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Flexibility potential analysis with quantifiable KPIs assessment for energy sector coupling leveraging advanced thermal storage solutions

Yangzhe Chen, Thomas Ohlson Timoudas, Qian Wang

Acknowledgments

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HYSTORE
Hybrid Services from Advanced Thermal Energy Storage Systems

Swedish Energy Agency

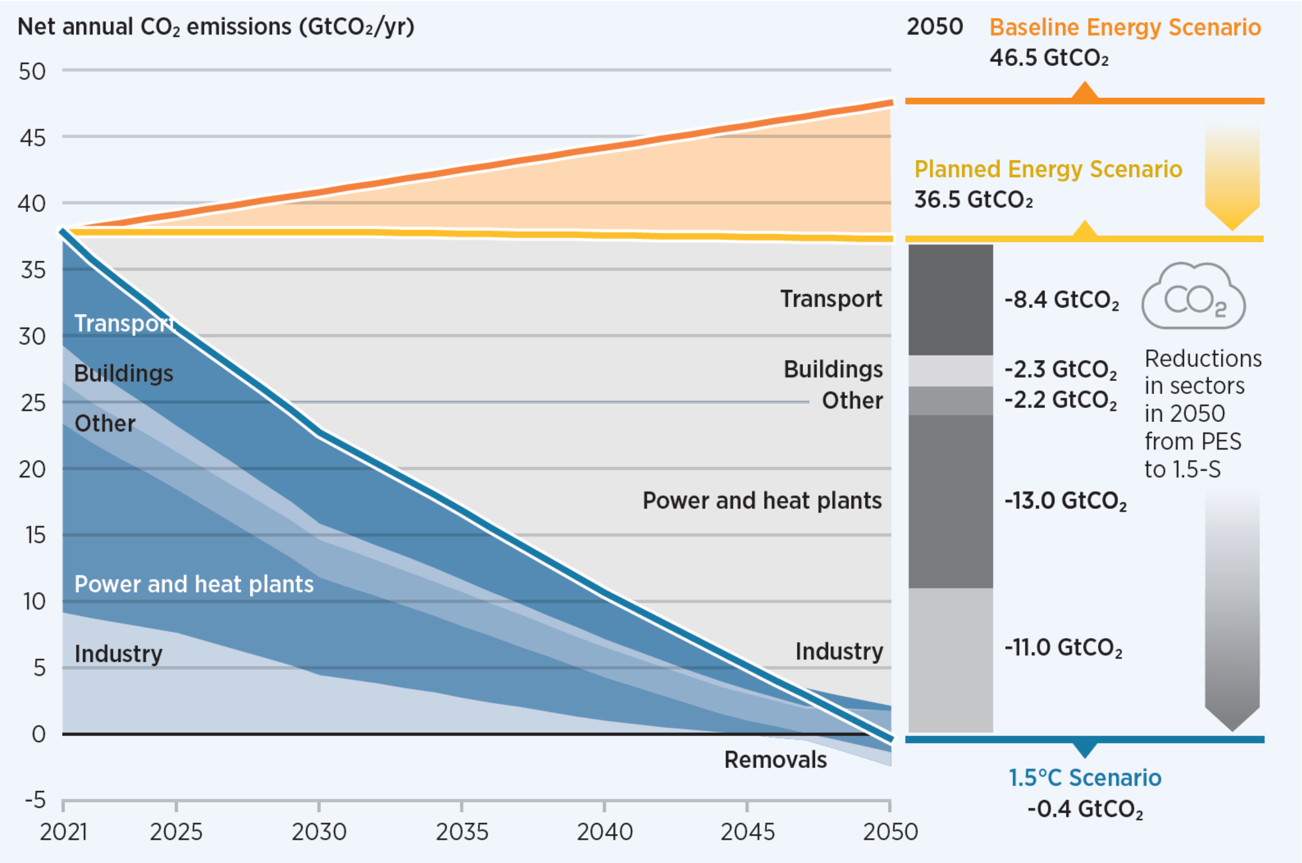
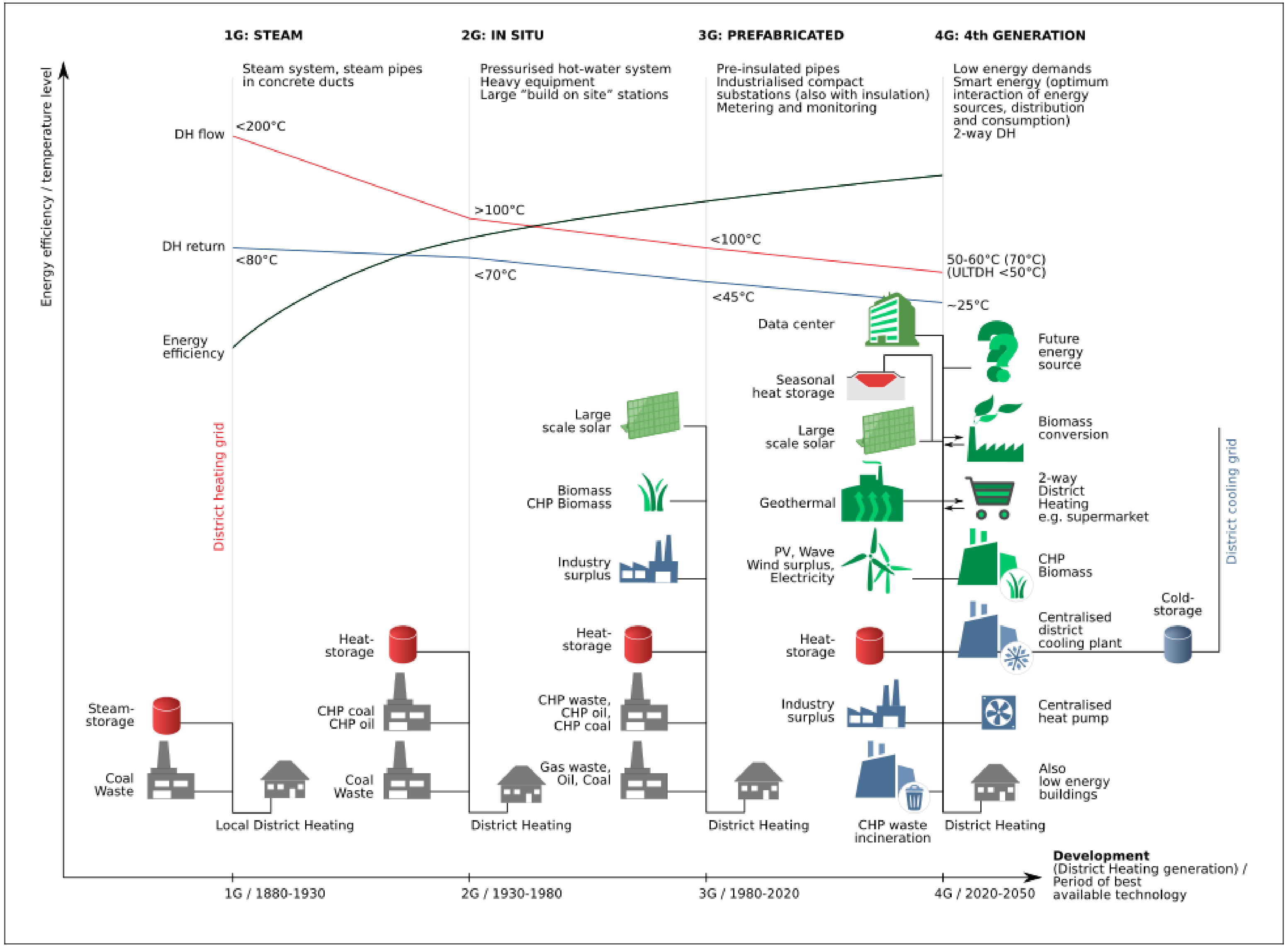


Figure 1: Global reduction in energy-related CO2 emissions needed by 2050 to achieve the 1.5°C climate target (IRENA, 2021a)

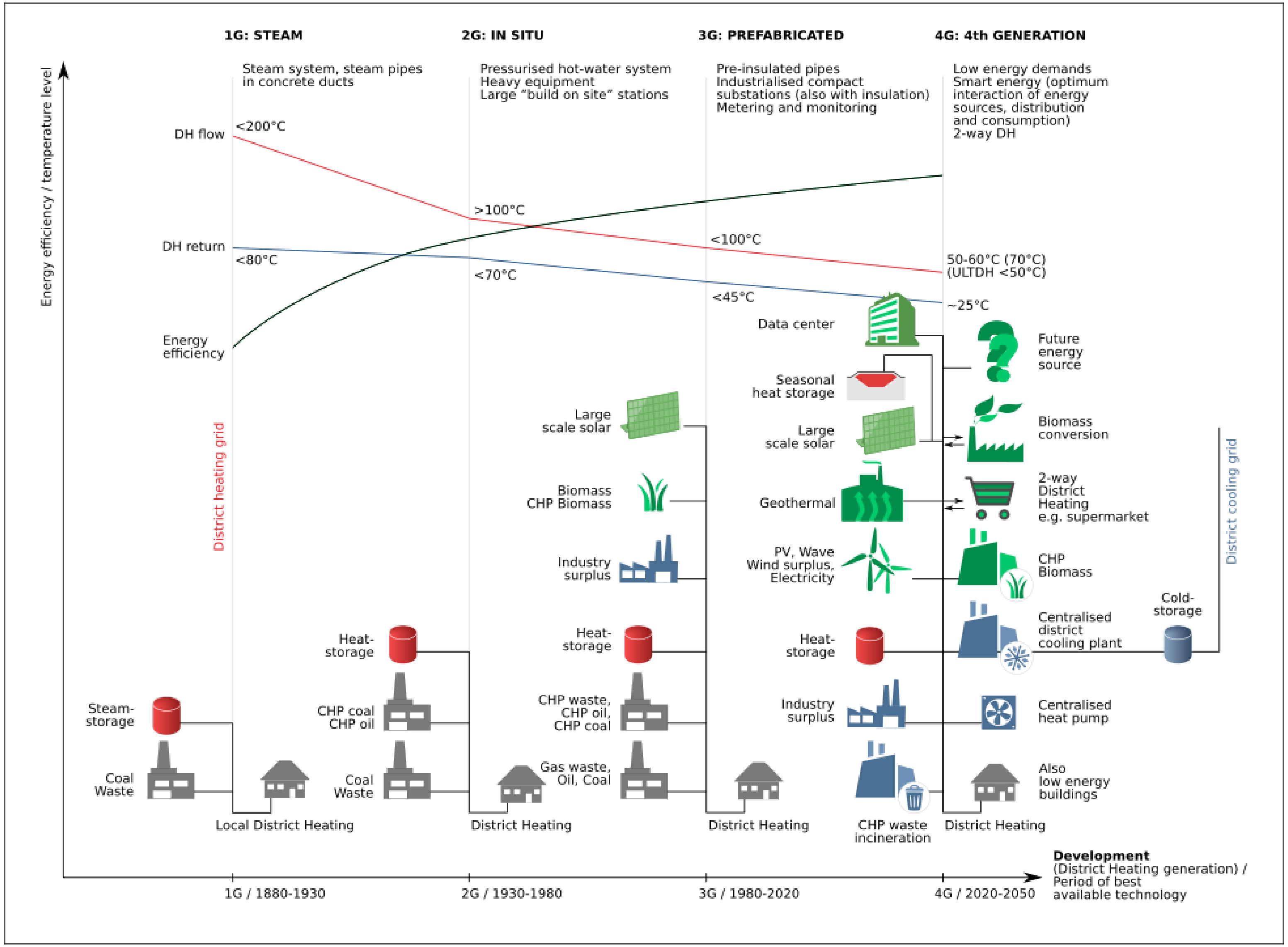
- Expansion of distributed energy resources (e.g., PV, storages…)
- End-use sectors hold huge potential for emission reduction through renewables and other low-carbon sources
- Future energy systems are supposed to be flexible



As DH transitioning to 4th generation:

- Higher energy efficiency;
- Integration of renewables;
- Bi-directional DH
- **Storage techniques**

Figure 2: The four different generations of conventional district heating systems and their energy sources.



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Sensible storage
(e.g. Water tank)

Latent storage
(e.g. PCM, TCM)

Figure 2: The four different generations of conventional district heating systems and their energy sources.

- Thermal energy storage (TES) plays a key role in building active energy management.
- The performance of water tank is limited (capacity & volumne).
- Phase Change Material (PCM) energy storage systems take advantages of the sensible and latent heat, which can further increase system efficiency and reduce the space.

Typical PCM profile

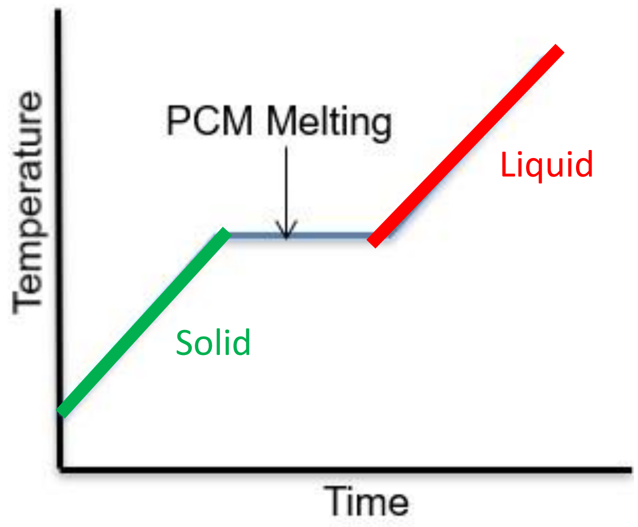

Figure 3: Theoretical performance of PCM

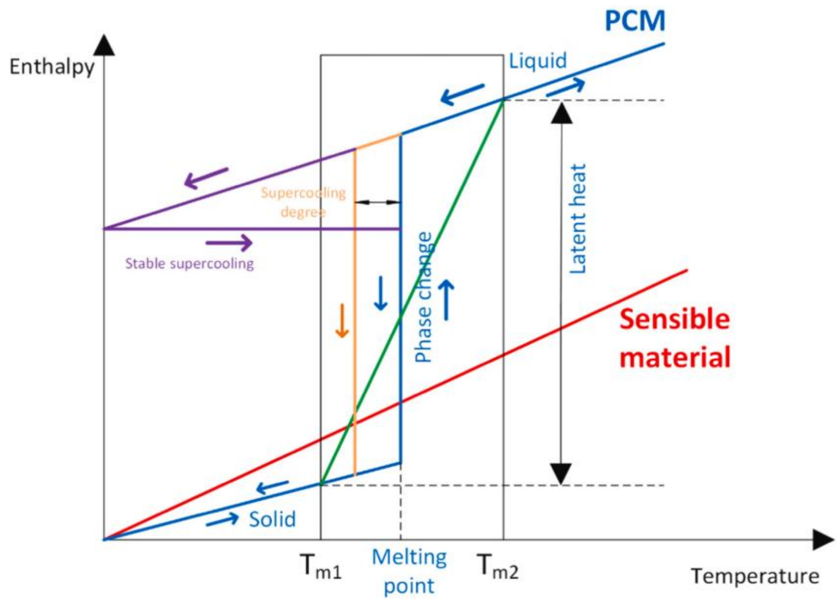

Figure 4: PCM Enthalpy change with temperature (Kong et al., 2022)

Objectives

1. Assess the performance of integrating advanced storages (PCM) in DH;
2. Quantify and analyze the flexibility potential.

PCM Material - RT65

Important properties	Values
Phase change margin [°C]	58-65
Heat storage capacity ±7.5% [kJ/kg]	150 (from 55 to 72 °C) / 42 Wh/kg
Specific heat capacity [kJ/kg·K]	2
Volume expansion [%]	11.3
Density solid [kg/l]	0.88
Density liquid [kg/l]	0.78
Max operation temperature [°C]	85
Heat conductivity (both phases) [W/(m·K)]	0.2

Figure 4: RT 65 from RUBITHERM®

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84 kJ/kg for water when ΔT=20 °C

Figure 4: RT 65 from RUBITHERM®

Enthalpy change in both melting and congealing

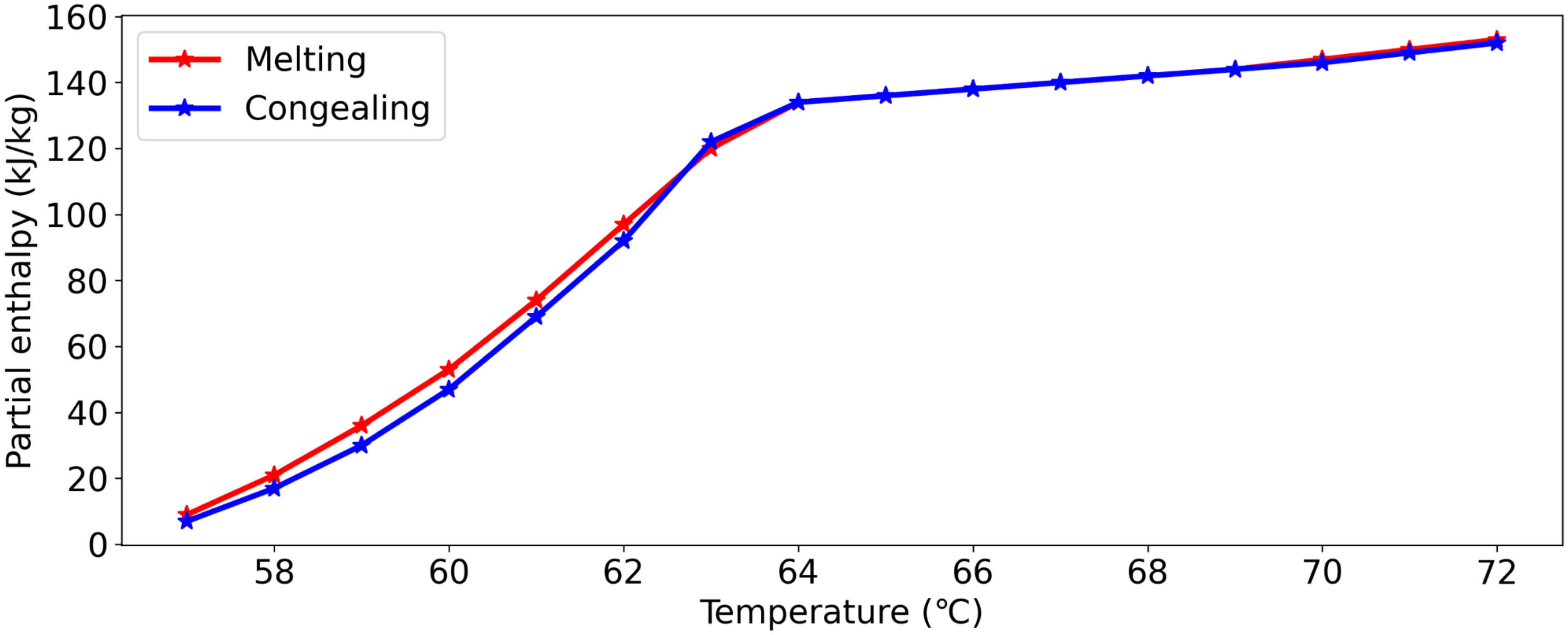


Figure 5: RT 65 enthalpy change in both melting and congealing process

Flexibility KPIs

Names	Equations	Ref.
Flexibility factor (FF)	$FF_P = \frac{\int_{lp} P\,dt - \int_{hp} Pdt}{\int_{lp} P\,dt + \int_{hp} Pdt}$	(Péan et al., 2019)
Shifting efficiency (η_shift)	$\eta_{shift} = \frac{-\Delta l_{heat\ discharged}}{\Delta l_{heat\ charged}}$	(Le Dréau & Heiselberg, 2016)

FF: the ability of shifting load to low-penalty period, [-1, 1];

η_shift: the load reduction ratio during active demand response, [0, 1].

Use case

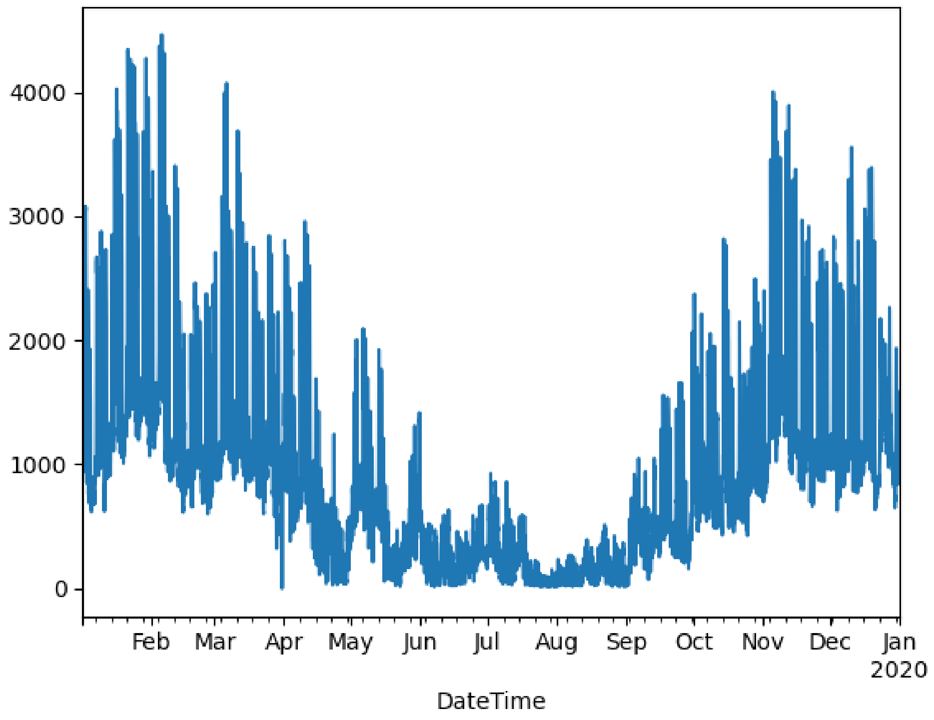


Figure 6: Load profile of the selected Scandinavian building district

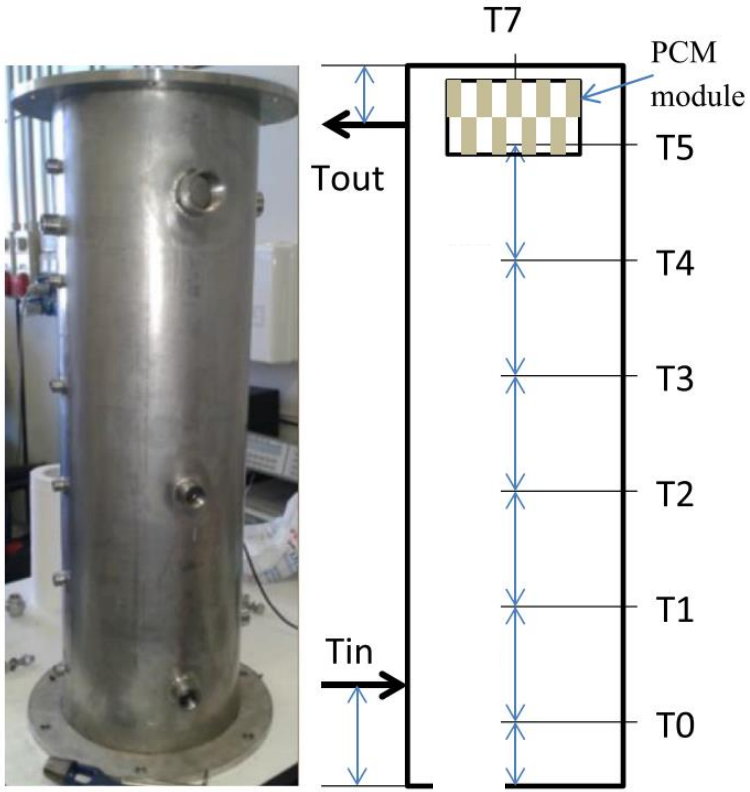
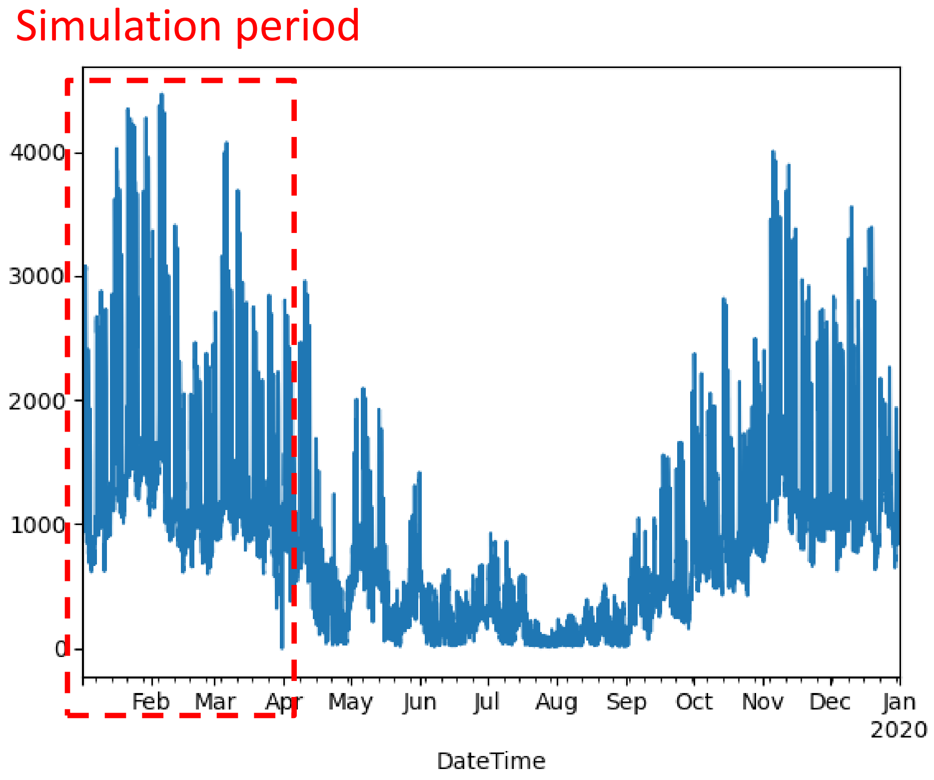


Figure 7: Scenario of integrating PCM with water tank

Use case



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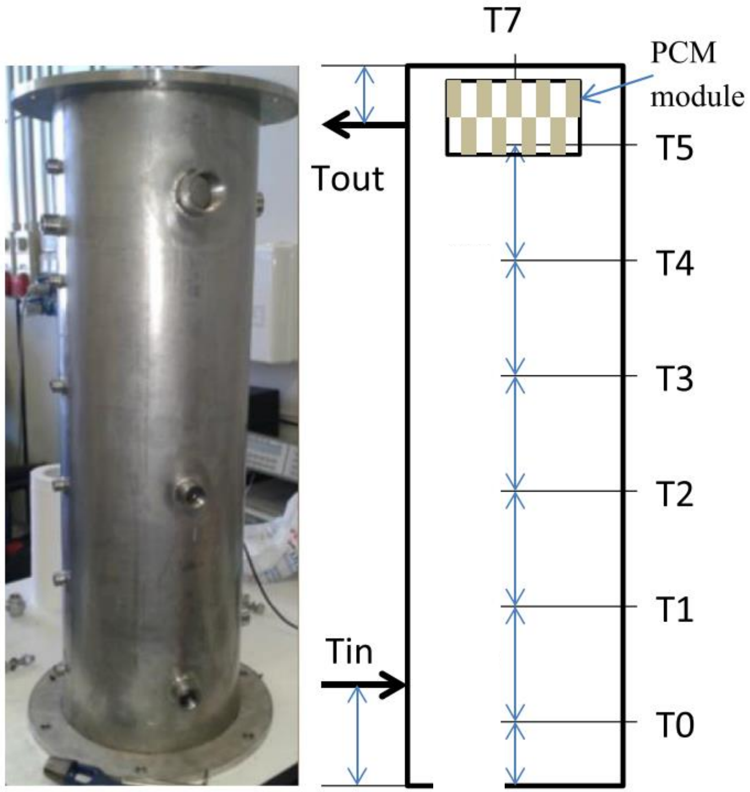


Figure 7: Scenario of integrating PCM with water tank

Results – Flexibility KPIs and performance evaluation

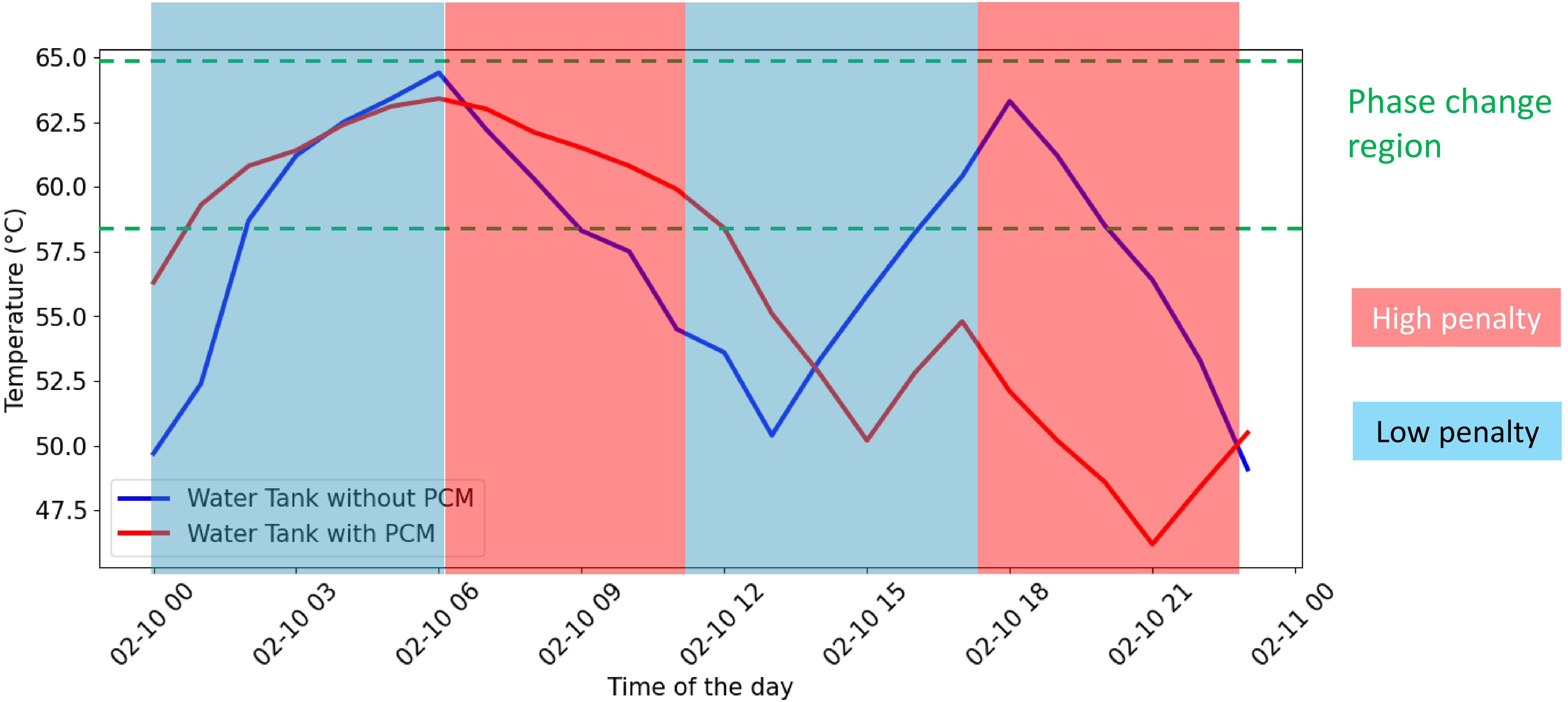
Scenario A: DH integrated with water tank without PCM

Scenario B: DH integrated with water tank with PCM

Phase change region: 58-65 °C

	Scenario A	Scenario B
Mean temp in TES [°C]	45	57
STD of temp in TES [°C]	6	9
Average discharging time of a day [h]	9	11
FF [-]	0.76	0.80
η_shift [%]	26	30

Results – Temperature profile in a typical day



Conclusions

1. TES with PCM yields a longer cycle of discharging for around 2 hours on a typical day.

2. The performance of TES-PCM in terms of FF and η_shift indicates that PCM has a substantial positive impact on demand-side flexibility.

3. One limitation is that the granularity of PCM model needs to be improved.

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THANK YOU FOR YOUR ATTENTION!

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