Energy performance of PV modules as adaptive building shading systems

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Abstract

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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

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actuate dynamic envelopes couples seamlessly with the mechanics required for facade integrated PV solar tracking.

Previous research of BIPV models 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].

The work presented in this paper is applied in the context of the Adaptive Solar FaÃ§ade (ASF) project. The ASF is a lightweight PV shading system that can be easily installed on any surface of new or existing buildings [10]. This paper will present a methadology of simulating this adaptive solar facade 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]. In our case the room is XX meters in length, YY meters wide, and X meters high. The solar facade consists of 400mm CIGS square panels that can rotate in two degrees of freedom. Existing ASF systems have independently actuated rows of panels, however for simplicity we group all panels into one cluster. 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. 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] to determine the incident insolation on the solar facade. Reflected and diffuse light are taken into account using the global radiation data, visible sky fraction for each panel, and the reflection of surrounding elements - See Comments. The approach enables us to calculate solar irradiance on the modules with high spatial resolution including the effect of module mutual shading 1. The results are coupled to an electrical circuit simulation of thin-film PV modules with sub-cell level representation [PVSEC 2015].

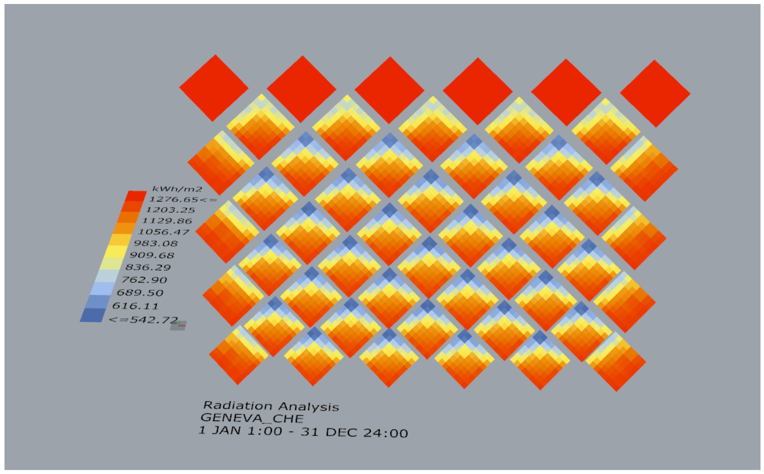

Figure 1: A simulation result from a single timestep for one configuration

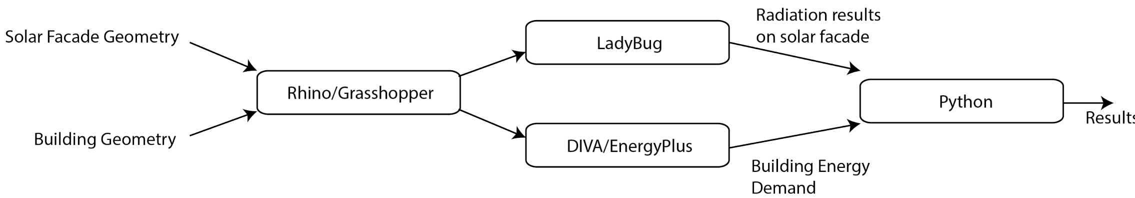

Figure 2: Workflow of the simulation (rough)

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

3. Results

The results 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.

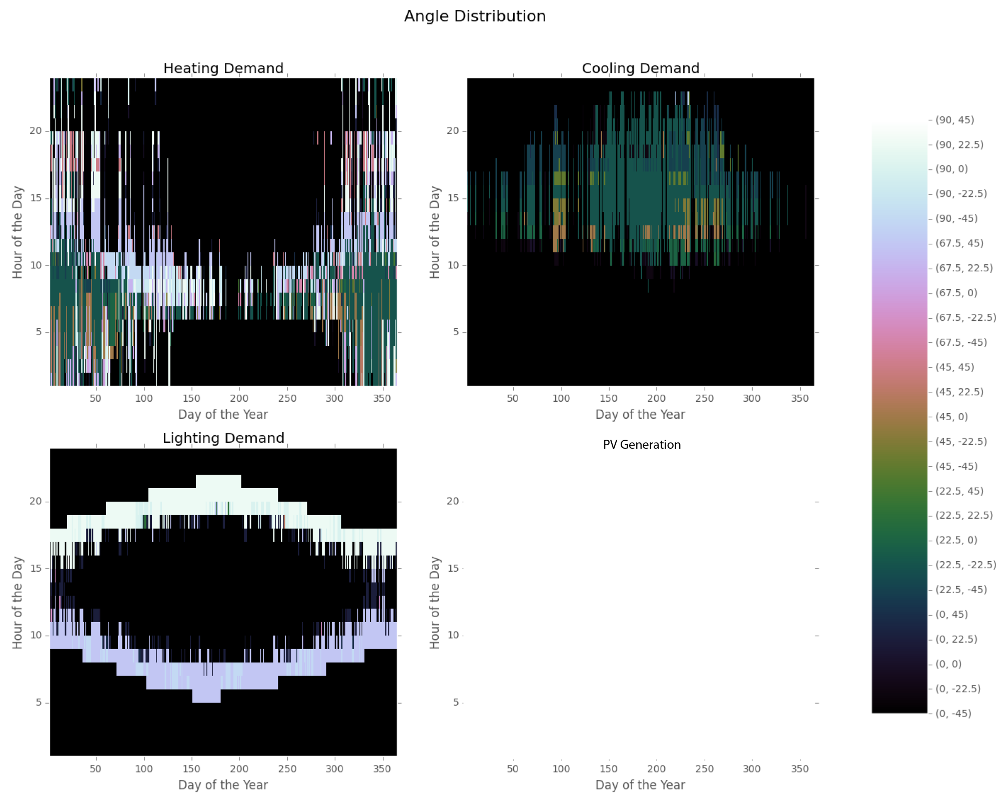

Figure 3: A carpet plot detailing the optimal configuration to minimise the heating demand, cooling demand, lighting demand and maximise PV generation

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 exists in an open position. 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....

The overall energy consumption, including PV generation is compared with static cases is sumarised in Table XX [If we get results].

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 find the balance of the most energy efficient position, resulting in savings of XX% compare to an equivalent static system. The choice of an open or closed configuration in areas of conflicting interests are sensitive to the building system and location. The use of LED lights for example reduces the importance of the lighting energy demand. Closed configurations that reduce cooling begin to overpower the open configurations. Likewise a highly efficient cooling system will give preference to open positions during these conflicting times.

5. Outlook

[To be Decided]

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