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Sensitivity of Building Properties and Use Types for the Application of Adaptive Photovoltaic Shading Systems

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Abstract

An adaptive solar facade can improve building energy performance by controlling solar heat gains and natural lighting, while simultaneously generating electricity on site. The adaptive control of the solar facade is determined through an optimisation algorithm that minimises the net energy demand. In this paper, we first evaluate the sensitivity of the adaptive solar facade to the thermal performance of the building envelope for a south facing room in Zurich. We then evaluate the performance of an adaptive solar facade on 11 building use types spanning six construction periods. In addition, we compare the performance of an adaptive system against an equivalent static photovoltaic system, and a facade with no shading system. Our results show that the adaptive solar facade performs best in buildings that have a high cooling demand and low heating demand. This is because the optimum configurations for cooling minimisation generate the maximum photovoltaic electricity. As a result, we notice a higher energy saving potential in newer buildings with low envelope thermal transmittance (U-value or infiltration). However, in buildings with a very high cooling demand, and no heating demand, there is only a small improvement in performance compared to an equivalent static system. An adaptive solar facade is therefore an optimum solution when there are both heating demands, and cooling demands present. Modern offices, retail stores, food stores, and schools have this property and perform well with an adaptive solar facade compared to an equivalent static system, and a facade with no shading.

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1. Introduction

The built environment is responsible for 19% of global greenhouse gas emissions [1]. Fortunately, the use of existing technologies such as building integrated photovoltaics (BIPV), thermal insulation, and efficient building systems can mitigate up to 50%-90% of this emission portfolio [1].

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Fig. 1: Left: An example of an ASF constructed at the House of Natural Resources. Right: a schematic describing how the facade can mediate solar radiation to optimise the internal environmental conditions [6]

Thin film photovoltaics (PV) in particular have improved in terms of efficiency, cost, and light weight integration [2,3,4,5], which influenced the development of the adaptive solar facade (ASF) [6]. The adaptive solar facade consists of an array of independently actuated photovoltaic panels that can move in two axes at a range of 90°. An example of this technology was built at the House of Natural Resources at the ETH Zurich Campus as seen in Figure 1. Through the control of solar radiation, the ASF is capable of minimising the building energy consumption in terms of heating, cooling and lighting demands, while simultaneously generating electricity on site.

The optimum panel angles of the ASF are determined through a model control algorithm [7]. Simulations of building energy performance and photovoltaic electricity supply are performed for every possible combination of angles for each time step. Through an exhaustive search, the optimum combination is chosen. An ASF built on a building with an inefficient heating system will tend to exist in a more open position in winter so that the room can heat naturally through solar radiation. Likewise, a building with an efficient heating system will tend to optimise more for the generation of electricity on site. This sensitivity to the building typology leads to an energy saving variation of 20% - 80% compared to an equivalent static system [7] [8].

This paper utilises the models proposed by Jayathissa et al. [7] to extend the evaluation to a variety of building archetypes in Zurich. We will first evaluate the sensitivity of the ASF performance to the envelope resistance, and infiltration. We will then evaluate 11 building use types spanning six construction periods from the the City Energy Analyst (CEA) for ArcGIS database [9]. By doing so, we can evaluate the optimum building properties and types for the application of an ASF.

The remainder of the paper is organised as follows. The next section describes the simulation methodology. In Section 3 we present the results of the case study which describes the sensitivity of the ASF to the building typology. Finally, Section 4 concludes the paper.

2. Methodology

A control methodology of adaptive photovoltaic shading systems to maximise PV electricity production while minimising the building energy consumption was proposed by Jayathissa et al. [7]. It will be briefly reviewed here for completeness.

- **Solar Radiation Model:** The radiation on the PV panels and window behind the ASF is calculated for a single configuration of the ASF using LadyBug/Radiance for a single time step of one hour [10,11].