HyTES
Hybrid PCM-Sensible storage systems for Single and Multi-Family Houses
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Heat is crucial for the energy transition

50%
Of our energy needs are heating and cooling

60%
Are fossil-covered for this.
Energy system without seasonal heat storage (STES)
Energy system with seasonal heat storage (STES)

- Electrical grid
- Solar
- Natural gas

**Sommer**
- PV
- Heat Pump
- STES
- Reduction
  
**Winter**
- PV
- Heat Pump
- STES
- Winter electricity demand by up to 4 TWh_{el}
Energy use in Switzerland
Large demand for residential heat

Only 1/3 of total heat demand can be potentially covered using medium to large scale thermal networks.

Remaining 2/3 require smaller scale single building solutions (Single and Multi-Family Houses)

Challenge for small-scale storages
Exponential increase of investment costs
Seasonal storage in buildings
OPTSAIS - Considered scenarios

Scenario 1
Integrated in the building

Scenario 2
Buried underground

Solar collectors
Storage tank
Floor heating
Storage tank with vacuum insulation
Cases of scenario 1
OPTSAIS - New building and retrofit

Scenario 1
Integrated in the building

New building

Retrofit

Solar collectors

Floor heating

Storage tank
**OPTSAIS MAIN FINDINGS**

**CAPEX comparison**

- **Loss of living space**
- **Building reconstruction**
- **Installation costs**
- **Components**

**CAPEX [kEUR]**

**Scenario 1 (retrofit)**
- Components
- Installation costs
- Excavation costs
- Loss of living space

**Scenario 1 (new building)**
- Components
- Installation costs
- Excavation costs
- Loss of living space

**Scenario 2**
- Components
- Installation costs
- Excavation costs
- Loss of living space

Legend:
- $C_{com}$
- $C_{inst}$
- $C_{const}$
- $C_{imo, loss}$

**Notes:**
- The diagram compares the cost components for different scenarios, including installation costs, components, and loss of living space due to building reconstruction.
- Scenario 1 involves retrofitting an existing building, while Scenario 2 involves building a new structure.
Motivation from OPTSAIS

- Storage inside the building too expensive → placement outside the ground
- Increasing energy density with Phase Change Materials (PCM)
- Solar thermal energy limited in flexibility → PV + heat pump
Introduction HyTES - Goals

Cost reduction by reducing the volume of a seasonal hybrid heat storage system

Use of water + PCM as storage medium

• Loading of the storage tank with heat pump + PV
• Coverage of the heat demand (room heating + BWW) of a representative MFH
• Solar coverage (degree of self-sufficiency) from 70 to 100%

Research questions:

• To what extent can you reduce the storage volume or costs?
• What is the optimal TES configuration in terms of PCM, capsule shape, capsule size, etc.
• What is the optimal system configuration in terms of storage size, PV area and HP performance?
• What is the cost composition of the individual system components?
• How do costs correlate with the degree of self-sufficiency?
• How can the domestic hot water be treated cost-effectively?
Methodology

Optimization variables (blue)

- Weather data
- Orientation
- Angle
- PV area

Predefined reference scenario (orange)

- SH profile
- DHW profile
- Power profile
- Building parameters
- Location

Power grid

- HP power

Hybrid TES

- Soil T. profile
- TES geometry
- TES insulation
- PCM
  - Capsule geom.
  - # of layers
  - Height of layer
  - Layer position

Storage concepts:
- Vacuum insulated storage
- FRP storage (energy4me)
- GEAS/HSLU storage
Methodology

Objective Function:
Costs (LCOH)

Preprocessing

Postprocessing

Black Box Optimizer
NOMAD

New input parameters
Methodology

- Multi-year simulations to achieve a steady state of the storage system
- Different storage temperatures
- Building data (room heating demand, heat reference area, number of inhabitants)
- Location: Bern
- Domestic hot water requirement according to SIA 385/1
- Use of PV modules commercially available in Switzerland
- Consideration of the heat loss of the storage tank over the ground
- Consideration of the temperature change of the soil depending on the depth and season
The following 3 storage scenarios are investigated:

Scenario 1: Vacuum insulated storage
Scenario 2: FRP storage (spherical shape)
Scenario 3: GEAS Storage

Case 1: Empty cellar
Case 2: New construction in the ground
Storage Model Overview

Discretization of energy equations:

- Spatial:
  - Diffusion Term: «Central Differencing Scheme»
  - Convection Term: «Up-/Down Wind Scheme»
  - Source/Sink Term: «Linear»
- Temporal:
  - «Fully Implicit Method»

- Solution algorithm:
  - Direct
  - «Tri-diagonal Matrix Algorithm» (TDMA)

- Independent storage geometry
- Capsule geometries are calculated by spherical analogies
- Flexible, adaptable and expandable
Capsule conversion of any geometry into a spherical capsule equivalent

- Identical capsule surface
- Identical PCM volumes

Hybrid Thermal Energy Storage Model

Experimental setup
Hybrid Thermal Energy Storage Model
Validation

**Charging**

Energy Charged
11.67 kWh (Sim)
12.06 kWh (Exp.)

**Discharging**

Energie Discharged
14.17 kWh (Sim)
14.44 kWh (Exp.)
- NOMAD = **Nonlinear Optimization by Mesh Adaptive Direct Search**

- Open Source

- Input Argumente:
  - Restrictions
  - Design Variables
  - Categorical variables

  → Allows the choice between different PCMs at a certain storage height

  – Objective function (weighed sum, e.B. LCOH and solar coverage ratio)

  \[ f(x) = \sum_{i=1}^{2} w_i f_i(x) \]

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2Audet et al. (2009). NOMAD user guide
Outlook

• Finish building the entire simulation model
• Comprehensive validation of all sub models
• Start of the optimization campaign:
  – Perform simplified parameter study to identify most relevant optimization parameters
  – Determine value ranges and step size of the optimization parameters
  – Perform benchmark simulations and make necessary adjustments
  – Perform sensitivity analysis
• Evaluation of optimization data
• Ongoing exchange with energy4me and COWA regarding costs and technical feasibility
• Planned Innosuisse project input with energy4me
Thank you for your attention!