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THERMAL ENERGY STORAGE FOR SUSTAINABLE FUTURE: IMPACT OF POWER ENHANCEMENT ON STORAGE PERFORMANCE

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Thermal Energy Storage

- Storage: relocates thermal load in time
  - Nominal power output → nominal efficiency
  - Load shift → low tariff cost, high chiller efficiency
  - Free cooling/waste heat, renewable sources→ sustainable future

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- **P**hase **C**hange **M**aterial: utilizes latent heat as storage
  - Latent heat→ high storage density
  - Small temperature swing, suitable phase change temperature→ tailored energy system

PCM Selection Criteria

- Match working temperature→ boundary conditions
- Material stability → life time
- System cost→ economics
- Environmental friendliness→ life cycle impact
- Phase change properties → power and capacity

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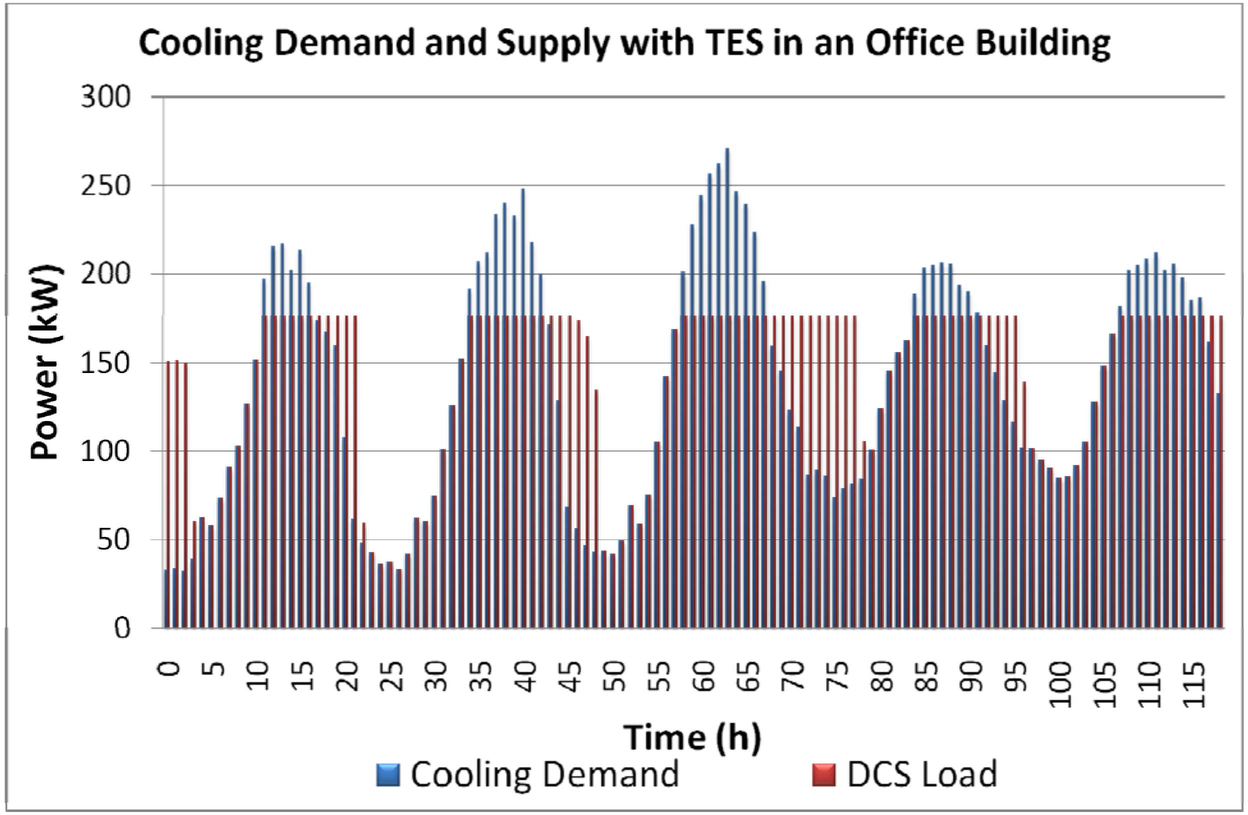
- Inorganic PCMs: subcooling
  - several K
- and low thermal conductivity
  - 0.2~0.7 W/m/K

Power Requirement

- Concerns in meeting fluctuating load demand



➢ Aim for power enhancement

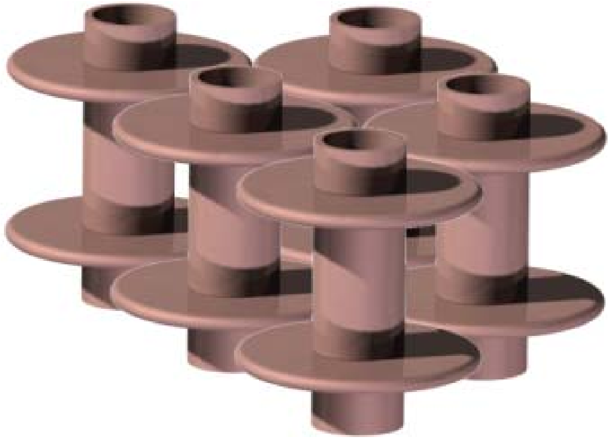
Power Enhancing Technologies

- Heat exchanger surface extension
  - Fins
  - Encapsulations
  - Metallic structures
  - ➢ 40-70W/m²K

- Thermal conductivity improvement
  - Metallic particles
  - Foams and matrices impregnation
  - ➢ up to 800W/m²K

➢ Study the impact of power enhancement on energy storage performance

Model



- Gelled salt hydrate
- Isotropic properties
- Symmetric model
- Constant heat exchanger wall temperature
- Adiabatic
- Equal distant fins and tubes
- Enthalpy method

$$Cp(T) = \begin{cases} Cp_{sol} \text{ if } T < Tm - dT \\ \dfrac{L(T)}{\Delta T} \text{ if } T \in [Tm - dT, Tm + dT] \\ Cp_{liq} \text{ if } T > Tm + dT \end{cases}$$

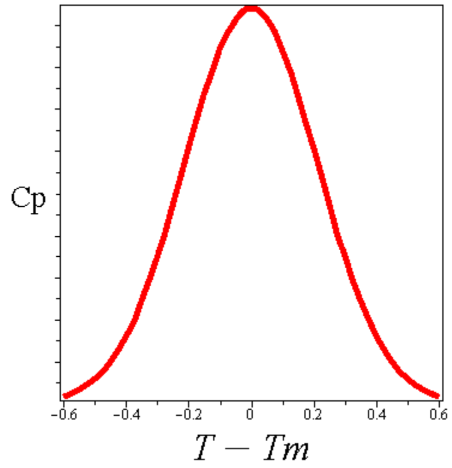
Model

Cp is thus expressed as

$$Cp(T) = H(Tm - T) \cdot Cp_{sol} + D(T) \cdot L + H(T - Tm) \cdot Cp_{liq}$$

with H, Heaviside function, and

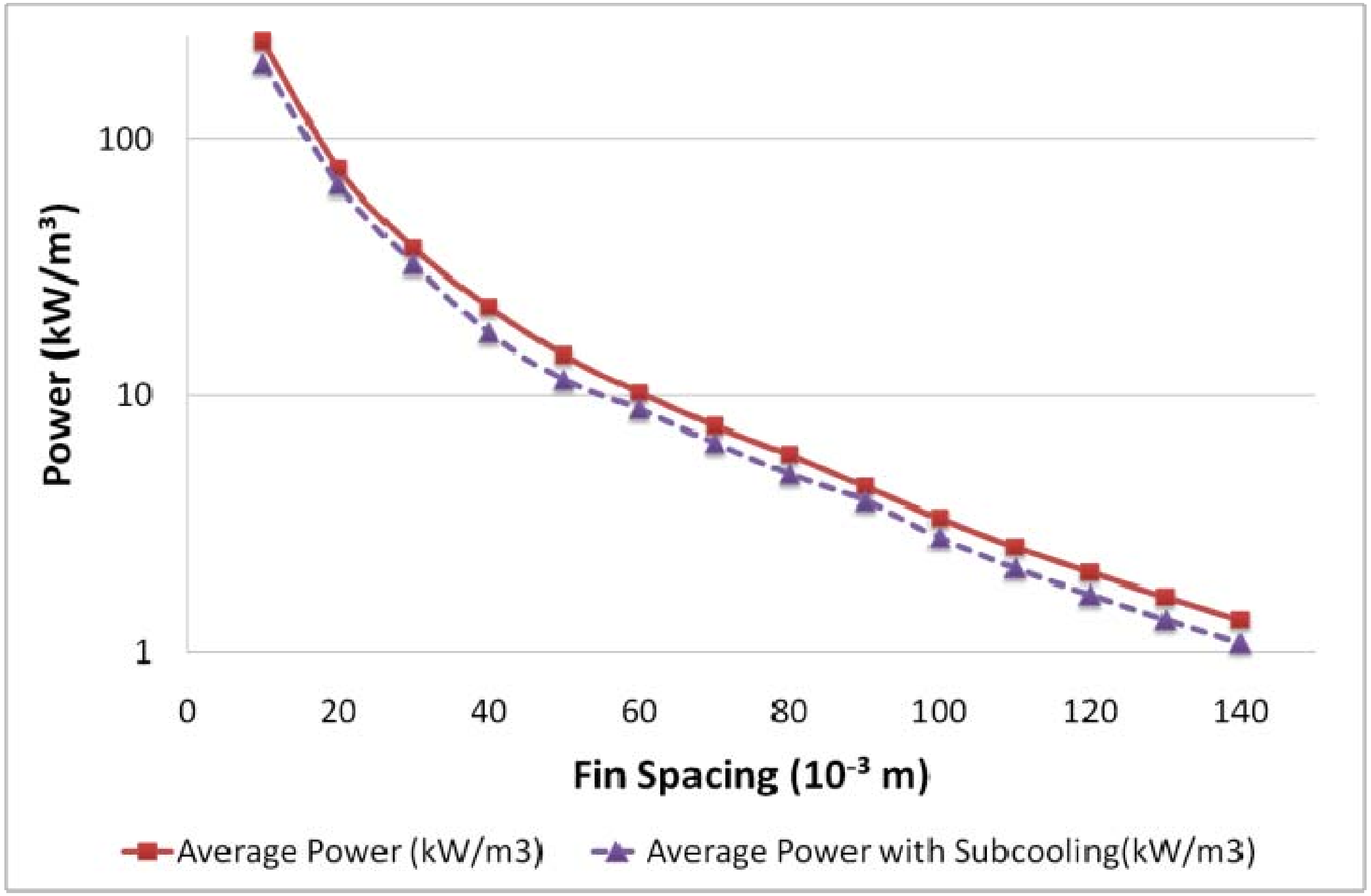
$$D(T) = \frac{dH}{dT} \cong \frac{e^{-\left(\frac{(T-Tm)^2}{b^2}\right)}}{\sqrt{\pi} \cdot b}$$



parameters are chosen to account for 1K phase change temperature range with latent heat peaking at phase change point

Results

- Power decreases exponentially as fin spacing widens
- Power is reduced by 16% with 1K subcooling



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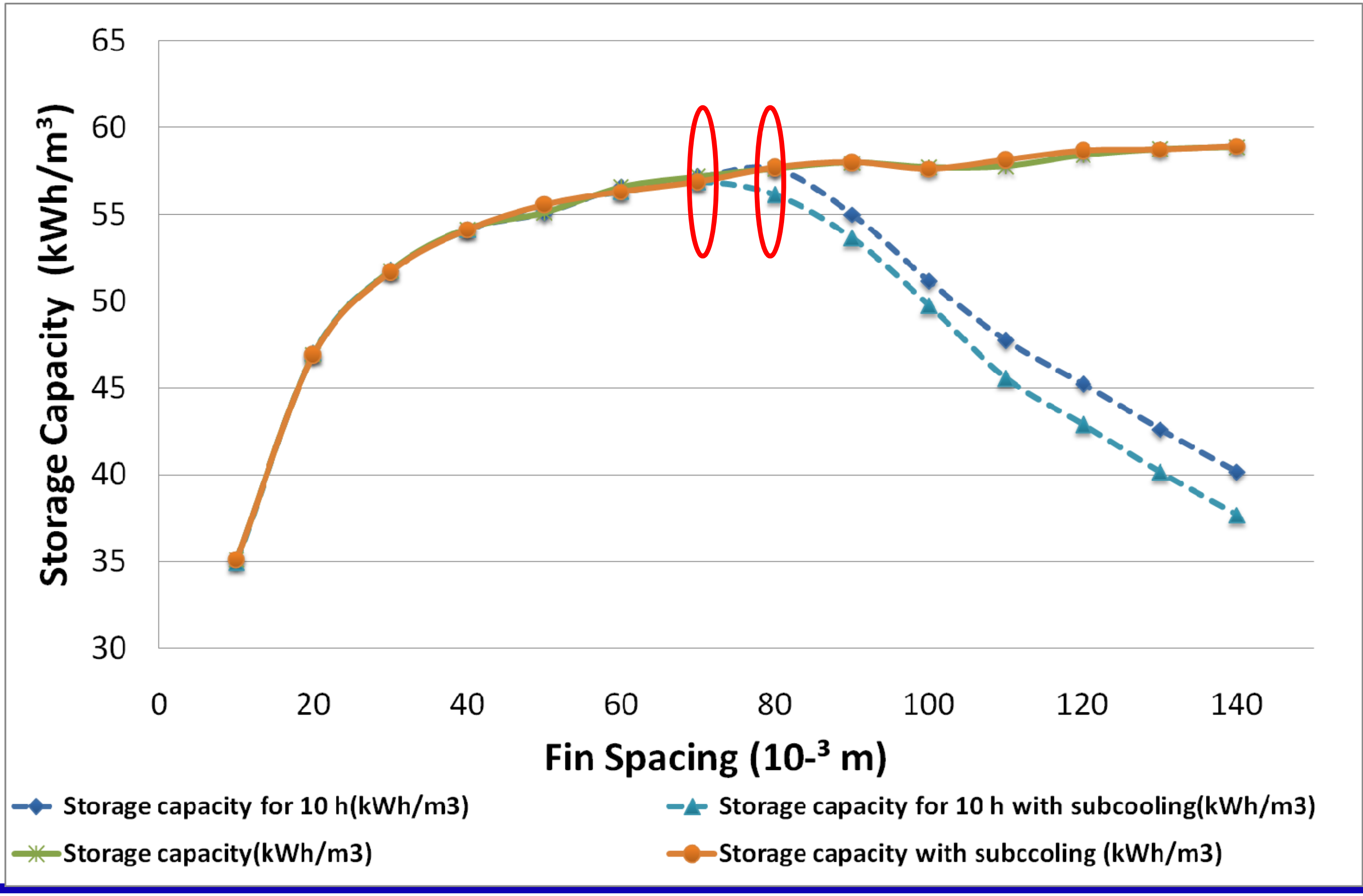
Results

- For 10 h charging, storage is not fully utilized for fins spaced 80mm apart (w/o subcooling), and 70mm (w subcooling)



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Results

- Ice Packing Factor (IPF)→ storage density
- Fin and Tube spacing→ solidification/melting time → power
- Fin and Tube spacing←→ IPF

➢ Storage density is a tradeoff to solidification/melting time and storable/extractable power.

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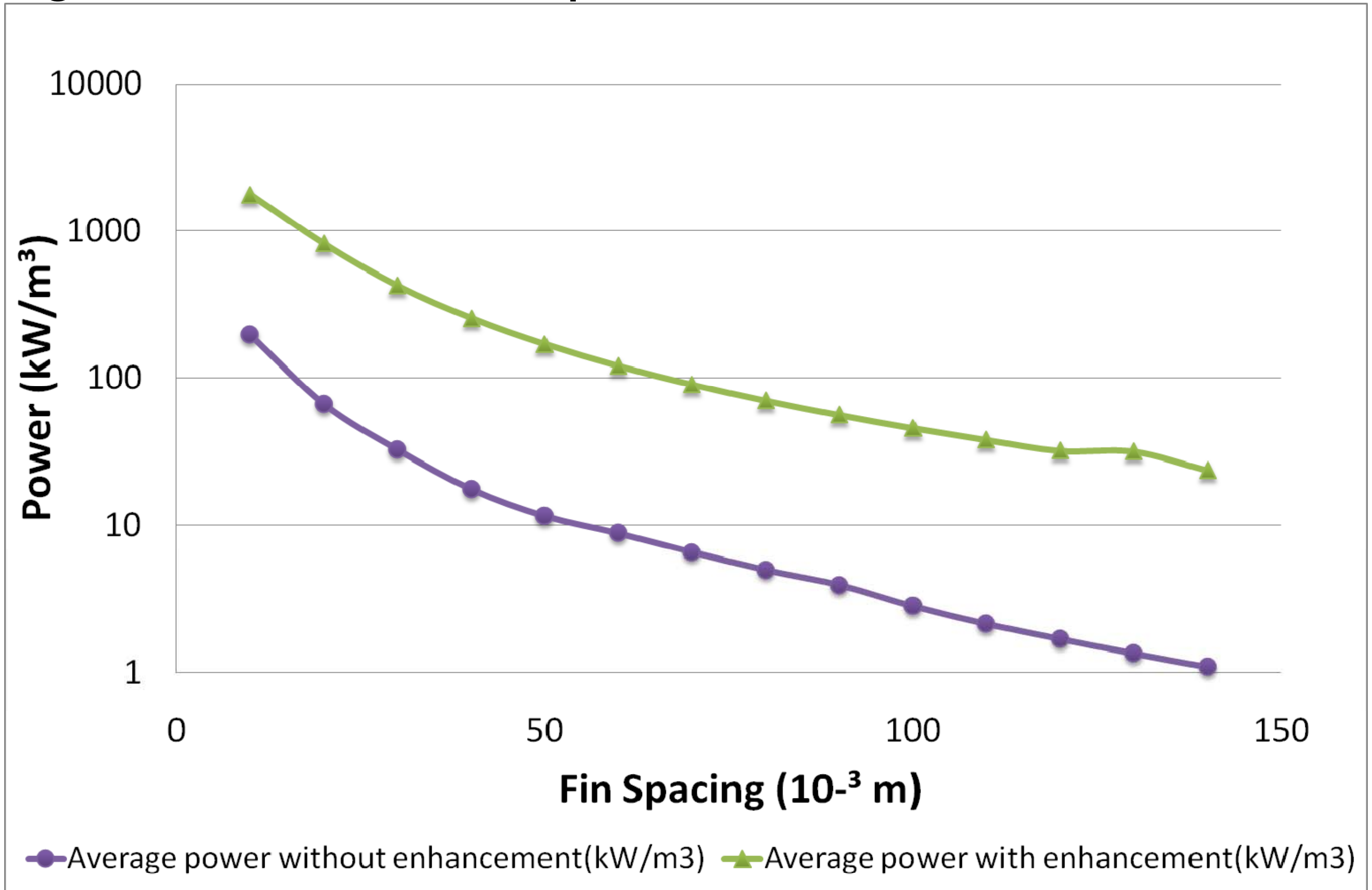
Fin and Tube Spacing (mm)	10	20	30	40	50	60	70	80	90	100	110	120	130	140
IPF	59%	78%	86%	90%	93%	94%	95%	96%	96%	97%	97%	98%	98%	98%
Solidification Time (hr)	0.18	0.71	1.6	3.1	4.8	6.4	8.7	11	14	18	21	25	30	35

Results

- Enhancement with 2% volume graphite or 30% lesser rings leads to 20 folds power increase



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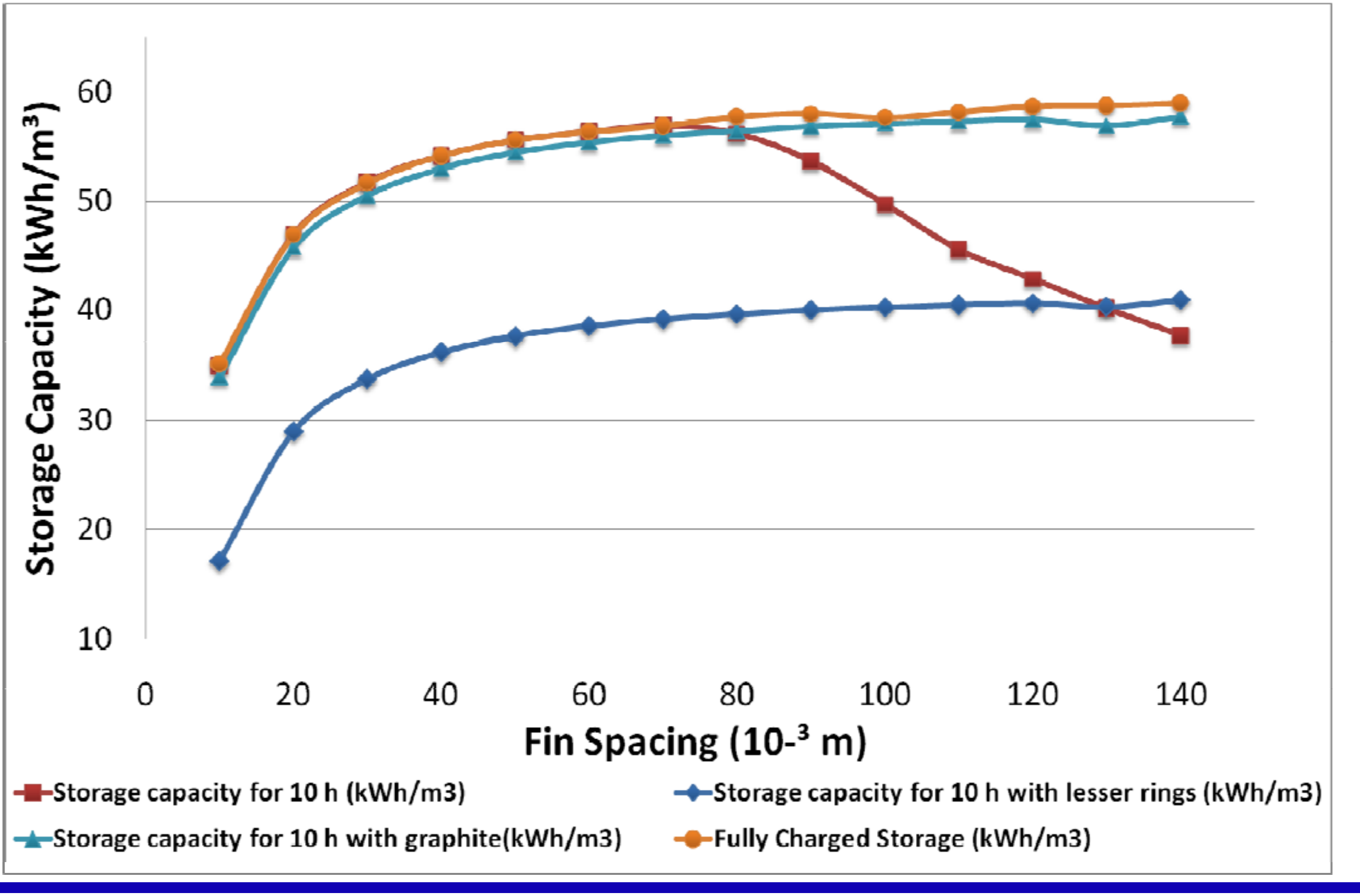
Results

- Thermal property enhanced PCM provides high power and also overcomes the charge/ discharge time constraint



Conclusion

- 1K subcooling contributes to 16% of power decrease, R&D for materials with low subcooling is needed
- Physical storage capacity depends on IPF
- Real storage capacity depends on heat exchange rate due to energy source availability
- For each application, there is an optimum design for fully utilizing storage capacity (70/80 mm in the studied case)
- Application of TES in an energy system is yet to be looked into from a holistic approach, namely system analysis and the techno-economical cost

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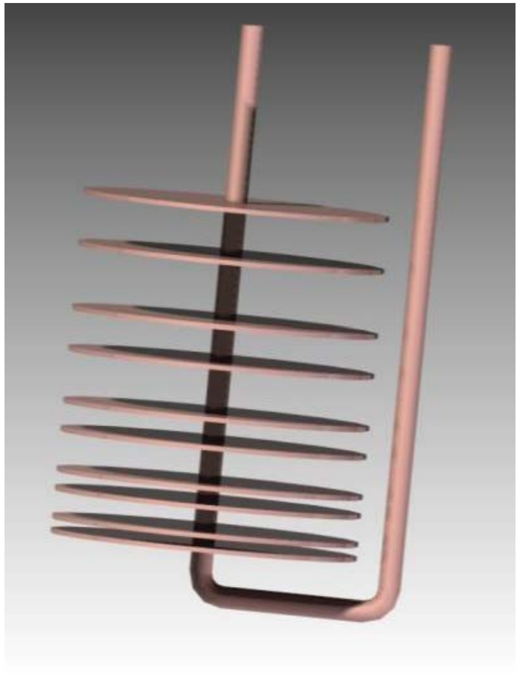
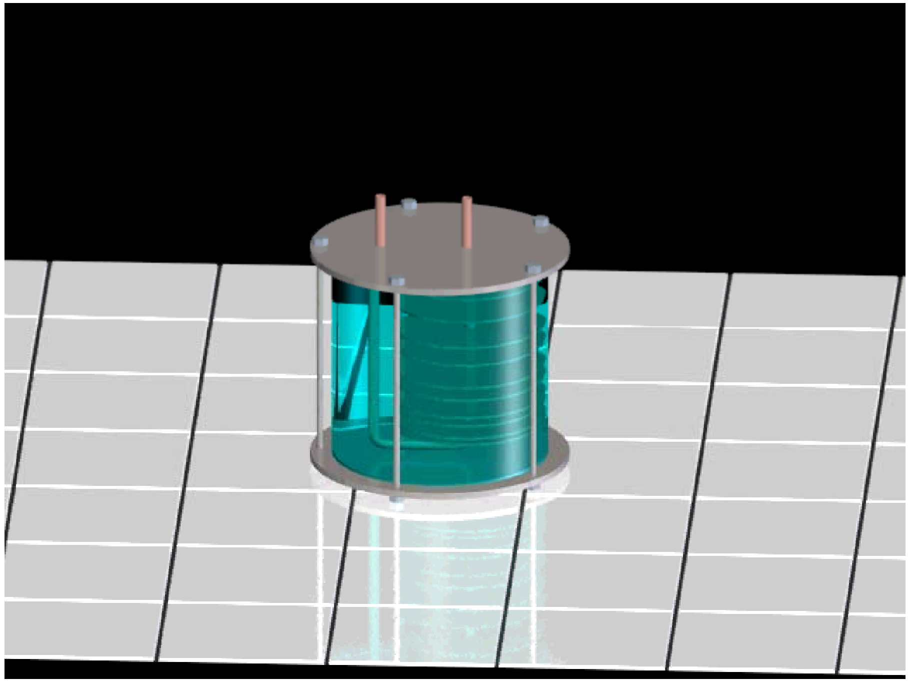
Ongoing Work

- Thermal Energy Storage Rig
  - Obtain experience with PCM and storage concept
  - Validate the theoretical study
  - Provide background study for 10~15kWh storage prototype





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Thank you

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