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. Furthermore, it 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 parametric Rhino / Grasshopper environment using a high resolution radiation analysis for the calculation of PV electricity generation. Building energy analysis is conducted through DIVA / EnergyPlus. From this simulation we can determine the optimum hourly 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) have 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] [9]. This paper expands on this work by analysing dynamic PV shading systems, while also taking into account mutual shading amongst modules and its effect on PV electricity generation. The approach allows us to reduce efficiency degradation due to partial shading of PV modules [10].

The work presented in this paper is applied in the context of the Adaptive Solar Facade (ASF) project [11]. The ASF is a lightweight PV shading system composed of CIGS panels, 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 software [12], and its parametric modelling plugin Grasshop-

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per [13]. 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 [11] have independently actuated panels and a continuous range of actuation, 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 EnergyPlus [14] through the DIVA [15] interface. The office environment is heated with a heatpump with an average COP of 5 and cooled with an average COP of 3. When required, the electric lighting consumption is 11.7 W/m^2. The geometric solar facade is interpreted in EnergyPlus as an external shading system. A solar radiance simulation is run in parallel using Ladybug [16], which uses Radiance [17] 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 [10].

A simulation of each possible dynamic configuration of the facade is run for each hourly timestep of the year using using a weather file for Geneva, Switzerland [18]. The results are then post-processed in Python [19] to extract the configurations that minimise building energy consumption and maximise PV electricity production. A corresponding workflow can be seen in Figure 2.

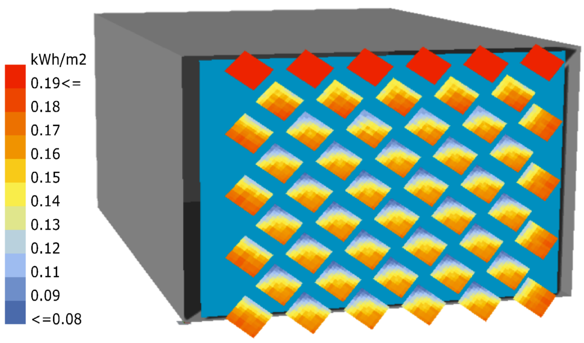

Figure 1: A simulation result showing module insolation from 11:00-12:00 on the 16 June for the used weather file and a specific module orientation.

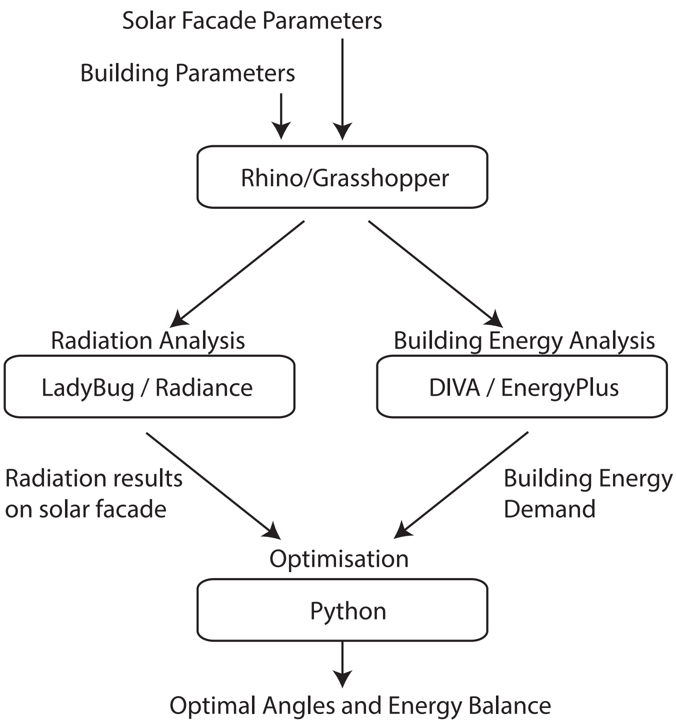

Figure 2: Simulation Workflow

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[1], 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 solutions 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 follows a solar tracking model for most hours and as far as the limited range of angles allows. This causes some issues during twilight summer hours as the actuator cannot physically align itself normal to the sunlight.

When the four optimisation cases are combined

[1]For this abstract, a constant efficiency of the PV modules of 7.2% was assumed. This includes constant losses due to shading and module edges not covered with PV. Note however that so far no detailed effects of efficiency degradation due to shading of PV modules have been considered.

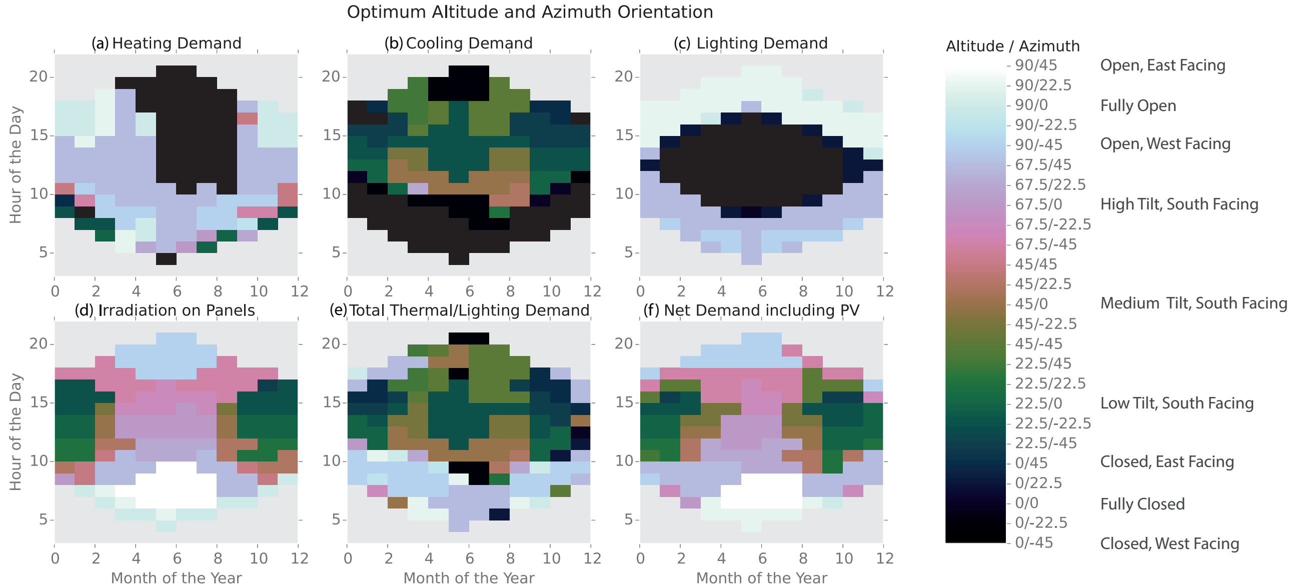

Figure 3: Carpet plots detailing the optimal configuration to minimise the (a) heating demand, (b) cooling demand, (c) lighting demand, and (d) maximise irradiance on PV panels. Each configuration is represented by an angle of orientation around the x-axis (Altitude) and y-axis (Azimuth) as seen in the legend. Figure (e) details the combinations for optimum building thermal management without PV production. (f) also includes the PV production

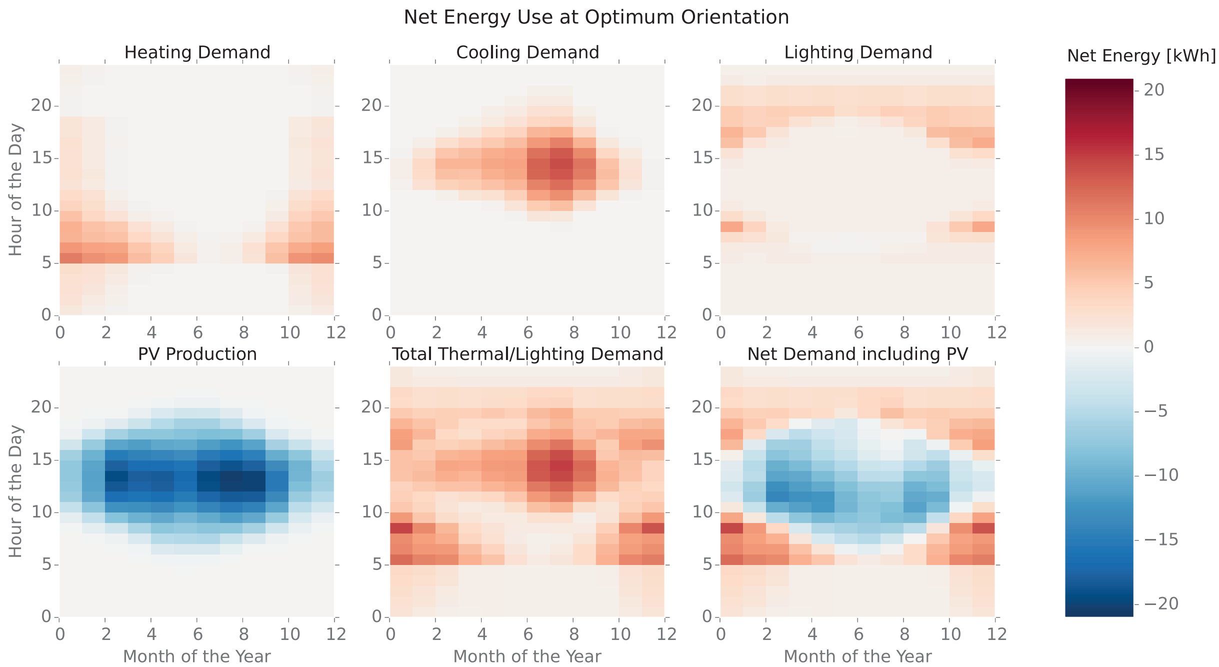

Figure 4: Carpet plots detailing the net energy consumption. Each square represents the total energy consumption for that specific hour of the entire month. Red colours detail the energy demand, while blue colours detail the energy supply.

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. The overall energy optimization including PV electricity production shows a strong tendency to follow the optimal PV production pattern. This, however changes if the building system becomes more inefficient. Less efficient heating for example, would result in configurations optimised for heating overpowering those of PV electricity generation.

Figure 4 shows the net energy use at these optimum angles. It is interesting to see how the combination of electricity generation and adaptive shading can compensate for the entire energy use during sunlit hours.

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 of the building. It is then coupled with a post processing python script to determine the optimum system configuration for control. The methodology can be applied to evaluate different PV system geometries, building systems, building typologies and climates.

The dynamic PV integrated shading system has clear advantages to a static system as it can adapt itself to the external environmental conditions. This enables it to orientate itself to the most energy efficient position. The optimum orientation however, strongly depends on the general efficiency of the building. Decreasing the efficiency of the heating, cooling or lighting systems will give higher preference for configurations optimised for building thermal management through adaptive shading, than for PV electricity production.

This work ultimately presents a methodology for the planning and optimisation of sophisticated adaptive BIPV systems. We are currently working on integrating the effects of module shading on PV efficiency, and the energy demand for the dynamic actuation. Future work will use this methodology to determine the environments and building typologies that could benefit from adaptive BIPV systems.

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