3D Solar Maps for the Evaluation of Building Integrated Photovoltaics in Future City Districts: a Norwegian Case Study

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Introduction

Fig. 1. Overview of the planned future city district Bjorndalen in southern Norway.

For sustainable development, cities should reduce their energy needs and start producing their own energy from clean, renewable sources such as solar energy [1]. Building regulations in the European Union (EU) state that by 2020, all new buildings should be 'nearly zero-energy' [2].

Building integrated photovoltaics (BIPV) is of special interest as it replaces conventional building materials and may, as the market develops, provide cost savings compared to traditional building applied photovoltaics (BAPV).

3D solar maps

A solar map is a geographic information system (GIS) providing the annual solar irradiation on building surfaces, mostly accompanied by information about the output of solar thermal or PV systems, e.g., [3], [4].

The challenge is how to work with the information gained from the solar maps:

- How can the results be translated into the most useful information for a municipality or a commercial developer?
- How can we best utilize the available solar resource at a given site?

Most solar maps only consider roof areas, not facades. **The utilization of facades** for energy production will become increasingly more important for sustainable city development in future due to nearly-zero energy requirements and the restricted roof area available on multistorey apartment blocks.

3D solar maps are presented based on simulations for the solar irradiation resource and the potential for BIPV energy utilization using the future city district Bjorndalen in southern Norway as a case study.

The results are used by the commercial developer to evaluate the potential for BIPV on facade and roof areas of the planned buildings, and to evaluate possible adaptations of early-stage site development plans.

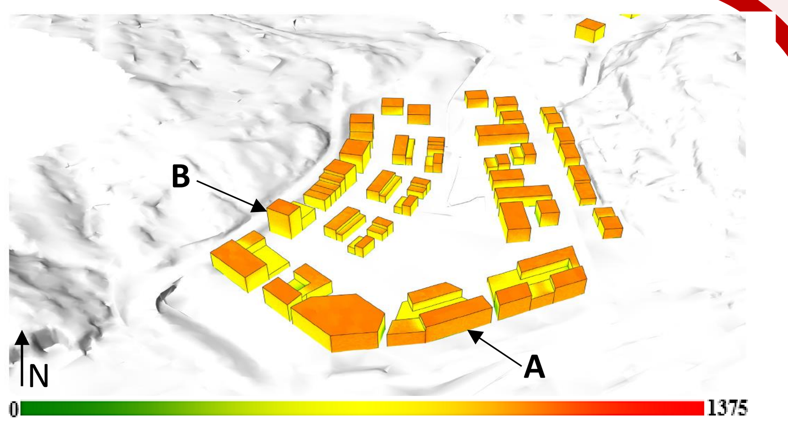

Fig. 2. Bird view from the South showing the annual solar irradiation on all surfaces of the building envelopes at Bjorndalen.

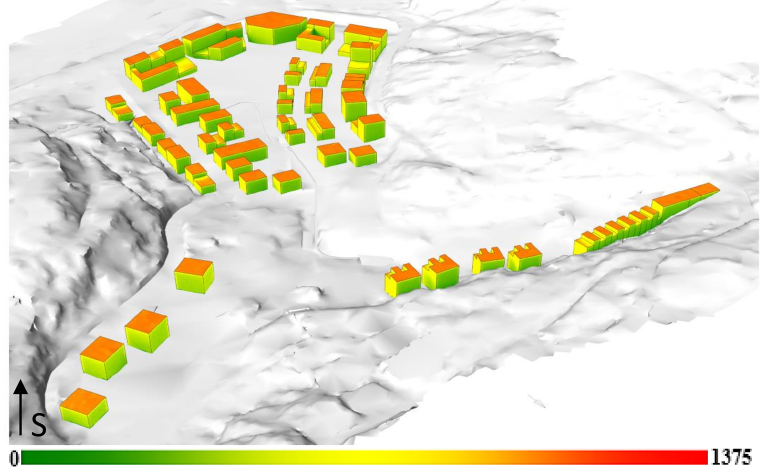

Fig. 3. Bird view from the North showing the annual solar irradiation on all surfaces of the building envelopes at Bjorndalen.

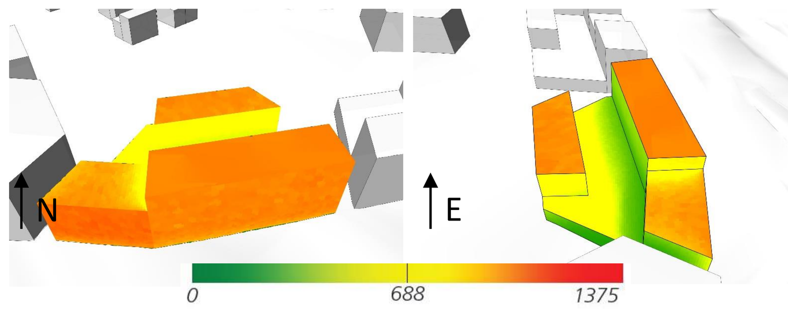

Fig. 4. Annual solar irradiation on the building labelled A in Fig. 1. Bird view from south (left) and from west (right).

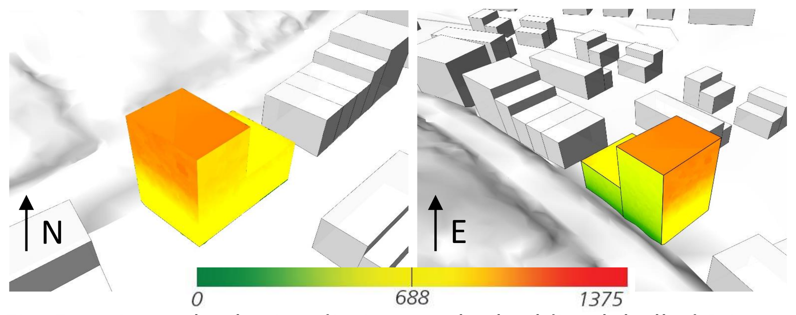

Fig. 5. Annual solar irradiation on the building labelled B in Fig. 1. Bird view from south (left) and from west (right).

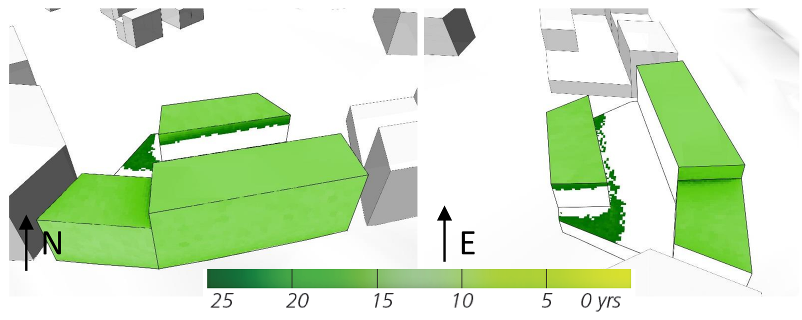

Fig. 6. Payback time for the building labelled A in Fig. 1. Bird view from south (left) and from west (right).

Radiance model

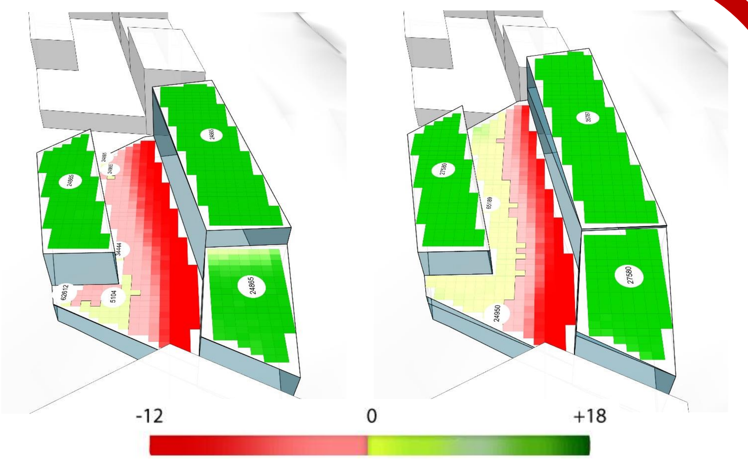

Fig. 7. Profit/loss analysis of the building labelled A in Fig. 1. Roof inclination 1° (left) and 10° (right). Bird view from west.

The solar maps were created by simulations in the ray tracing software *Radiance*. A rather complex approximation of landscape and buildings was imported into the CAD program *Rhinoceros* and linked to Radiance through the *Grasshopper* editor and *DIVA-for-Rhino* plugin.

A pre-processor generated the cumulative sky radiance distribution from a climate file (with local irradiance data) used by Radiance during runtime [5]. The simulations take into account diffuse light, shading and reflectance from surroundings. Facade and roof surfaces were considered to be Lambertian diffusers with 35 % reflectance and the landscape albedo was set to 20 % [4].

Fig. 8. BIPV façade solution proposed for building A. (Image source: Skanska Norge/Egerdahl&Nordbø.)

Alternative profit/loss maps

Although solar maps may be of interest for commercial developers, their main question is whether the investment will be sound or not. We therefore implemented a simplified model to evaluate **surface areas producing a profit or a loss** over the PV system lifetime. For each square meter of building surface, the PV investment costs (USD/m^2) are compared with the value of PV generated electricity within the same square meter over the system lifetime. Fig. 7 shows the resulting profit/loss map for one of the buildings analysed, with profit areas displayed in yellow to green.

Flat and tilted roofs

TABLE I: ANNUAL ENERGY PRODUCTION OF THE SURFACES OF BUILDINGS A AND B WITH AN ANNUAL PROFIT, FOR 3 ROOF INCLINATION ANGLES.

Building	Incl.1° (kWh)	Incl.5° (kWh)	Incl.10° (kWh)	Gain ref. incl.1° (5° / 10°)
A	200110	219770	244623	10% / 18%
B	39057	38304	38704	-2% / -1 %

Although some BIPV solutions for flat roof exist, these are not optimal in terms of soiling loss. Roof designs with a slight pitch angle instead of horizontal, will improve self-cleaning properties during rain- and snowfall and may also increase annual energy output. Table I gives annual production in kWh for the roof surfaces with an annual profit, for three investigated inclination angles (with reference to buildings A and B in Fig. 2).

Conclusion

The utilization of roof and façade area for energy production will be important for future city developments. 3D solar mapping of buildings is a useful tool to identify the optimum areas for BIPV and review possibilities for altering building shape, orientation or position in the landscape to maximize utilization of the solar resource. 3D solar maps and a new type of profit/loss surface maps were created for the case study of a future city district in Norway. The results will help the commercial site developer to find solutions for nearly zero-energy buildings that comply with new EU regulations.

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