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Thermocline Storage Design for AA-CAES Using Constrained Multi-Objective Optimization

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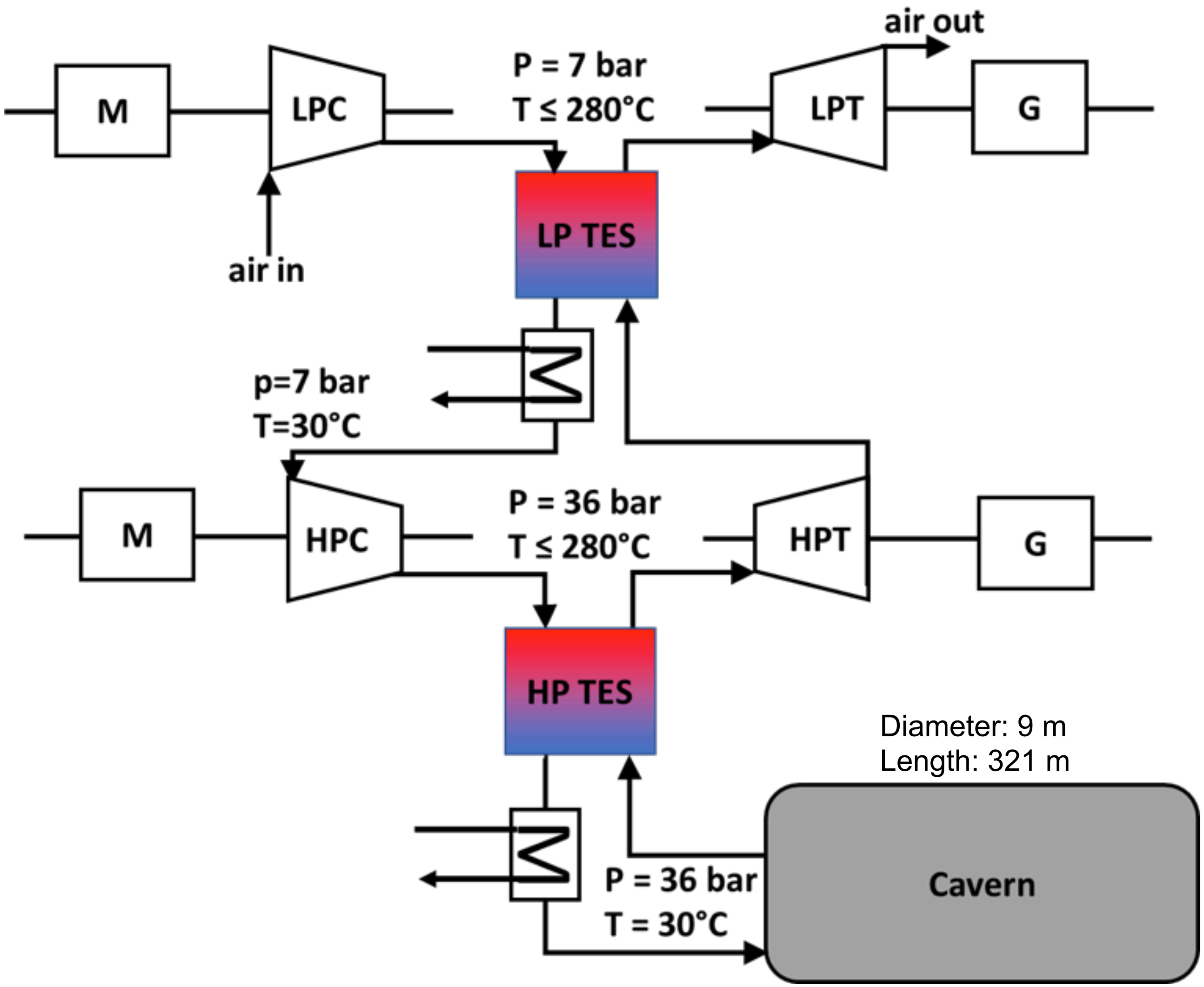
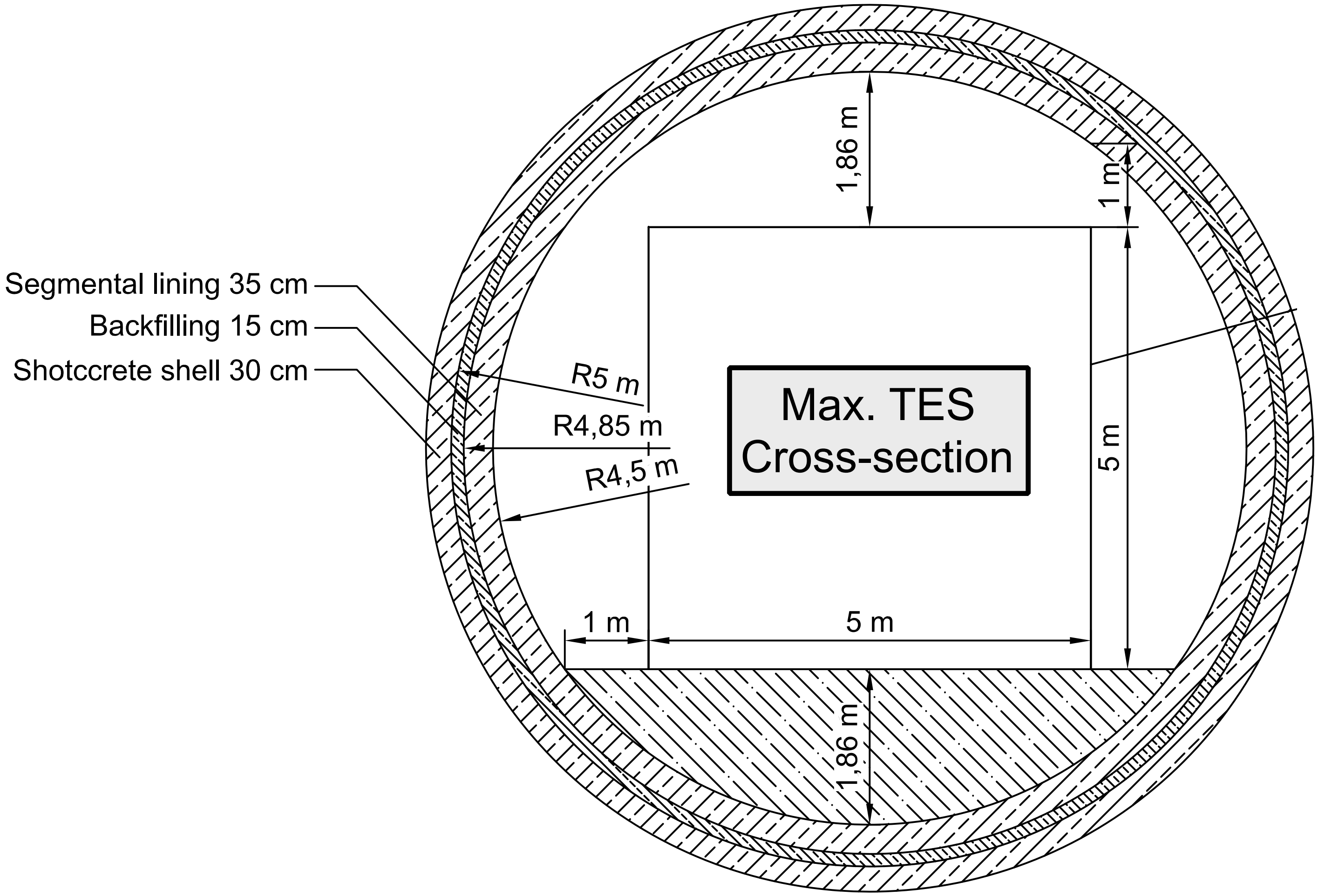
RICAS 2020

RICAS 5 MW_{el} Test Plant



RICAS Cavern



Storage Design

Specific question:
Given constraints on some of the dimensions, how to design the two TES for RICAS test plant?

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General question:
How to design TES for any application?

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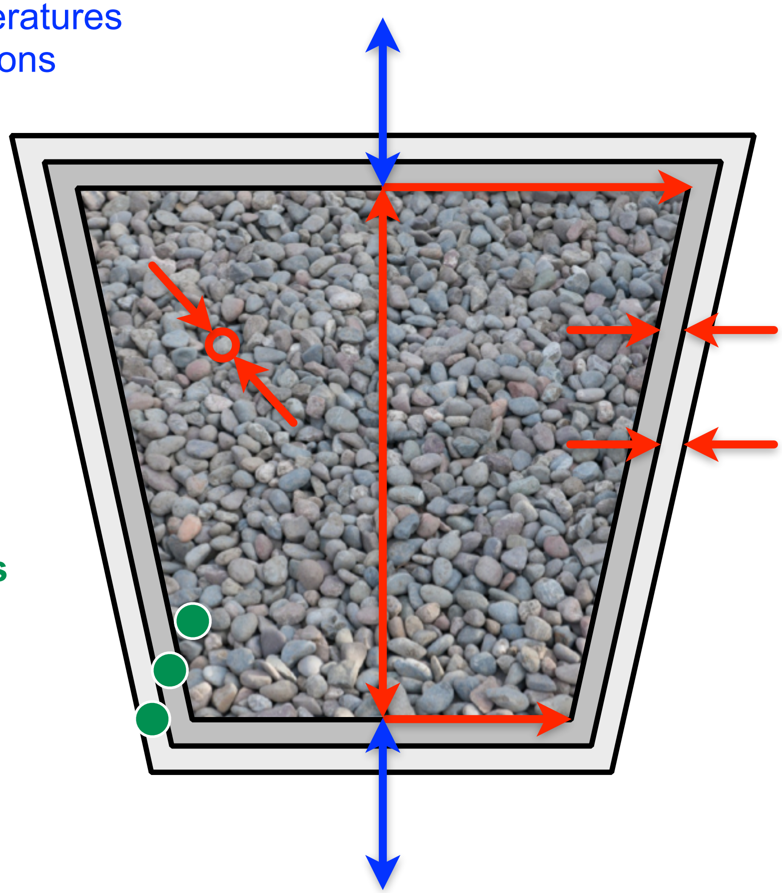
Storage Design

Operational parameters
- Charging/discharging mass flows
- Charging/discharging temperatures
- Charging/discharging durations
- Pressure

Geometrical parameters
- Storage height
- Storage top/bottom radii
- Structural thicknesses
- Insulation thicknesses
- Rock diameter
- Porosity



Thermophysical parameters
- Specific heat capacities
- Thermal conductivities
- Densities
- Viscosity

Performance parameters
- Fully charged capacity
- Net discharged energy
- Utilization factor
- Outflow temperature changes
- Energy/exergy efficiencies
- Material costs

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Determine…

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Such that attain or maximize/minimize…

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Thermophysical parameters
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Old design method
- Brute-force approach (run through all combinations)
- Prohibitively expensive (combinatorial explosion)

Determine…

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- Storage height
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New design method
- Constrained multi-objective optimization
- Pareto front (efficiency vs. material costs)
- Significantly faster than old method

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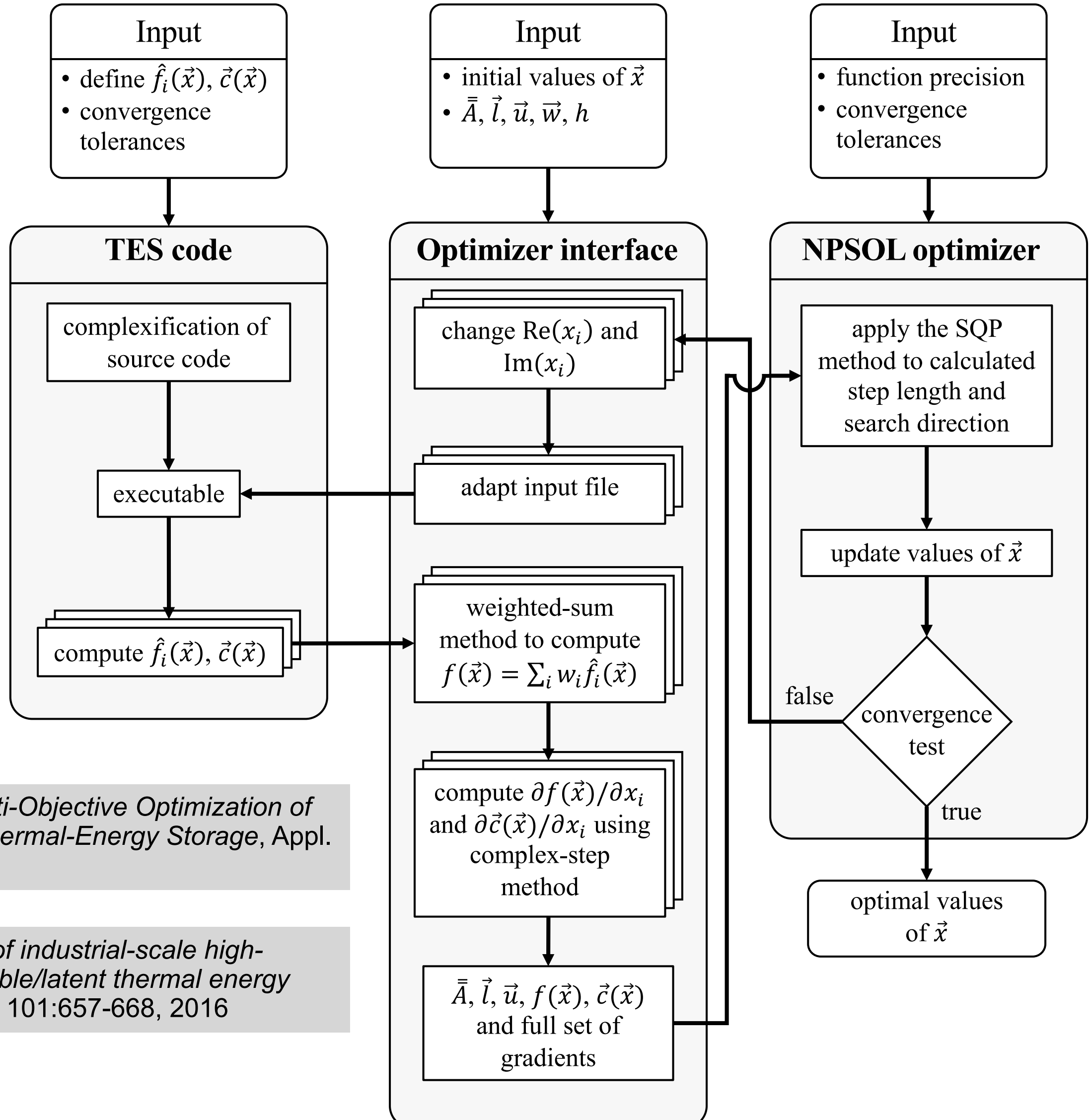
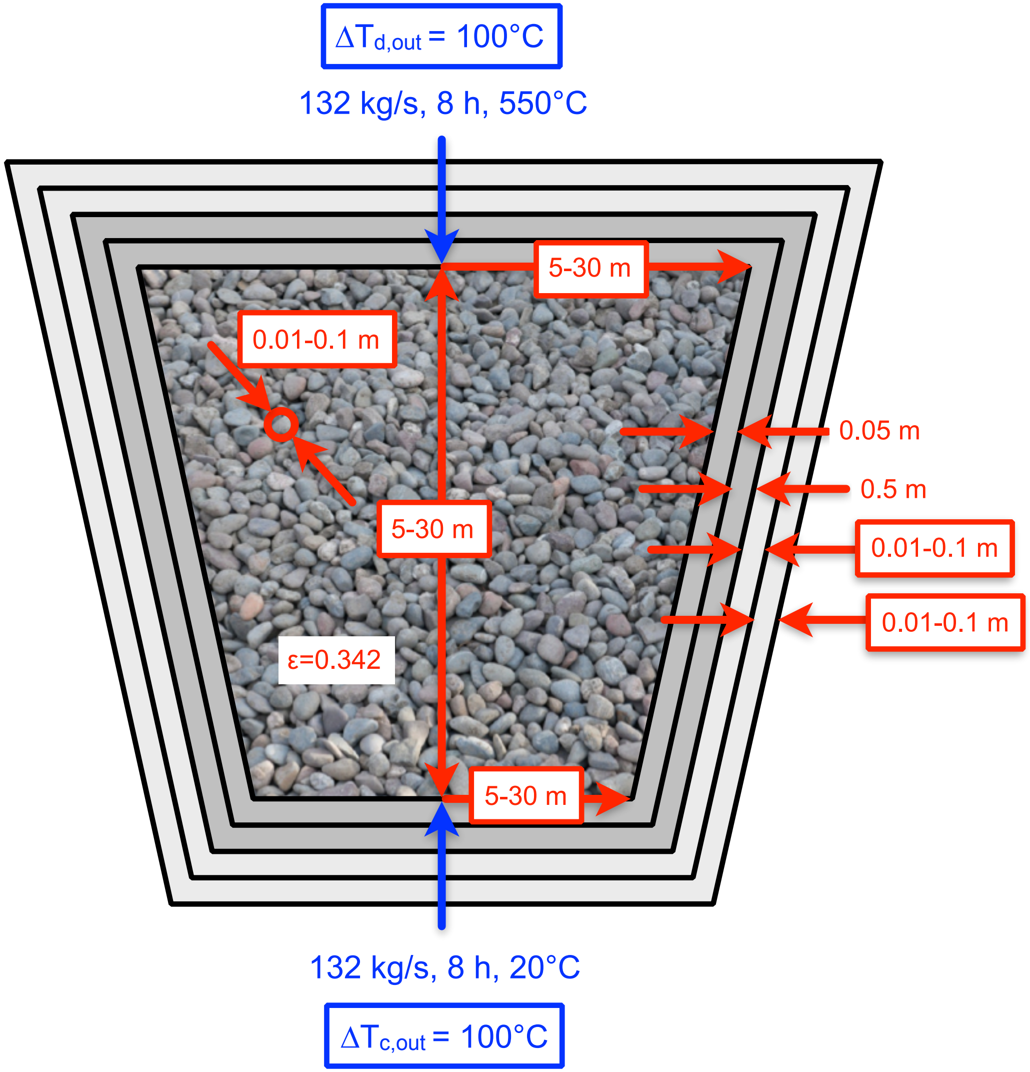
Optimization Method



Marti et al., *Constrained Multi-Objective Optimization of Thermocline Packed-Bed Thermal-Energy Storage*, Appl. Energy, 216:694-708, 2018

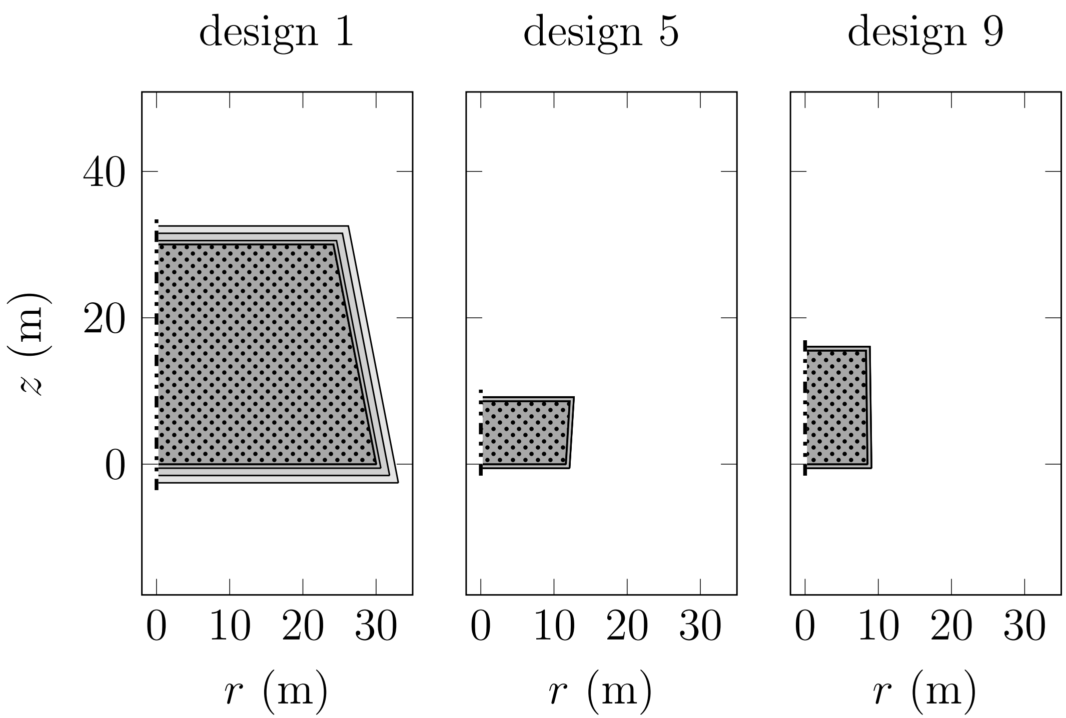
Geissbühler et al., *Analysis of industrial-scale high-temperature combined sensible/latent thermal energy storage*, Appl. Thermal Eng., 101:657-668, 2016

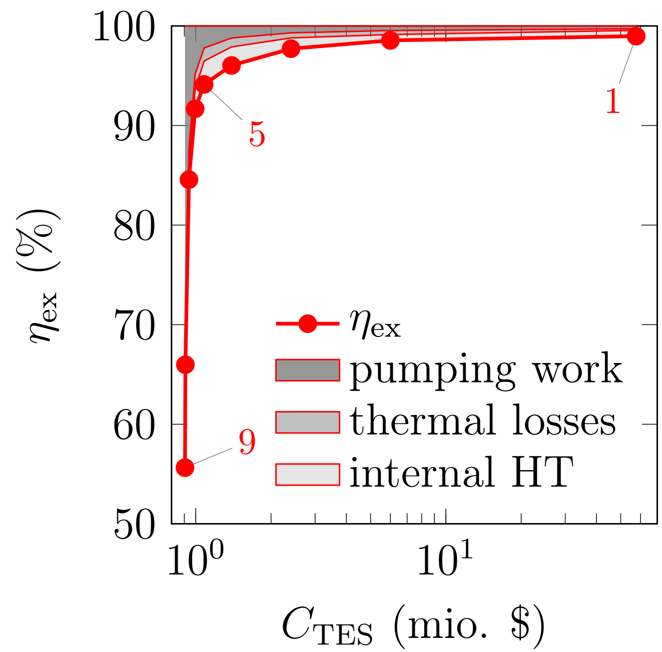
Example



$\Delta T_{d,out}$ = 100°C
132 kg/s, 8 h, 550°C
5-30 m
0.01-0.1 m
0.05 m
0.5 m
5-30 m
0.01-0.1 m
0.01-0.1 m
ε=0.342
5-30 m
132 kg/s, 8 h, 20°C
$\Delta T_{c,out}$ = 100°C

Example

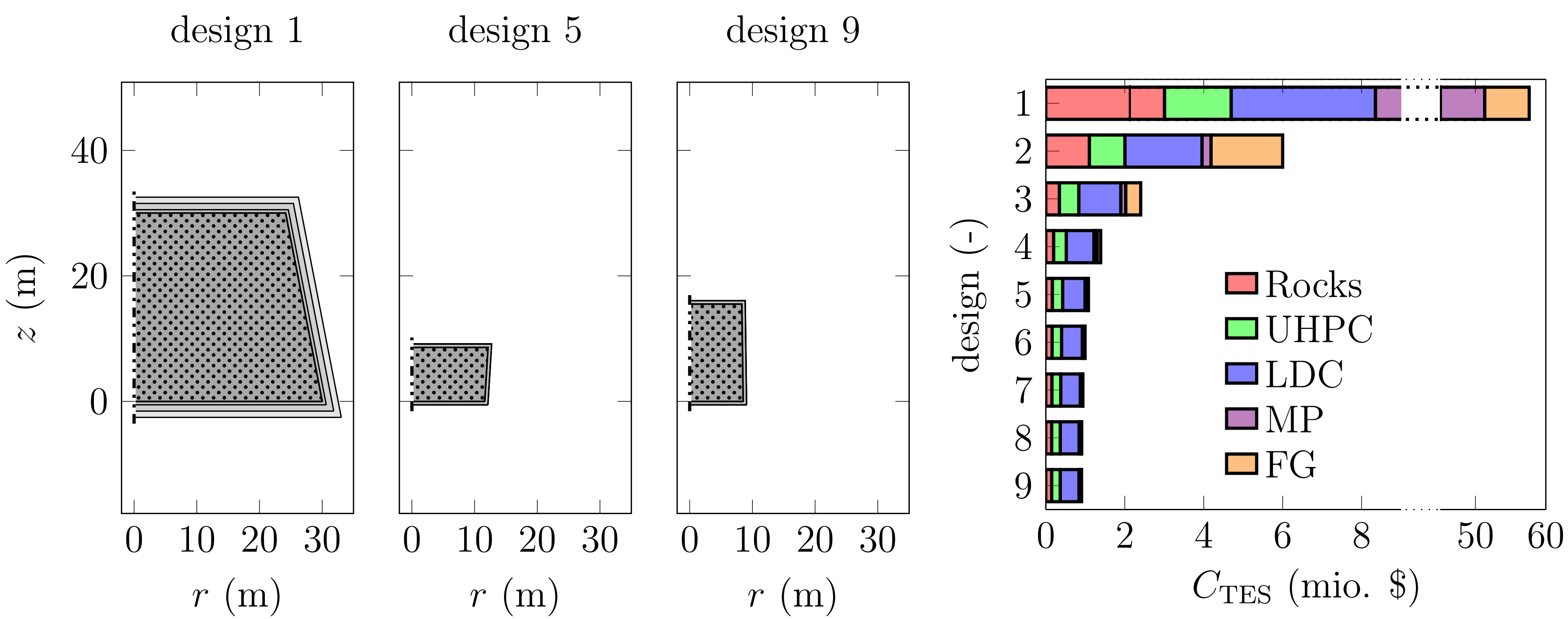




$$f = \omega(1-\eta_{\mathrm{ex}}) + (1-\omega)\frac{C_{\mathrm{TES}}}{C_{\mathrm{TES,ref}}} \qquad C_{\mathrm{TES}} = \sum_{i=1}^{N_m} c_i V_i$$

Design	1	2	3	4	5	6	7	8	9
ω	1.0	0.99	0.95	0.8	0.5	0.2	0.05	0.01	0.0

Example



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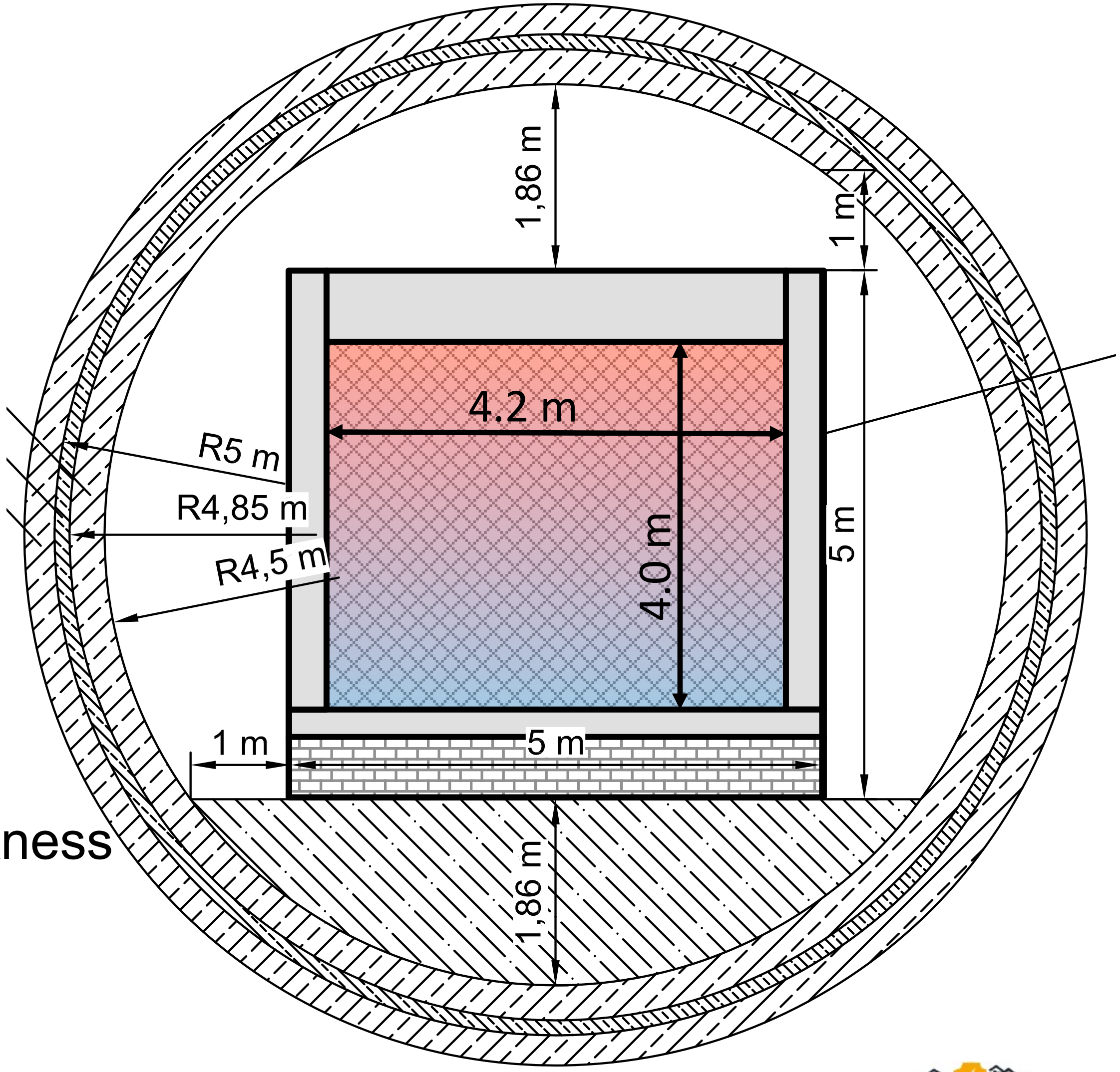
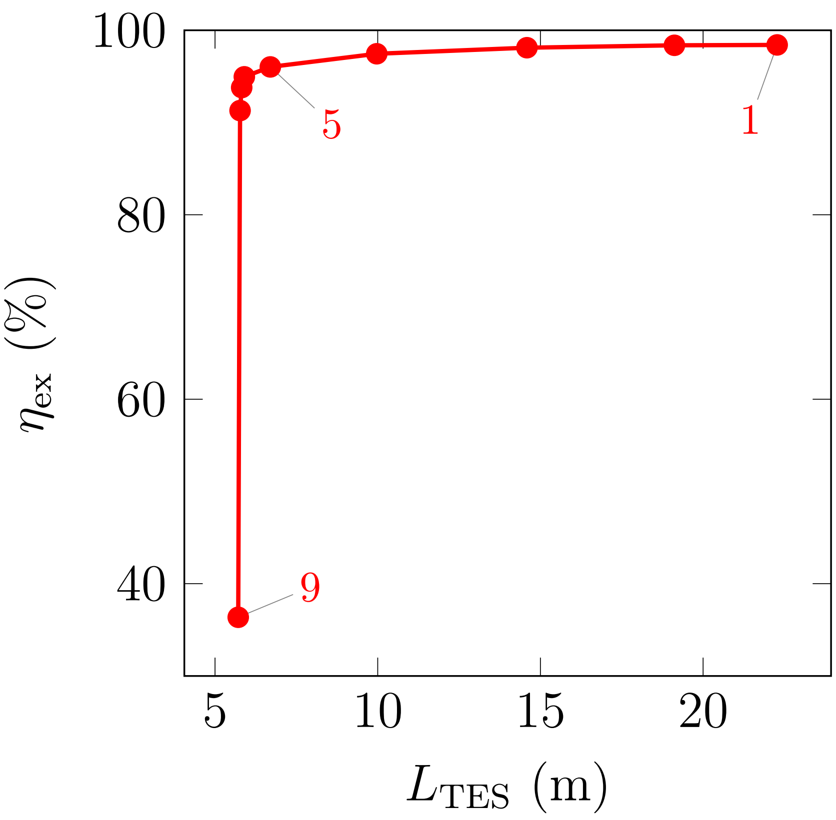
RICAS TES 1

- Fixed parameters:
  - Packed bed:
    - Height: 4.0 m
    - Width: 4.2 m
  - Structure/insulation:
    - UHPC: 0.01 m
    - LDC: 0.1 m
    - FG: 0.29 m
- Variable parameters:
  - Packed bed: Length
  - Insulation: Cover thickness

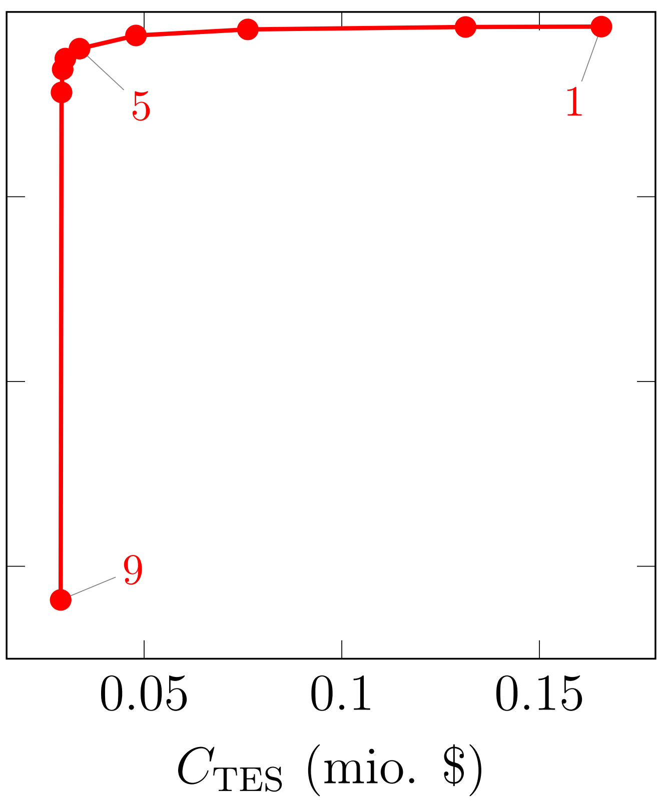


RICAS TES 1

Exergy efficiency as function of TES length



Exergy efficiency as function of TES material costs



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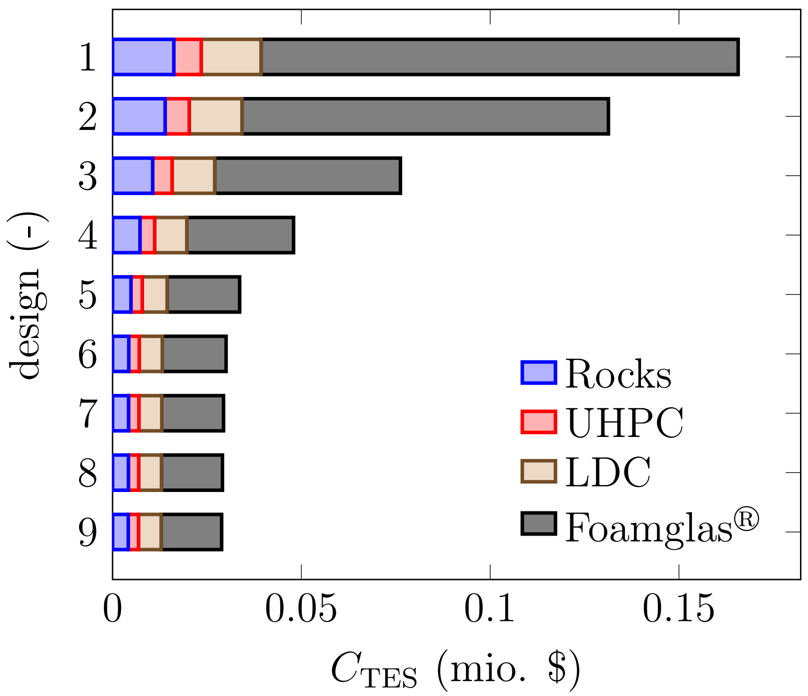
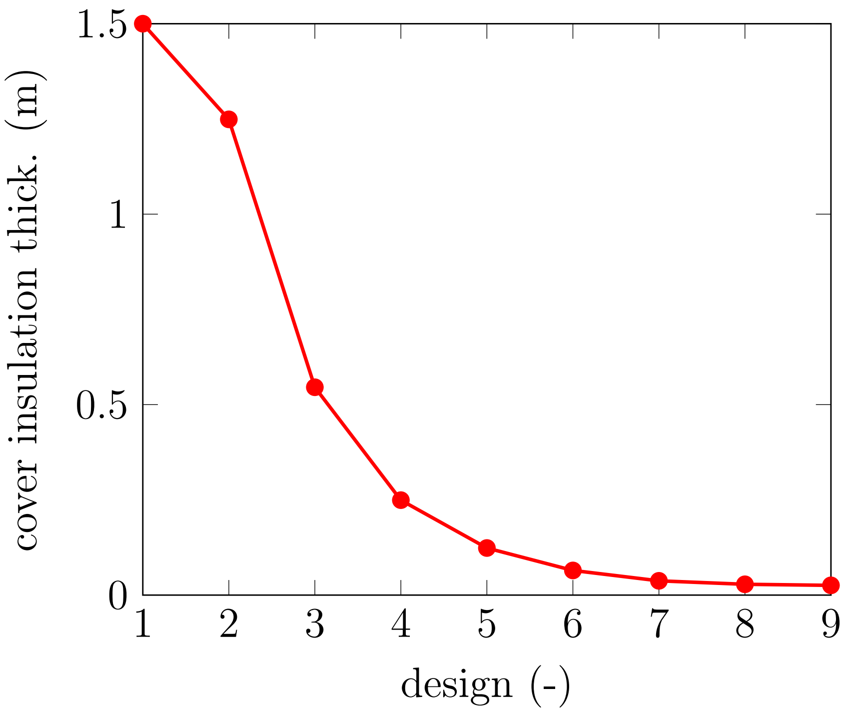
RICAS TES 1

Cost breakdown

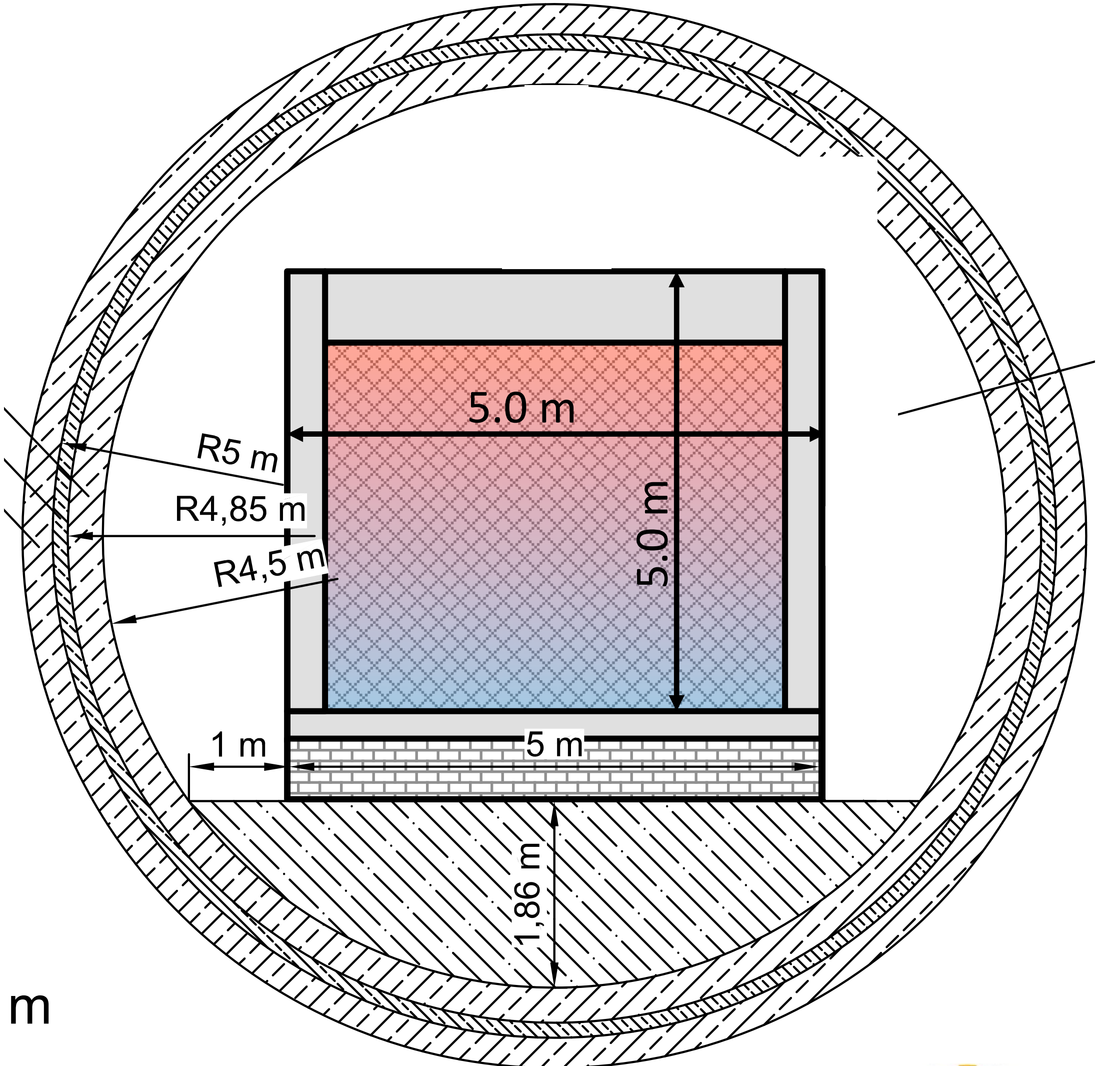


Thickness of cover insulation



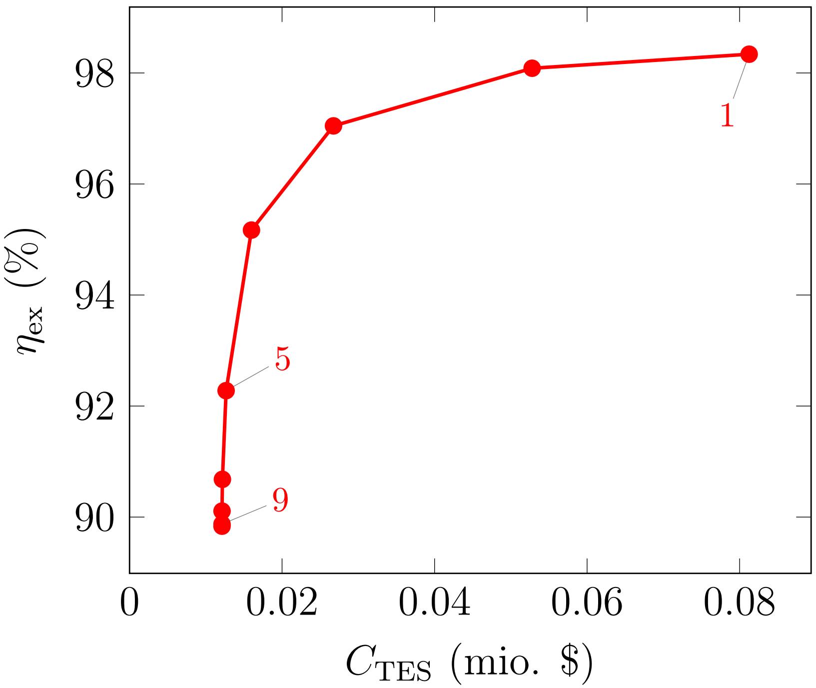
RICAS TES 2

- Fixed parameters:
  - Structure/insulation:
    - UHPC: 0.01 m
    - LDC: 0.1 m
- Variable parameters:
  - Packed bed:
    - Length, height
    - Width
  - Insulation:
    - Cover thickness
    - Side thicknesses
- Constraints:
  - TES height, width: 5.0 m

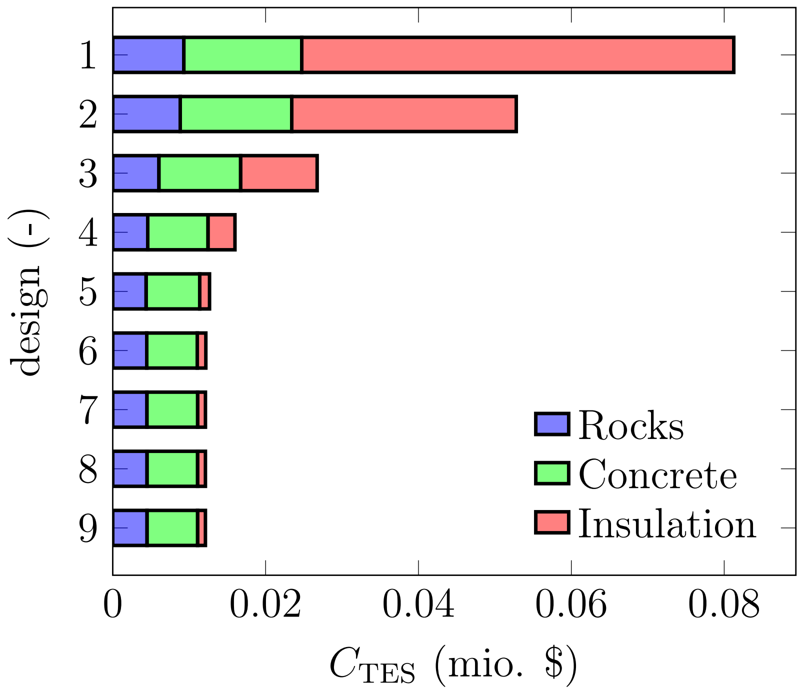


RICAS TES 2

Exergy efficiency as function of TES material costs



Breakdown of TES material costs



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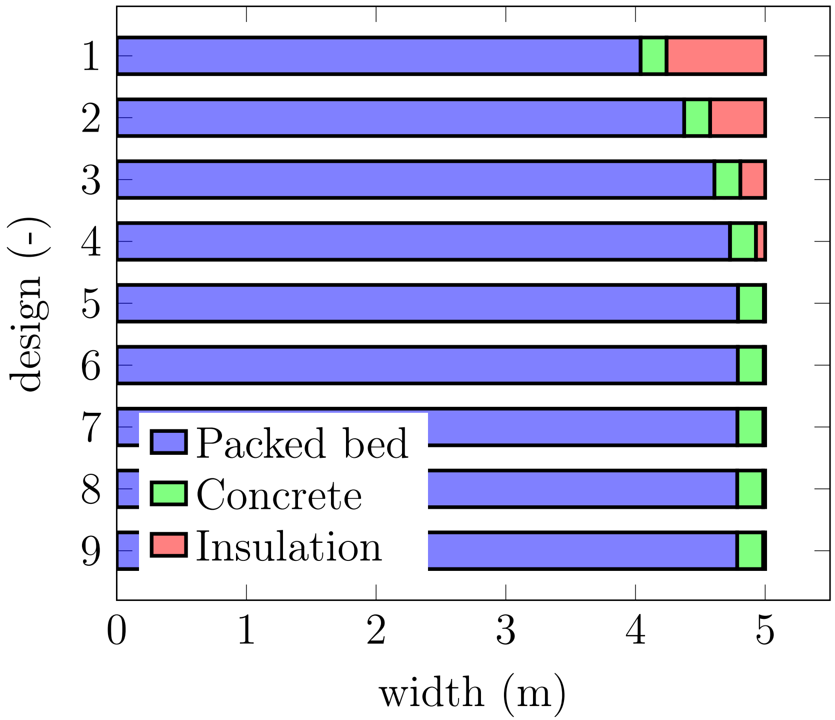
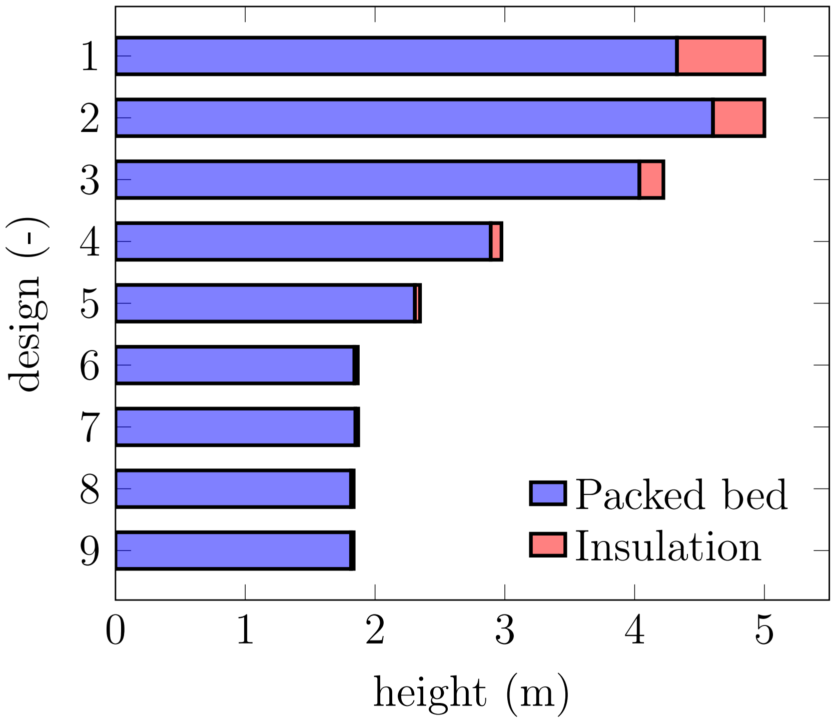
RICAS TES 2

Width breakdown



Height breakdown



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Conclusions

- Design of TES for practical applications can be viewed as constrained optimisation problem
- Presented method allows identifying TES design with maximum exergy efficiency for given material cost
- Applied to TES design in AA-CAES caverns, where constraints are imposed by tunnel cross section

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