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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

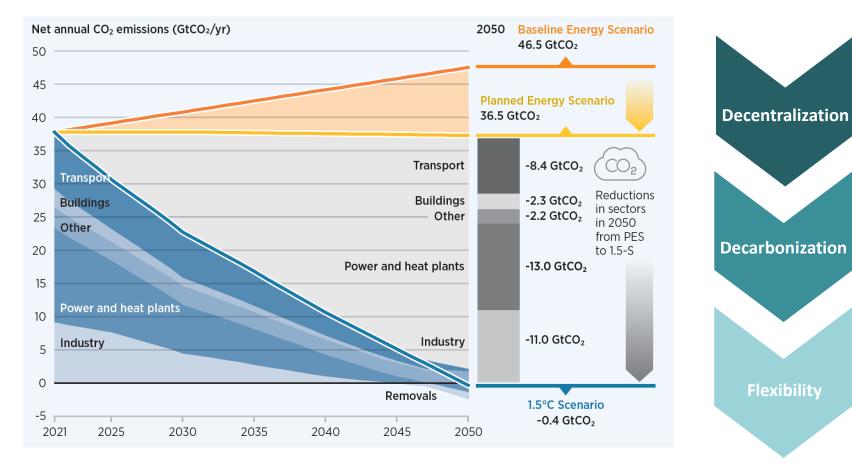
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## 





**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...)

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- End-use sectors hold huge potential for emission reduction through renewables and other lowcarbon sources
- Future energy systems are supposed to be flexible





1G: STEAM **3G: PREFABRICATED** 4G: 4th GENERATION 2G: IN SITU Pressurised hot-water system Low energy demands Steam system, steam pipes Pre-insulated pipes Energy efficiency / temperature level in concrete ducts Heavy equipment Industrialised compact Smart energy (optimum interaction of energy substations (also with insulation) Large "build on site" stations Metering and monitoring sources, distribution and consumption) 2-way DH <200°C DH flow >100°C <100°C DH return <80°C 50-60°C (70°C) (ULTDH <50°C) <70°C <45°C ~25°C Data center Future Energy efficiency energy source Seasonal heat storage Large Biomass grid scale solar Large conversion scale solar grid District heating Ð 2-wav District Biomass CHP Biomass Geothermal Heating • e.g. supermarket PV, Wave Industry CHP Wind surplus, surplus Biomass Electricity Coldstorage Centralised district cooling plant Heat-Heat-Heatstorage storage storage CHP waste, Industry Centralised 63 Steam-CHP coal CHP oil, surplus heat pump storage CHP oil CHP coal Gas waste, Also Coal Coal Oil, Coal low energy buildings Waste Waste Local District Heating District Heating District Heating CHP waste District Heating incineration Development (District Heating generation) / ➤ Period of best 1G / 1880-1930 2G / 1930-1980 3G / 1980-2020 4G / 2020-2050 available technology

As DH transitioning to 4<sup>th</sup> 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.

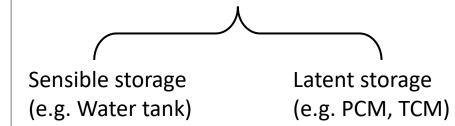




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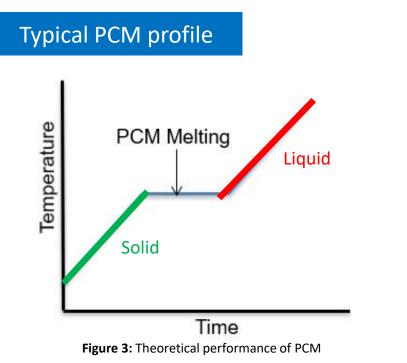


**Figure 2:** The four different generations of conventional district heating systems and their energy sources.





- 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.



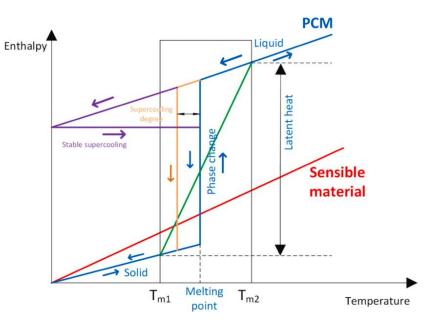


Figure 4: PCM Enthalpy change with temperature (Kong et al., 2022)





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 $\pm$ 7.5% [kJ/kg]	150 (from 55 to 72 $^{\circ}{ m C}$ ) / 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 <sup>·</sup> K)]	0.2



Figure 4: RT 65 from RUBITHERM®





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[W/(m <sup>·</sup> K)]	24 kl/kg for water when AT-



Figure 4: RT 65 from RUBITHERM®

84 kJ/kg for water when  $\Delta T=20 \ ^{\circ}C$ 





#### Enthalpy change in both melting and congealing

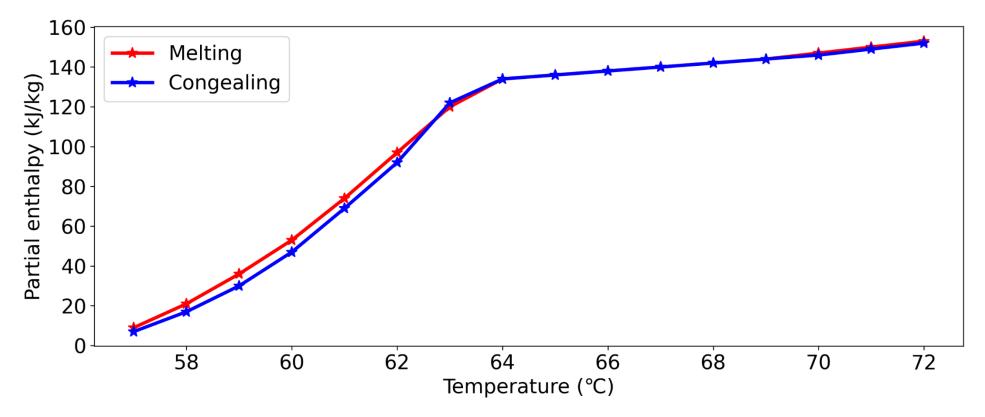


Figure 5: RT 65 enthalpy change in both melting and congealing process





#### **Flexibility KPIs**

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

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

 $\eta_{shift}$ : the load reduction ratio during active demand response, [0, 1].



Use case



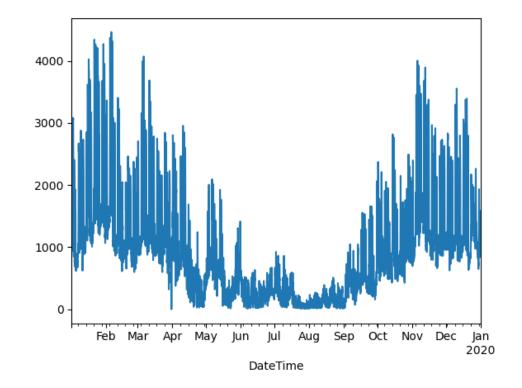


Figure 6: Load profile of the selected Scandinavian building district

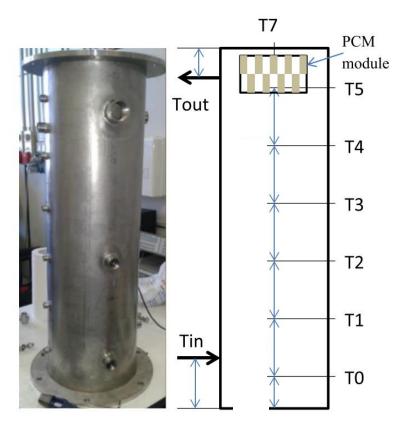


Figure 7: Scenario of integrating PCM with water tank







#### Simulation period

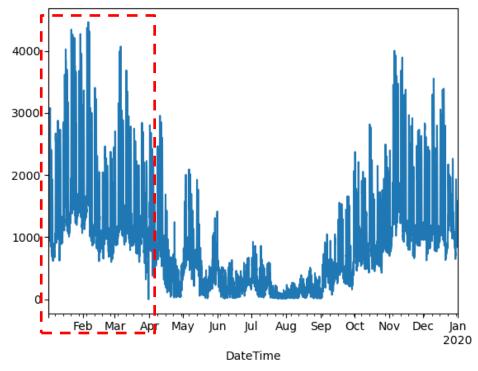


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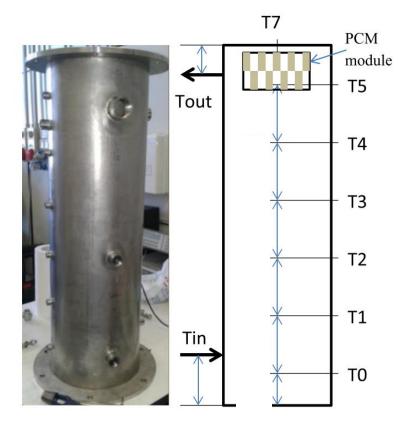


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### **Results – Flexibility KPIs and performance evaluation**

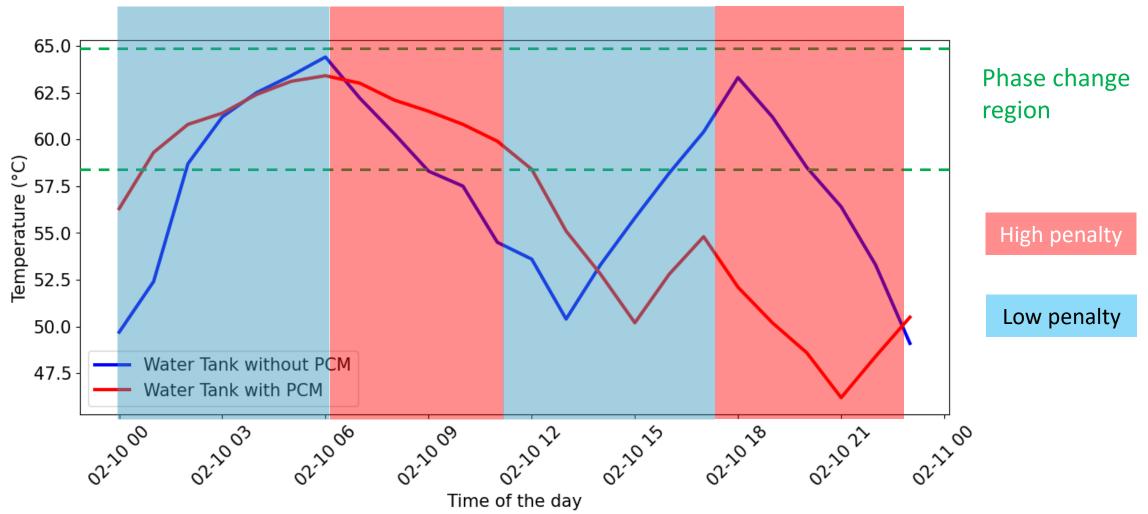
Scenario A: DH integrated with water tank without PCM Scenario B: DH integrated with water tank with PCM Phase change region: 58-65 °C

	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_ <i>shift</i> [%]	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  $\eta_{shift}$  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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