A Review of Thermal Energy Storage Systems with Salt Hydrate Phase Change Materials for Comfort Cooling

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Justin Ning-Wei Chiu, Dr. Viktoria Martin, and Prof. Fredrik Setterwall

Department of Energy Technology
Royal Institute of Technology (KTH)
Stockholm, Sweden

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Background

- Latent heat thermal energy storage (LHTES) with phase change materials (PCMs) : high energy storage density and small temperature change.
  - District cooling network
    → additional cooling power
  - Chiller based system
    → alleviate peak grid electricity
    → lower marginal electricity cost
    → Increase production efficiency
  - Free Cooling storage
    → night time storage, daytime use

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Methodology

- Salt hydrate based cold thermal energy storage systems for comfort cooling.
- Review of 100 papers focusing on enhancement of TES:
    - Phase Separation
    - Subcooling
    - Encapsulation
    - Heat Transfer Enhancement
    - Experimental and Numerical System Studies

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Phase Change Materials

Table 1 Comparison of Organic with Inorganic PCMs

	Organic	Inorganic	Eutectic
Pros	• Low Cost (120Euro/kWh) • Self nucleating • Chemically inert and stable • No phase segregation • Recyclable • Available in large temperature range	• Moderate cost (130 Euro/kWh) • High volumetric storage density (180-300 MJ/m³) • Higher thermal conductivity (0.6W/mK) • Non flammable • Low volume change	• Sharp melting point • Low volumetric storage density
Cons	• Flammable • Low thermal conductivity (0.2W/mK) • Low volumetric storage density (90-200 MJ/m³)	• Subcooling • Phase segregation • Corrosion of containment material	• Limited availability

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Phase Change Materials

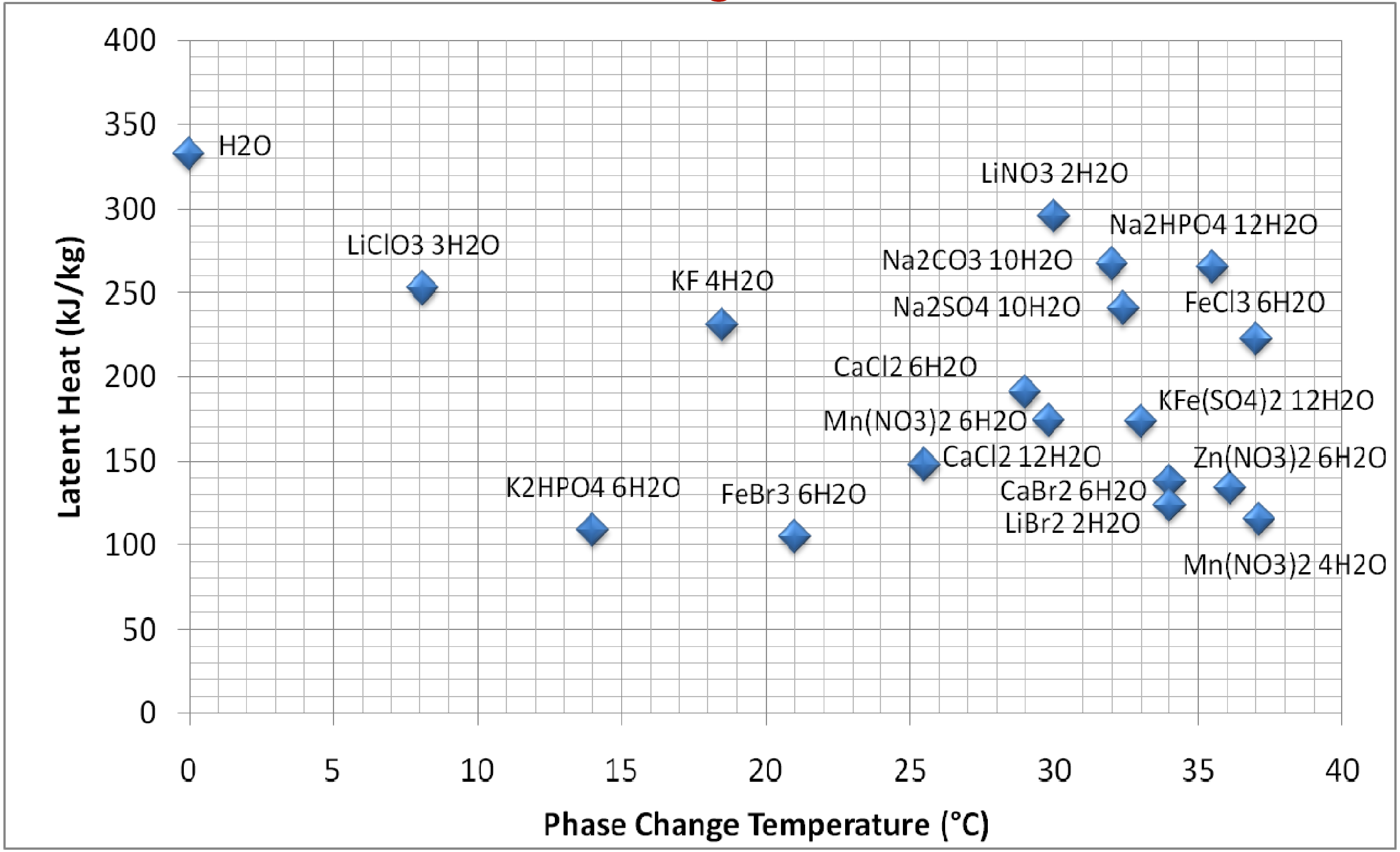


Figure 1 Analytical Grade Salt Hydrates

Phase Change Materials

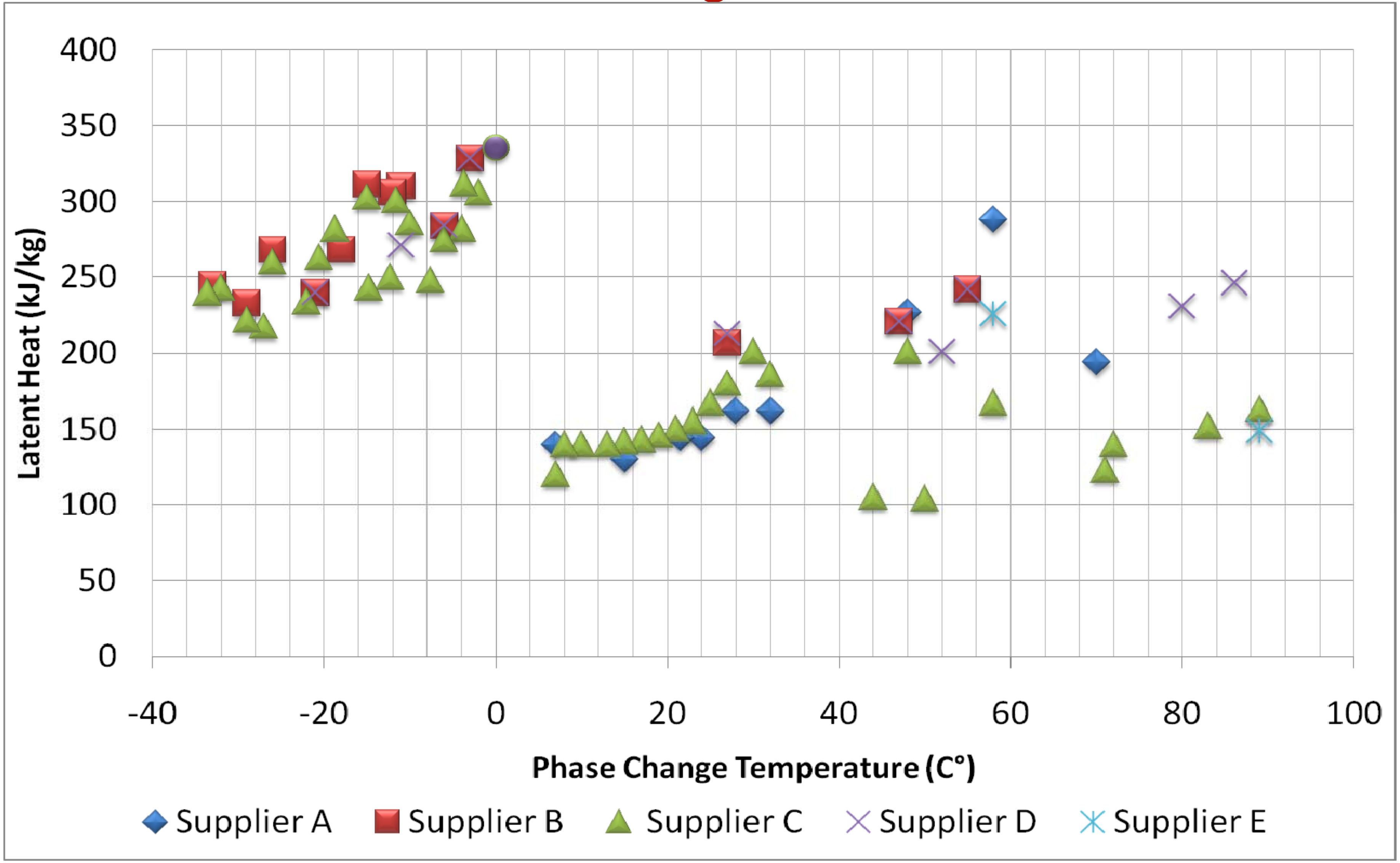
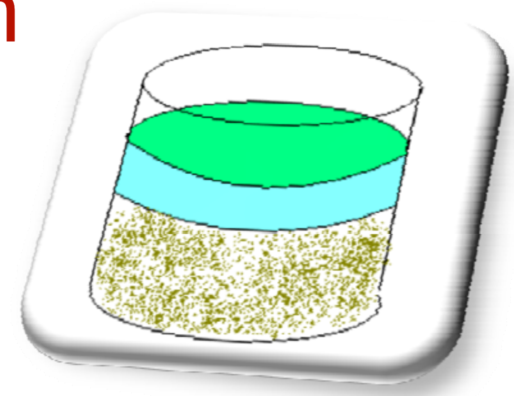


Figure 2 Commercialized Salt Hydrate Products

Thermal Energy Storage System Performance

-Phase Separation



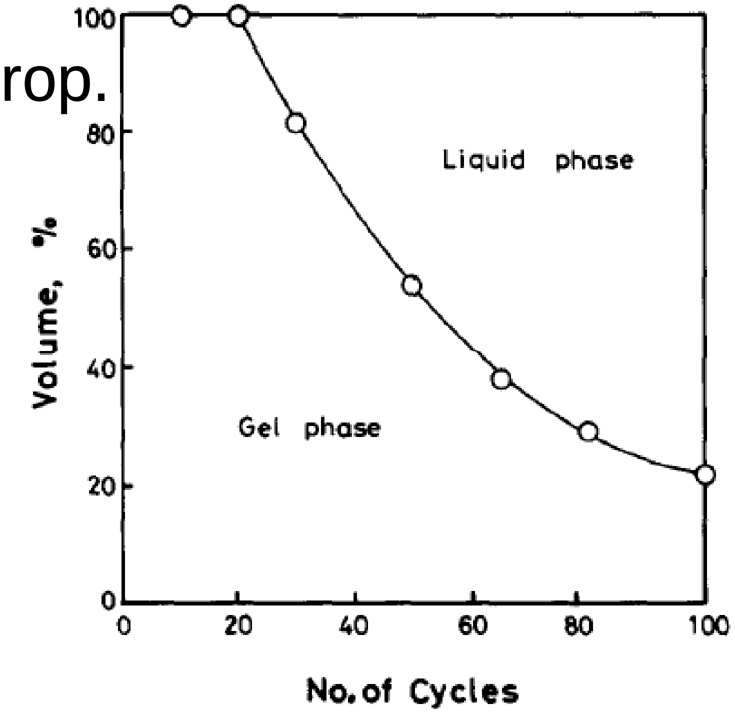
- **Incongruent Melting**

→ Gelling agents: bentonite, starch, cellulose, super absorbent copolymer, carboxymethyl cellulose, etc.

- 20%~35% latent enthalpy drop.

Artificial mixing heat storage system

-parasitic electricity load



Ryu et al. 1992

Thermal Energy Storage System Performance

-Subcooling

→Cold finger, porous heat exchange surface, and nucleating agents: carbon nanofibers, copper, titanium oxide, potassium sulfate, borax, etc.

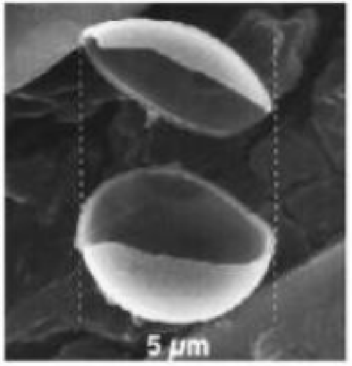
Supercooling range of the thickened PCMs with the respective nucleating agents

PCM	Thickener	T_m (°C)	Nucleating agent (size, μm)	Supercooling (°C) w/o nucleator	Supercooling (°C) w/nucleator
$Na_2SO_4 \cdot 10H_2O$	SAP	32	Borax (20×50–200×250)	15–18	3 –4
$Na_2HPO_4 \cdot 12H_2O$	SAP	36	Borax (20×50–200×250)	20	6 –9
			Carbon (1.5–6.7)		0 –1
			TiO_2 (2–200)		0 –1
			Copper (1.5–2.5)		0.5–1
			Aluminum (8.5–20)		3 –10
$CH_3COONa \cdot 3H_2O$	CMC	46	Na_2SO_4	20	4 –6
			$SrSO_4$		0 –2
			Carbon (1.5–6.7)		4 –7
$Na_2S_2O_3 \cdot 5H_2O$	CMC	57	K_2SO_4	30	0 –3
			$Na_2P_2O_7 \cdot 10H_2O$		0 –2

Ryu et al. 1992

•Subcooling reduced from 20°C to 2°C, 2°C = high efficiency loss.

Thermal Energy Storage System Performance
-Encapsulation



BASF

Serve as heat transfer surface, prevents PCM from reacting, and adds mechanical strength.

- **Macro encapsulation**: easy handling, but low IPF

  $H_{\text{spherical capsules}} > H_{\text{cylindrical}} > H_{\text{plate type}} > H_{\text{tubular capsules}}$

- **Micro encapsulation**: prevents phase separation, but has high production cost

- **Bulk storage**: no packaging cost and high storage density.

EPS

Thermal Energy Storage System Performance

-Heat Transfer Enhancement

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•Fins placed in the same direction as tubes for vertical tube setup: 90W/m²K and 250W/m²K

•Dispersion of aluminum and graphite

→1.6X to 20X

•Impregnation of PCM into a graphite matrix

→20X to 1000X

❑Today: **organic compounds**

→ Tomorrow: **salt hydrates**

Thermal Energy Storage System Performance
-Experimental and Numerical System Studies

•Space thickness, HTF entry temperature, encapsulation conductivity and solid phase PCM conductivity have significant influence on melting/ solidifying process.

•Passive walls with PCM : better performance than masonry wall of 5X thickness.

•Case study in Saudi Arabia: 23% to 40% cooling power reduction.

•Case study of office building in Stockholm: 5% to 30% reduction.

•Peak cooling demand may be reduced by 40% to 90% with **proactive control** and weather forecasts.

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Conclusions

- Techno-economical PCM systems: lower cost, higher power, and larger storage density
  - advanced material research: low subcooling, phase separation
  - system performance modeling, design optimization and experimental work
- Lack of accurate commercial PCM property→ discrepancies between design model and actual TES system.
- Move towards standardization of property measurement.

❑ Salt hydrate based TES seems to be one of the most promising technologies for integration in the built environment.

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Thank you

justin.chiu@energy.kth.se