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Matching visual impact, solar energy production potential and energy system optimization for an enhanced solar integration

An experience with a novel pre-design tool

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ABSTRACT: This study focuses on developing a BIPV pre-design computational platform combining visual impact assessment, building simulation and energy system optimization. The outdoor exposed surface of a pavilion court building block is evaluated through a physiologically reliable indicator of visibility that determines three scenarios of PV coverage ratio. Solar PV generation and demand for heating and electricity are simulated on hourly basis. Hourly PV energy that does not match electricity needs is used to fit a multi energy hub featuring PV panels, a battery bank and an internal combustion generator. A Pareto optimization is conducted considering levelized cost of energy and grid integration level, without showing a dominant solution: this outcome encourages the development of a Multi Criteria Decision Making (MCDM) tool.
KEYWORDS: BIPV, Multi Criteria Decision Making (MCDM), visual impact, building simulation, grid integration

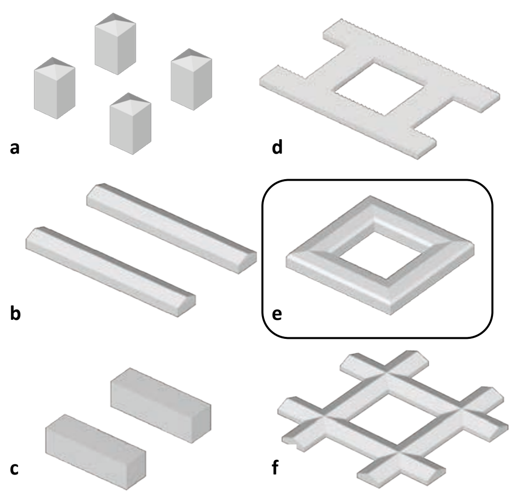

Figure 1: Building archetypes and analysed archetype

1. INTRODUCTION

It is foreseen that more than half of the global PV capacity from now to 2050 will be installed on buildings, producing a little less than half the total PV electricity needed [1]. The continuous cost reduction of solar technologies enhances the diffusion of new technical solutions [2]. However, it is still a challenge to integrate PV both in coherence with the architectural context [3] and within the energy system configuration [4]. Most of recent studies neglect the influence of PV on visual [5] and thermal perception [6] in urban contexts. It is interesting to experience a new design process centred on human perception to customize the PV arrangement at the building scale and assess the impacts on the energy systems at the urban scale. This makes it important to develop a pre-design tool bringing together experts from multiple disciplines such as architects, building physicist, energy engineers and urban planners.

2. OBJECTIVE

This study focuses on developing a BIPV pre-design computational platform combining visual impact assessment, building simulation and energy system optimization. A Multi Criteria Decision Making (MCDM) technique based on Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) will accompany the computational platform to support urban planners in identifying a coherent integration of PV panels, by considering conflicting criterions.

3. METHODOLOGY

The proposed methodology is subdivided into the following parts: i) buildings typology, ii) visual impact assessment, iii) energy demand and BiPV production and iv) energy systems optimization.

A modular and repeatable urban form has been adopted for the current analysis, from consolidated environmental research [7] (Fig. 1). The typological set includes six LOD2 archetypes. For an effective comparison, heated floor area is kept constant for all typologies. A different roof type is assigned to every typological unit, to create a palette of possible urban configurations. The current paper focuses on a specific building typology: the pavilion court with mansard roof (Fig. 1e), a recurrent scheme in late 19th century developments. The building block is arranged around a square courtyard with a 35 m long side. Each wing is 15 m wide and covered with a two slopes mansard roof (60 and 10 degrees' tilt). The buildings are located in the city of Lausanne (Switzerland).

As a second step, the visual impact of each outdoor exposed surface is evaluated into detail through a physiologically reliable indicator. Thirdly, three scenarios with variable PV sizes are defined, based on the available surface and its visibility. The building block is simulated on hourly basis in order to quantify solar radiation on each envelope surface, solar PV generation and demand for heating and electricity.

The hourly energy demand and PV production is then exported into the energy hub model, in order to optimize the energy system.

4. RESULTS

4.1 Visual impact assessment of the building envelope

Visual impact is here intended as the visibility of the building envelope from the public space: viewpoints are sampled on a sidewalk around the block at an average observer's eye level (1.5 m). The envelope surface is split in 2.5 m sized mesh faces that constitute the analysis grid. To perform visibility analysis, visibility rays are cast from the viewpoints to the mesh faces. Visual stimulus is calculated as the average solid angle, produced by a target feature (mesh face) on the spherical visual field of each observer (viewpoint) and related to the smallest perceived stimulus (threshold). The outcome, called "visual amplitude", represents a physiologically robust visibility index (Fig. 2). At this point, the envelope surface can be classified in three bins: low, medium and high visible surface according to the minimum visual acuity needed to detect a unitary mesh face.

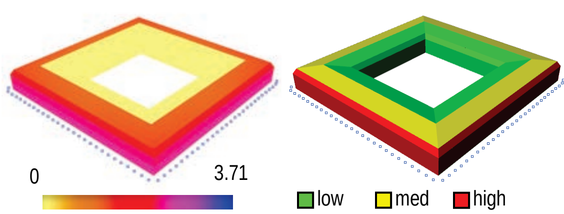

Figure 2: Visual amplitude index and its classification.

4.2 Load match and grid optimization

Energy demand of buildings, as well as BiPV production is assessed via the CitySim tool, in hourly values. BiPV sizing is based on the visibility map, which determines three scenarios of surface coverage ratios: i) 70% on low visibility, ii) 45% on medium visibility and iii) 20% on high visibility portion. For a 143 Wp/m^2 system, the annual average production amounts to 85 kWh per m^2 on the low visibility envelope portion, and to 75 kWhm^{-2} on medium and high visibility surface. Finally, hourly PV energy that does not match electricity needs (for appliances and space heating via air-source heat pump) is used to fit a multi energy hub featuring PV panels, a battery bank and an internal combustion generator. A Pareto optimization is conducted for each of the three visibility levels, considering levelized cost of energy and grid integration level (Fig. 3). Each Pareto solution gives a unique energy system configuration.

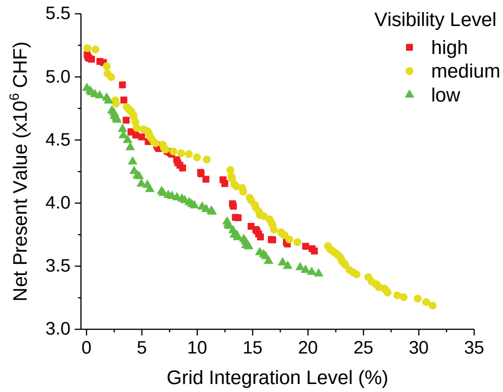

Figure 3: Pareto front of the three visibility scenarios

5. CONCLUSION

The absence of a dominant solution after optimization demonstrates the need of a MCDM tool, to handle BiPV visibility, energy demand of buildings and optimization of energy systems simultaneously at the urban scale. This paper represents a first step in this direction, proposing a new methodology for sustainable urban planning that focuses both on energy optimisation and on pedestrian's perception.

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