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METHODOLOGICAL DEVELOPMENT OF A REDUCED-ORDER DATA-DRIVEN MODEL FROM DETAILED NUMERICAL SIMULATIONS FOR SEASONAL THERMAL ENERGY STORAGE (STES)

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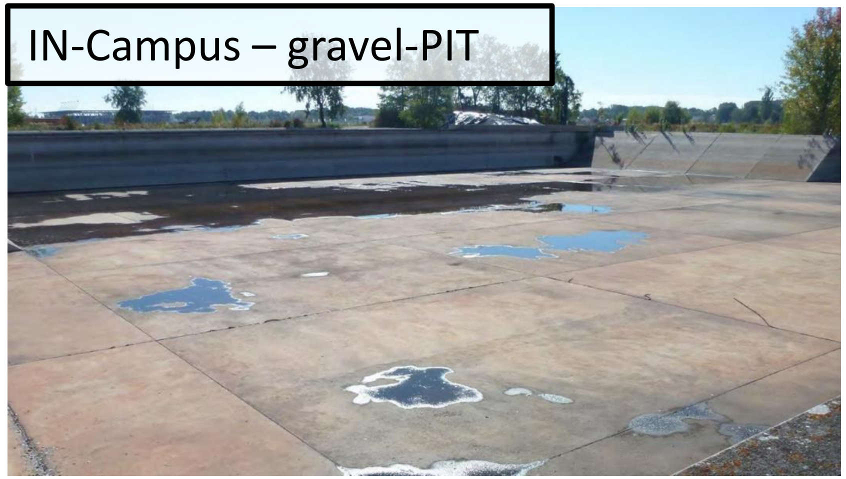
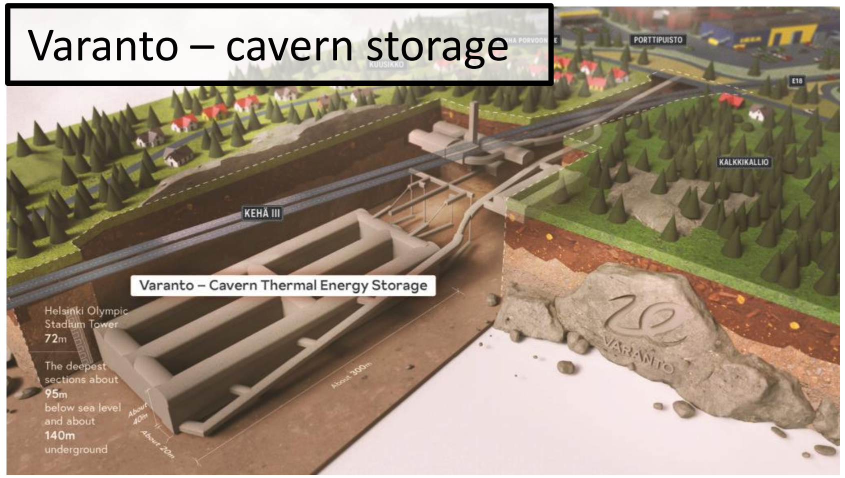
Introduction

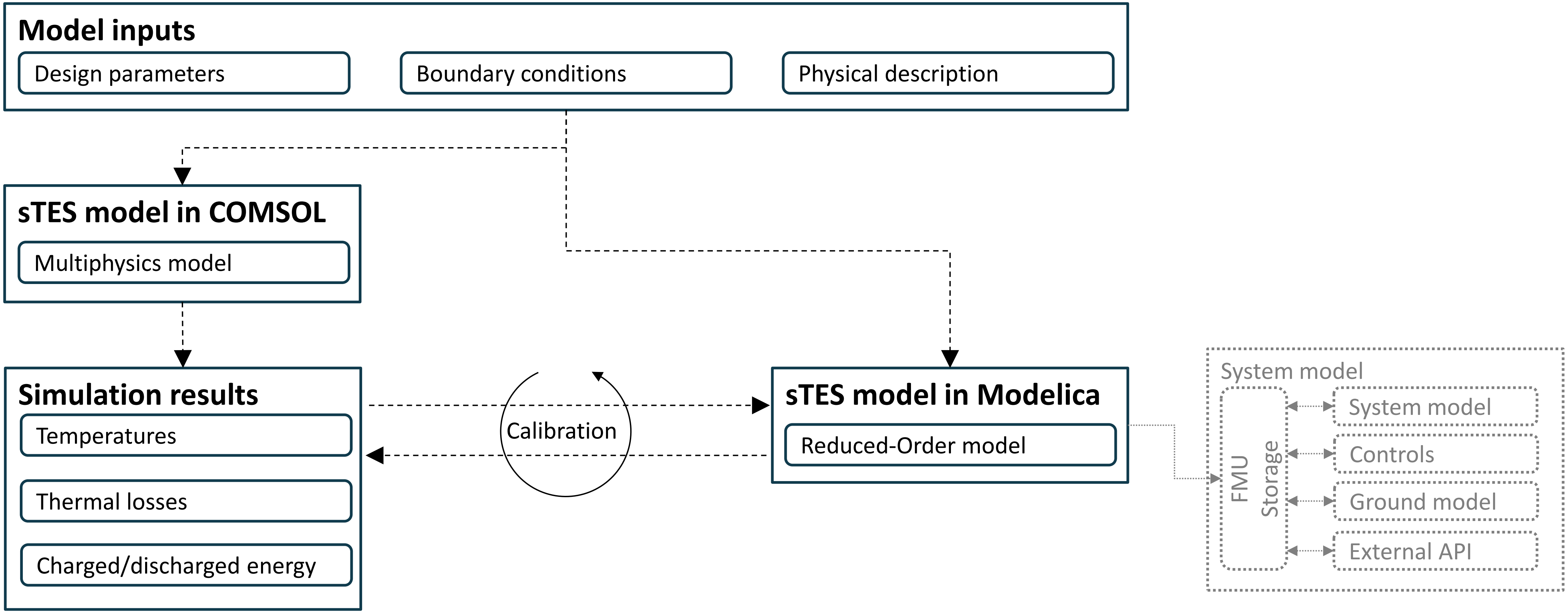
- HORIZON Project INTERSTORES
  - 14 Partners from 9 countries
- 2 demo-sites
  - Large sTES at IN-Campus (18,000 m^3)
    - Combination with 5GDHC, LowEx and waste heat
    - Re-purposing of existing infrastructure as sTES
  - World's largest sTES at Varanto (1,000,000 m^3)
    - High-temperature storage
    - Combination of electric boilers and large heat pumps
- As WP4 (Systems) lead, we will develop system models and optimal control strategies





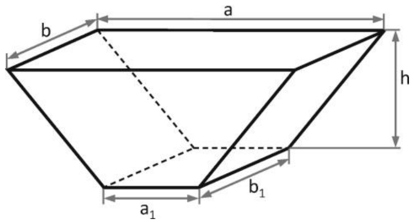
Source: https://interstores.eu

Modeling process



sTES design values for modeling

- Ideal operation cycle: 360 days
- Duration: 5 complete cycles
- sTES size:

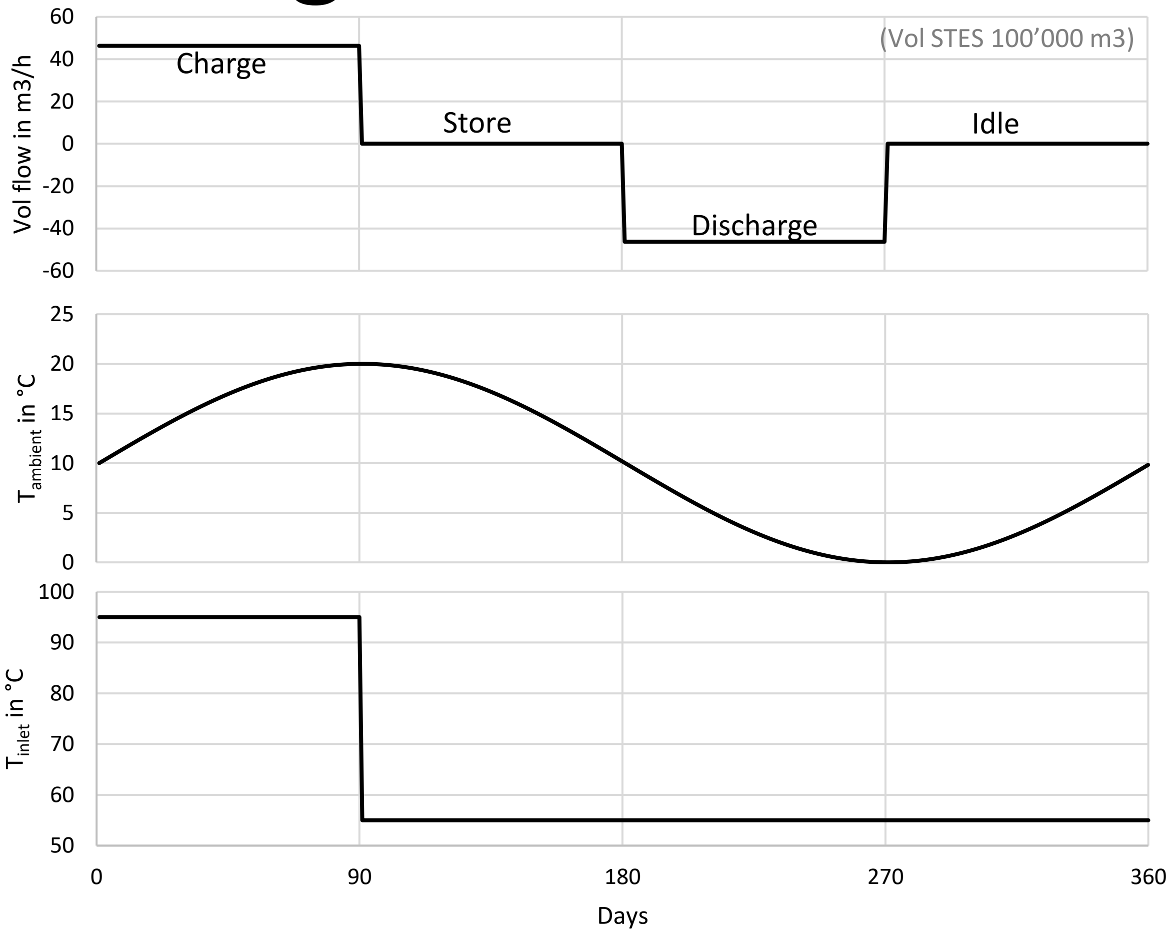


Volume (m3)	20’000	50’000	100’000	150’000	200’000
a&b (m)	62.5	84.8	108.4	124.0	135.8
Height (m)	8.5	11.5	13.5	15.5	17.5
a1&b1 (m)	33.0	45.0	61.6	70.3	75.2
Slope (°)	30.0	30.0	30.0	30.0	30.0

- Insulation and soil:

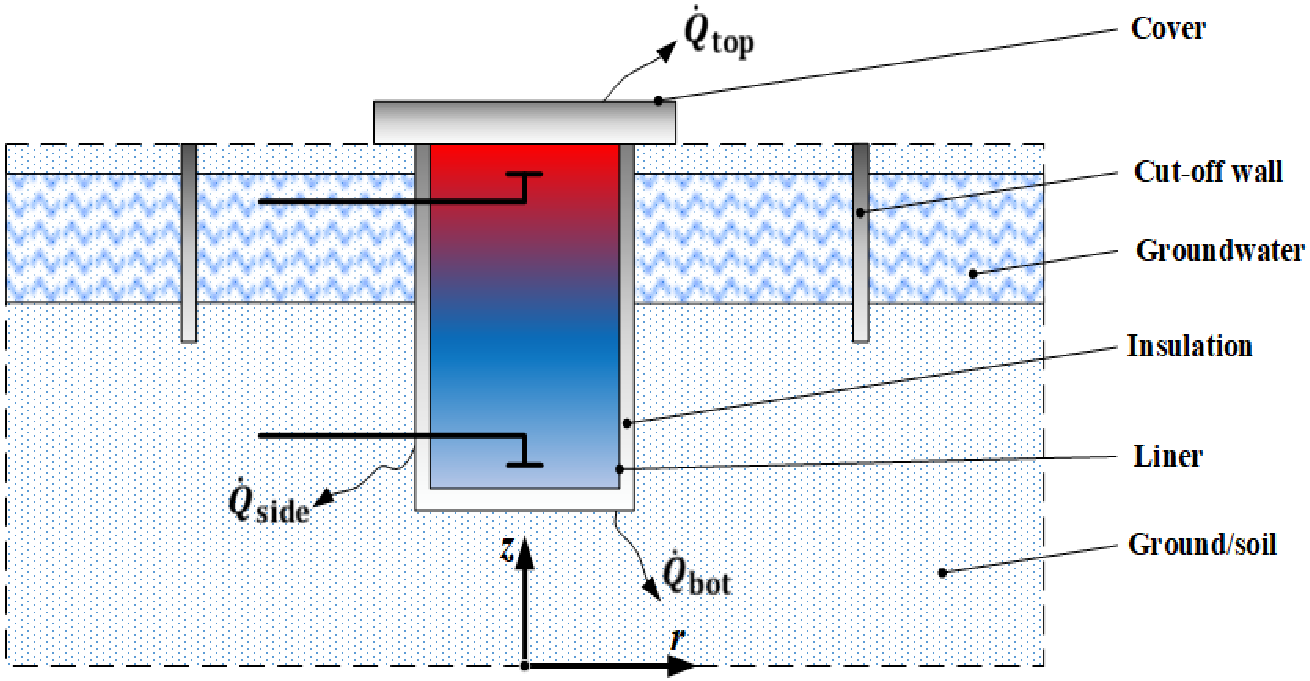
U-Value	well insulated	non insulated
Top	0.1 W/m²K	0.1 W/m²K
Side & Bot	0.15 W/m²K	90 W/m²K

Soil data		
	Density	2100 kg/m3
	Thermal conductivity	1.8 W/mK
	Specific heat capacity	1333 J/kgK



Detailed, multiphysics model

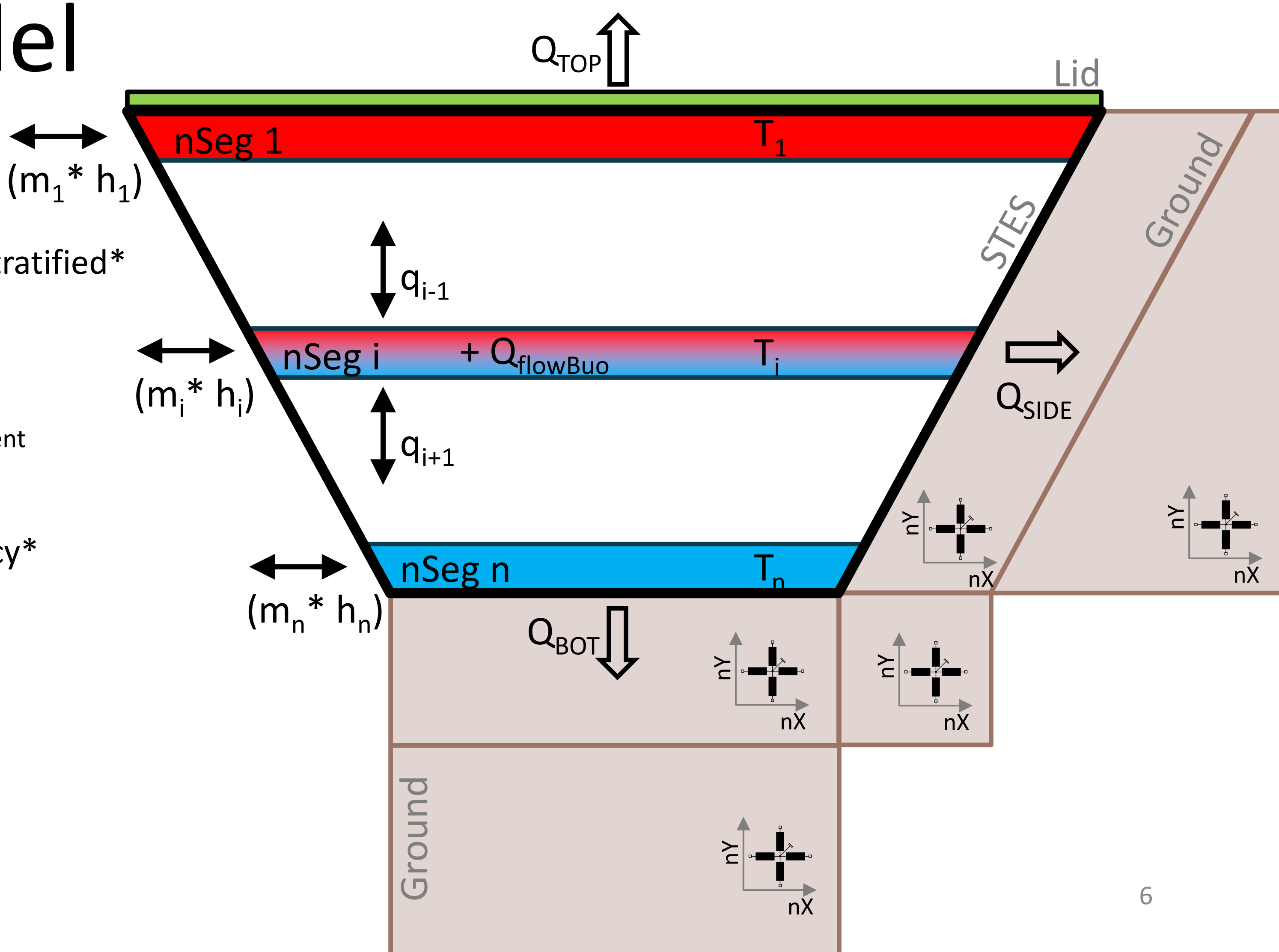
- Numerical model of large TES in COMSOL Multiphysics© supported by finite element method;
- Features:
  - Dimensionality:
    - 2-D (tank, cone), 3-D (pyramid)
  - Storage media:
    - Water, water-gravel, sand
  - Construction type:
    - freestanding, buried (partially or fully)
  - Geometry:
    - tank, cone, pyramid
  - Ports:
    - different numbers of inlet/outlet ports (diffusors)
  - Surroundings:
    - soil/ground, groundwater existence



Source: Dahash et al. (2020). Toward efficient numerical modeling and analysis of large-scale thermal energy storage for renewable district heating systems. *Applied Energy, 279*. doi: 10.1016/j.apenergy.2020.115840.

sTES Modelica model

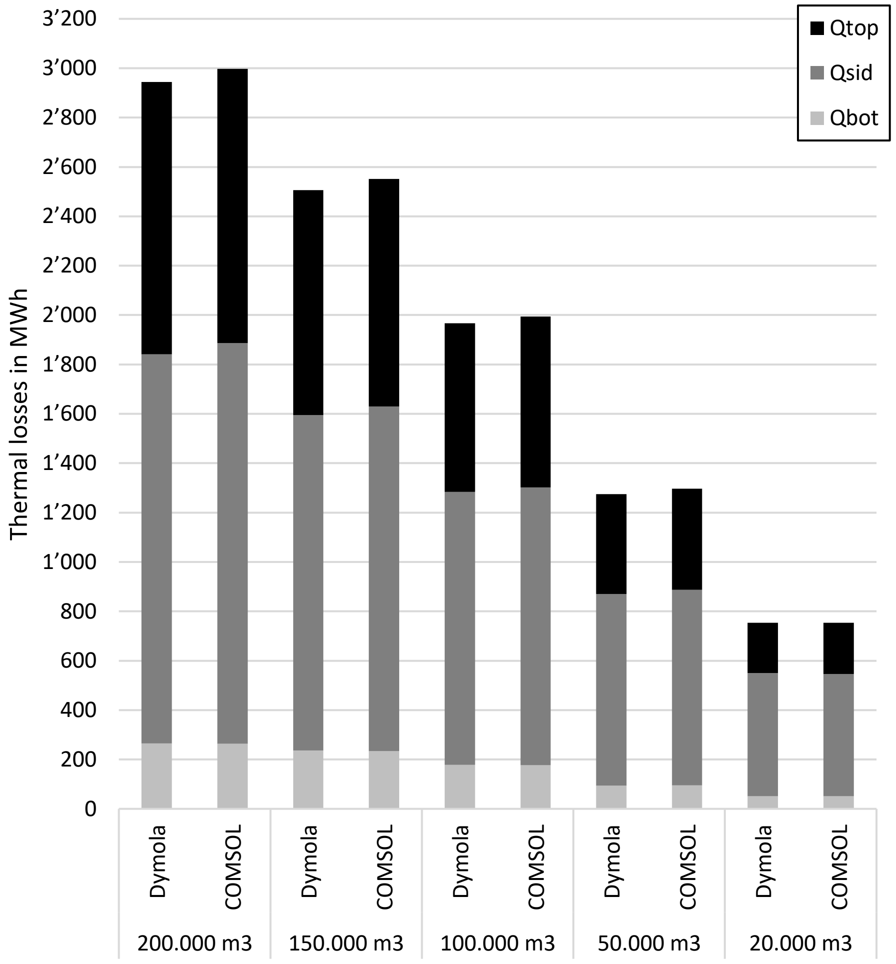
- Stratified tank model
  - Buildings.Fluid.Storage.BaseClasses.PartialStratified*
  - Modifications:
    - Shape of truncated pyramid
    - Equidistant discretization
    - Fluid connector for in/out connection to each segment
- Buoyancy model
  - Buildings.Fluid.Storage.BaseClasses.Buoyancy*
  - Modifications:
    - Different volume sizes for each segment
- Ground model
  - 2D grid using finite volume method
  - Each element has 4R1C



*Buildings Library 11.0

Results – thermal losses

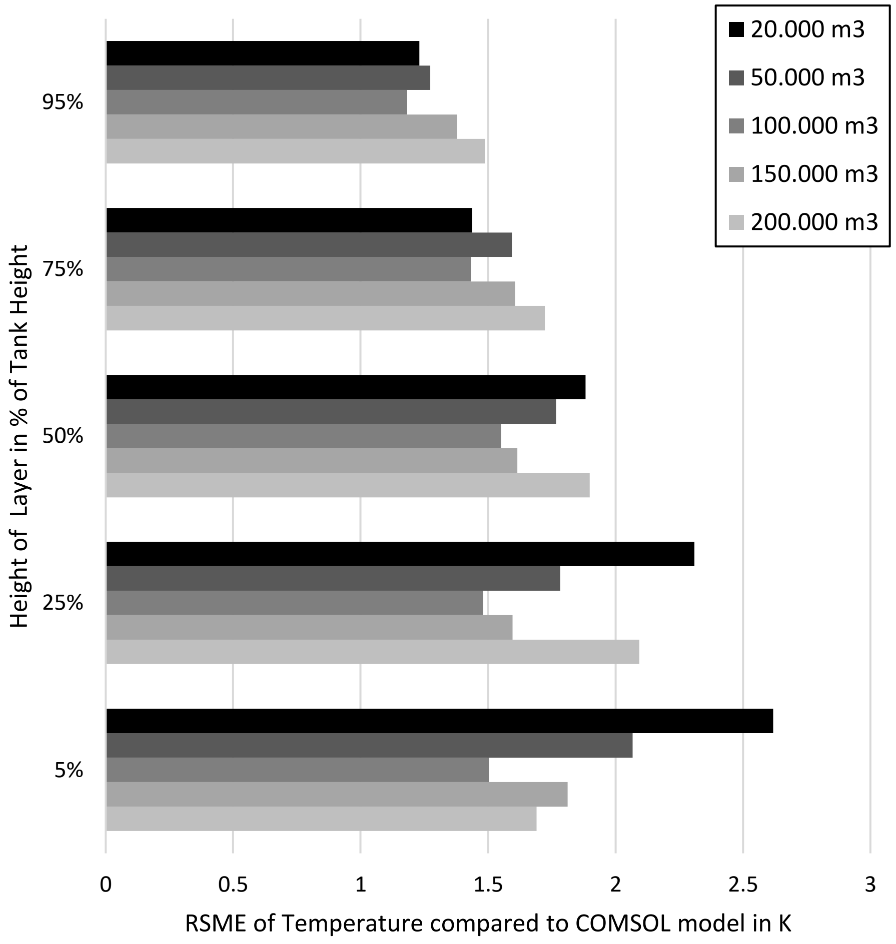
- Total losses Q_{tot}:
  Difference ranges from -1.8% (200k m³) to -0.2% (20k m³)
- Top losses Q_{top}:
  Differences increase with decreasing volume: -0.7% to -2.4%
- Side losses Q_{sid}:
  Difference largest at higher volumes (-3.0%), positive at lowest volume (0.7%)
- Bottom losses Q_{bot}:
  Difference between -0.3% (100k m³) and 1.2% (150k m³)
- Summary:
  - Consistency in Q_{total}: good agreement to COMSOL results
  - Volume dependency: differences increase with bigger volumes



Results – temperature deviation

- RMSE Top layers (95% & 75%) on average 1.4 K
- RMSE Mid layer on average 1.7 K
- RMSE Bot layers (25% & 5%) on average 1.9 K

- Summary:
  - Consistency in temperature: Both tools closely aligned
  - STES Model performs best for the 100k m^3
    - Volume impact: Smaller/larger tanks show larger RMSE

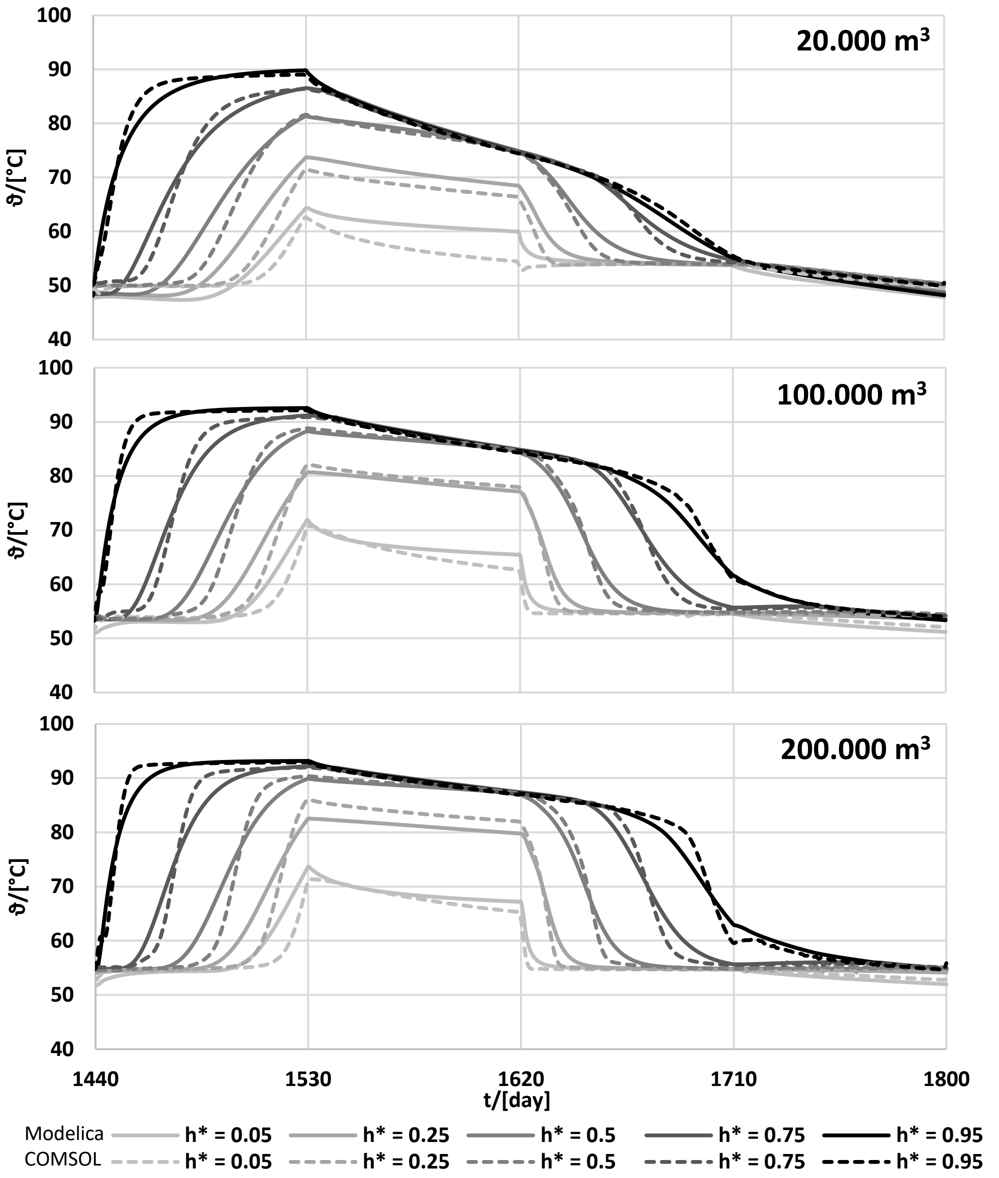


Results – temperature

- 5 relative heights
  - 95% represents temperature close to the lid
  - 5% represents temperature at the bottom
- Fluid temperatures diverge immediately after changing between charging and discharging
- Temperatures converge to similar values under steady-state conditions
- Bottom of storage

  Modelica model overestimates maximum temperatures
- Top of storage

  Model underestimates temperatures



Results – energy balance

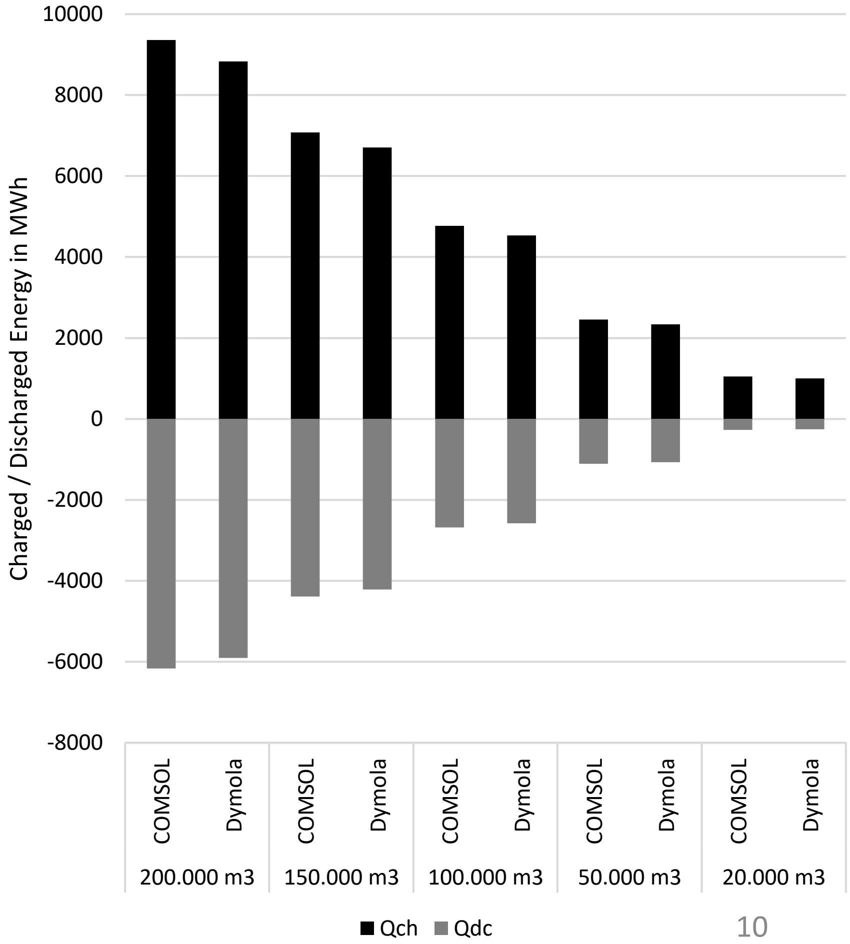
- Charged energy

  4-6% lower compared to COMSOL

- Discharged energy

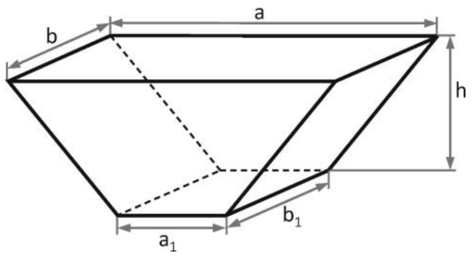
  4% lower across all volumes compared to COMSOL

- Summary
  - Dymola consistently underestimates energy compared to COMSOL
  - Volume Impact: differences remain relatively stable across tank sizes



Results – dynamic behavior

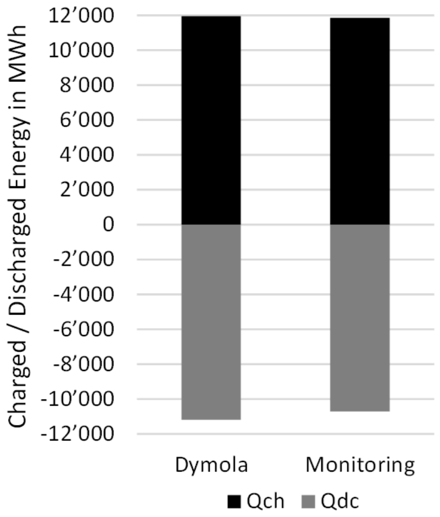
- Comparison with Dronninglund PTES storage
  - Data Source Dronninglund monitoring
  - Measurement period: 2016

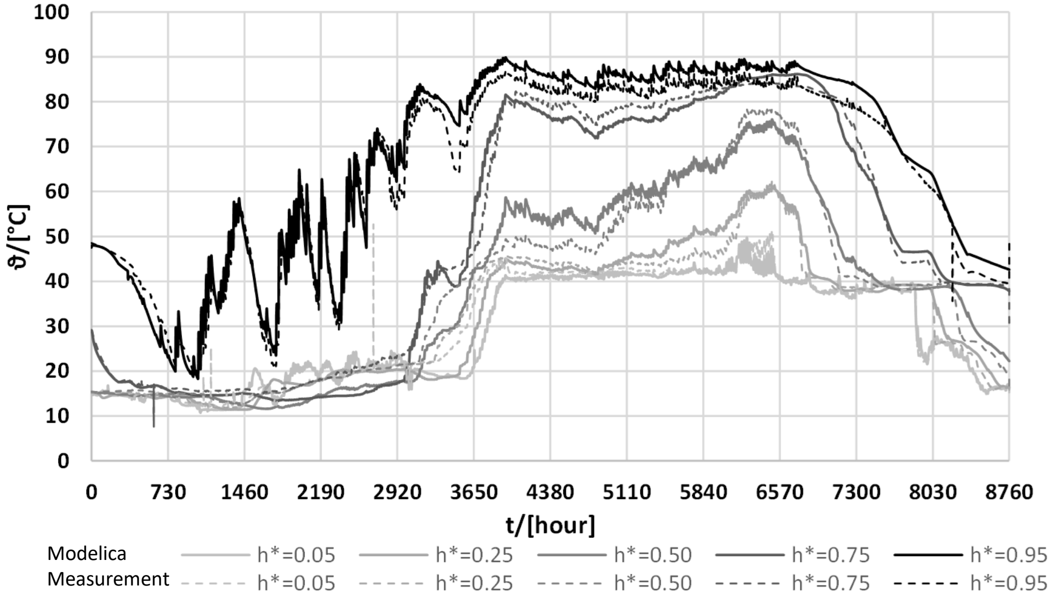


Volume (m3)	59’287
a&b (m)	90
Height (m)	16
a1&b1 (m)	26
Slope (°)	26.5

- RMSE
  - Top layers (95% & 75%) 3.1 K
  - Mid layer 3.3 K
  - Bot layers (25% & 5%) 2.8 K
- 0.8% higher charging and 4% higher discharging

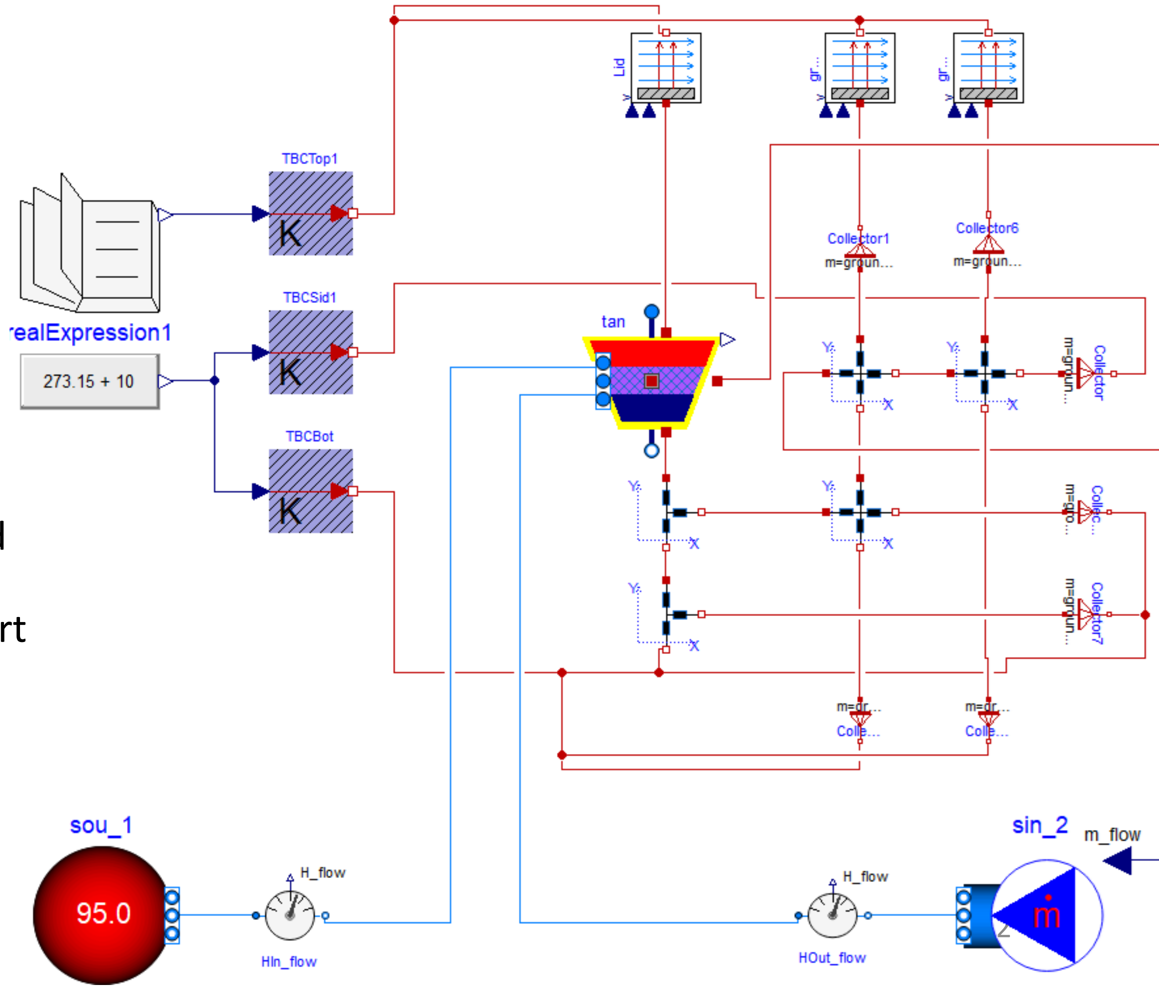

Source: PlanEnergi





Conclusion & outlook

- Model performance
  - Deviation < 2%: High accuracy in temperature simulations
  - 4 sec. simulation time for 1-year simulation (time step 1day)
  - RMSE < 3K in dynamic case (Dronninglund – 2016)
- Calibration & Enhancements
  - FMU Export → Enabled parameter calibration via Python
  - Future Enhancements:
    - Introduce different storage media, like gravel, for increased versatility
    - Model refactoring → improve simulation speed and support open access
- Implementation Goals
  - MPC Integration for real-time control



THANK YOU FOR YOUR ATTENTION

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Project Info

Contact