Ideenwettbewerb „Stadt 2.0
Wie bringen wir die Erneuerbaren in die Stadt?"

Semi-transparent PV window for zero energy office buildings

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Semi-transparent PV window for zero energy office buildings

The growing energy consumption in developed and developing countries is becoming an important issue to be faced by the economies of these countries. Buildings are today responsible for nearly 40 % of the globally used energy and the percentage of their energy consumption is growing due to poor design, inadequate technology and inappropriate behavior. However, opportunities exist to reduce the buildings' energy use at lower cost and with higher revenue than in other sectors.

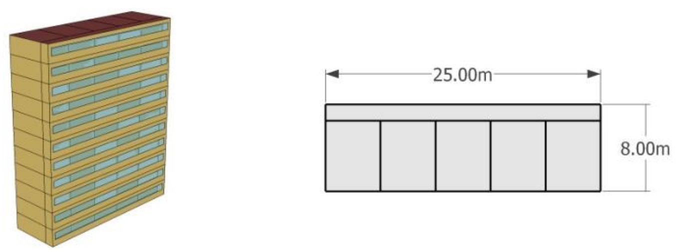
Designing buildings with minimal energy consumption requires combining climate adapted construction strategies with renewable energy sources, such as photovoltaic (PV) modules. By this means buildings can save and generate energy and it is possible to reach an equalized energy balance. Such buildings are called zero energy buildings (ZEB). Photovoltaic elements have numerous application possibilities in a ZEB scenario, due to their energy generation characteristics and constantly decreasing price, which makes them competitive to other building materials.

The energy generation period of PV panels is well suited for office buildings, whose occupation period and highest energy consumption are during daytime, the same time when the PV modules produce electricity. Excess energy can be fed into the electric network. In multi-storey office buildings the available area for PV installation is limited. The building envelope might not be sufficient to fulfill the building’s energy needs, using conventional PV application. In this case, semi-transparent PV windows could be used to replace tinted glass, which are common beneath clear glass windows in cooling dominated multi-storey office buildings.

Semi-transparent PV windows have a significant potential to reduce the annual electricity consumption for cooling and in addition generate energy. However, some care should be taken with buildings located in urban areas, since parts of the buildings envelope can be shaded which should be avoided in order to not reduce the PV module efficiency. This study investigates the performance of semi-transparent PV windows for Brazilian zero energy office buildings especially regarding the influence of the surrounding urban context on them.

Building context

A representative model for Brazilian office buildings was defined (Figure 1). The building characteristics, materials and internal heat loads were obtained from previous studies [1]. For the analysis the representative building was transformed into an efficient building by means of energy efficiency strategies and regulations. The reduction of the energy consumption is a necessary step in the transformation of a building into a ZEB but it is not sufficient. The used electric energy must be generated.



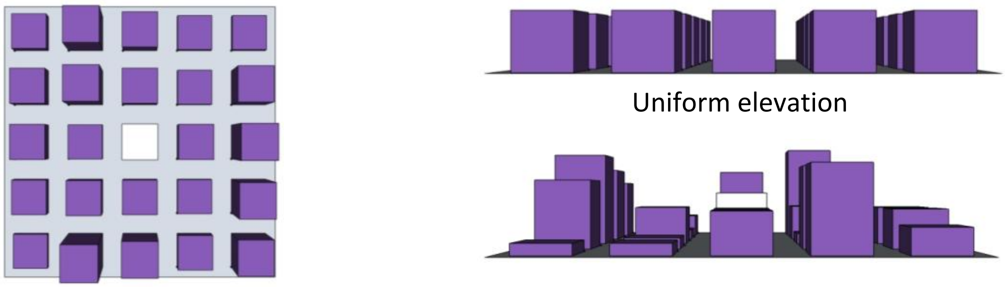
Ceiling height: 2.7 m
Total height: 29.7 m
Total area: 2200 m²
N° of floors: 11

Figure 1: Representative building model.

Different photovoltaic technologies were chosen for the building envelope. The selected crystalline (m-Si with efficiency of 20.1 %) and thin film (CSI with efficiency of 13 %) solar cell technologies have the highest efficiency available on the market today. The m-Si panels were placed on the roof and the CSI ones on the facade and on the overhangs. The organic (OPV efficiency of 3 %) solar cell integrated into the window was selected due to its homogenous semi-transparent characteristic. In addition, plastic encapsulated organic solar cells promise low production costs. However, until now this PV type is not available on the market.

For this study all area suitable for PV application on the roof was used. A PV module coverage of 90 % for the East and West facades and 100 % for the overhangs and the windows was chosen (the window to wall ratio is 90 %). On the roof an inclination of 27° was used for the PV modules in Florianopolis and 3° in Fortaleza, which is equal to the angle of the local latitude. For both cities the modules on the roof were oriented to North. On the facades and windows the PV modules were applied with a tilt of 90°, i.e. flat on the facade. On the overhangs the PV panels were applied horizontally (tilt of 0°) equal to the solar protection position.

The building was simulated oriented with the largest facades towards North-South and East-West. Three different scenarios were used: without surrounding, with an uniform elevation layout and with a random elevation layout (Figure 2). These scenarios made it possible to evaluate the impact of an urban environment on the available solar irradiation for energy generation.



Uniform urban plan   Random elevation

Figure 2: Scheme of the urban layouts.

The urban context is represented by 25 buildings, forming a 5 x 5 mesh of regularly distributed buildings. Only the building in the centre of the mesh, in white, is analyzed Figure 2. For the urban plan density, a site coverage ratio of 40 % was used. The plot ratio, which is defined as the ratio of a building's total floor area to the site area, is fixed for the uniform elevation layout but varies for the random elevation layout, according to building height (number of floors). The building height is one of the parameters most influencing daylight availability and solar irradiation on the facades within urban contexts.

Semi-transparent PV window

The used semi-transparent PV window consists of a double glazed window with an encapsulated solar cell layer between the glass panes. The window is composed of two glass layers with a thickness of 3 mm separated by an air filled 12 mm wide gap. The PV cell is placed at the inner side of the exterior glass. To increase the photovoltaic performance a low iron solar glass was used for the outside pane. For the interior glazing a low-E coated glass was used to prevent the heat generated by the PV from entering the building (Figure 3). The organic solar cell has an efficiency of 3 % and transmittance of 30 % [2]. The semi-transparent PV window has a U-value of 1.67 W/(m^2 K), a VT of 0.23 and a SHGC of 0.22.

The encapsulated PV cell was modelled and applied to the outer glass pane as a thin film within the Optics 6 program. The glass with thin film was imported into the WINDOW 7 program where the window system could be modelled and simulated. As it is not possible to directly integrate a model for semi-transparent PV windows into EnergyPlus it was necessary to separate the thermal energy balance of the glazing system as well as the energy yield calculation of the PV from the simulation of the whole environment to obtain the total energy consumption. Thermal calculations to extract the temperatures inside the window were performed according to [3].

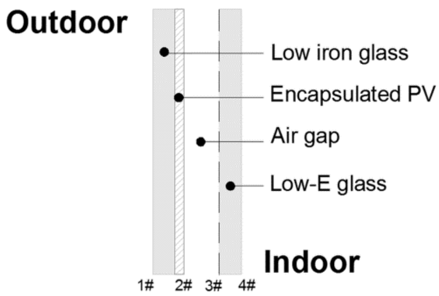


Figure 3: Schematic of the semi-transparent PV window.

Building analysis

The energetic building analyses was obtained through an integrated computer simulation using two programs: Daysim/RADIANCE and EnergyPlus. Daysim was used to evaluate the daylight behaviour and to obtain the use of artificial lighting for the integrated simulation with EnergyPlus, which was used to obtain the overall energy consumption i.e. cooling, heating, equipment and lighting and the energy generated by PV modules on the envelope.

The analysis was divided into two parts. The first part was the performance analysis of semi-transparent PV window used in Brazilian zero energy office buildings. As windows were identified as an important factor on the overall energetic performance of a building the behaviour of semi-transparent PV window systems was investigated. The analysis including PV windows considered daylight and thermal analysis, determination of the energy consumption and calculation of the electricity generation.

The second part was the influence of the urban context on the energy generated by PV windows. The urban environment has a significant influence on the energetic performance of buildings compared to unobstructed sites. Surroundings with different geometric properties were modelled and a method for the analysis of a building within its surrounding was performed using the computer program Diva-for-Rhino.

The simulations were carried out for two Brazilian cities, which were chosen based on their geographic location and climatic differences. Fortaleza/CE is located on the north-east coast of Brazil (3°43'6'' S, 38°32'36'' W). It is one of the Brazilian cities with the highest solar irradiation with an average daily irradiation of 5.67 kWh/m². Florianopolis/SC is located in the southernmost part of Brazil (27°35'49'' S, 48°32'58'' W). It is one of the cities with the lowest solar irradiation with an average daily sum of 4.77 kWh/m².

Results

The multi-story office building's annual energy consumption and the generated electric energy, for Florianopolis and Fortaleza are presented in Figure 4. Between 1 % and 11 % more energy was generated than consumed in Florianopolis and 6 % and 14 % in Fortaleza which can be fed into the electricity grid. As expected, Fortaleza has a higher energy demand than Florianopolis, however more energy is produced as well

The distribution of the generated energy according to the different PV installation surfaces can be seen in Figure 5. The photovoltaic modules on the roof produced 29 % to 35 % of the energy in Florianopolis and 38 % to 39 % in Fortaleza. Despite having less installed PV area than the other surfaces, this is expected as the modules have the best orientation relative to the sun and they have the highest efficiency. In Florianopolis the PV modules on the facade generated the largest part of the totally produced energy 44 % and 32 %. The semi-transparent PV windows generated between 17 % and 21 % in Florianopolis and 11 % and 16 % in Fortaleza.

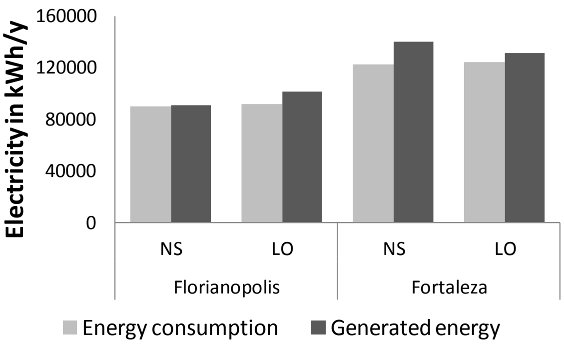


Figure 4: Annual energy consumption and generation for the models oriented North-South (NS) and East-West (EW) without surrounding.

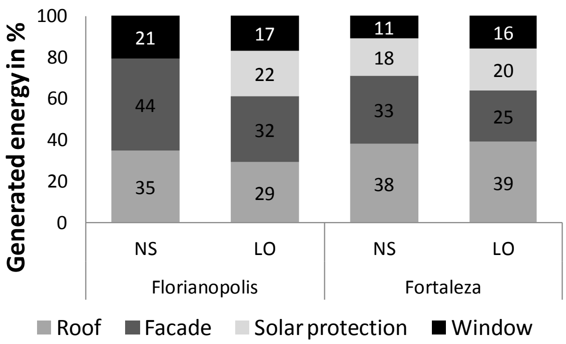


Figure 5: Generated energy from different surfaces for the models oriented North-South (NS) and East-West (EW) without surrounding.

In Figure 6 is possible to observe the reduction of the generated energy with shading on the PV windows. This reduction changes from 19 % to 63 % depending on the urban layout, city and orientation. In general, in Fortaleza higher reduction values can be observe than in Florianopolis and the East-West orientation shows the highest loss of generated energy due to shading for both cities.

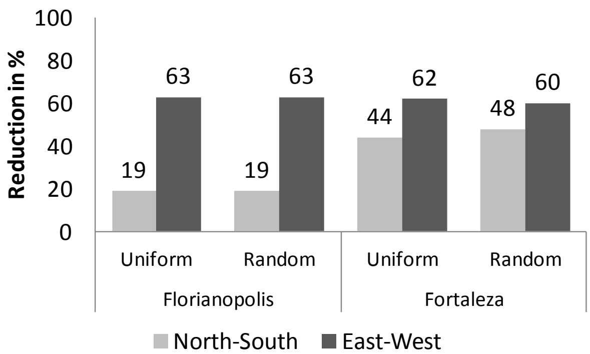


Figure 6: Reduction of the PV window generated energy with surrounding for uniform and random urban layouts.

The analysis of the semi-transparent PV window technology revealed that due to the low visible transmittance of the semi-transparent PV existing on the market today, their application is recommended only for places with low required illumination levels and short permanency. However, semi-transparent PVs can be an interesting element for high-rise buildings as they had a significant contribution to the generated energy in suitable cases. In urban centers the PV windows of the lower floors can be replaced by normal clear glass windows, as due to the surrounding little light reaches them.

Conclusion

The biggest disadvantage of the semi-transparent PV windows is the additional heat produced by the PV cells, which can reach values around 70°C. This temperature level can be a serious hazard for users or cause other types of risks. The PV window technology is not applicable for all orientations and cities, the local climatic conditions, especially the available daylight and temperature have to be considered carefully. For the use of PV windows in environments that do not require artificial cooling, a study using different transmittances and efficiencies is recommended.

The evaluation of the influence of the urban context on a PV window energy generation shows that the type of urban context has a big influence on a ZEB. For example, the analyzed building does not remain ZEB when inserted in an urban context. The shading influences the energy consumption for cooling and lighting, since less solar irradiation reaches the building reducing the cooling load and increasing the required artificial lighting. However, the shading also reduces the generated energy by PV modules applied on the envelope.

Semi-transparent PV windows are an interesting option for ZEB especially for multi-storey office buildings anyway for the analysis of either retrofitted buildings or new constructions it is always necessary to model the building's environment.

Reference

[1] SANTANA, M. V.: Influence of constructive parameters on the energy consumption of office buildings in Florianopolis (Influência de parâmetros construtivos no consumo de energia de edifícios de escritório localizados em Florianópolis), Universidade Federal de Santa Catarina (UFSC), 2006

[2] LTI: LTI - Personal Communication. Karlsruhe (2012).

[3] WAH, W. P.; SHIMODA, Y.; et al.: Field Study and Modeling of Semi-Transparent PV in Power, Thermal and Optical Aspects. In: Journal of Asian Architecture and Building Engineering vol. 4 (2005), Nr. 2, pp. 549–556.

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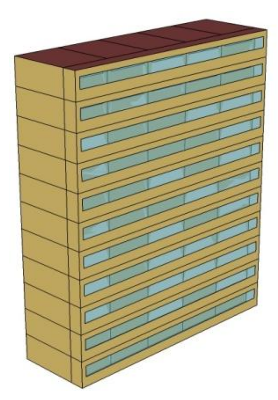
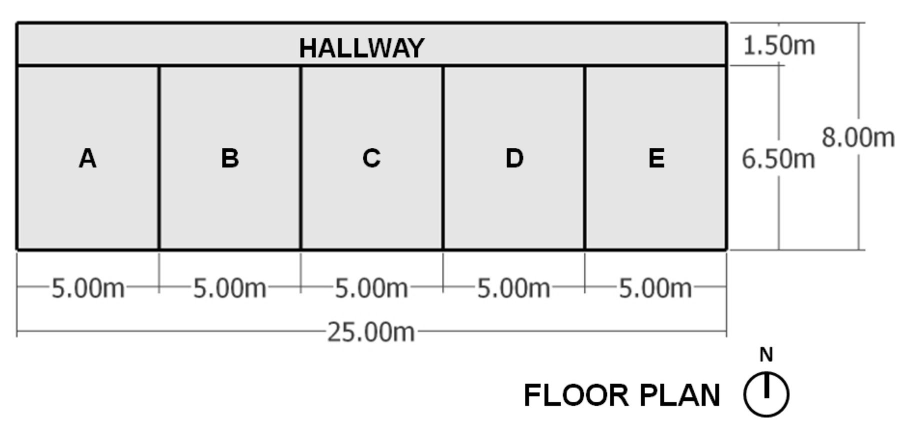
Objective

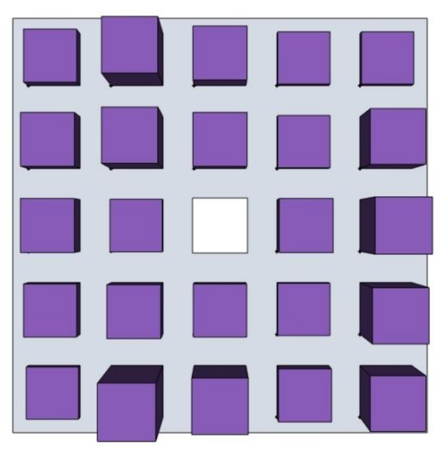
Investigate the performance of semi-transparent PV windows for Brazilian Zero Energy Office Buildings (ZEB) especially regarding the influence of the surrounding urban context on them.

Building context

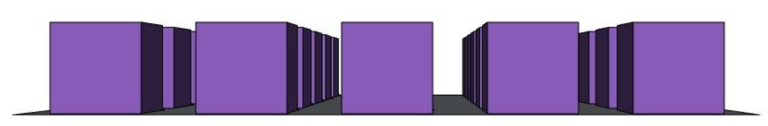
Building model



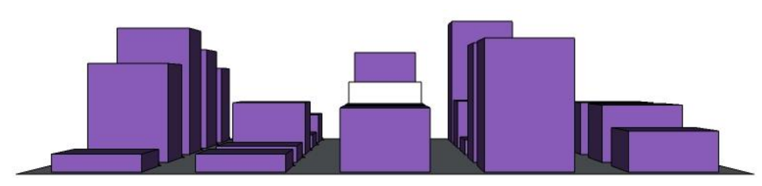




Uniform urban plan



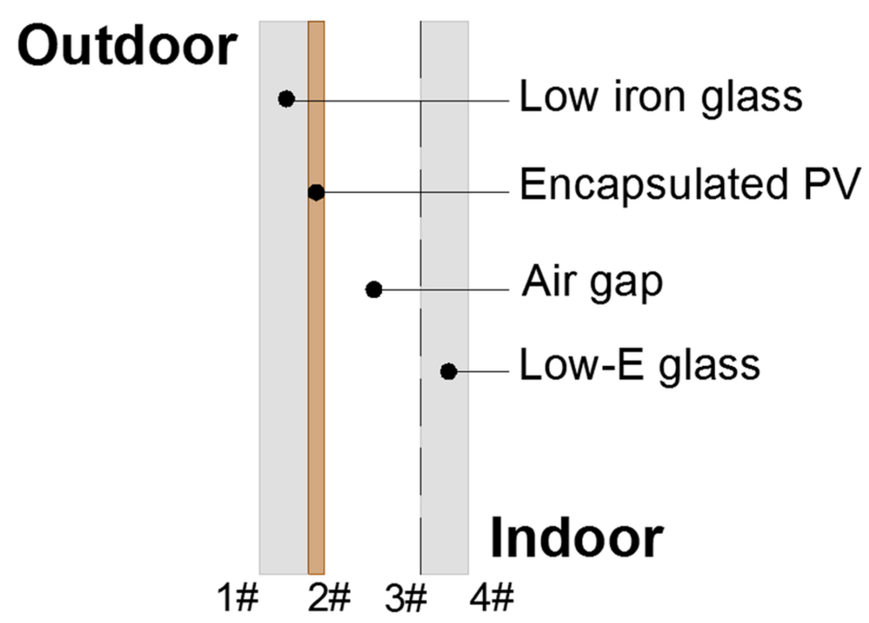
Uniform elevation



Random elevation

City	Latitude	Longitude	Altitude (m)	Region/Country
Fortaleza	3°78' (S)	38°53' (W)	25	Northeast/Brazil
Florianopolis	27°67'(S)	48°55' (W)	5	South/Brazil

Semi-transparent PV window

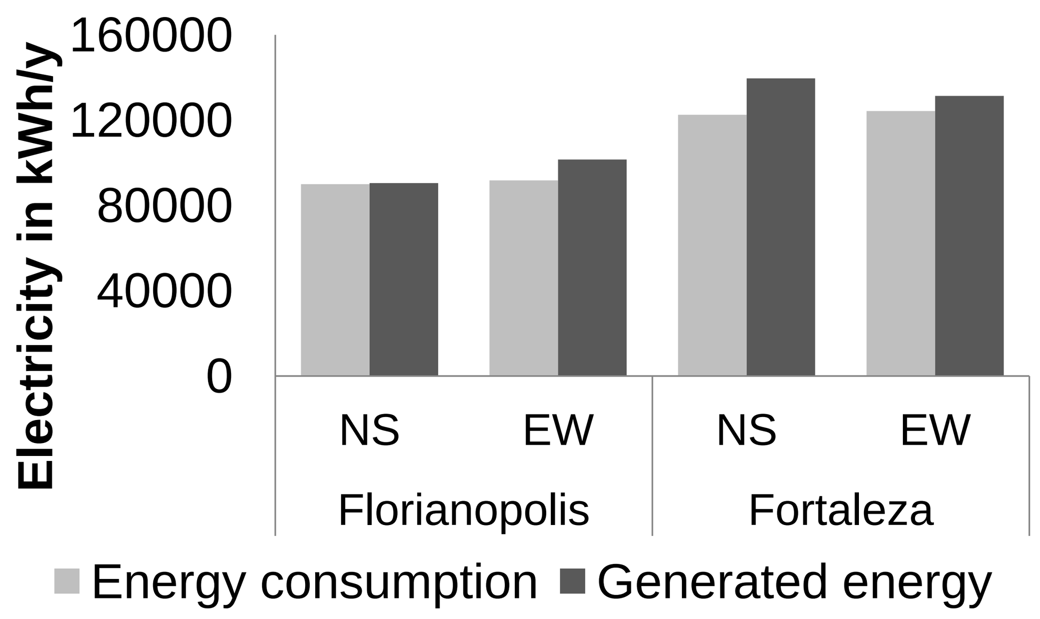


Transmittance = 30 %
Efficiency = 3 %

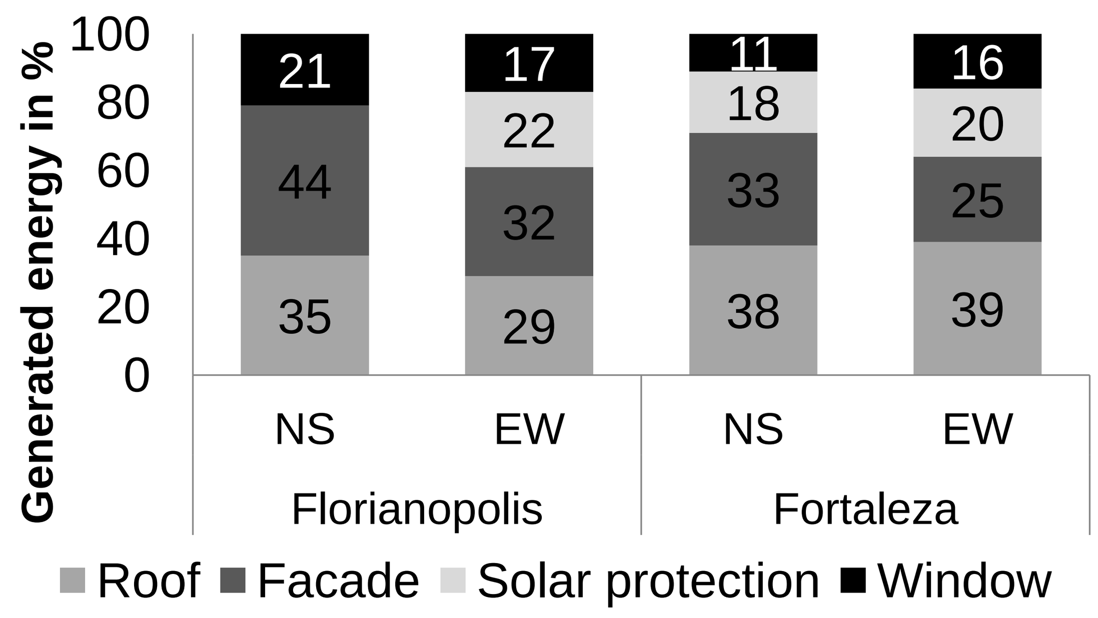
Building analysis

Performance of the window system → Strategies towards zero energy office buildings → Influence of the urban context

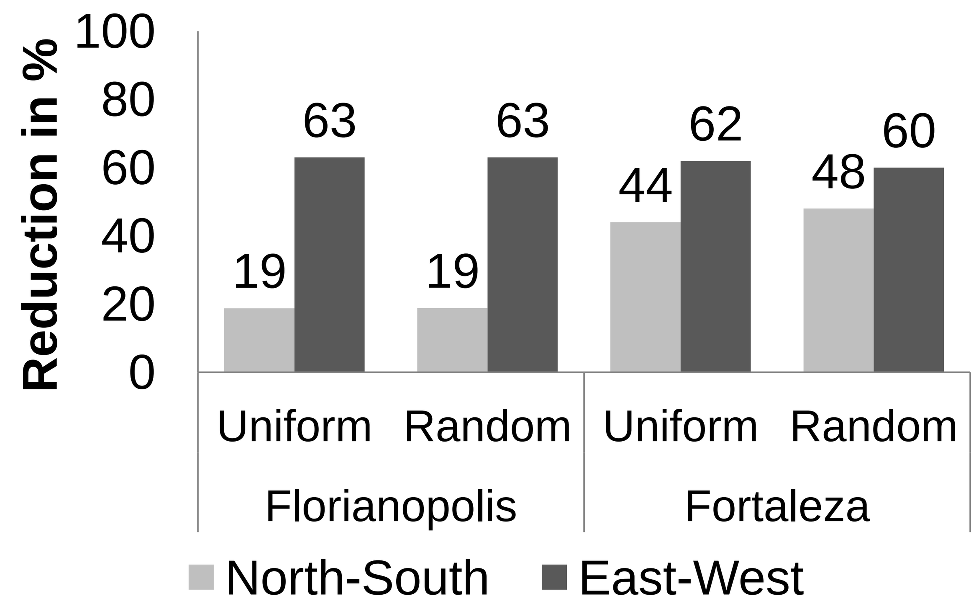
Results



Annual energy consumption and generation without surrounding



Generated energy from different surfaces without surrounding



Reduction of the PV window generated energy with surrounding

Conclusion

- Semi-transparent PV window is an **interesting option for ZEB**;
- For the analysis it is always necessary to **model the building's environment**;
- PV window is **not applicable for** all orientations and cities: daylight and temperature have to be considered carefully;
- **Disadvantage:** additional heat produced by the PV cells can reach 70°C.