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The EPFL campus in Lausanne: new energy strategies for 2050

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Abstract

The increase of the urban population and the climate change are issues that scientists and stakeholders are facing nowadays; in this optic a sustainable design should address buildings, and all the physical phenomena that interact with them, from the urban to the district scale. The Swiss Federal Institute of Technology in Lausanne (EPFL) located in Switzerland is now facing this problematic, and its sustainable strategy “Energy Concept 2015-2045” aims to reduce the energy demand per person by 30%, and the CO_2 emissions by 50% in 2035. The university campus is growing -the energy reference area has increased by 25% from 2001, and is expected to continue in the next years- and the actual district heating system (two heat pumps with a combined heat and power facility installed in the early 70s) is facing peak power limitations nowadays. Looking for an answer for this issue, a new concept called Energy Hub is sought for the campus: an intelligent unit able to stock and redistribute energy with different carriers. This paper presents the pre-requisite for a potential energy hub on the site of the EPFL campus in Lausanne: the validation of a dynamic heating energy demand model (correlation factor R^2=0.89 compared to monitoring) and a BiPV power plant model for the solar electricity produced on the EPFL buildings roofs (correlation factor R^2=0.93 compared to monitoring). Finally, two hypothetical refurbishment of the site, according to the Swiss Minergie and Minergie-P labels, are proposed; they reduce the heating demand of buildings by 38% and 44% respectively. Refurbishments are analysed using actual weather data (average data from the last ten years), as well as future scenarios for 2050, showing the impact of climate change on the building thermal behaviour.

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Keywords: climate change; district energy modelling; energy hub

1. Introduction

The increase of world population, mostly in urban environment, and climate change are problems that scientist and politics are facing nowadays, and oblige them to rethink our way of living introducing new technologies and land policies to reduce our energy footprint [1] [2] [3]. The Ecole Polytechnique Fédérale de Lausanne (EPFL) is one of

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the largest universities in Switzerland, and hosts around 15.000 people (including students and professional) each day. According to Energy Strategy for 2050 (Swiss federal energy policy), EPFL is working to define the "Energy Concept 2015-2045", a strategic report that aims to reduce the energy demand per person by 30% of final energy and 25% of primary energy in 2035, to increase the percentage of electricity coming from renewable energy and to reduce by 50% CO_2 emission by 2035 [4]. The campus is heated by renewable energy (56% by district heating system using lake water and 18% Swiss hydroelectric), but as the energy reference area has increased by 25% from 2001, and is expected to increase in the next years, the actual district heating system (two heat pump combined with heat and power facility) is facing limitation [5]. With the goal of reducing the energy demand of the site, the EPFL is part of an innovative project called IDEAS4cities that tends to develop an Energy Hub: an intelligent unit able to collect, store and redistribute energy from different energy carriers, according to the need of buildings [6] [7] [8].
This paper presents the first approach to create an energy hub on the site of the EPFL: the validation of the energy model of the site and the optimisation of the energy demand by refurbishment. The energy demand for heating and the electricity produced by the BiPV power plant are analysed with the software CitySim -an urban energy modelling able to analyse the energy demand of buildings at the urban scale [9]- and validated with on-site monitoring [10]. Finally the existing model and refurbishment scenarios (according to Minergie and Minergie-P Swiss standards) are analysed for three scenarios for 2050 (2050-B1, 2050-A1B and 2050-A2), showing the impact of climate change on the energy demand of the site, and proposing an optimal strategy for the future development of the campus.

2. Methodology

EPFL campus is located near the city of Lausanne, the capital of Vaud Canton, in Switzerland (46.53 N, 6.56 E); the university is near the Geneva Lake, at 400 meters above the sea level. The university is composed by more than 50 buildings, interconnected with a pedestrian circuit. The climate in Lausanne is temperate by the Geneva Lake, however presenting cold winters and warm summers. A typical meteorological year (TMY) climate file is created with the software Meteonorm [11] using average radiation data for the period 1991-2010 and average temperature for the period 2000-2009. The highest temperature during the summer is 30°C, and the lowest temperature is -9.5°C during the month of January. The relative humidity is comfortable during the year; the total precipitations are 1,142 mm per year and showing by snow during the winter time.

2.1. Heating demand and BiPV production

The university was built in two main phases, which characterize the geometry and materials of buildings: first phase in 1972-1984 and second one in 1980-2002 [12]; later buildings were added to the site such as the Rolex Learning Centre and Swiss Tech Convention Centre. Buildings' envelopes are defined according to the period of construction: buildings built in the same period are part of a homogenous architectural plan and present the same physical characteristics, summarized by their U-value in Table 1.

Table 1 Envelope of the buildings, defined according to their period of construction

Construction phase	U-value Roof ($W \cdot m^{-2} \cdot K^{-1}$)	U-value Wall ($W \cdot m^{-2} \cdot K^{-1}$)	U-value Floor ($W \cdot m^{-2} \cdot K^{-1}$)
First Phase (1972-1984)	0.33	0.33	0.56
Second Phase (1980-2002)	0.31	0.38	0.56
Minergie Building (since 2002)	0.16	0.16	0.16

The geometry of the campus is based on an existing 3D model [13], and the occupancy profile is defined according to SIA 2024/2006 [14]: the number of occupants and their presence is based on the liveable surface of the building and its function (office, restaurant, classroom and dormitory). A different profile is applied during the Christmas holidays, when the university has a limited number of occupants. The Swiss Tech Convention Centre and the adjacent residences are analysed without occupants, because they were inaugurated in 2014 and consequently no monitored data are available yet.
The EPFL campus is heated by a central heat pump, that uses the water from the Geneva Lake: the water is pumped

from 68 m underwater, and has a constant temperature of 6-7°C during the year; after the use the water is then thrown again in the river Sorge and back to the lake [15]. The roofs of the buildings are covered by photovoltaic panels, with a total power of 2 (MW) annual and a total area of 12,285 (m^2). The photovoltaic panels were installed in three different phases in 2010, 2011 and 2014 by the electricity carrier Romande Energie. Each phase of construction is characterized by a different types of panel (monocrystalline, polycrystalline, thin film and silicium) and manufacturer [16]. The characteristics of these panels for the first two phases are described in Table 2; the third phase is under construction and for this study characterised as in the second phase.

Table 2: Photovoltaic farm on the roof of the campus. Description of the panels, according to their phase of realization

Construction phase	Manufacturer and model	Type	Nominal power (Wp)	Tilt (°)
First phase	Jinko JKM-240M	Monocrystalline	240	17°
Second phase	Hareon TRITEC HR-225W Poly	Polycrystalline	225	20°
Second phase	Flexcell FLX-MO160	Thin film	165	Curved roof
Second phase	Schott Protect ASI 100 Thin-Film	Silicium Amorphus	100	90°_on the facade

2.2. Refurbishment of the campus according to Minergie and Minergie-P scenarios

The refurbishment of the site considers the reduction of the energy needs for heating by applying the Minergie and Minergie-P standards to the envelope of all buildings. The Minergie envelope for this case study is characterized by a U-value of 0.16 ($W \cdot m^{-2} \cdot K^{-1}$), using 25 cm of Polystyrene insulation (EPS); the Minergie- P envelope has 35 cm of EPS, and a U-value of 0.11 ($W \cdot m^{-2} \cdot K^{-1}$); finally the actual windows are replaced by triple glazing windows filled with argon. For the future scenarios nine simulations are defined, showing the impact of climate change in the thermal behaviour of buildings, compared to the existent (2014), Minergie and Minergie-P scenarios. The best and worst scenarios are then optimized to improve their efficiency: the shading strategy, which considers the automatic closing of the shading when the facade irradiation is above 150 ($W \cdot m^{-2}$), and the windows opening strategy, which automatically opens the windows during the summer period (70% of glazed surface is considered as openable) if the external temperature is 1°C lower than the internal one.

2.3. Future climatic scenarios: IPCC models for 2050

To analyse the campus energy behaviour in 2050, three different scenarios are envisaged, based on the IPCC studies [17] [18]:

- Scenario 2050-B1: rapid growth of population (8.7 billion) and use of new clean technologies (30% share of zero carbon energy sources in primary energy).
- Scenario 2050-A1B: rapid economic growth, rapid growth of population (8.7 billion), and new efficient technology across all sources (36% share of zero carbon energy sources in primary energy).
- Scenario 2050-A2: continue increase of population (11.3 billion) and reduced research in new technologies (18% share of zero carbon energy sources in primary energy).

These scenarios are defined by Meteonorm, and contain the projected climatic data for the future: temperature, precipitation and global radiation of the periods 2011–2030, 2046–2065 and 2080–2099 [11]. On average the air temperature will increase by 3.5°C, and maximal temperature during the summer will reach 35°C: 5°C higher than the actual weather conditions. Futures scenarios for precipitations predict a reduction by 12 % in precipitation during the summer period (drought events) and an increase of snow events during the winter months by 21%. The total annual precipitations will be reduced by 10 %, from the actual 1,142 mm to 1,043 mm in scenario 2050-A2.

3. Results

3.1. Heating demand and BiPV production

Figure 1a shows the 3D model of the campus with photovoltaic panels (coloured in grey) and the annual solar irradiation (short-wave, expressed in $kWh \cdot m^{-2}$). Figure 1b shows the energy demand for heating: buildings AI and SV have the highest energy demand (around 150 $kWh \cdot m^{-2}$) since they host the Life Sciences faculty, with its experimental laboratories that need an important ventilation rate (heated during the winter period) to maintain the correct indoor temperature. New constructions (BC building, Rolex Learning Centre and Swiss Tech Convention Centre) are built according to the Minergie standards, and they present a performant envelope and an efficient air exchange system. The EPFL annual heating demand and electricity production by BiPV, defined in this paper, are validated with on-site monitoring (correlation factor R=0.89 and R^2=0.93 respectively). Experimental laboratories present wide differences between model and monitoring, because of their powerful equipment and high ventilation rate; for example in buildings ELG and ELH the difference between simulation and monitoring data rises up to 26%.

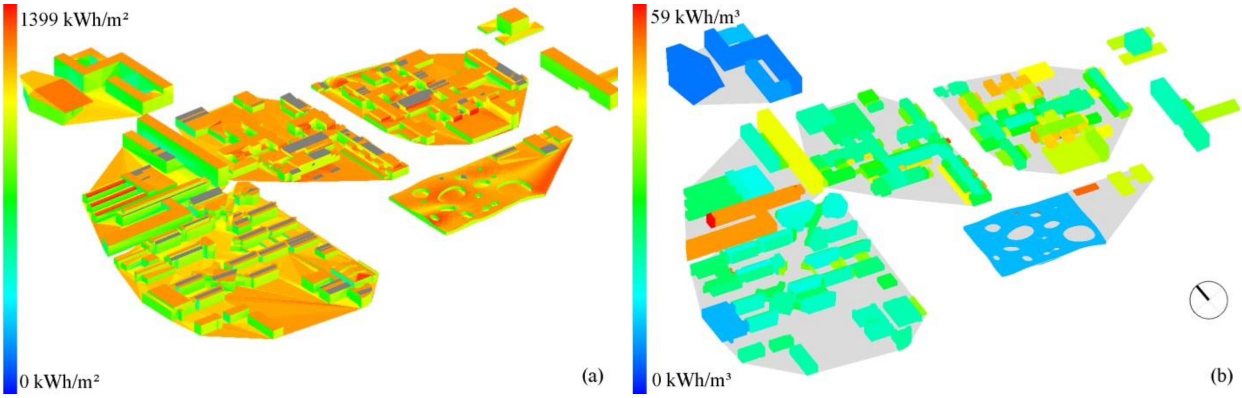

Figure 1 (a) Annual solar irradiation on the campus, with PV geometry on the roofs (grey). (b) Annual heating demand of the campus, expressed in ($kWh \cdot m^{-3}$)

3.2. Refurbishment of the campus according to Minergie and Minergie-P scenarios

A refurbishment of the site, according to Minergie (maximal energy demand 55 $kWh \cdot m^{-2}$) and Minergie-P, is proposed; the new envelope has a U-value of 0.16 ($W \cdot m^{-2} \cdot K^{-1}$) with 25 cm of EPS insulation in the Minergie scenario, and a U-value of 0.11 ($W \cdot m^{-2} \cdot K^{-1}$) with 35 cm of EPS insulation in the Minergie-P scenario. In both scenarios the existing windows are replaced by triple glazing windows with argon. The renovation, according to Minergie, reduces the energy demand for heating by 38 %: buildings realized in the first phase, as GC, reduce their heating demand by 44%. According to the renovation, 80% of buildings would be Minergie; naturally buildings with animal laboratories, as AI and SV could not reach the Minergie target, as the internal gains dominate the thermal behaviour of the building. In the Minergie-P scenario the average heating demand is reduced by 44%, and the average energy demand for heating of the site is 44 ($kWh \cdot m^{-2}$).
The second approach considers the impact of the internal temperature on the heating demand of buildings in Minergie renovation scenarios. The minimal internal temperature (the set point temperature for heating) is reduced to 20°C and then raised to 24°C. Results show that a set point temperature of 20°C reduces the heating demand by 13%, and consequently 85% of buildings have a heating demand lower than 40 $kWh \cdot m^{-2}$. On the other side, increasing the indoor temperature reduces the energy performance of buildings by 16 %.

3.3. Future climatic scenarios: IPCC models for 2050

The future scenarios, defined with the software Meteonorm, show the impact of climate change in the thermal behaviour of the campus in 2050. Three models are realized (Minergie, Minergie-P and current buildings scenarios) and each of them is analysed with the future weather data 2050-A1B, 2050-A2 and 2050-B1. According to climate change, the best option for the EPFL will be the Minergie-P scenario 2050-B1 (increase of cooling demand by 50% and decrease of heating demand by 89%, referring to the existing scenario), and the worst situation will be the existing buildings projected in scenario 2050-A1B (increase of cooling demand by 57% and decrease of heating demand by 20%, according to the real scenario).

The best and worst scenarios are manually tuned introducing a smart building control, able to improve natural cooling strategies:

- Blinds strategy: automated blinds are closing if the facade irradiation is higher than 150 W m^{-2}.
- Windows strategy: systematize windows opening during summer if external temperature is 1°C lower than the internal one.

According to both optimizations the new energy demand for each scenario is shown in Figure 2 and described as:

- Worst scenario (Existing in 2050-A1B) reduces its heating demand by 1%, and its cooling demand by 60%. The total energy demand (heating and cooling) is 35.9 GWh, higher than Minergie (14%) and Minergie- P (17%) for the same climatic data.
- Best scenario (Minergie- P 2050-B1) maintains the same heating demand, but reduces the cooling demand by 53%. The total energy demand is 25 GWh, lower than existing (37%) and Minergie scenario (17%) for the same climatic data.

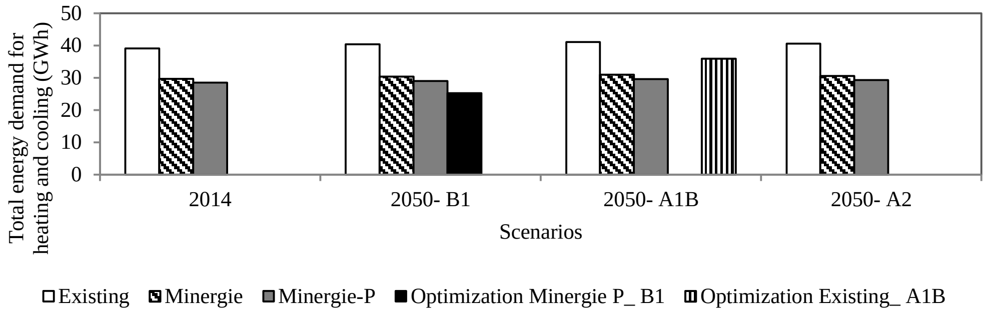

Figure 2 Total energy demand for heating and cooling (GWh), according buildings envelope e, Minergie and Minergie-P, and climatic scenarios (2014, 2050-B1, 2050- A1B and 2050-A2)

The analysis of the indoor comfort sensation in the LESO experimental building at the heart of the EPFL campus according to the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied [19] [20] are carried out during summer months (June, July and August). The indoor office activity is taken as 1.2 (met) and clothing insulation equals to 0.7 clo (underwear, shirt, trousers, socks and shoes). Figure 3 shows the average PMV during the summer months for the current LESO building today, the existing and Minergie-P building in the future climatic scenario 2050-B1. Actually the average thermal sensation in the building is neutral (June and August) to slightly warm (July), but in the same building in 2050-B1 the PMV will increase from slightly warm to warm, underling the need of an air conditioning system, or a Minergie-P refurbishment, as the same climatic scenario for Minergie-P building ensure a neutral thermal environment.

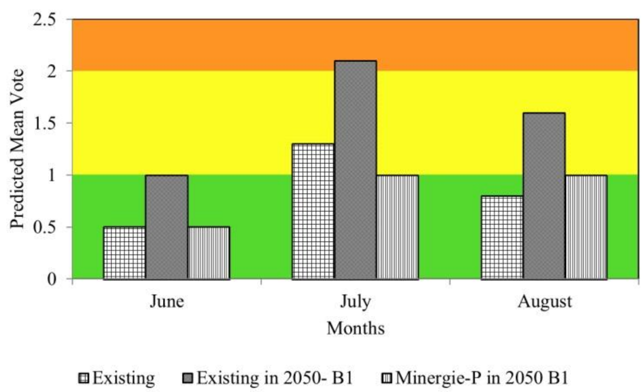

Figure 3 Average Predicted Mean Vote in LESO building, for the months of June, July and August, as function of the existing building today, in 2050-B1 and the refurbishment Minergie-P in 2050-B1.

3 Conclusion

The EPFL campus stakeholders pay particular attention to the sustainability and energy efficiency of the site, and the strategy "Energy Concept 2015-2045" defines the future guidelines to reduce the energy demand per person, to increase the percentage of electricity coming from renewable energy sources and to reduce the CO_2 emissions. The main part of the campus is composed of old buildings, which consume and dissipate a lot of energy; the model, realized with the software CitySim, shows how two hypothetical refurbishment (according to Minergie and Minergie-P Standards) could reduce the heating demand by 38% and 44% respectively. Considering the climate change, three future scenarios of the EPFL are defined, according to IPCC model 2050-B1, 2050-A1B and 2050-A2; simulations show the future behaviour of the campus, characterized by lower heating demand and higher cooling demand. The optimal energy saving solution for the EPFL in 2050 will be as expected the refurbishment of buildings according to Minergie-P, reducing the energy demand by 37% compared with the actual physical characteristics of buildings projected in 2050; in this scenario natural ventilation and shading strategies, by smart building control, are applied.

Actually, the EPFL campus is heated by two central heat pumps that are facing their peak power limitation and passive strategies ensure the cooling needs; considering IPCC climate change model and if the built environment is not refurbished, it will be necessary to create a cooling system for the campus within the next 40 years, as the actual passive strategies will not be enough to guarantee the occupants' thermal comfort.

Future work will comprise the development of an energy hub model on the EPFL campus, able to collect stock and redistribute energy from different energy carriers (water from the lake, PV panels, geothermal and wind) and ensuring continuous provision of energy from intermittent renewable sources.

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