC.
- [9] J. Hofer, A. Groenewolt, P. Jayathissa, Z. Nagy, A. Schlueter, Parametric analysis and systems design of dynamic photovoltaic shading modules, EU PVSEC 2015 conference, Hamburg, Germany (paper in review).
- [10] Z. Nagy, S. Bratislav, J. Prageeth, B. Moritz, H. Johannes, L. Gearoid, W. Anja, A. Schlueter, The adaptive solar facade: From concept to prototypes, under review.
- [11] Rhinoceros v5 (2015).
URL <https://www.rhino3d.com/>
- [12] Grasshopper - algorithmic modeling for rhino (2015).
URL <http://www.grasshopper3d.com/>
- [13] D. B. Crawley, L. K. Lawrie, C. O. Pedersen, F. C. Winkelmann, Energy plus: energy simulation program, *ASHRAE journal* 42 (4) (2000) 49–56.
- [14] Diva for rhino.
URL <http://diva4rhino.com/>
- [15] M. Roudsari, M. Pak, A. Smith, Ladybug: A parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design.
- [16] G. J. Ward, The radiance lighting simulation and rendering system, in: *Proceedings of the 21st annual conference on Computer graphics and interactive techniques*, ACM, 1994, pp. 459–472.
- [17] EnergyPlus, Geneva weather file.
URL <http://bit.ly/1PXIYJM>
- [18] Python.
URL <https://www.python.org/>