SEASONAL UNDERGROUND THERMAL ENERGY STORAGE FOR DISTRICT HEATING AND COOLING IN THE CZECH REPUBLIC: POTENTIAL AND CHALLENGES

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PREMISES

Generous subsidies in the Czech Republic **are boosting the energy efficiency** of residential buildings (especially family houses) by supporting the installation of photovoltaic (PV) panels, heat pumps, and heat and electricity accumulation systems. **PV roofs** generate considerable savings (>55% in typical installations). In summer, however, they **cause overflows** to the grid, which contribute to the volatility of electricity prices. In winter, the production is insufficient to power air-source heat pumps.

Hot water tanks and electric batteries can only compensate for load imbalances on a daily scale. National-scale solutions for longer-term storage are not viable. Distributed systems for the seasonal accumulation of thermal energy seem an attractive solution.

The underground space could be used as a heat source or sink, exploiting soil layers that are deep enough to ensure stability against seasonal fluctuations in temperature propagating from the surface, but also sufficiently shallow to ensure reasonable costs of installation.

In new constructions, **heat exchangers could be embedded in foundations or installed in boreholes below common areas** such as access roads, parking lots and gardens. Similarly, they could be fitted in already built-up areas and scaled in such a way as to maximise their efficiency without disturbing the mechanical stability and performance of existing buildings and infrastructures.

In the Czech Republic, despite a growing demand for the **creation of energy communities**, their technical and regulatory viability remains unexplored. This is especially true for shallow underground seasonal thermal energy storage systems (UTES). In part, this relates to an **insufficient knowledge of the ground response to thermo-hydro-mechanical forcing** and possible ground-structure interactions.

TYPICAL NEW HOUSES AND BACK-OF-THE-ENVELOPE CALCULATIONS

New **family houses** typically have an 80–150 m^2 usable area. Row houses are the most frequent, but semi- and fully-detached houses are common. One- and two-storey buildings are equally common. These houses have sufficient roof areas to install **PV systems** (e.g., **5.4 kWp**, 12 panels, 26 m^2). These PV systems **can produce ~6 MWh/year**. Almost 150,000 such systems have been installed in the last few years, which typically come with **7–14 kWh batteries** to compensate for daily imbalances.

New constructions rely on **air-source heat pumps, underfloor heating,** and hot water tanks (150-200 L); they are not connected to the gas network, nor do they use wood stoves.

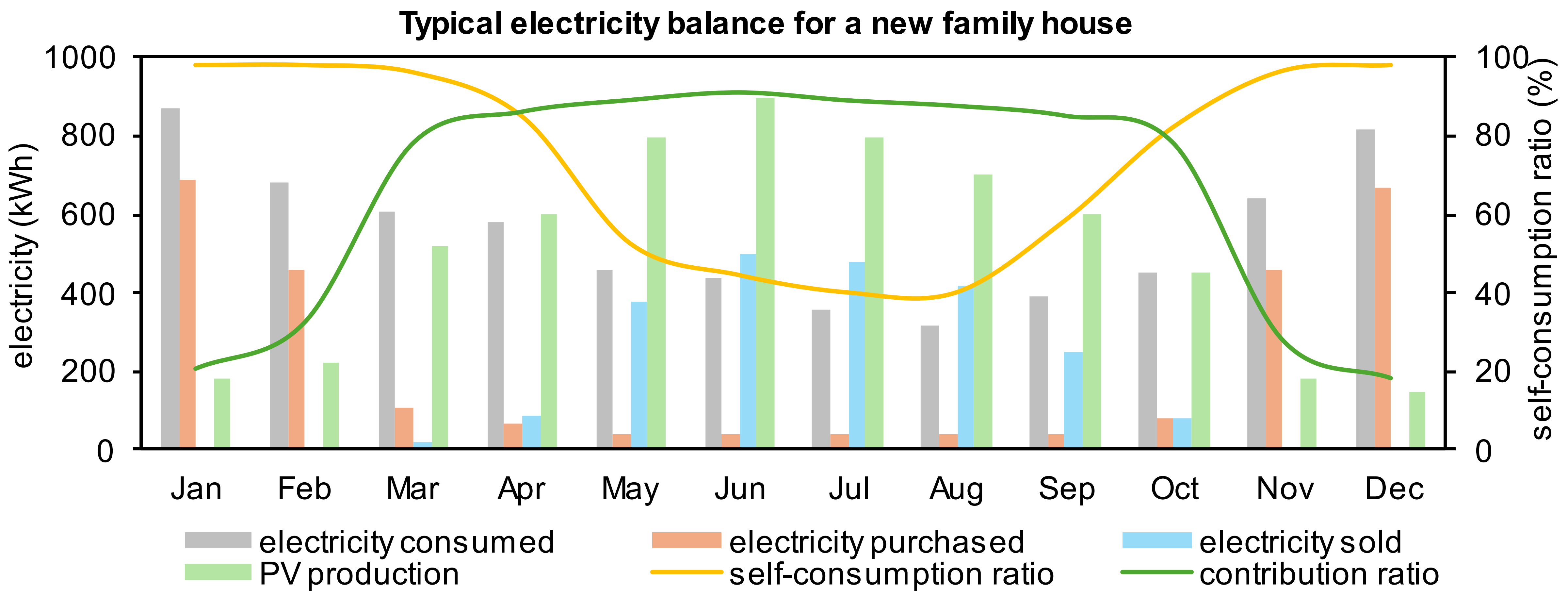
For **hot water** production, a consumption of **40–80 kWh/month** is recorded, varying according to the outdoor air temperature and the loss from the tank and pipes. The coefficient of performance (COP) to produce 50°C water is 2.5–5 with an outdoor air temperature of 0–30°C.

For **heating**, the consumption can be up to **500 kWh/month** in winter. No heating is usually needed from mid-April to mid-October. A COP of 3–4 is warranted as underfloor heating operating at just 25–30°C can ensure an indoor temperature of 20°C throughout the day. This can be further stabilised with the help of **heat recovery ventilation**.

Climatisation in summer **is uncommon** as indoor temperatures rarely exceed 25°C. Natural nighttime ventilation and daytime use of blinds ensure comfort on most summer days. Active air-conditioning is typically justifiable for **less than 15 days/year** (but the climate is changing…). With a pre-cooling strategy, consumption can be limited to less than **150 kWh/year**. Notably, most air-source heat pumps in new houses can also provide climatisation via underfloor cooling.

Electric vehicles (EVs) are on the rise. Subsidies cover the cost of home charging stations. Families use EVs for short-distance commuting (**~1000 km/month**), requiring **~160 kWh/month**.

Overall, the **energy demand** for a family house with one EV is **~6.6 MWh/year**. The mismatch between demand and PV production is such that families need to buy ~2.8 MWh/year (0.25 €/kWh) but sell a surplus of ~2.2 MWh/year (0.08 €/kWh). This corresponds to a monetary **saving of 65%** (75% if the saving from the EV is considered, compared to an ICE vehicle). While these are encouraging figures, these new family houses are far from a net-zero goal.



↓ 6.0 MWh

1.6 MWh

0.6 MWh

2.0 MWh

2.4 MWh

↓ 0.6 MWh

ARGUMENT FOR A DISTRICT-SCALE SEASONAL HEAT STORAGE

The summertime surplus could be stored in UTES and retrieved in the wintertime. This could be achieved by powering a **heat pump to heat the ground while cooling the air indoors** (air-conditioning) **or outdoors**. A COP of 3–5 can be expected, corresponding to a thermal energy input of over **6–10 MWh$_{th}$/year** if the temperature differential remains small (e.g., heating the ground to 40–50°C when the outdoor temperature is 20–30°C.

The ability to retrieve usable heat depends on many factors, including the soil type and permeability, groundwater regime, thermal insulation (if present), and the UTES's geometry (number, position, and depth of boreholes). However, considering that storage capacity and heat loss depend on the UTES's volume and boundary area, it is clear that **larger UTES can offer larger efficiencies**.

Development projects in the Czech Republic typically consist of districts of 20–40 houses and often feature common areas (access roads, playgrounds, greenery) in addition to private parking spaces and backyards. These common areas are the ideal location for UTES thanks to expected the limited interaction with buildings' foundations. **Areas of 500–1000 m^2 with 50–150 boreholes down to 20-30 m** (storage volumes of 10,000–30,000 m^3) may be sufficient.

With a retrieval efficiency of 50%, each house would receive 3–5 MWh$_{th}$ during wintertime in the form of warm water usable for underfloor heating or sanitary hot water (after additional heating). This would reduce the electricity consumption of the heat pump by more than half. Overall, **the houses would become net exporters of electricity** (0.5 MWh/year, better than the non-zero goal) **and they would not disrupt the grid at peak production hours.**

District-scale heating-cooling systems would offer economies of scale thanks to centralised heat pumps and hot water tanks, possibly accompanied by centralised control of PV panels, electric batteries, and EV charging. This should be allowed under the new regulations on **energy communities** and opens possibilities for the intelligent use of IoT devices and AI-powered controllers.

CHALLENGES

After the start-up years, **the UTES's heat balance must be guaranteed** to avoid drift towards excessive cooling (and freezing) or overheating. This requires active management of the centralised facility, although compensation at the pluriannual scale is admissible. Degradation of the components (heat pumps, PV panels, boreholes) and climate change may pose critical challenges.

Fine-grained soils are common. They are desirable as they **reduce heat loss** through water seepage owing to their low hydraulic conductivity; **however, their thermo-hydro-mechanically coupled and time-dependent responses may be an issue.** Swelling pressures (0.1–1 MPa) and/or swelling/shrinkage (2–20 cm) may arise during heating-cooling cycles, as well as permanent deformations of the same magnitude and pore water pressure excess. While these may not pose a risk to the buildings (if sufficiently distanced), they could still damage roads, pavements, and pipelines. Clearly, **an in-depth study of the integration of the UTES within the district is necessary.**

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