Modelling framework for optimizing hybrid photovoltaic-thermal systems in combination with seasonal heat storage


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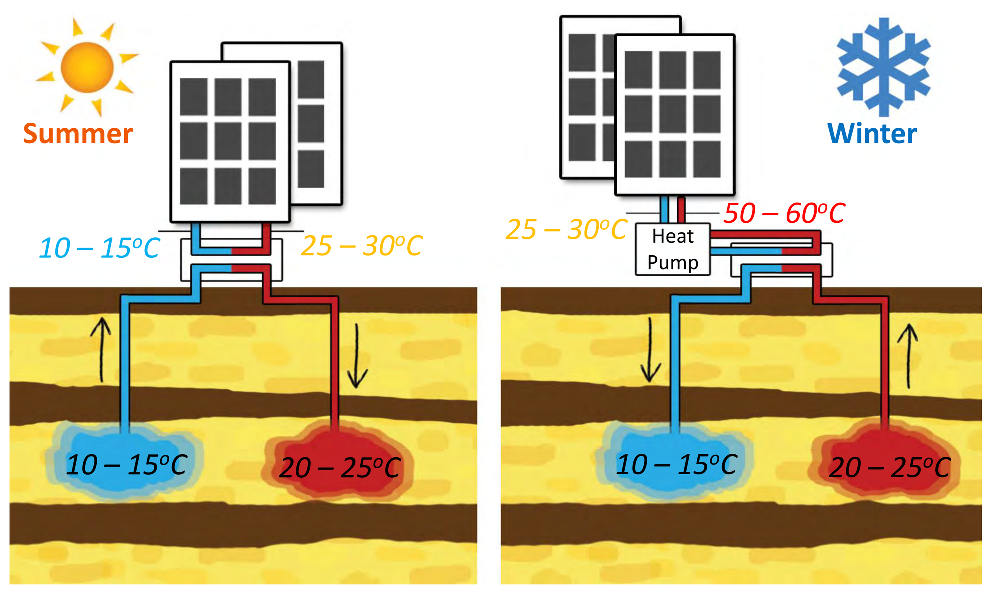
Motivation

- In summer, excess solar supply leads to solar panels being switched off.
- In winter, limited solar energy forces reliance on natural gas for heating.
- A solution is to couple solar collectors [1] with seasonal aquifer thermal energy storage (ATES). Figure adapted from [2].

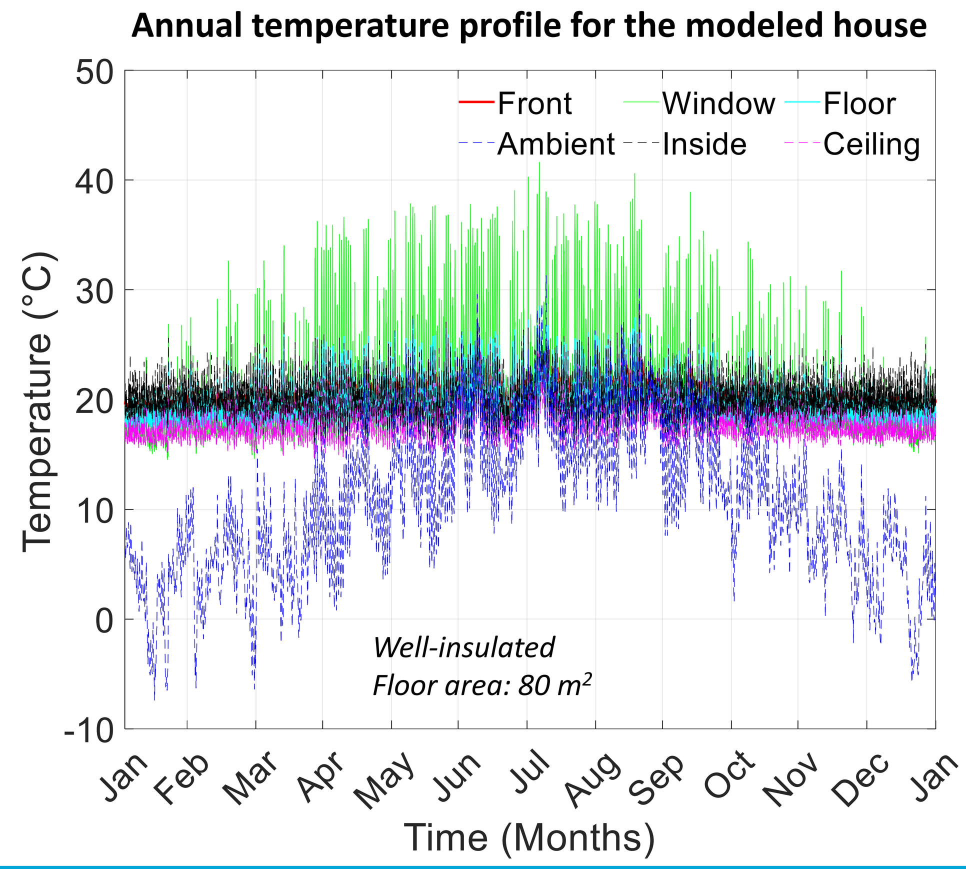


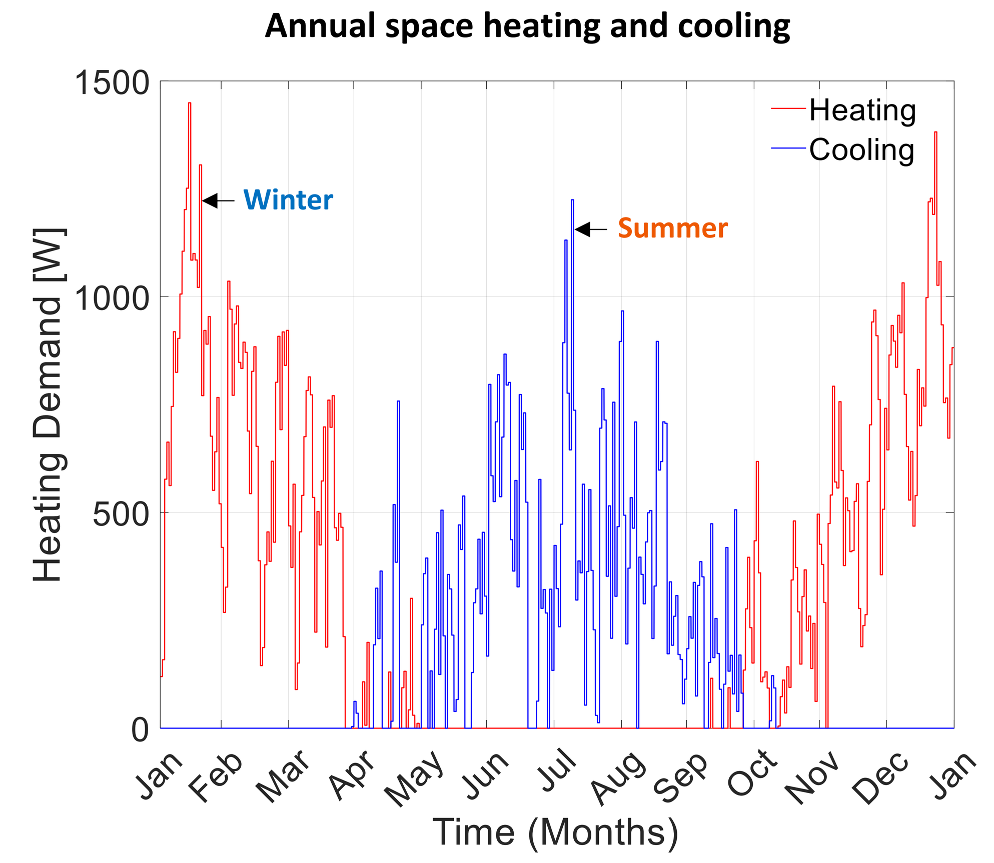
- Extending **lifespan** of PV modules through cooling [3].
- Address literature gap on occupant behavior and building characteristics through the development of a heat demand model.

Heating model

- Developed using **thermal resistance network**, incorporating building geometry, thermal properties and insulation.
- User can adjust thermal properties to simulate different household types.

High-energy vs *low-energy consumers*
Inside temperature (18 – 24°C)
Heating demand (almost doubled)

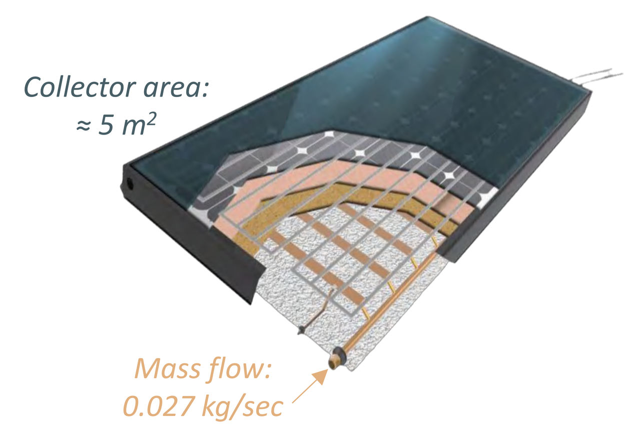




Modelling framework

- Numerical **models** are developed to simulate and evaluate heat storage solutions, considering heat loss mechanisms:
  - Conduction
  - Natural and external convection
  - Radiation
- Modeled **heat storage solutions**, categorizing hours as excess or deficit based on modules output versus demand:
  - Domestic storage tank (**short-term**)
  - ATES-Doublet (**long-term**)
- **Seasonal storage** integrated with PVT and in-built heat exchanger.
  - Aquifers shape assumed as perfectly cylindrical.
  - Heat exchanger effectiveness remained 40% year-round.
  - Homogenous temperature across aquifers depth.
- Models are integrated into the **PVMD Toolbox** [4] which can already predict the energy yield of PV systems.
- Developed a **dynamic model** of a PVT using energy conservation principle.

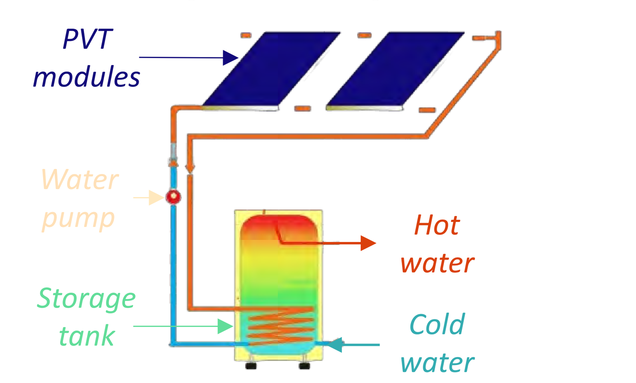
Water-based PVT collector

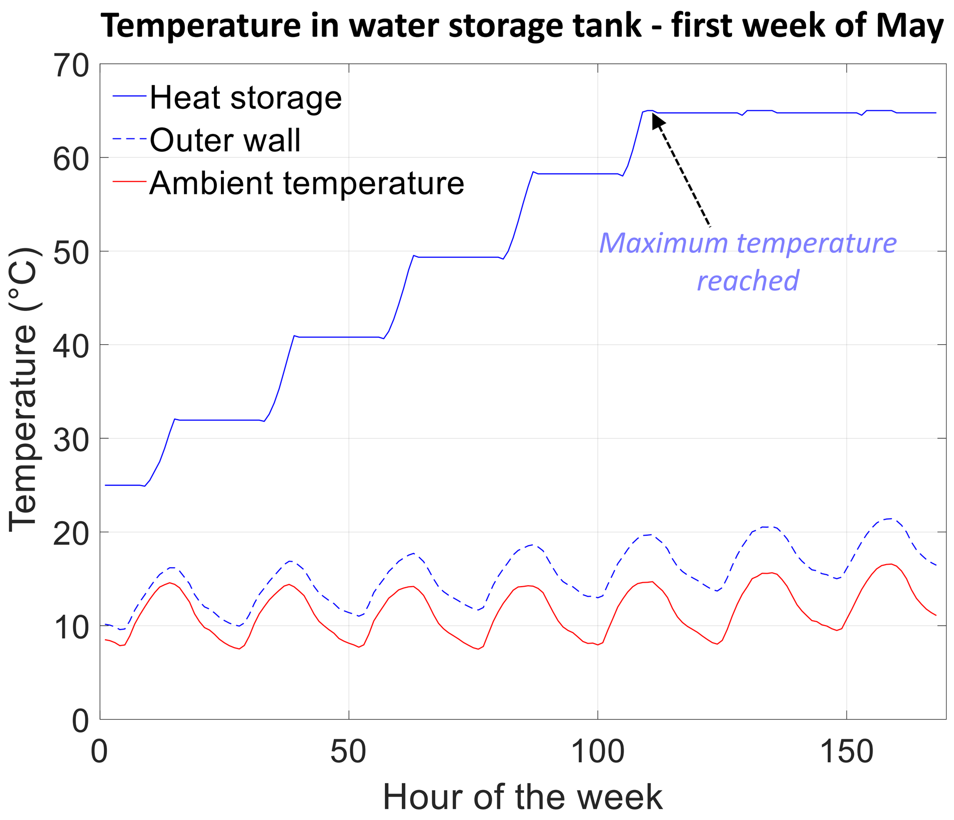


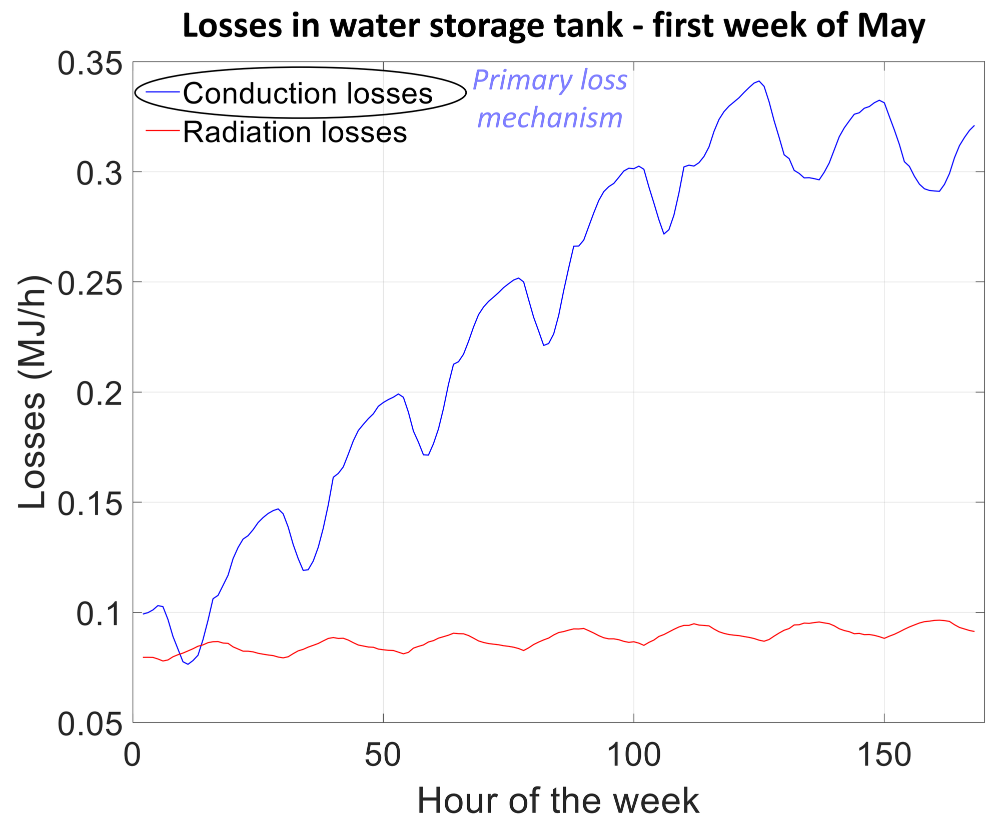
Short-term solution: Domestic storage tank

- Single apartment equipped with **two modules**.
- Heat storage tank, radius 0.45 m and height 0.60 m.
- To minimize heat losses, storage insulation measures 0.10 m.
- Conduction loss, significantly impacting overall efficiency, with **combined losses** totaling approximately 0.30 MJ per hour.
- ***Small heat storage*** *tank of 0.38 m³ is* ***effective for short-term*** *energy storage.*

Domestic storage tank integrated with PVTs

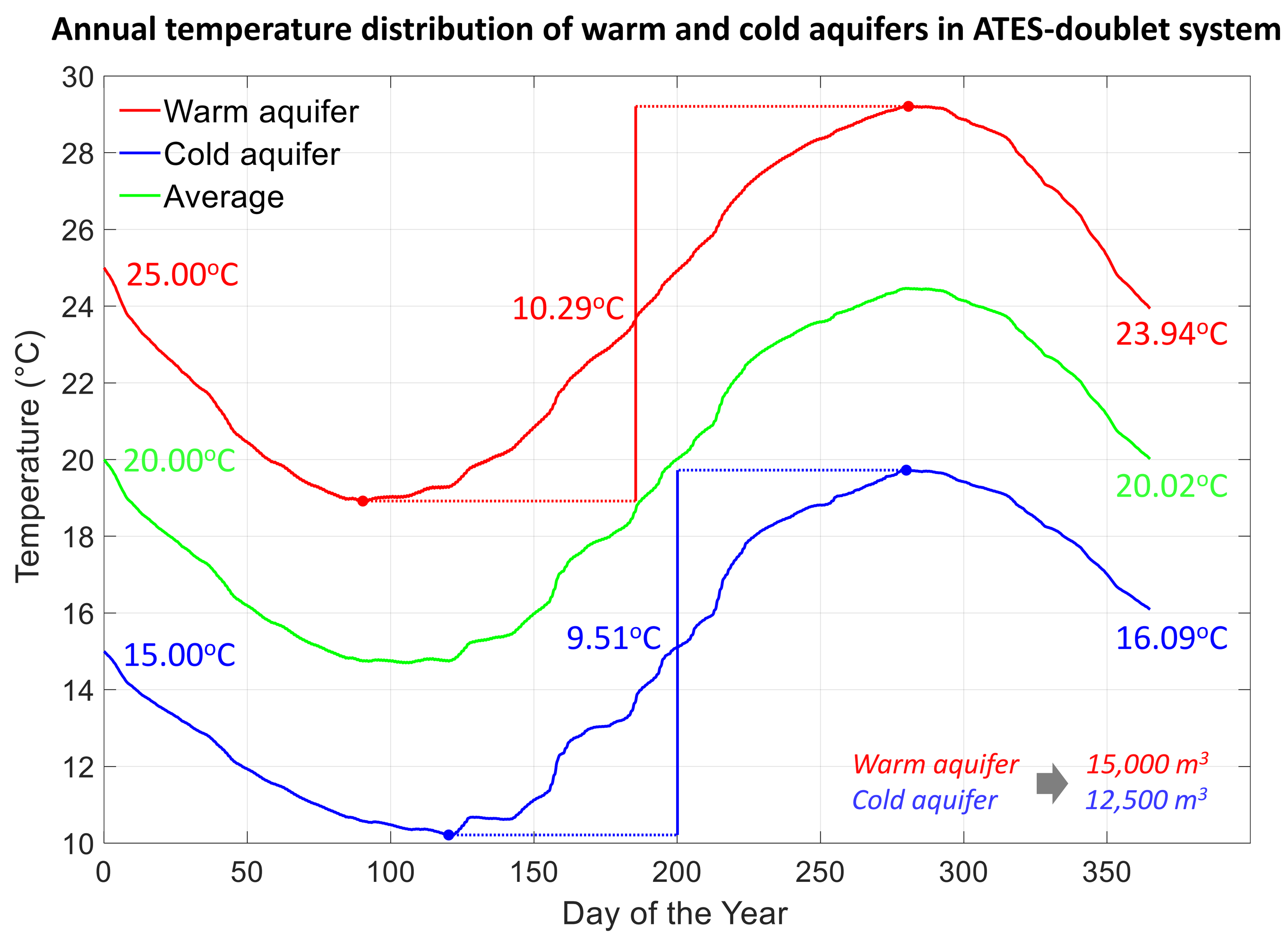


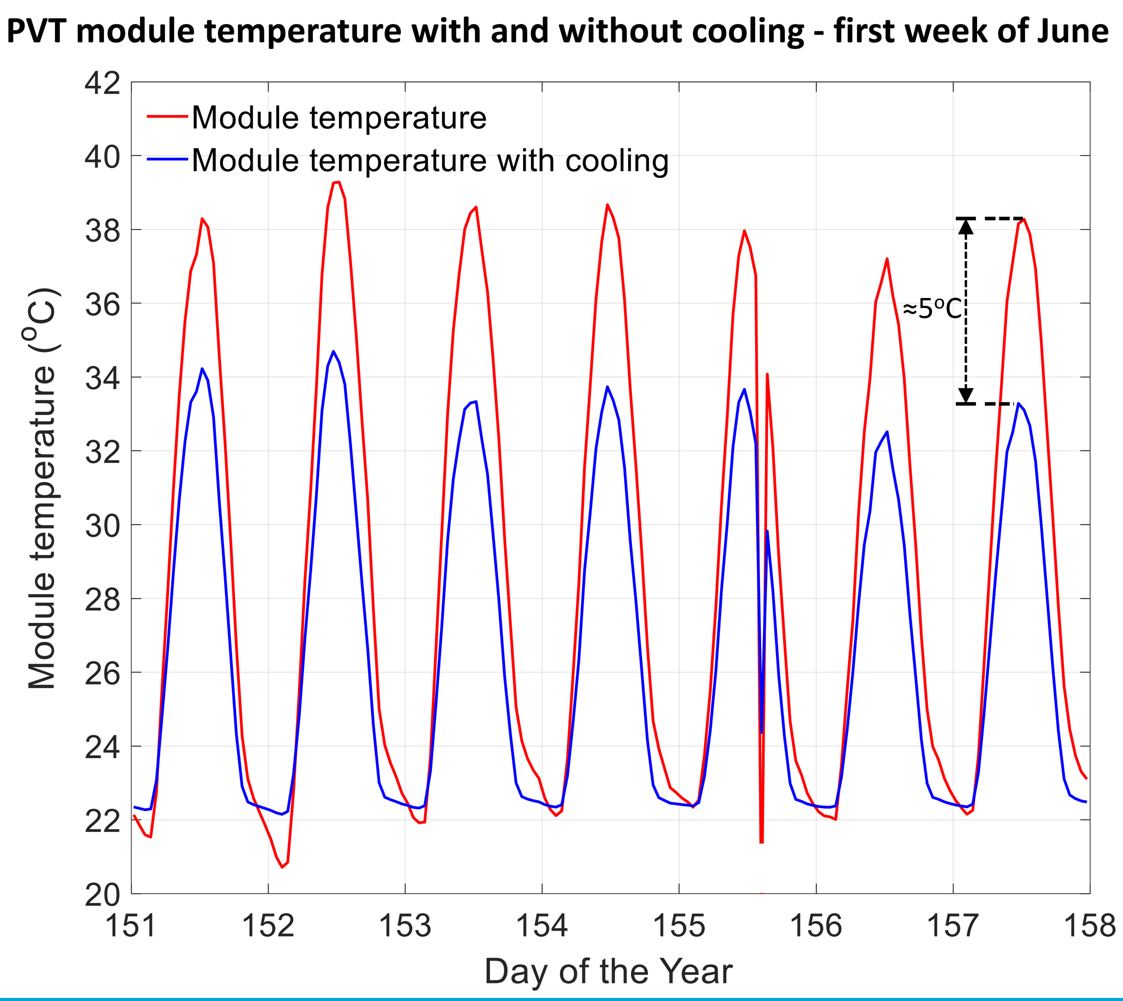




Long-term solution: Aquifer thermal energy storage

- 100 apartments, each equipped with three PVT modules.
  - Similar PVT module is used in both storage cases.
- Climate data affects **module performance**.
- Heat storage system extend the **lifespan** of the module through **effective cooling**.
- Seasonal storage system has **sufficient capacity** for the whole year.
- The **levelized cost** of thermal energy is approximately €0.12/kWh .
  - It is total annual cost divided by thermal demand delivered.





Conclusions

- Dynamic model developed for **PVT collector** generating both solar electricity and heat.
- 0.38 m³ heat storage tank is **not suitable** for seasonal energy storage.
- ATES system for 100 homes is an **effective seasonal heat storage** with limited heat loss.
  - Offer **long-term sustainability** and efficiency for urban energy systems.
- Cooling of PV cells has added advantage of **increased efficiency** and lifetime.

References

[1] S. Kranz, et al., **2015**, World Geothermal Congress, 4.
[2] M. Blomendal and T. N. Olsthoorn, **2018**, Adv. in Geosci., 45, 85-103.
[3] P. Royo, et al., **2016**, Energy, 101, 174-189.
[4] M. Vogt, et al., **2022**, Sol. Energy Mat. Sol. Cells, 247, 111944.

Acknowledgements

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