Cost-optimal nZEB HVAC configurations with onsite storage

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Abstract

By 2021, all new buildings in the European Union must be nearly zero-energy buildings (nZEB) to contribute to the achievement of the EU-CO_2 neutrality by 2050. As the technical options to achieve highly-efficient building envelopes are available and well-known, there is no doubt that the most promising Heating Ventilation and Air Conditioning systems will include heat pumps and photovoltaic panels. However, there exist ongoing discussions on the optimal system layout and the integration of storage to achieve nZEB. In particular, there are some good arguments in favour of very low demand, while contrariwise also high flexibility is seen as an important feature to enable so-called grid-reactive operation of the building stock. Integration of onsite storage and its influence on the energy demand of the buildings and the corresponding electric load profile with focus on peak power is investigated.

Introduction - Nearly Zero Energy Buildings and flexibility

By 2021, all new buildings in the European Union must be nearly zero-energy buildings (nZEB) to contribute to the achievement of the EU-CO2 neutrality by 2050. According to EPBD, an nZEB is a nearly zero-energy building, with a very low energy demand due to efficiency measures that include efficient HVAC technology (e.g. Heat Pump-HP) and utilization of Renewables (RE) to meet the very low demand to a considerable extent. The Net zero-energy Building (NZEB) is better known outside Europe. A NZEB can be realized as a "grid-connected building that on annual basis generates the same amount of energy from on-site RE energy sources as it consumes" (IEA SHC T40 / HPT A40).

This work aims to show for the investigated virtual case in Tyrol (Austria) as an example, the potential of integrating passive and active solar technology and the role of onsite storage. A methodology was developed to analyse and compare different solutions with a special focus on HP integrated with RE in nZEB buildings.

While previous studies focused on the micro-economic aspect, this work investigates the influence of onsite storage on a macro-economic scale. It is important to determine the reduction of the grid electricity demand and the PV excess electricity depending on the sizing of the (thermal and/or electric) storage. The research question is, whether in a 100% RE-based scenario, onsite storage will play a significant role. Furthermore, it is investigated how onsite storage capacity influences the required back-up power or central storage capacity.

Energy Storage

Energy storage can be beneficial in terms of buffering short, mid-term and seasonal mismatch between energy source and energy demand. Storage can be integrated into the energy system in large central units or decentral in buildings.

Figure 1 gives an overview of the existing electric and thermal energy storage. While long-term electric and thermal storage systems are typically large-scale central units (e.g. District Heating–DH [1]), short-term electric and thermal storage can be scaled for a wide range of applications and can be applied in buildings. Latent and thermo-chemical (TC) storage are subject of research [2].

Through energy storage, energy flexibility in buildings could provide generating capacity for energy grids, and better accommodate RE sources in energy systems, possibly reducing costly upgrades of energy distribution grids.

Two types of storage on building level are possible:

- Electric: Buildings equipped with a PV can benefit from the introduction of batteries (increased self-consumption).
- Thermal: It is possible to store hot water when surplus energy is available or when electricity prices are low.

Solid sensible storage is either a massive part of the building or fillings made of gravel or rocks.

Figure 2 gives an overview of building-integrated storage systems.

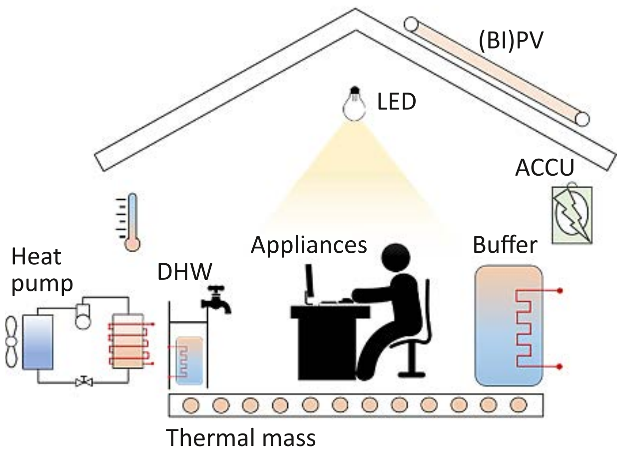

Figure 2. Schematic presentation of energy storage in buildings.

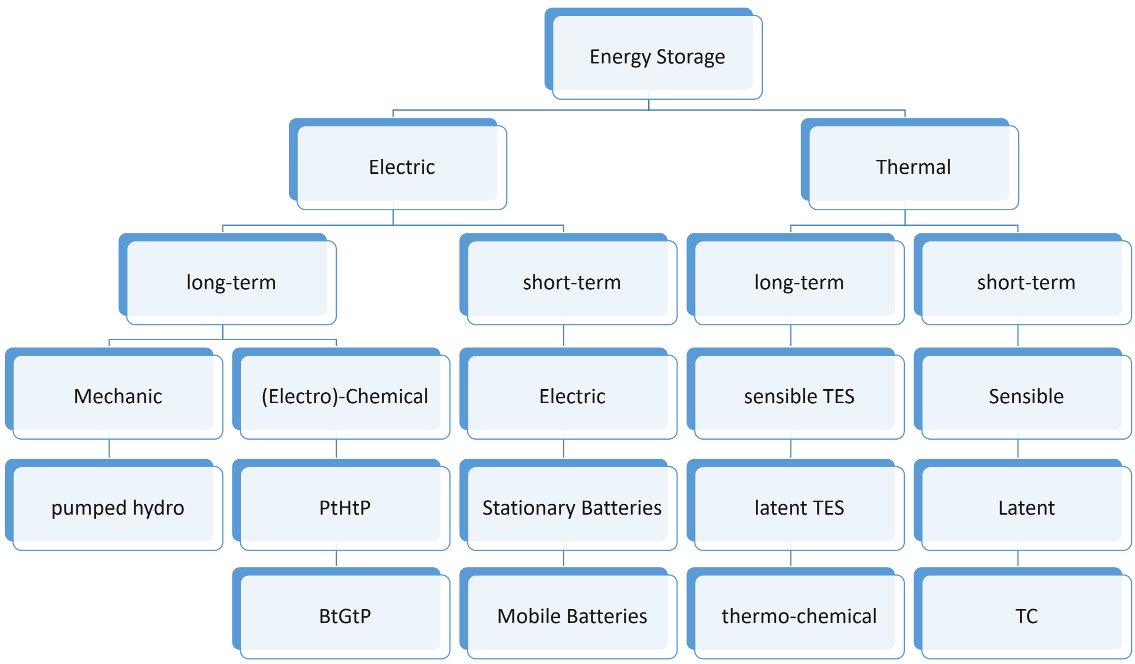

Figure 1. Overview of electric and thermal energy storage (TES); PtHtP: Power to Heat to Power BtGtP: Biomass to Gas to Power.

Building Stock Model

The building stock of Tyrol (Austria) is taken as an example (scenario Tyrol 2050 [3], total phase-out of fossil heating systems) and it is represented by 6 types of prototypical buildings i.e. SFH, small Multi-Family House (s-MFH), large MFH, office, Hotel and Industry. Each building is simulated with its individual energetic quality (representing the average status of 2050 according to [3]) and is equipped with either an HP, or a Direct Electric (DE) system, with and without PV and battery storage, representing different load patterns for the electricity grid.

The following results focus on the residential buildings (see **Table 2)** with 21% SFH, 29% s-MFH and 11% l-MFH in Tyrol.

Electric Energy Balance with onsite PV and storage

The monthly electricity consumption for the SFH is reported in **Figure 3** together with the PV yield and self-consumption for the following cases: (a) with heat pump without PV; (b) with 5 kW_p PV; (c) with

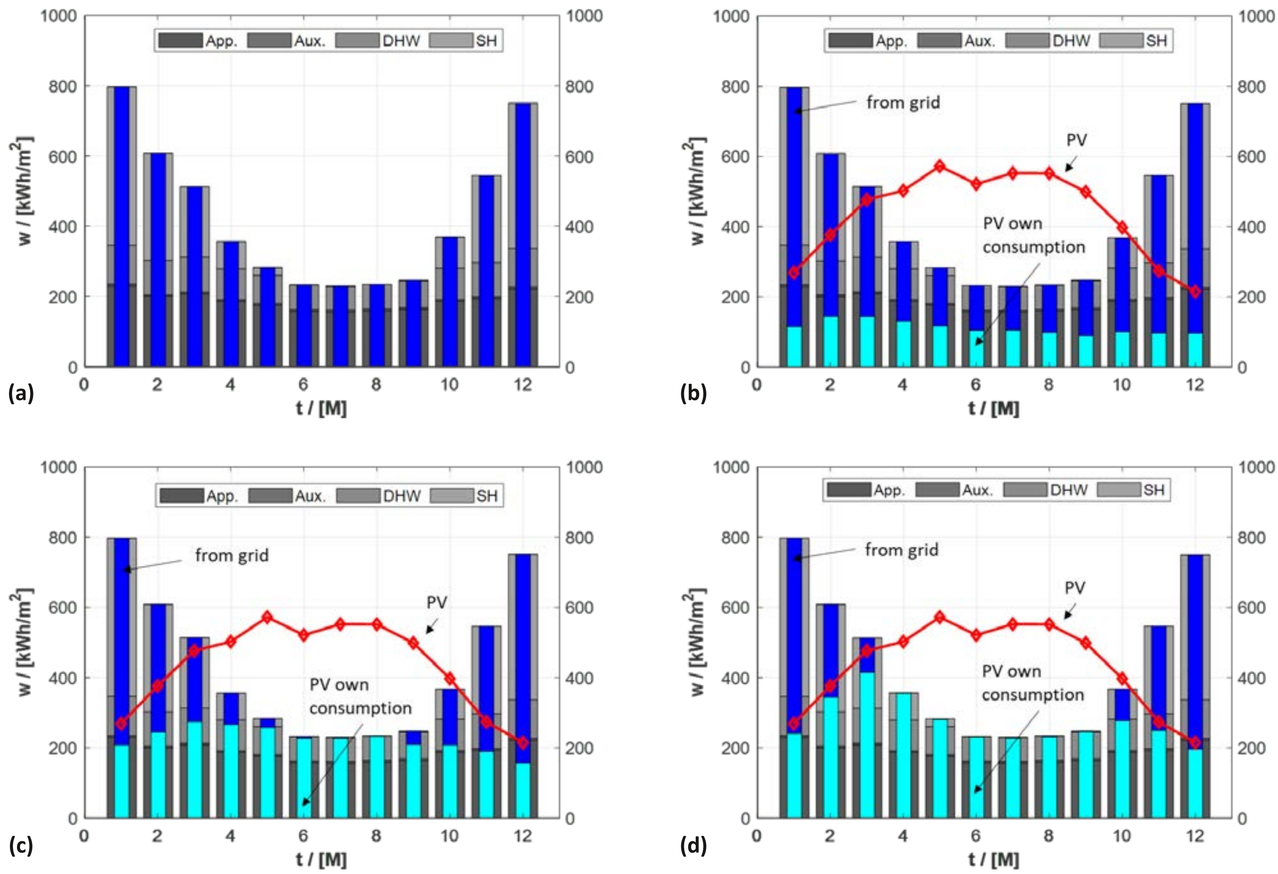

Figure 3. Monthly electricity demand, PV yield and self-consumption for the SFH with heat pump (a), with HP and PV (b), heat pump, PV and small battery (c) as well as HP, PV and large battery (d).

Table 2. Heating demand, gross floor area, available roof surface, number of buildings and installed PV peak power per building type [3].

	SFH	s-MFH	l-MFH
Heating Demand [kWh/(m²a)]	37.8	31.6	35.9
Gross floor area [m^2_{GFA}]	182.9	405.3	2 090.1
Number of floors	2	3	10
Roof surface [m²]	91.5	135.1	209.0
No of buildings	10 6579	67 592	5 063
Installed PV [kWpeak]	5	8	12
PV Yield [GWh/a]	1 200 (1 047 kWh/kW_p)		

PV combined with small battery (6.67 kWh); and (c) with PV combined with large battery (8 × 6.67 kWh).

The usage of the PV without battery (case b) can cover 26% of the base electricity demand throughout the whole year exploiting 26% of the PV yield, reducing the grid electricity consumption. When additionally, a small battery is used (case c) the electricity demand covered by the solar energy is notably increased (52%) reducing the excess electricity and the electricity required from the grid. A further increase of the battery size (case d) is beneficial only in spring and autumn therefore of limited use. However, in all cases, the battery does not influence the peak power, since it is fully charged most of the time in summer and empty most of the time in winter. In consequence, there is also no relevant capacity for electricity buffer from PV of other buildings in summer, neither surplus of electricity for other buildings in winter, in case of a heating-dominated climate like Innsbruck.

Electric Energy Demand Building Stock

The total electric load of the residential building stock (acc. to the scenario Tyrol 2050 [3]) can be calculated considering the share of building types (SFH, s-MFH, l-MFH) and the corresponding share of heating systems (HP, DE and rest (biomass, DH)). In **Figure 4** the electricity demand and the load curves represent an average residential building for the case without PV, with PV, with PV plus small battery and with PV plus large battery. Again, extensive use of PV has a significant influence on the bought and sold electricity, however, the peak load is hardly reduced also with large storage capacity in the buildings. The peak power is ca. 2 200 W and the excess PV electricity supplied to the grid is ca. 5 000 W with or without onsite storage.

Discussion and Conclusions

Future nZEBs, will have a relatively low heating demand (15 to 45 kWh/(m² a)) and a DHW demand of the same order of magnitude (between 10 and 20 kWh/

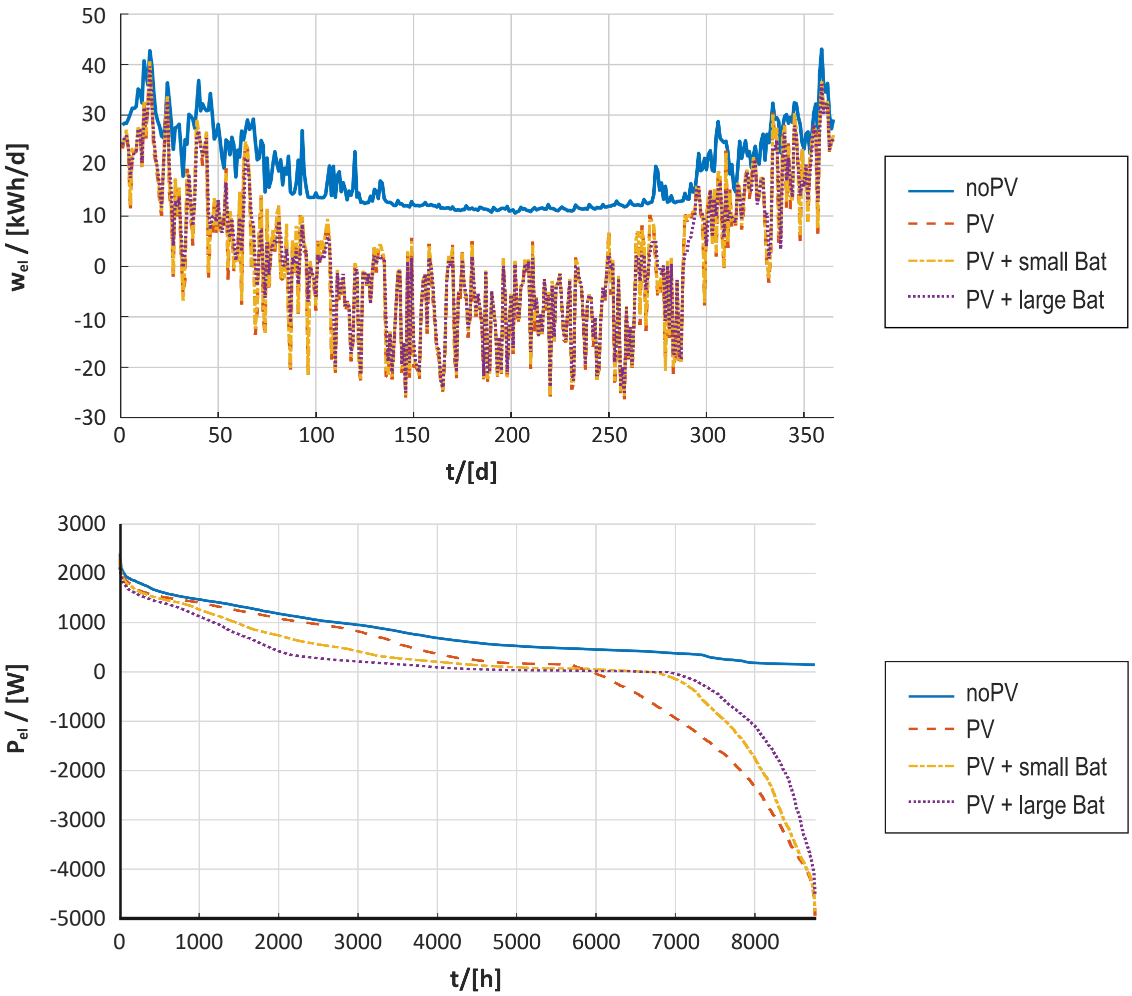

Figure 4. Total grid load of residential building with different combinations of PV and battery presented with an hourly resolution (top) and as a duration curve (bottom).

(m² a)). Assuming heat pumps being the standard heating system in the future, the total electric demand for SH and DHW is in the range of 10 and 25 kWh_{el}/(m² a) and of the same order of magnitude as the electricity demand for appliances (typically between 15 and 20 kWh_{el}/(m² a)). On an nZEB SFH with 5 kW_p PV system, the net PV yield is of the same order of magnitude as the annual total electricity demand. Hence, electric storage could cover theoretically 100% of the total demand (SH + DHW + appliances), while thermal storage could theoretically cover around 50% of the total energy demand (SH + DHW). In MFH, because of the relatively small roof area related to the GFA, the theoretical contribution of PV is significantly less.

Overall, onsite storages can be beneficial to reduce the grid electricity demand, however, they hardly influence the grid load (electricity buy and electricity sell). Hence, if at all, extensive onsite storage should be considered only on short and mid-term to promote the extended use of PV in buildings (in particular when buyback tariffs are low). On macro-economic scale, in spite of energy savings, an additional application of storage in buildings or use of existing storage will lead to higher losses without reducing the peak loads or the central storage capacity.

Based on the presented results design guidelines can be elaborated for buildings located in heating-dominated climates like Innsbruck. ■

Acknowledgements

The work presented in this paper is based on the results of a collaboration within IEA HPT Annex 49. Financial support was provided by the Austrian Ministry for Transport, Innovation and Technology and the Austrian Research Promotion Agency (FFG) through the IEA Research Cooperation. Furthermore, the authors thank Land Tirol for funding the project "Energiespeicher Tirol 2050", which also contributed to this work.

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