ASSESSING THE CHALLENGES OF CHANGING ELECTRICITY DEMAND PROFILES CAUSED BY EVOLVING BUILDING STOCK AND CLIMATIC CONDITIONS ON DISTRIBUTION GRIDS

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ABSTRACT

The buildings sector in Switzerland accounts for more than 40% of the country's overall energy demand and CO_2 emissions. The predicted future weather conditions, according to the Intergovernmental Panel on Climate Change (IPCC), will even reinforce this trend.

Due to the foreseeable further electrification of heating and cooling demand in buildings their electric load demand will likely increase. For these reasons it is essential to reduce the energy demand of buildings, and optimize it by using renewable energy sources (RES) in conjunction with suitable storage elements, such as thermal energy storage (TES). These two factors will, however, drastically change today's observed "typical" building load demand profiles. Higher peak load demand during cold and hot weather conditions as well as significant PV power production on sunny days will induce new challenges for electric distribution grid operation and planning such as more frequent and higher power spikes. These challenges will be assessed and possible mitigation options, i.e. the usage of storage elements, discussed in this paper. The paper presents the energetic analysis of an office building, the Solar Energy and Building Physics Laboratory (LESO-PB), located in the EPFL campus in Lausanne. The building's energetic model was realized with the software CitySim, and validated with on-site monitoring for the time period 2011 to 2013. Further analysis shows its thermic behaviour in future climatic scenarios (IPCC model for the year 2100, scenarios B1, A1B and A2).

The electrical load demand of the building and the electricity production by the BiPV system can be optimally matched, during the different months and hours of the day, by means of thermal and/or electrical energy storage. This enables the maximization of the building's self-consumption from PV power production.

An assessment of the challenges for the electric distribution grid due to changing electric load demand patterns is presented for a residential as well as an office usage profile.

Keywords: Electricity grid, climate change, renewable energy, storage systems

INTRODUCTION

Impacts of changing electric load demand patterns on distribution grids

One the one hand, there is a notable shift from fossil fuel usage to electricity, notably substituting natural gas for heating needs by using heat pumps and liquid fossil fuels for mobility by means of electric vehicles. These additional electric load units will lead to a significant increase in electricity consumption, inevitably leading to higher average load demand as well as higher peak load events in the electric distribution grids. On the other hand, PV installations for instance on building roof-tops and facades will lead to significant decentralized electricity production within distribution grids. Both trends create new challenges for distribution grid operation and planning. Both peak load demand and peak

PV power feed-in can create local voltage problems and, potentially, also line overloading within the distribution grid topology. In this paper we assess these challenges by looking at the LESO building. Typical residential and office load patterns, as derived by representative occupancy profiles are analysed.

The LESO building is located in the EPFL campus in Lausanne, and its thermic behaviour was well documented in previous researches [1] [2]. The object of this paper is to create a dynamic thermic model of the building, showing the heating demand and the photovoltaic production in actual and future climatic scenarios. Weather data for future climatic conditions are realized with Meteonorm [3], and are based on IPCC’s climatic scenarios [4].

METHOD

Energetic model of LESO-PB

The solar energy and building physic laboratory (LESO-PB) was built in 1981 and refurbished in 1998, as test building for experimental anidolic facades and indoor climatic monitoring by intelligent microprocessors. The object of the renovation was to reduce the use of non-renewable sources, by creating a performant envelope, increasing the availability of natural light, improving the summer comfort by night cooling and using photovoltaic to produce electricity. The thermic envelope, defined according to [2], is summarized in Table 1. The South facade presents a performant envelope, externally covered by wood, with anidolic windows on the upper layer of each room, and double glazing windows on the lower part.

Element	U-value (W/m²·K)
Wall South	0.3
Wall North	0.2
Double windows with infrared coating	1.4
Anidolic windows	1.4

Table 1 – Thermic envelope of LESO-PB building

Photovoltaic panels are integrated in the rooftop (BiPV), a total area equal to 28 m, oriented south and with a peak power of 3.2 kW. According to previous monitoring, the total energy demand of building is equal to 287 MJ/m², and the net demand is equal to 75 MJ/m², by removing the useful gains by occupants, lighting, devices and solar gains [1].

LESO building presents an unobstructed South facade, facing a garden, and is connected to a second building on the North side. In the energetic model, realized with the software CitySim, the internal temperature is set at 20°C during the winter time, and the occupancy profile is defined according to SIA 2024 [5], including occupants and electrical devices. A hypothetical refurbishment according to actual Minergie and Minergie P scenarios is proposed, increasing the thermal efficiency of envelope (U-value lower then 0.2 W/m²·K) and windows (by replacing the actual windows with triple glazing windows). The energetic model is realized in actual and future climatic scenarios; for the energy behaviour in the year 2100, three different scenarios (provided by Meteonorm [3]) are envisaged according to the IPCC studies [6] [4]:

- **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 population growth (8.7 billion), new efficient energy technology (36% share of zero carbon energy sources in primary energy).
- **Scenario 2050-A2**: continued increase of population (11.3 billion) and reduced research in new technologies (18% share of zero carbon energy sources in primary energy).

The future energetic behaviour of the LESO building is analysed according to two different occupancy profiles: office and residential, showing the impact of the occupancy profile in the energy demand of buildings, and in the grid optimization. The occupancy profile is defined according to SIA 2024/2006 [5]: the number of occupants and their presence during the day is added to internal gains related to appliances; the profile is based on the liveable surface of the building and its function (office and house). Figure 1 shows the occupancy profile (ranging from 0 – unoccupied, up to 1 – maximal occupancy) during a typical day for an office and a house: the house is occupied during evening and night-time; on the contrary the office has the highest occupancy during day-time.

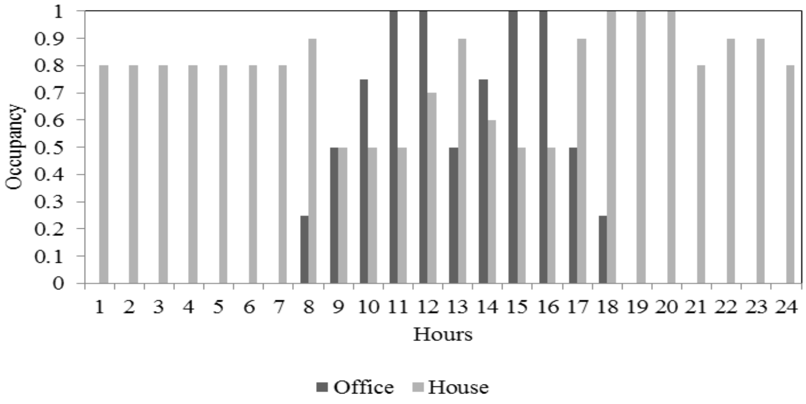

Figure 1 – Typical daily occupancy profile for an office and house building, as sum of people presence and internal gains related to appliances.

RESULTS AND DISCUSSION

Energetic model of LESO-PB

On-site monitoring, realized by ENERGO [7] (average heating demand of LE buildings, 2009-2011), are compared with the simulations, showing a difference of 3% between them.

Figure 2 shows the heating demand of LESO building, expressed in kWh/m³, using the average climatic data provided by Meteonorm (average solar radiation for the period 1991-2010, and average temperature for the period 2000-2009). The South part of LE building (LESO building) has the lowest energy demand compared to the Northern part (LIPID building), completely glazed but without a performant envelope. The warehouse between LESO and LIPID present the highest heating demand, as it is shadowed by bordering building, it has a light metallic structure present no windows.

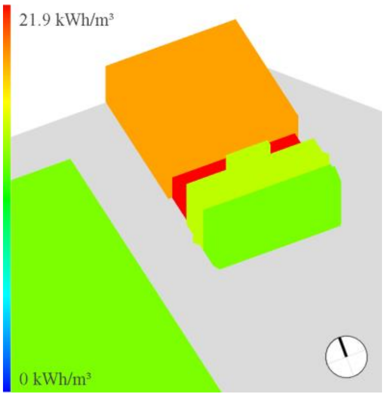

Figure 2 – Heating demand of LE buildings: LESO building (South) and LIPID (North).

In the building simulations, two house types are considered: the existing LESO building setup (E) and an upgraded Minergie Plus building setup (MP) in conjunction with new electricity generation unit (PV) as well as new load consumption types, i.e. heating and cooling demand as provided by heat pump and air-conditioning units. The BiPV production, according to the CitySim model, is equal to 3’350 kWh$_e$/y (difference of 1% compared to monitoring [1]).

This leads to a change in electric energy demand and, more importantly, the resulting electric load consumption profiles.

Resulting Electric Load Demand Profiles

One the one hand, the shift from fossil fuel usage to electricity, notably substituting natural gas for heating needs by using heat pumps and liquid fossil fuels for mobility by means of electric vehicles, will inevitably lead to higher average electric load demand as well as higher peak load events in the electric distribution grids.

On the other hand, PV installations for instance on building roof-tops and facades will lead to significant decentralized electricity production within distribution grids albeit with a strong seasonal and daily pattern, i.e. peak production during summer noon hours and almost negligible production during winter days, as is exhibited by Figure 3.

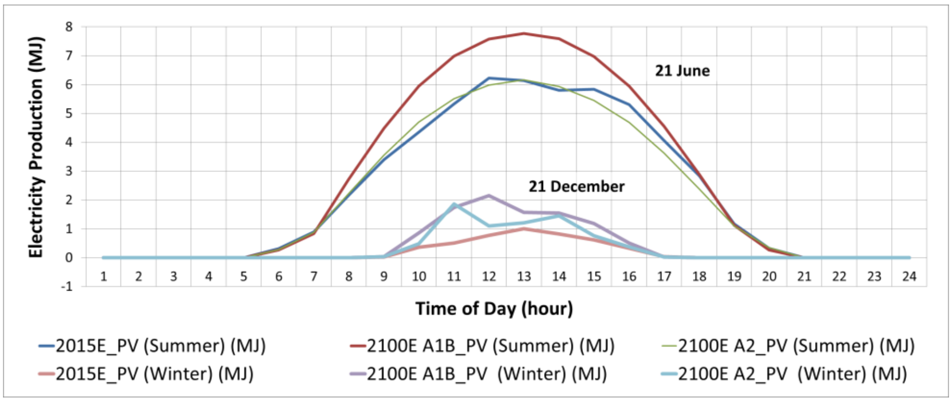

Figure 3 – LESO building’s PV production (Summer – 21 June, Winter – 21 December).

Residential Building Load Profile

Figure 4 shows the daily electric load profile of a typical summer day (21 June). The additional load demand for all future building setups, mostly electric cooling, would significantly increase the load demand during day-hours with respect to the nominal setup (2015E). For the most extreme scenario (2100E A1B), the peak load demand (at 18-19h) doubles. Load increase is much lower for Minergie and Minergie Plus building setups.

In case a PV unit is present, a significant net electricity production occurs during noon hours (12h) in all setups – depending on the building setup, this can have about the same magnitude as the peak load demand. Also, a sharp load ramping happens in the afternoon when PV production is rapidly falling while load demand is increasing at the same time.

Figure 5 shows the daily electric load profile of a typical winter day (21 December). Contrary to the summer, overall load demand for all future building setups would be significantly lower than in the nominal setup (2015E). Also, PV feed-in is significantly lower and leads only in some building setups to a net power feed-in into the distribution grid.

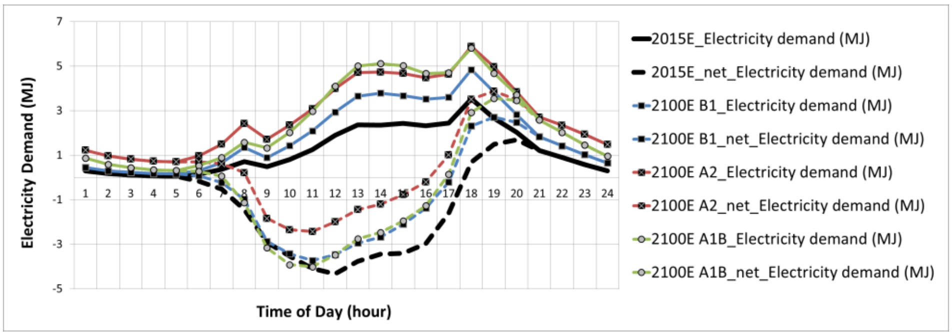

Figure 4 – Residential LESO building's (net) load demand & PV profile (21 June).

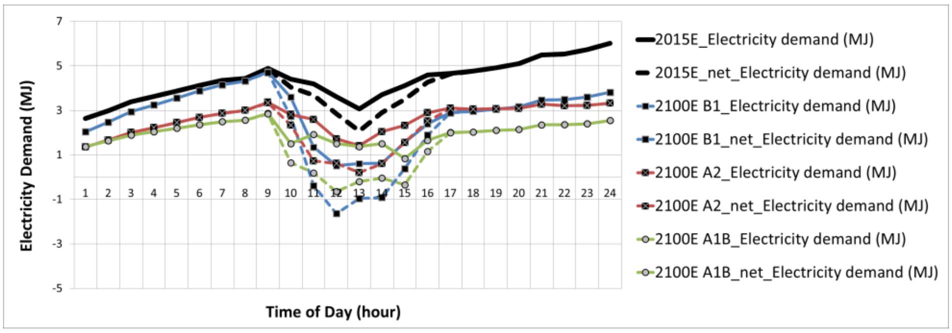

Figure 5 – Residential LESO building's (net) load demand & PV profile (21 December).

Office Building Load Profile

Figures 6 and Figure 7 show the daily electric load profile of a typical summer day (21 June), respectively winter day (21 December). This occupancy mode creates qualitatively similar load demand patterns as in the residential building case. The evening ramping is however less pronounced, i.e. people return home when the sun sets thus not creating additional load demand in the office environment – this happens instead in the residential dwellings.

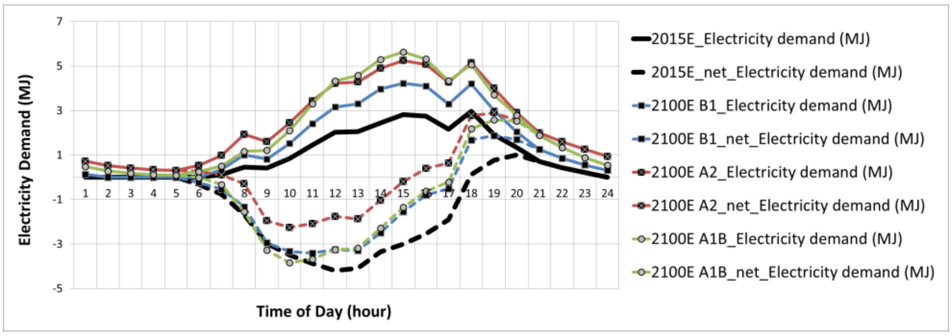

Figure 6 – Office LESO building's (net) load demand & PV profile (21 June).

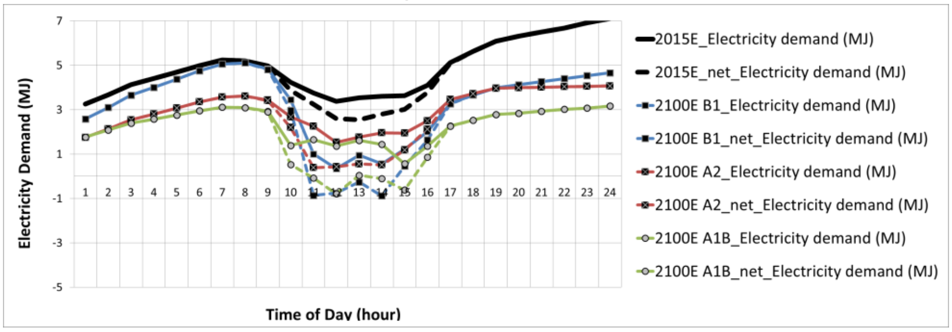

Figure 7 – Office LESO building's (net) load demand & PV profile (21 December).

Impacts for Distribution Grid Operation and Planning

Of the two LESO building usage profiles presented above, the LESO residential summer profile exhibits both the highest peak load demand as well as the highest (positive) power ramping over all studied IPCC scenarios. Compared to the reference case, i.e. today's building setup without PV unit, peak load may increase by up to 65% (2100 A1B) and power ramping increases three-fold for all scenarios with PV unit (up to 349%, 2100E A1B), Table 2.

Scenario	**Peak Load Demand (18:00 or 19:00)**		**Power Ramping (16:00 – 18:00)**	
	with PV unit	**without PV unit**	**with PV unit**	**without PV unit**
2015E	48	**100 (= Reference)**	305	**100 (= Reference)**
2100E B1	77	137	307	110
2100E A2	110	167	309	118
2100E A1B	101	165	349	95

Table 2 – Quantification of peak load and peak ramping (LESO residential usage, 21 June).

Such drastic changes in electric load demand profiles inevitably have impacts on the distribution grid to which the building stock is connected to. Rising electricity consumption and higher peak load demand are eventually necessitating upgrades of the distribution grid infrastructure. Net power in-feed created by the roof-top PV units creates reverse power flows from the lowest voltage levels of the distribution grid up to medium voltage levels and, eventually, also the transmission grid. Peak load demand and peak PV power feed-in create local voltage problems and, potentially, also line overloading within the distribution grid. This requires additional grid upgrade investments. The larger load demand ramping notably in the afternoon hours needs to be covered by sufficiently flexible backup generators (for the characteristic load profiles given by the results in Fig. 4–7, compare also with [8]). In case these backup units are not available, coordinated PV curtailment would be necessary in order to reduce the load demand ramping trajectory. This, however, would result into significant energy losses, i.e. the curtailed PV feed-in, leading to an inefficient power system operation. Energy storage technologies, be it direct electricity and/or thermal storage units, can be used to smoothen the load demand profile. Peak events, both of load demand and of PV power feed-in, can thereby be effectively reduced. The optimal choice of the storage technology (thermal, chemical and electricity), storage unit sizing and placement will be decisive for an efficient distribution grid operation.

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