Energy Flexibility for an Institutional Building with Integrated Solar System: Case Study Analysis

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NTNU
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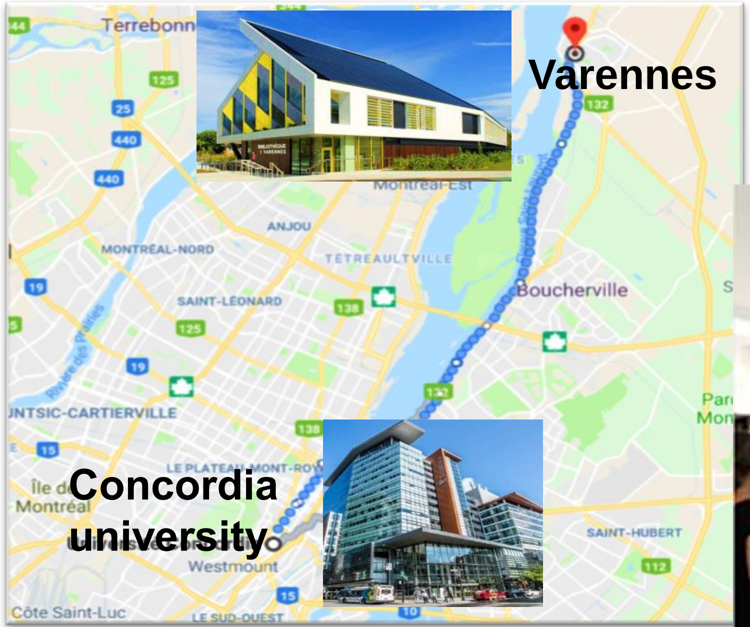
ZEN
Research Centre on
ZERO EMISSION
NEIGHBOURHOODS
IN SMART CITIES

Introduction (1)

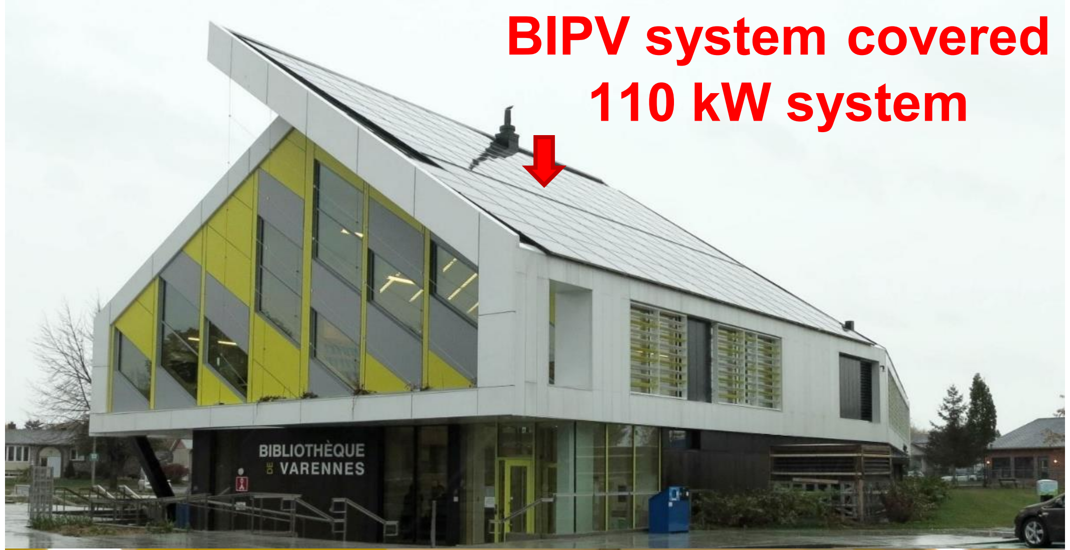
Varennes Library location



Official opening: May 16, 2016

First institutional designed solar NZEB in Canada & its operation

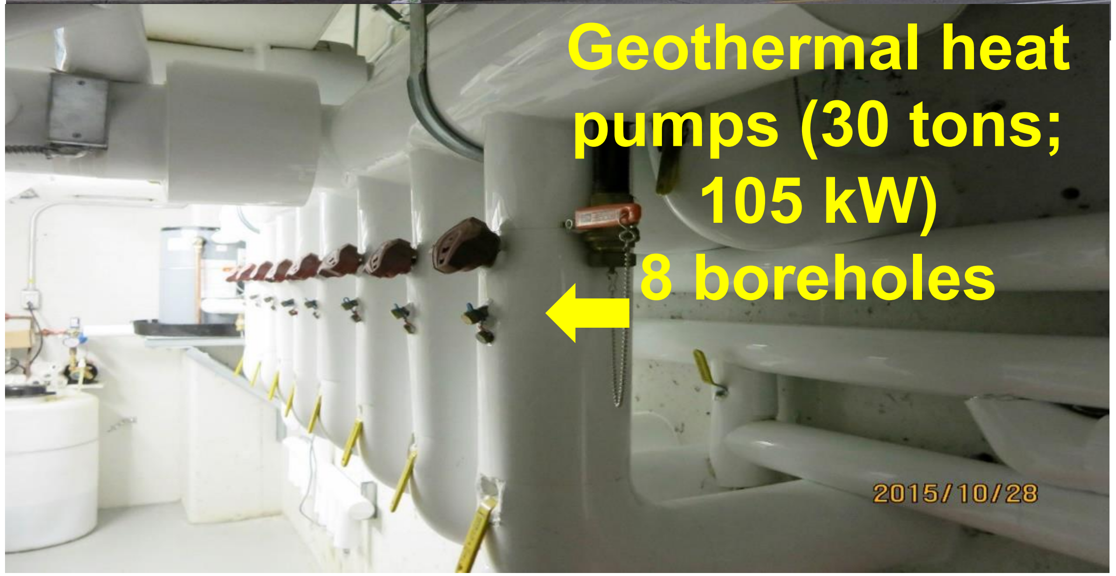
Introduction (2)


BIPV system covered 110 kW system


EV charging


Hydronic radiant slab

2015/10/28


Geothermal heat pumps (30 tons; 105 kW)

8 boreholes

2015/10/28

Introduction (3)

- The combination of different technologies such as: **building-integrated photovoltaic (BIPV), geothermal heat pumps, hydronic radiant slab for thermal storage and battery storage** can offer many strategies of flexibility to reduce peak load and electricity consumption over a certain period of time.

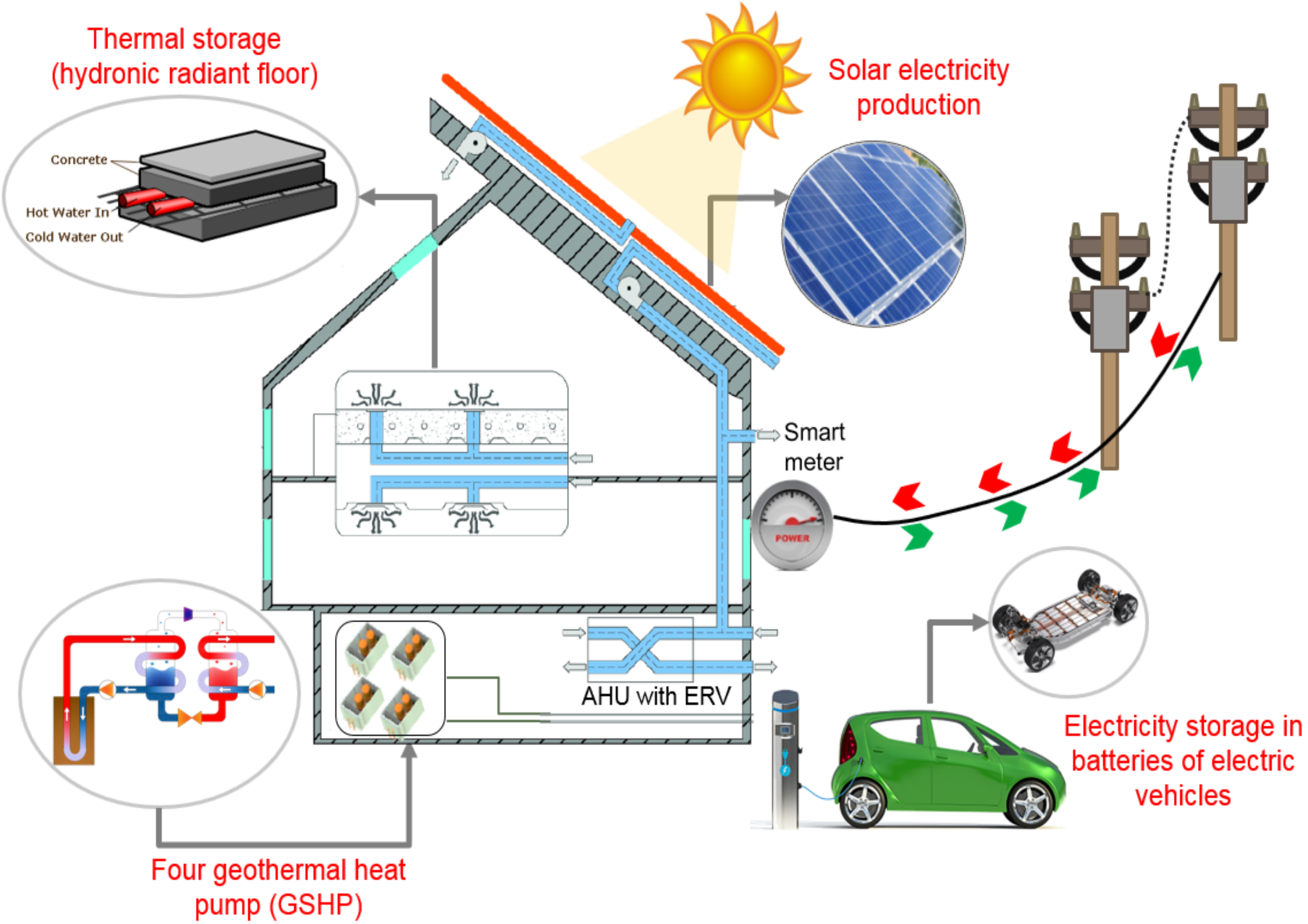
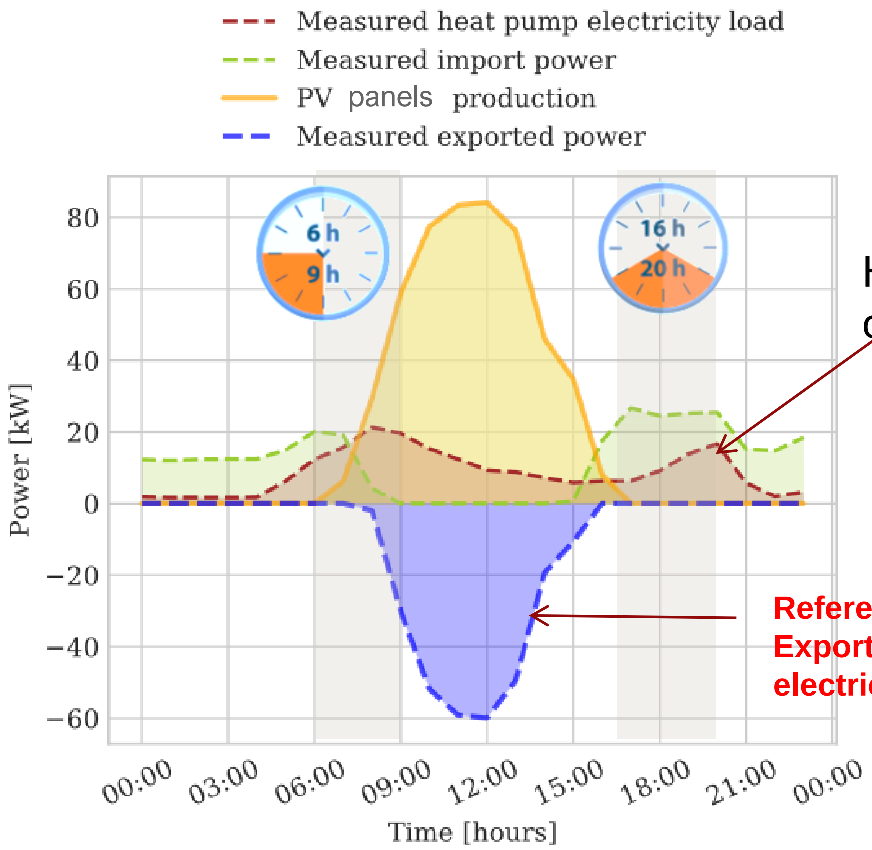


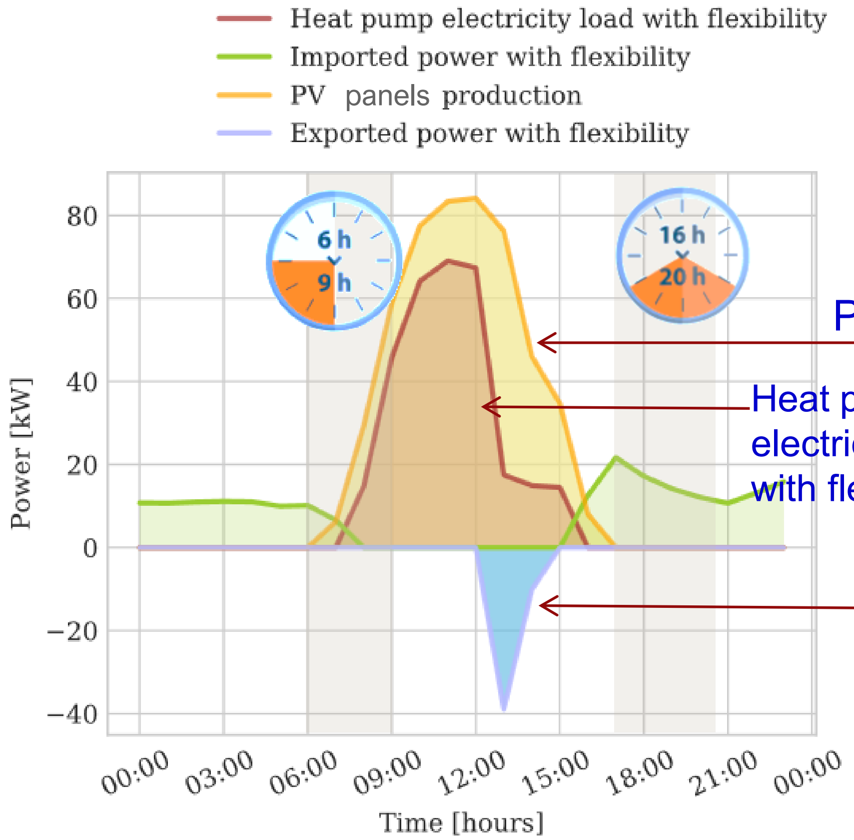
Illustration of different energy technologies that can be used to enhance flexibility in the operation of the Varennes library

Energy flexibility for Varennes library (1)



Heat pump consumption

Reference Exported electricity



PV production

Heat pump electricity consumption with flexibility strategy

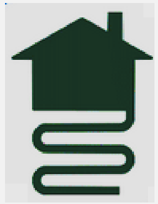
Exported PV electricity after flexibility strategy

Measured data as a reference scenario sunny cold day on February 2, 2018

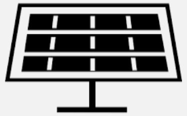
To reduce consumption during peak periods of the grid and **increase self consumption of PV electricity** (outside peak periods)

Energy flexibility for Varennes library (2)

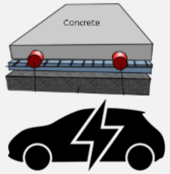
Library components



Geothermal heat pump



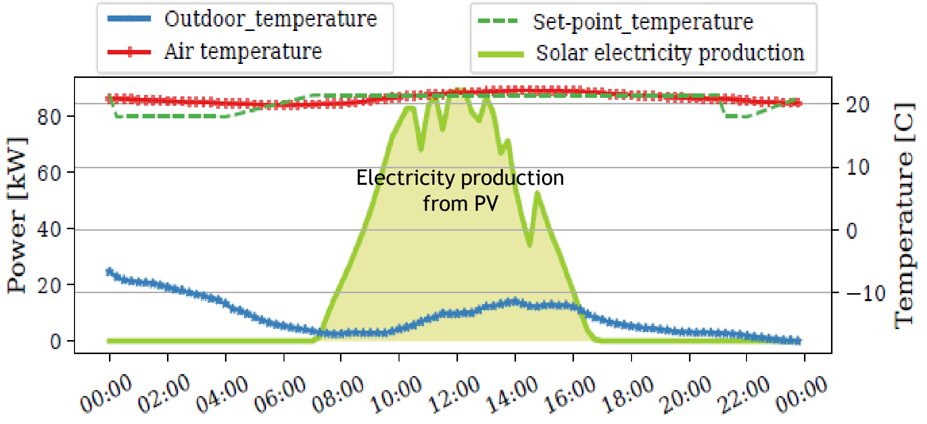
Solar panels

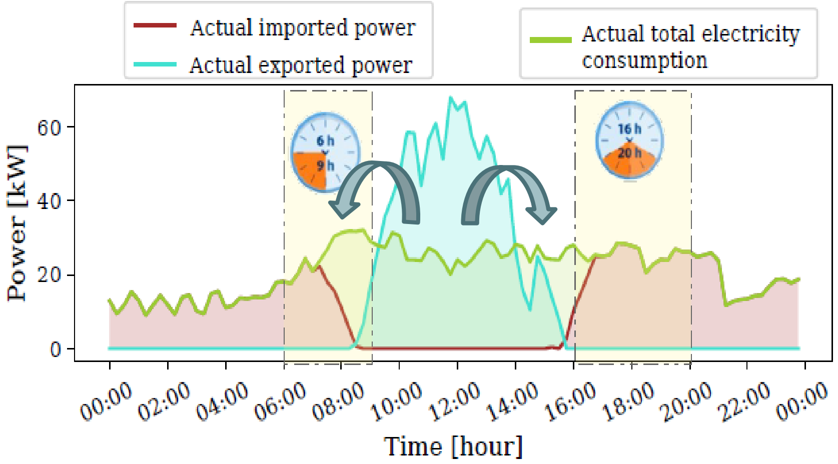


Storage (thermal/ electrical)

Energy flexibility

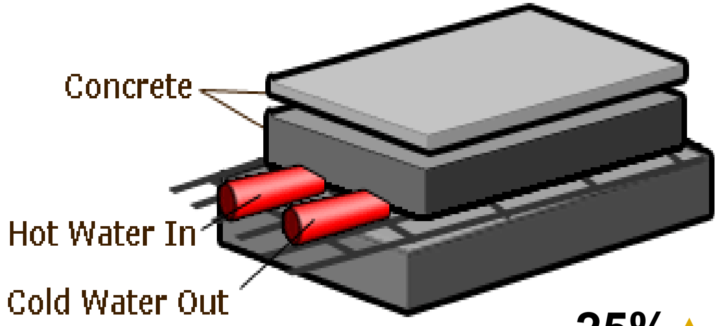
The ability to **reduce the building energy demand and the peak load** during a certain period of a day through shifting or postponing consumption compared to reference scenario





- **Peak load shifting/reduction**
- **Energy consumption shifting**

Data-Driven modeling (black box) oriented for the energy flexibility quantification (1)



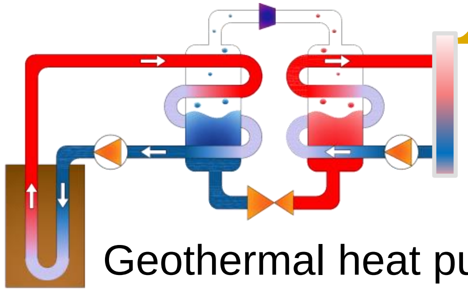
25%

Hydronic radiant slab model

75%

- Air handling unit
- Fan coil thermal unit

Building model



Geothermal heat pump

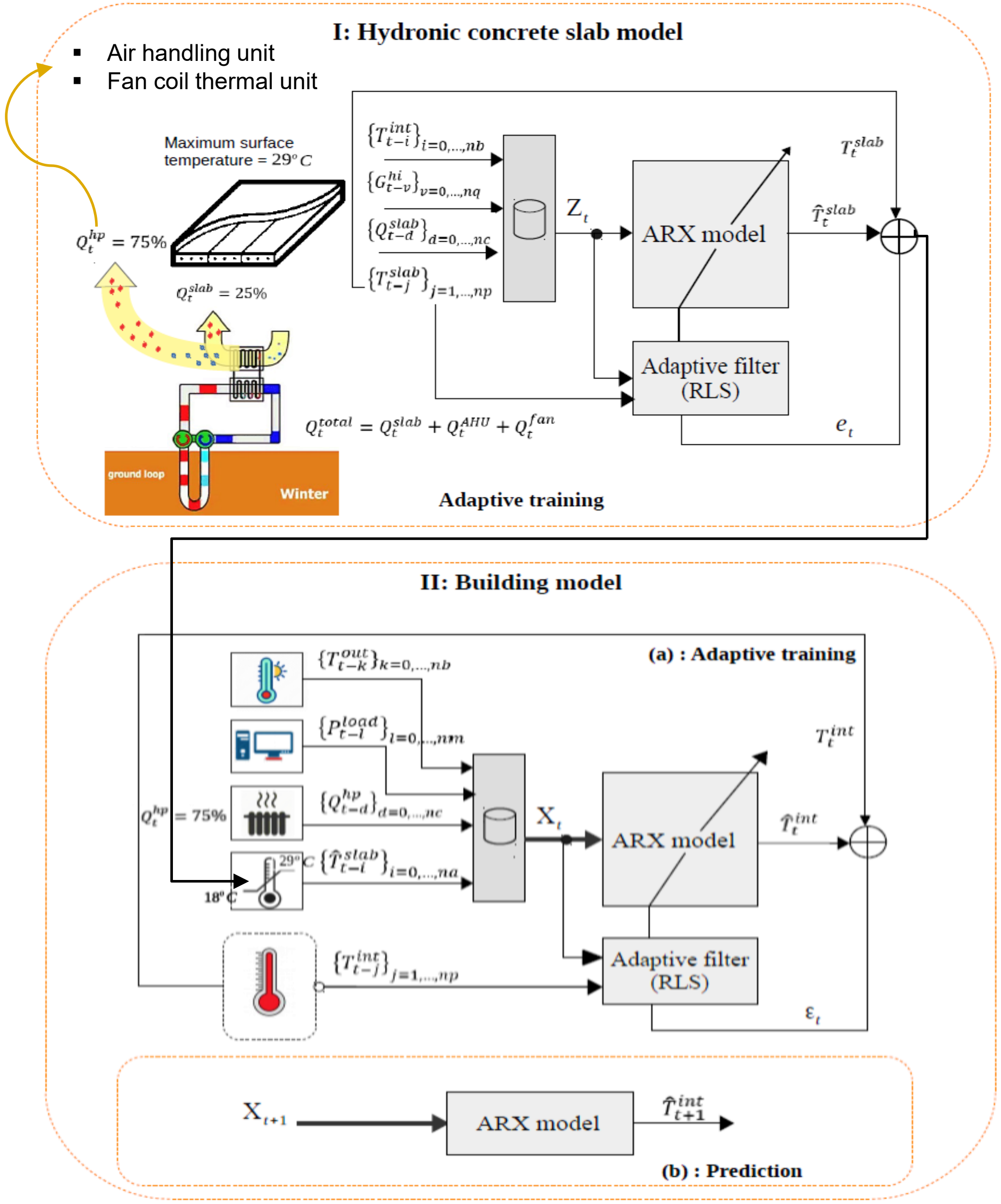
Data-Driven modeling (black box) oriented for the energy flexibility quantification (2)

- **Hydronic radiant slab modeling:** The first adaptive ARX aims to model the concrete slab temperature, as is given by:

$$T_t^{slab} = \sum_{j=1}^{p} \theta_j T_{t-j}^{slab} + \sum_{i=1}^{b} \varphi_i T_t^{int} + \sum_{d=1}^{c} \phi_d Q_t^{slab} + \sum_{v=1}^{q} \rho_v G_t^{hi} + e_t$$

- **Building model:** The second adaptive ARX model is used to predict the average air temperature, as is expressed by :

$$T_t^{int} = \sum_{j=1}^{p} \alpha_j T_{t-j}^{int} + \sum_{i=1}^{a} \vartheta_i \hat{T}_t^{slab} + \sum_{k=1}^{b} \beta_k T_t^{out} + \sum_{d=1}^{c} \gamma_d Q_t^{hp} + \sum_{l=1}^{m} \psi_l P_t^{load} + \varepsilon_t$$



Energy flexibility quantification (1)

- The quantification of the energy flexibility is an optimization problem with an objective function and affine equality and inequality constraints.

- Penalizing the imported electricity from the grid to reduce the peaks load in kW and the energy consumption in kWh.

- $\min \sum_{t=0}^{h} (imp^t - exp^t)$ Objective

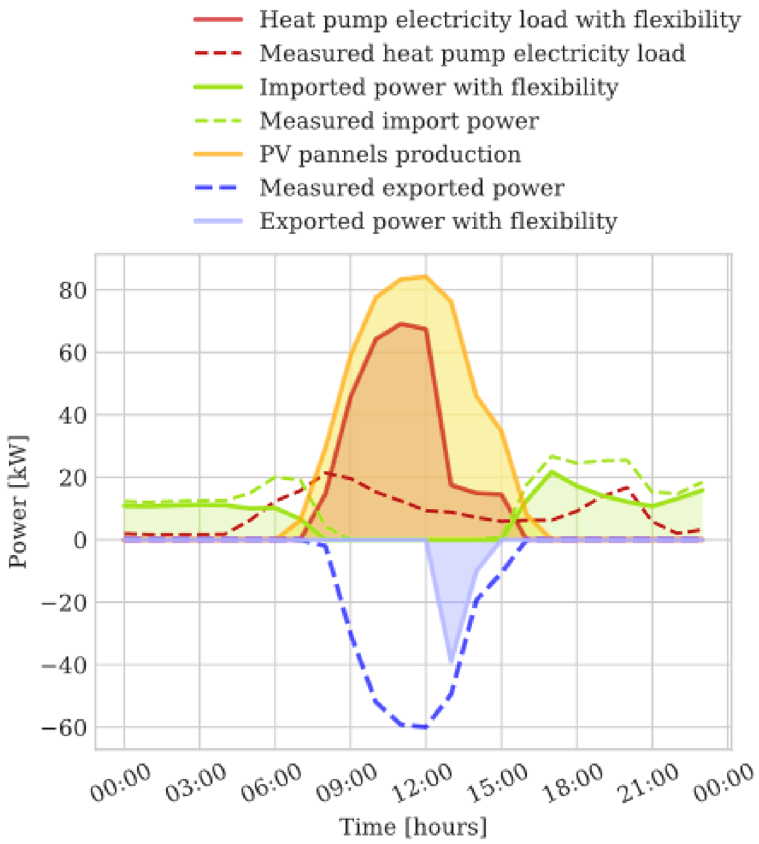
- $\begin{cases} T^{slab} \geq 20^{\circ}C \\ T^{slab} \leq 29^{\circ}C \\ T^{int} \geq 18.5^{\circ}C \\ T^{int} \leq 24^{\circ}C \\ hp \geq 0\ kW \\ hp \leq 105\ kW \end{cases}$ **Inequality constraint** to satisfy comfort and maximum output of heat pumps

- $\mathrm{PV} + \mathrm{imp} - \mathrm{hp} - \mathrm{other\_load} = 0$ Equality constraint Energy balance

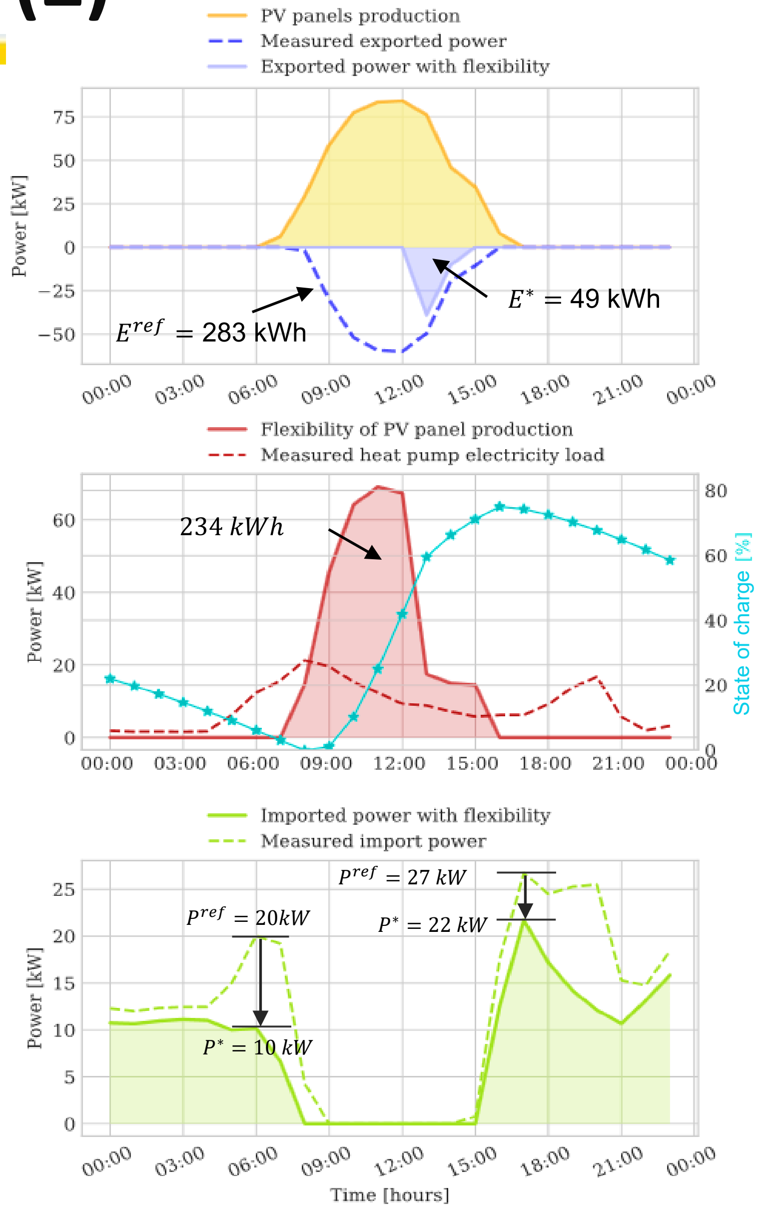
- $\begin{cases} T^{int} = 21^{\circ}C \\ T^{slab} = 21^{\circ}C \end{cases}$ Initial conditions

Note **comfort constraint**: for slab Tmax is $29^{\circ}C$

Energy flexibility quantification (2)



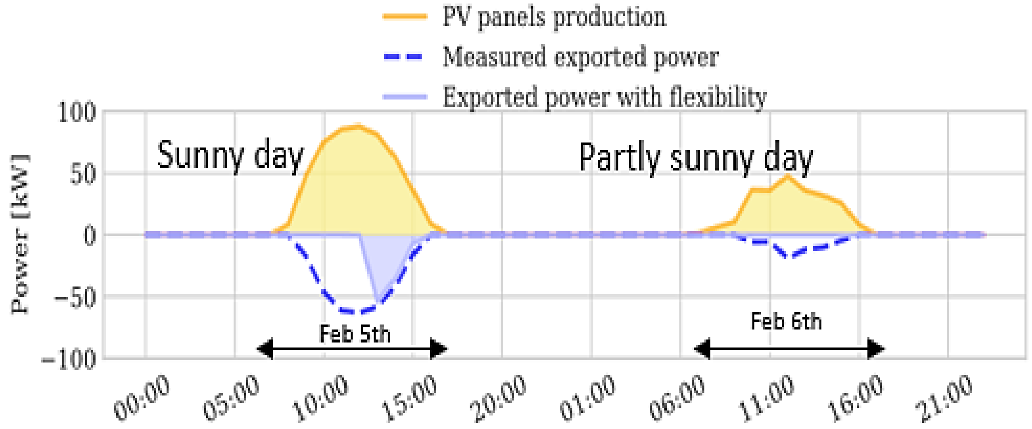
Energy flexibility quantification considering a sunny cold day on February 2th, 2018

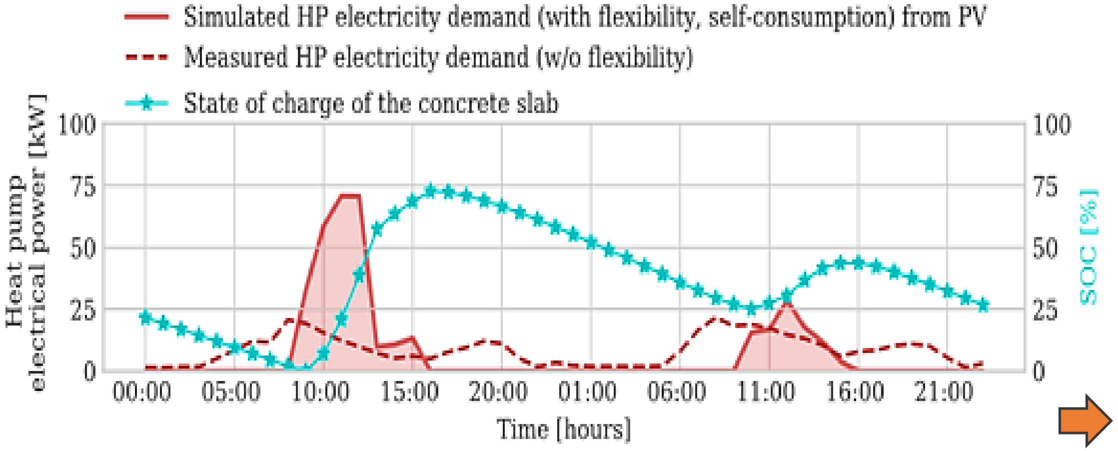


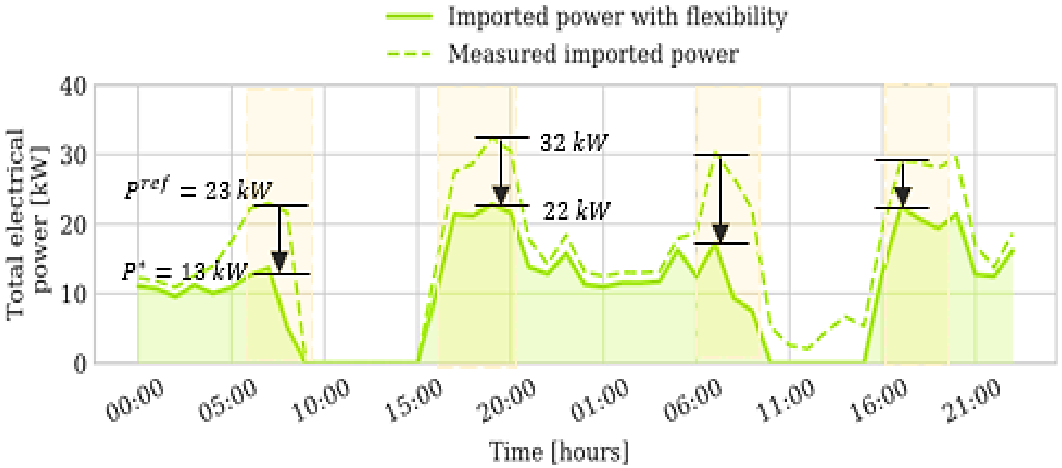
- Measured exported power 283 kWh;
- Exported power with flexibility strategy 49 kWh

- Increasing the self-consumption of PV electricity by 308 kWh;
- Increasing the charge of the concrete slab by 72%;
- Decreasing the heat pump electricity demand during the evening peak period.

- Reduction of about 50% and 18% of peak load during morning and evening periods, respectively.







Using the electricity production from PV panels, to run the heat pumps outside the peak periods and storing the heat into the concrete slab

Flexibility quantification

Peak reduction (%) $= \frac{|P_i^{\text{ref}} - P_i^*|}{P_i^{ref}} \cdot 100\ \%$

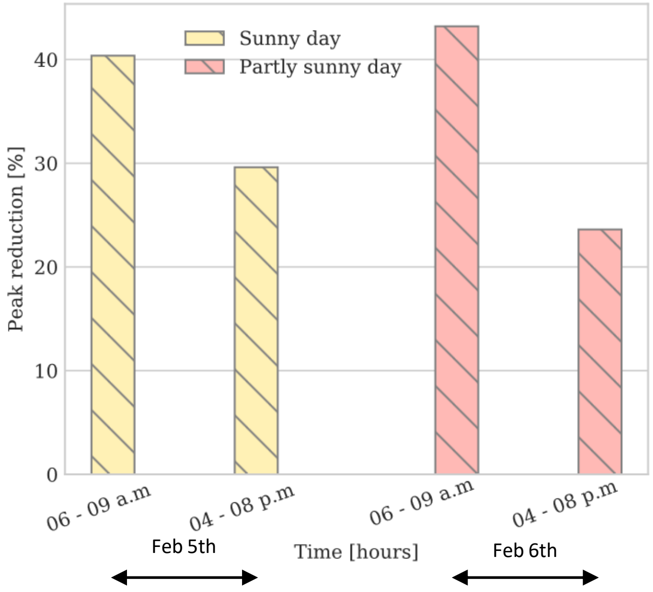
Where $i \in [6\ to\ 9\ a.m.] \cup [4\ to\ 8\ p.m.]$

Energy reduction (%)$= \frac{|E_i^{\text{ref}} - E_i^*|}{E_i^{ref}} \cdot 100\ \%$

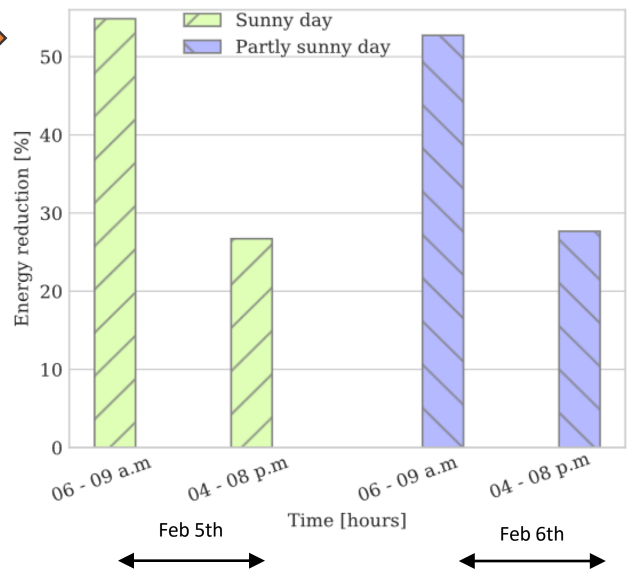
State of charge (%) $= 100 \cdot \frac{|\hat{T}_t^{slab} - T_t^{ref}|}{29 - T_t^{ref}}$

Where $T_t^{ref} = 20^{\circ}C$ is the reference air temperature

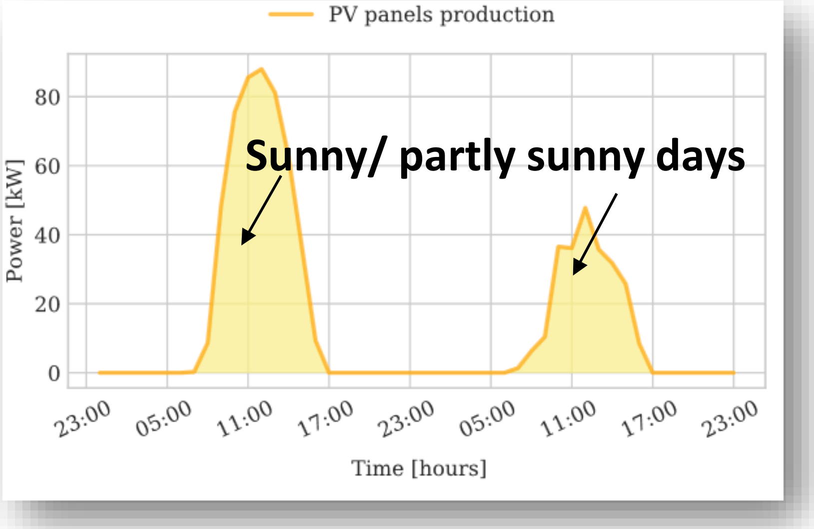
Possible reduction in the peak

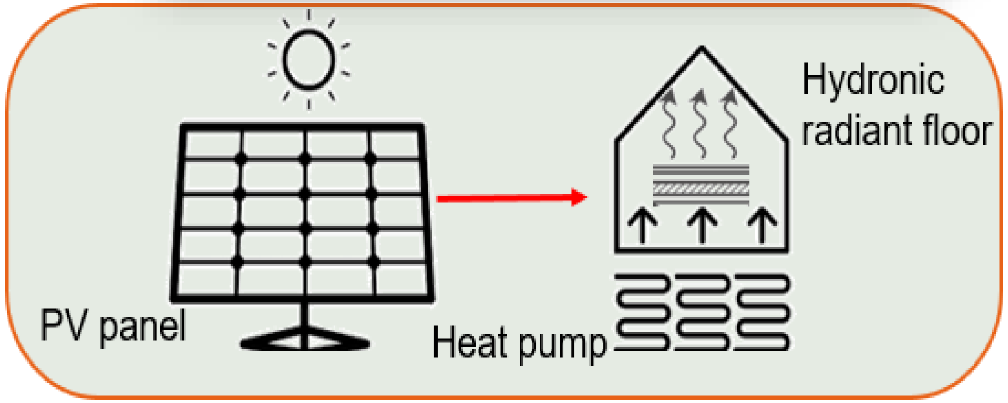


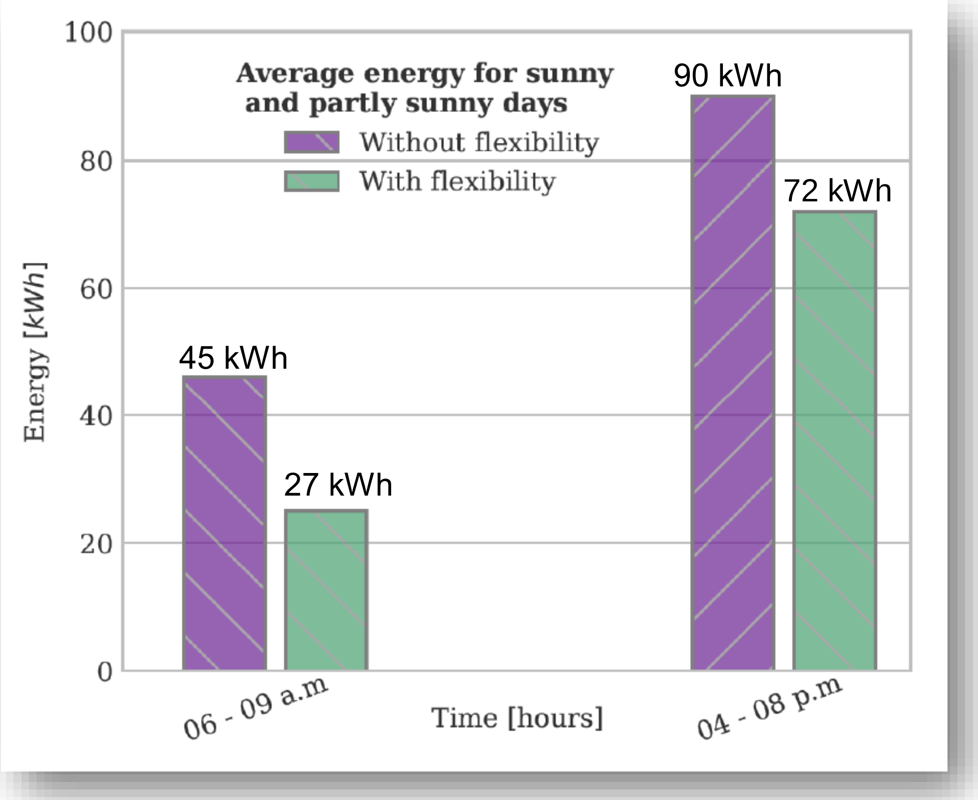
Possible reduction in the energy consumption



Energy flexibility quantification (4)







- Using the electricity production from PV panels to run the heat pumps outside the peak periods and storing the heat in the concrete slab of the building.

- Average energy flexibility for sunny and partly sunny days for two months interval from January to February 2018.

Conclusion

- A data-driven modeling (black box, with a little knowledge of building physics) is used to describe the relationship between (a) the geothermal pump system, (b) the thermal storage, (c) the PV panels production, and (d) the temperatures of the indoor air and the concrete slab surface.
- These outputs are then used to assess the potential state of charge (SOC) of the slab (thermal storage in slab). The modeling results are used to quantify the possible flexibility related to reducing peak load and energy consumption over peak periods.
- The flexibility strategy considering a sunny cold day can achieve reduction in peak load of 40% and 30% during morning and evening periods, respectively.