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Distributed Urban Energy Systems (Urban Form, Energy and Technology, Urban Hub)

Positive energy building with PV facade production and electrical storage designed by the Swiss team for the U.S. Department of Energy Solar Decathlon 2017

Philippe Couty[a*] , Moncef J. Lalou[a], Peter Cuony[b], Samuel Cotture[c], Victor Saade[c]

[a] Energy Institute, University of Applied Science of Western Switzerland, HES-SO//Fribourg, HEIA-FR, Bd de Pérolle 80, 1700 Fribourg, Switzerland

[b] Groupe-E Connect SA, route du Madelain 4, 1753 Matran, Switzerland

[c] EPFL ENAC, Team Swiss Living Challenge, www.swiss-living-challenge.ch , 1015 Lausanne, Switzerland

Abstract

In the framework of the Solar Decathlon 2017 in Denver, Colorado, the Swiss team will propose a community house powered by solar energy and smart grid interaction. Thanks to an integrated design with multi-oriented façades, which were boosted by customized opening gates equipped with c-Si PV panels and power optimizers, a net positive energy building has been realized. An energy management system has been implemented to monitor and control the 9.715 kWp PV system and the electrical storage of 10.8 kWh capacity. The realized microgrid has been modelled and simulations have been performed using hourly meteorological data. As first results, measured BIPV production during the building commissioning has been compared with the simulated production at Fribourg.

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Keywords: U.S. Department of Energy Solar Decathlon 2017; Photovoltaics; BIPV; Power optimizers; Hourly simulations; Electrial storage, Microgrid; Energy management.

* Corresponding author. Tel.: +41 78 719 0907
E-mail address: philippe.couty@hefr.ch, Philippe.couty@smarsys.com

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1. Introduction

1.1. The U.S. Department of Energy Solar Decathlon 2017

The Swiss Living Challenge (www.swiss-living-challenge.ch) is a project developed by more than 50 students from different backgrounds (engineering, architecture, communication, marketing, etc.) whose goal is to design and build an innovative sun-powered house to participate in the Solar Decathlon 2017 in Denver, Colorado (www.solardecathlon.gov). Launched in 2002 by the U.S. Department of Energy, this competition soon became the most internationally awaited and visible event in the field of the built environment of the future (more than 90'000 visitors in 2015). Boosted by a strong collaboration between the École polytechnique fédérale de Lausanne (EPFL), the School of Engineering and Architecture of Fribourg (HEIA-FR), the Geneva School of Art and Design of Geneva (HEAD) and the University of Fribourg (UNIFR), our team will confront thirteen other universities to defend Europe's know-how in sustainable development. The aim of the project is also to launch strong and long term collaboration between universities and industrial partners.

1.2. Passive building design and energy efficiency

Designing an energy efficient and low consumption building was one of the main objective of the project. Therefore, some key elements were gathered in the passive design, such as a well-insulated and tight building envelope, windows providing sufficient natural light, zenithal windows providing natural ventilation and solar protections. Our building is a community house called 'NeighborHub' which comprises two main zones : a conditioned space called 'Core' where the comfort conditions must be very well controlled, and a tempered space called 'extended skin' providing less restrictive comfort conditions and allowing various collective activities to happen 50% of the year (see Fig 1. a, b). In the concept, the extended skin is used for the electricity production with BIPV elements.

(a) (b)

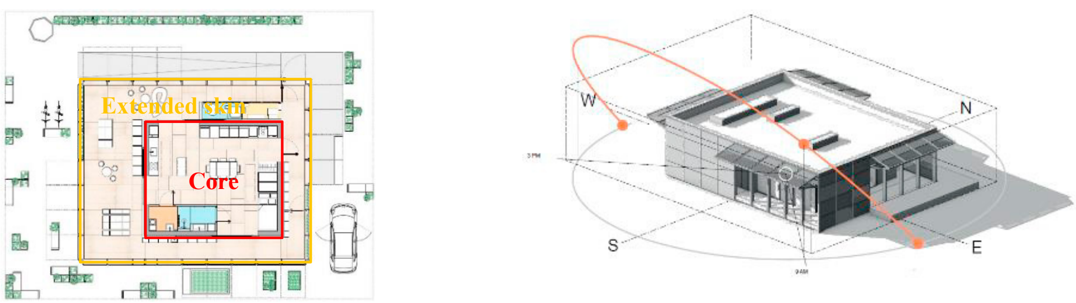

Fig. 1. (a) Plan view of the NeighborHub with the 'core' space (red) and the 'extended skin' space with BIPV elements (orange); (b) Shaded axonometric 9 a.m., Source U.S. Department of Energy Solar Decathlon competition 2017 Denver, Colorado, Delivrable D6 & D7 Swiss Living challenge.

1.3. The strategy for energy production

Nowadays, photovoltaic panels are mostly installed on roofs with optimum inclination and orientation to maximize the return on investment. Thanks to the dramatic drop of photovoltaic prices and the improvement of photovoltaic conversion efficiency, PV on facades now represent a good potential for PV production. Moreover, with the territorial densification currently happening in most European countries, including Switzerland with its LAT (laws on land use planning), the solar potential of facades should be better exploited. Solutions to introduce new renewable energy in this urban renewal process are needed [1,2,3]. Instead of conventional roof positioning with optimized tilt, our house wants to showcase how BIPV on facades could answer to electricity production on densified buildings. Furthermore, it was decided to make the whole envelope surface – walls and roof – productive. The building envelop has been designed to produce solar electricity, domestic hot water, collect water and grow food. The Building-integrated photovoltaics (BIPV) concept should be applied as well, with the PV modules playing the double function of electricity production and building element, promoting the reduction of embodied energy of the building. Therefore, the South, West and East facades of the extended skin have been covered with BIPV elements (47.2 m2). Thanks to the movable doors supporting PV panels with a final inclination 17°, the production will be particularly boosted in summer time and in the mid-season. The advantage to use East and West facades is to slightly increase production in the morning and in the evening respectively, thus improving the self-sufficiency of the NeighborHub.

2. The PV system and simulations

2.1. BIPV technology

High efficiency monocrystalline panels Sunpower X21-335-BLK black have been installed on the three facades South, East and West. The selection criteria of PV panels were the following :

- Panels compliant with the UL certification which is mandatory for the competition.
- Best efficiency 21.1% to maximize energy production on facades while keeping transparency of the extended skin.
- Aesthetic aspect for an integration as perfect as possible on the facades of the NeighborHub.
- High reliability of the panels, greater than 25 years.
- Minimum weight, standard laminated PV panels 3.2 mm
- Easy handling of the panels to mount and unmount on the metal frames of the extended skin.
- Low environmental impact GWP and CED of high efficiency c-Si panels [4].

2.2. Installed power

To show the importance of producing in an urban context and sharing energy with Neighborhood consumers at district scale, the electrical energy balance has been targeted positive. Thus, the installed power is 9’715 kWp which is close to the maximum of 10 kWp allowed by the competition. Installed power could be increased in the future by adding panels on the roof which is collecting rain water.

2.3. Multi-orientation and shadowing issues

Because of the three different facade orientations as well as the variable inclination of the opening gates (see fig 2.a.), the use of six inverters would be needed. To match the minimum required number of panels of the inverter and to limit the PV system cost, only one inverter with one string per façade has been installed, i.e three inverters in total. To overcome the problem of current-voltage mismatch between panels of a same string, power optimizers have been connected to each panel. The use of power optimizers has also the advantage to reduce the efficiency drop due to any shadow caused by surrounding buildings and the opening gates. Note that the use of micro-inverters DC/AC was not possible because of the high power of the 96 c-Si cells panels. The Solaredge system comprises 29 DC-DC power optimizers P404-5R-M4M RM, 1 DC/AC inverter SE 3500H for the South string and two inverters SE2200H for the East and West strings , see Fig 2.b. for the PV layout on facades.

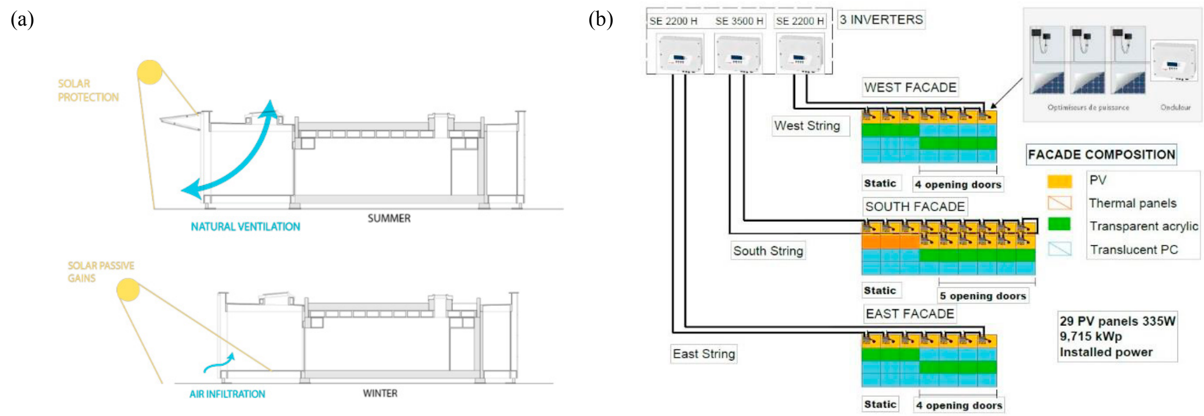

Fig. 2. (a) Doors of the extended skin have multiple functions : solar protection, natural ventilation and PV production ; (b) PV layout the 3 strings on the 3 facades including power optimizers and inverters Solar edge connected with the Sunpower X21-335-BLK black panels.

2.4. Production simulations and energy balance

The PV system has been simulated with the help of the software PVsyst for annual yield and Crmsolar for hourly simulations. Simulations have been performed for both Fribourg (see Table 1. annual yield) and Denver and for variable door configurations. The production in Fribourg with all doors opened (inclination 17°) is 8'649 kWh whereas 7'059 kWh with all door closed. In Denver the productions are 13'698 kWh and 10'664 kWh respectively. The electrical demand estimation has been based on both scenarios: on the one hand a community house located in Fribourg, and on the other hand a house compliant with the competition requirements in terms of comfort and equipment. The energy demand for the competition takes into account all the electrical devices installed in the house, mainly air conditioning, lighting, ventilation appliances and an electrical vehicle. The total consumption of electricity during the competition has been estimated to 185 kWh for the 8 days of the competition in October at Denver. Hourly simulations have been performed for Denver over the period corresponding to the competition in October. With an average production of 28 kWh per day in the open position of the gates, thus 224 kWh for 8 days, the 185 kWh electrical needs should therefore be covered.

Table 1 : Annual yield, PVSyst simulations at Fribourg site with open doors,.

PVsyst @ Fribourg	Inclination	Number of panels	String	Power kWp	Production kWh
West doors open	17°	4	West	1.340	1107
West vertical static	90°	3	West	1.005	504
East vertical static	90°	3	East	1.005	571
East doors open	17°	4	East	1.340	1148
South vertical static	90°	5	South	1.675	1755
South doors open	17°	10	South	3.350	3564
		29		**9.715**	**8649**

3. Electrical storage and microgrid

3.1. Electrical storage

To improve the building's self-sufficiency, the PV system is coupled with a double lithium ion battery 10.8 kWh. Smart grid algorithms are under development to optimize the building self-sufficiency and to limit the effect of the intermittent nature of renewable resources [5]. The lithium-ion technology has be chosen for the static electrical storage. Two batteries BMZ ESS7.0 with a total capacity of 10.8 kWh has been coupled with 8000VA charger inverter Studer Innotec XTH 8000-48V. With 5000 cycles at 80% depth of discharge (DOD), the environmental indicators GWP [kg CO2eq/kWh] 0.024 and CED_{nr} [MJ/kWh] 0.41 are low. This can be compared with indicators for traditional Lead Acid battery technology with GWP 0.21 and CED_{nr} 5.63 [6].

3.2. Microgrid and energy management

The NeighborHub's microgrid is illustrated in Fig 3. The energy management will consist in dispatching and distributing available electrical energy in the microgrid. The self-sufficiency is promoted by the direct consumption of PV produced electricity. Then, thanks to a charger inverter in AC coupling mode, the battery will be able to store the PV overproduction and give this energy back in case of negative balance between production and consumption. In the case of full battery, the overproduction will be injected into the grid. Finally, in case of lack of energy with a negative balance, an algorithm is able to choose between taking the energy from the grid or from the battery by taking into consideration other constraints such as grid carbon content [7] and electricity pricing. At the time this article was written, the energy management was under development. The Swiss Team will be delighted to present the experimental results during the oral presentation.

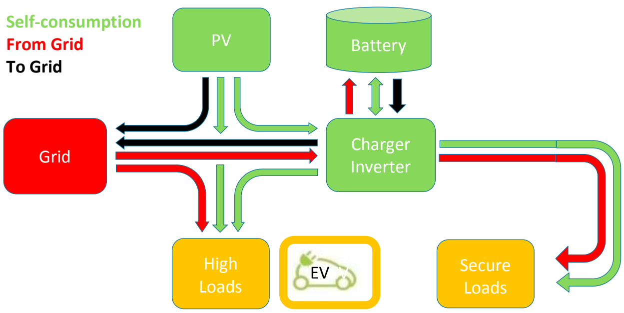

Fig 3. : Microgrid layout of the NeighborHub and electrical energy flux between PV, consumers, storage and grid.

4. Experimental validation of the PV Production

The hourly PV simulations take into account the measured meteorological irradiation and temperature from the closest meteorological station Fribourg / Posieux (meteosuisse data), without shadowing. Simulations have been compared with the production measurements at Fribourg, see fig. 4 (a). They have been performed for the two configurations: closed and open doors. During the period considered, the doors have been opened and closed for building commissioning purposes. On the 28 and 29th of May, the doors were open the whole day. It is worth noting that the measured production curve clearly lies between the two simulations curves corresponding to gate configurations, with a good matching on the 28 and 29th of May. In fig. 4 (b), productions and simulations per facade are shown for the 28th of May. Simulations reproduce well the measured production. The relative deteriorating of weather in the afternoon is revealed by both the simulations and the measurements. The East measured production can be clearly identified in the morning as well as the opening of south gates at 7h with a vertical positive shift of power (yellow dashed line). Low irradiation and low incidence conditions need to be calibrated for the morning and the evening production.

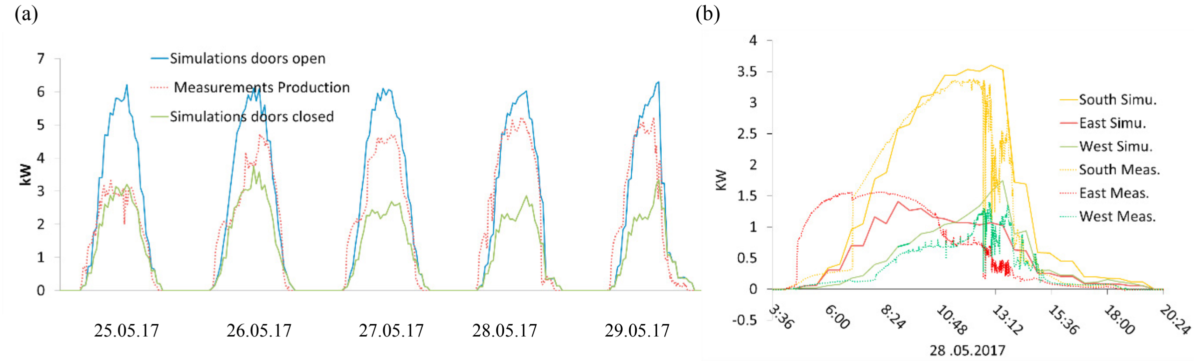

Fig 4. : (a) Comparison of PV simulations with measured output production (UTC time). The blue and green curves correspond to the open gate/ closed gate configurations respectively, measurements in red. (b) Simulations and measurements per facade 28.05.17.

5. Conclusions and perspectives

Thanks to the comparison of the PV power measurements with the hourly PV simulations, the production yield of the PV system has been rapidly confirmed during the commissioning of the building. By extrapolating these results with Denver production simulations, which are compared with the consumption estimation during the competition period, a positive energy balance is expected for the competition. As a matter of fact, the power optimizers is a good solution to overcome shadowing as well as variable irradiation condition on panels of a same string. Also, the opening gates has been revealed very effective to boost the production over the considered period. The validation of the production yield was a first step towards self-production optimization. The forecasting of PV production will be then used to adjust the dispatch between the grid and the electrical storage.

Acknowledgements

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