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Simulation-Based Design Optimization of Large-Scale Seasonal Thermal Energy Storage in Renewables-Based District Heating Systems

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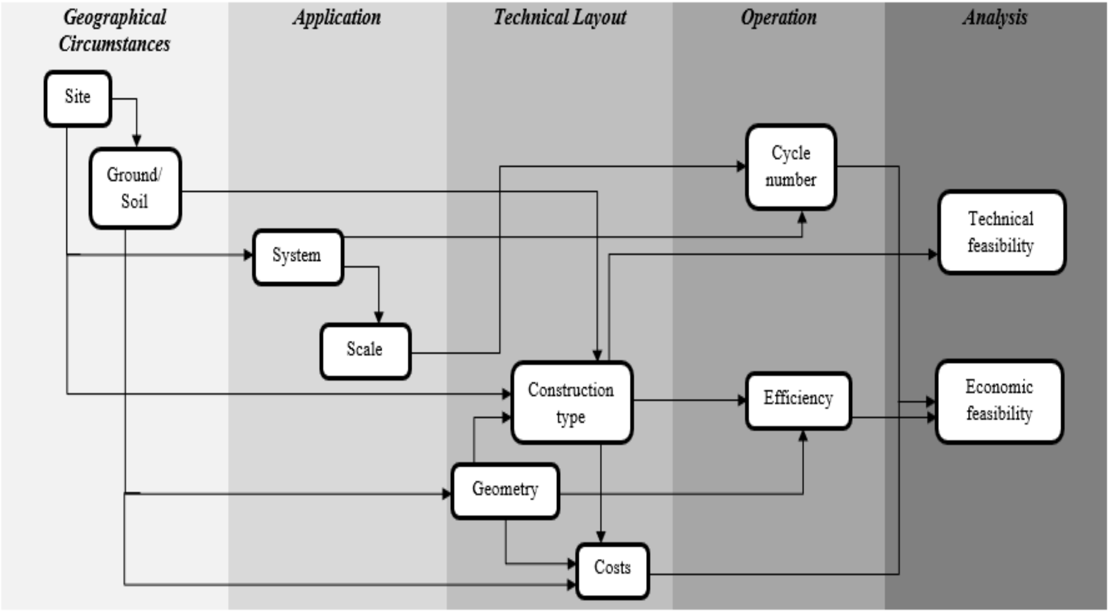
Introduction



- A sophisticated interconnected process;
- Each category has strong dependency on other categories;
- Crucial to avoid risks ➔ cost, performance;
- Simulations found a place in this domain.

Dahash, A. et al. (2019). **Advances in Seasonal Thermal Energy Storage for Solar District Heating Applications: A Critical Review on Large-Scale Hot- Water Tank and Pit Thermal Energy Storage Systems**. *Applied Energy, 239*, 296-315. doi:10.1016/j.apenergy.2019.01.189

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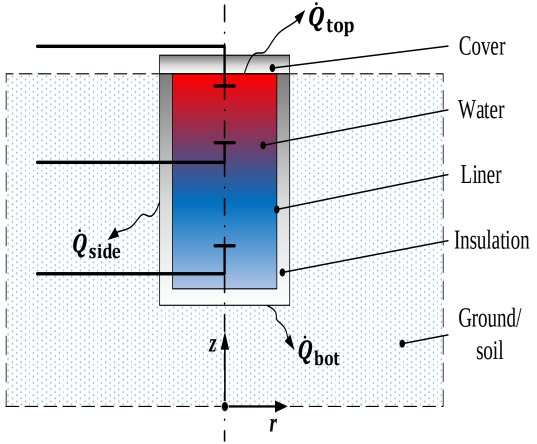
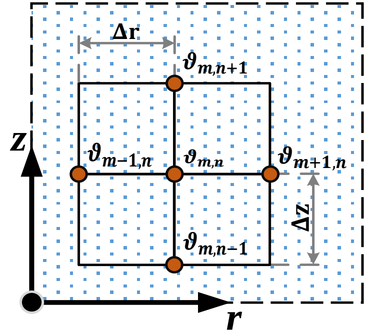
Modeling of Large-Scale TES

- Tool: Modelica/Dymola
- TES base model source:
  - Modelica Buildings Library
- Modifications:
  - Adaptation of buoyancy model: $\lambda_{\mathrm{w,enh}} = C \cdot \left(\frac{\partial T}{\partial z}\right)^{k}$;
  - Various side heat ports;
  - Initialization with different temperatures.
- Development of 2-D soil model.

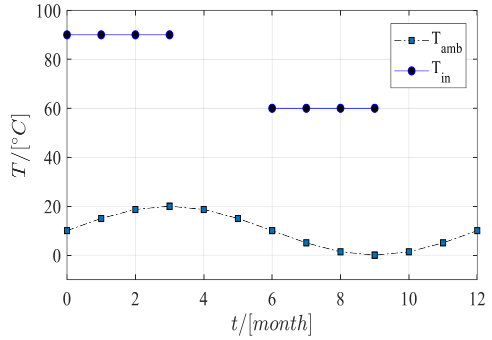


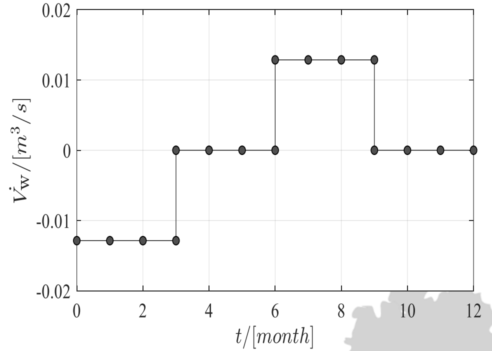


Wetter, M. et al. (2013). **Modelica Buildings library**. *Journal of Building Performance Simulation, 7(4)*, 253-270. doi: 10.1080/19401493.2013.765506

Modeling of Large-Scale TES

- To keep simulations simple:
  - Simplified representative DH profile with 90°C /60°C;
  - Cylindrical tank;
- Operation profile:
  - 3 months charging;
  - 3 months storage;
  - 3 months discharging; and
  - 3 months idle.
- Ambient temperature varies between 0°C and 20°C.





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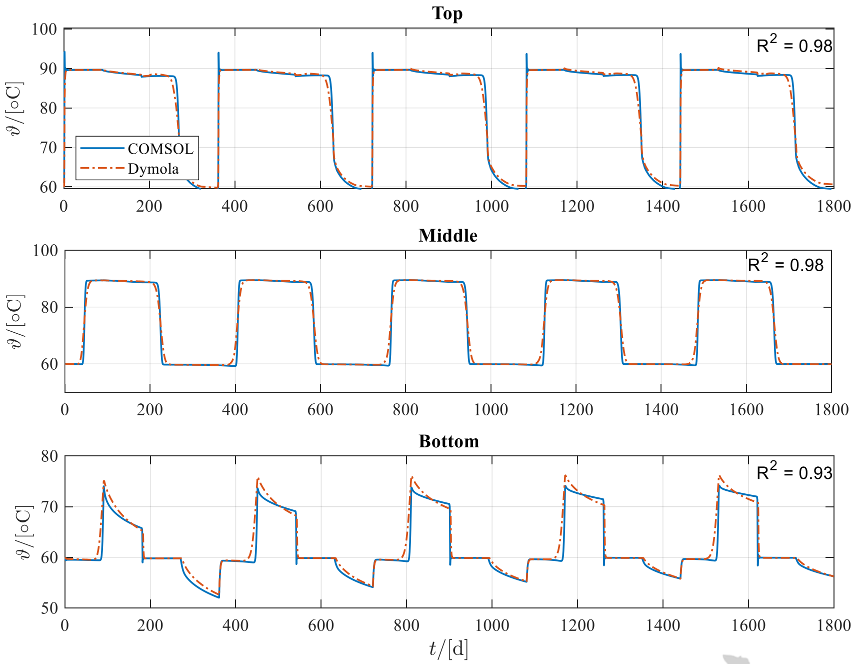
Results

- Cross-validation against a valid finite-element model in COMSOL Multiphysics.

- Cross-validation case:
  - Buried tank with 2,000,000 m^3;
  - Depth: 50 m;
  - U_{top} = 0.15 W/(m^2.K);
  - $U_{side} = U_{bot}$ = 0.3 W/(m^2.K);
  - 5 simulation years.

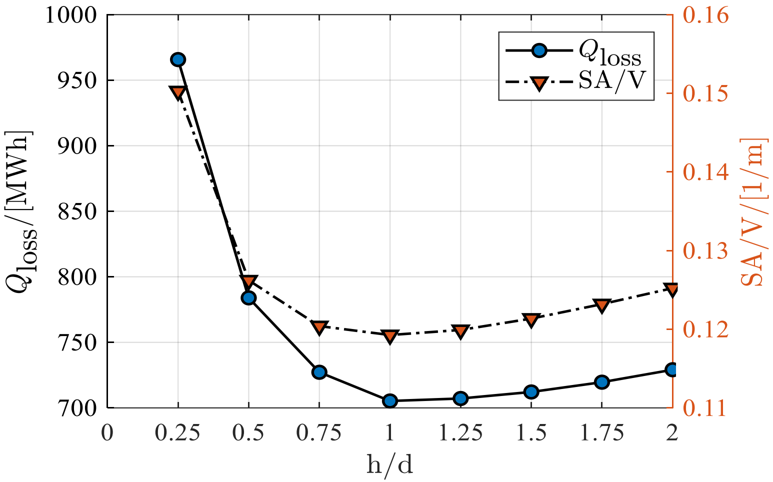
- Considerable matching in temperature.

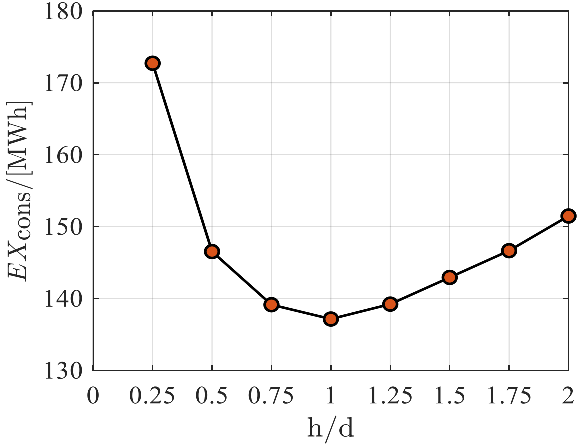


Dahash, A. et al. (2020). **Toward Efficient Numerical Modeling and Analysis of Large-Scale Thermal Energy Storage for Renewable District Heating** . *Applied Energy, 279*. doi: 10.1016/j.apenergy.2020.115840.

Results

- Influence of tank shape:
  - Buried tank with 100,000 m^3;
  - U_{top} = 0.15 W/(m^2.K);
  - $U_{side} = U_{bot}$ = 0.3 W/(m^2.K);
  - Evaluation at the end of 5th year.
- Tank losses:
  - Internal losses (exergetic) ➔ (h/d);
  - External losses (energetic) ➔ (SA/V).
- Obviously, h/d =1 is the optimal due to:
  - Smallest (SA/V);
  - Lowest Q_{loss} and EX_{cons}.
- Very good agreement with COMSOL simulations.

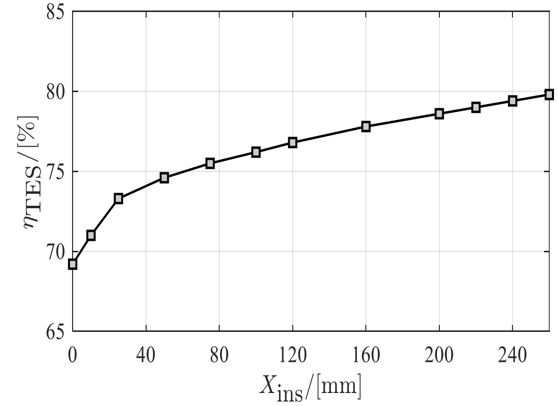




$$EX_{cons} = EX_{des} + EX_{loss}$$

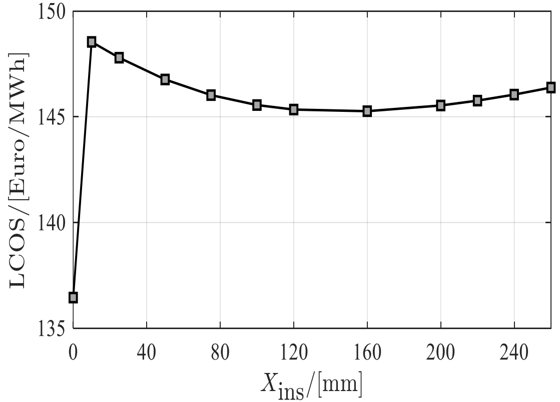
Results

- Influence of insulation thickness:
  - Buried tank with 100,000 m^3;
  - U_{top} = 0.15 W/(m^2.K);
  - X_{ins} = [0-260] mm
  - Evaluation at the end of 5^{th} year.



$$\eta_{TES} = 1 - \frac{Q_{loss}}{Q_{TES}}$$

- An increase of ~ 10 %!
- LCOS increase as insulation is included in fixed cost;
- Optimum at 160 mm when insulation is considered;
- Without insulation is a global optimum.



$$\text{LCOS} = \frac{C_{fix} + C_{O\&M}}{Q_{dis}}$$

$$C_{fix} = C_{inv} \cdot ANF_{n,i}$$

$$C_{op} = 10\,\% \cdot C_{fix}$$

Contents

Conclusions

- Planning of large-scale TES is an interconnected process;
- Simulations found their place favorably for planning purposes;
- A Modelica-based TES model was further developed and validated;
- Tanks with (h/d = 1) ➔ better performance and stratification;
- Future work will focus on developing TES model further to capture different TES geometries (e.g. pit) and system simulations.

Acknowledgments

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Questions and Comments

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