Thermal energy storage modelling – device scale prospective

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Outline

- Thermal energy storage technologies
- Relevant scales in TES – focus on device
- Modelling similarities and distinctive features of TES technologies
  - Sensible
  - Latent
  - Thermochemical
- Couplings across scales
- Conclusions

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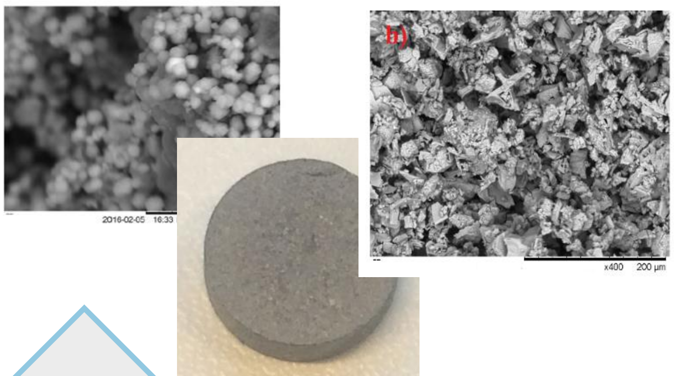
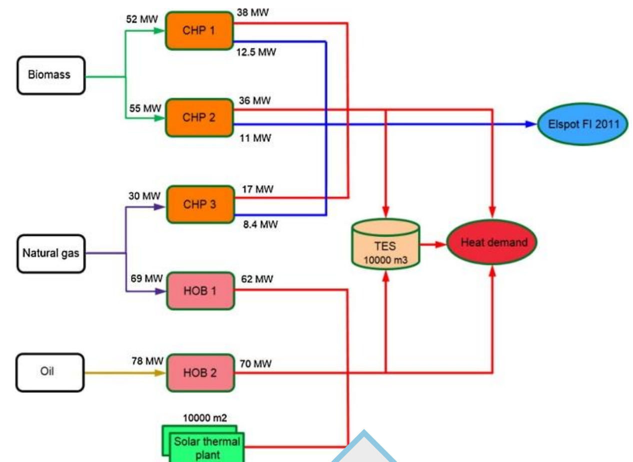
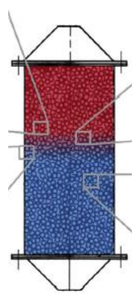
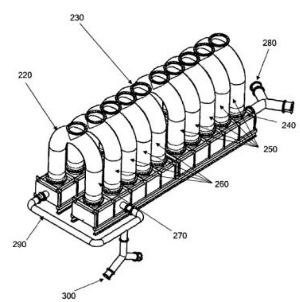
TES modelling scales – focus at device scale





Informed by fundamental science





Informed by techno-economic

TES DEVICE

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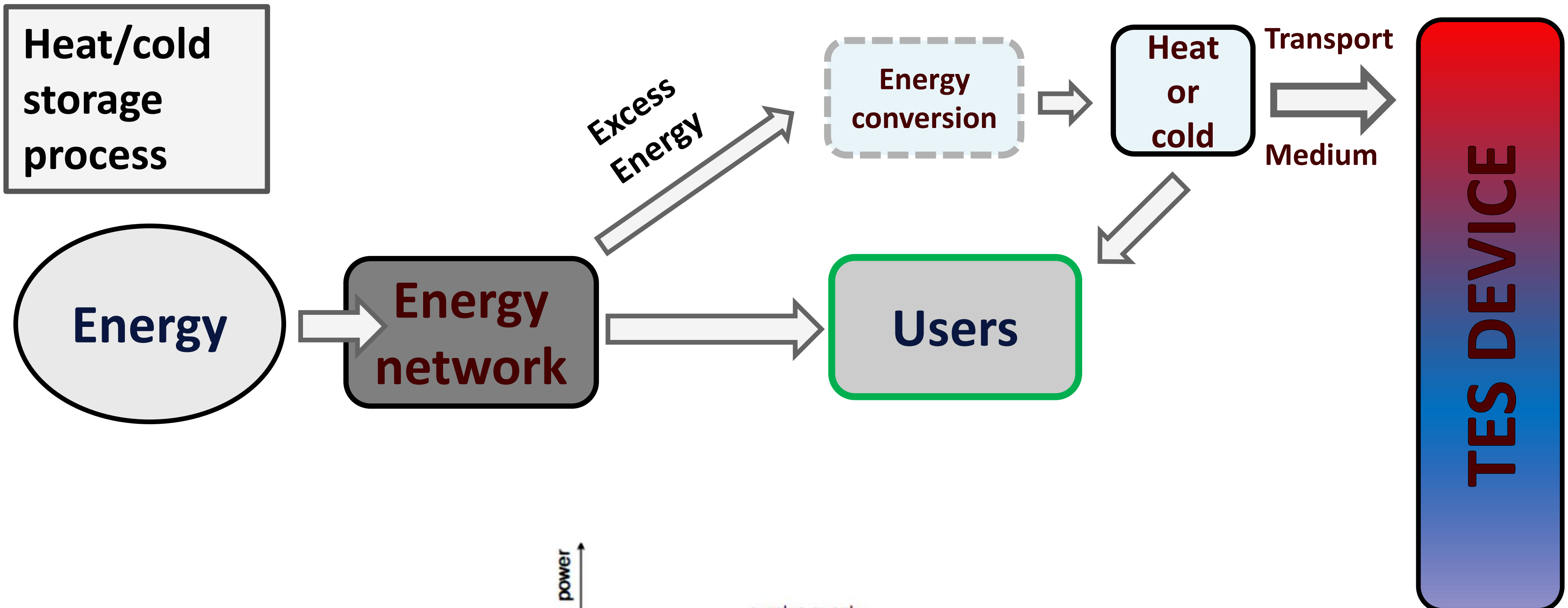
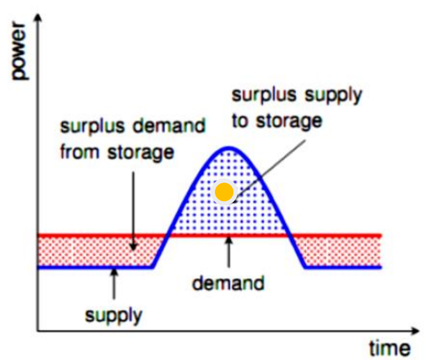
TES technologies – Top down view





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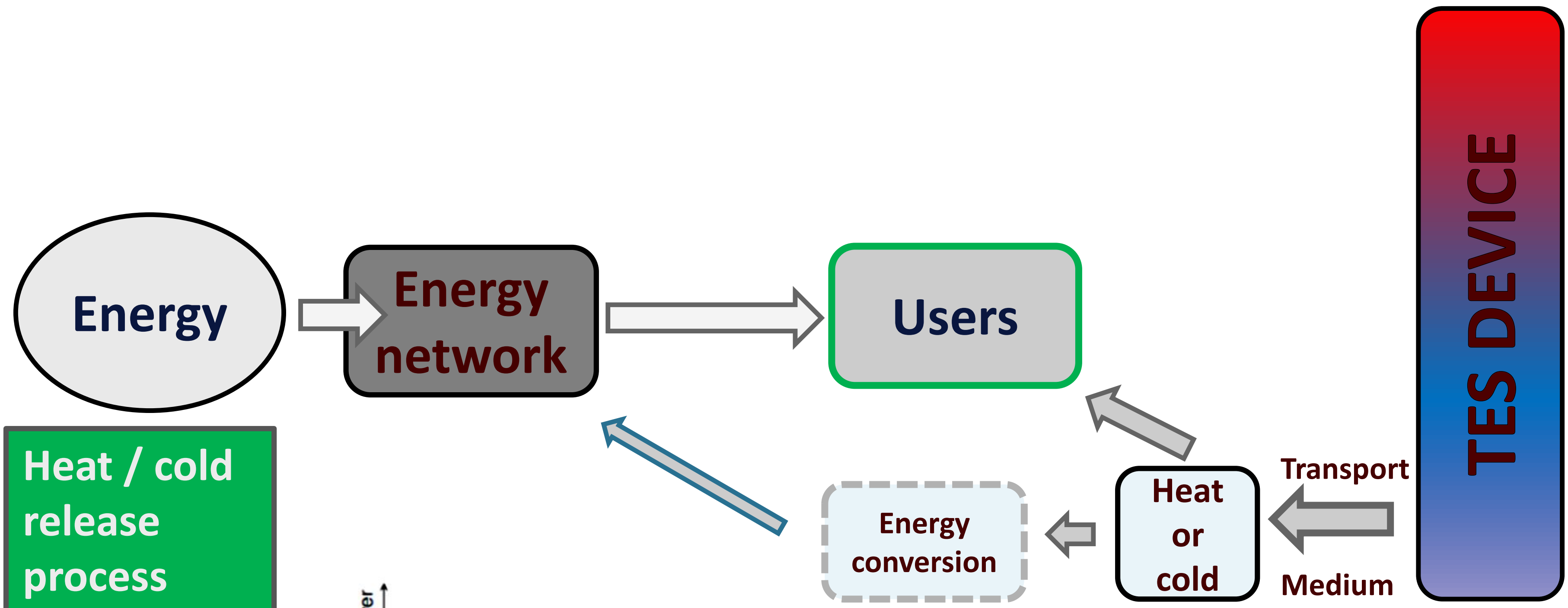
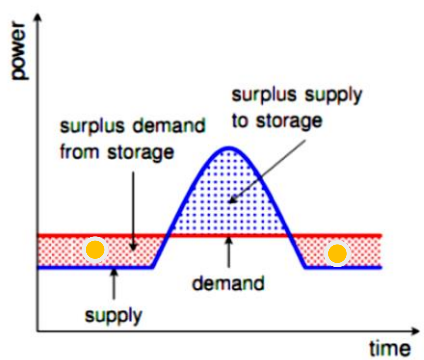
Ding, Y et al. **UK TES** (2015).

TES technologies – Top down view





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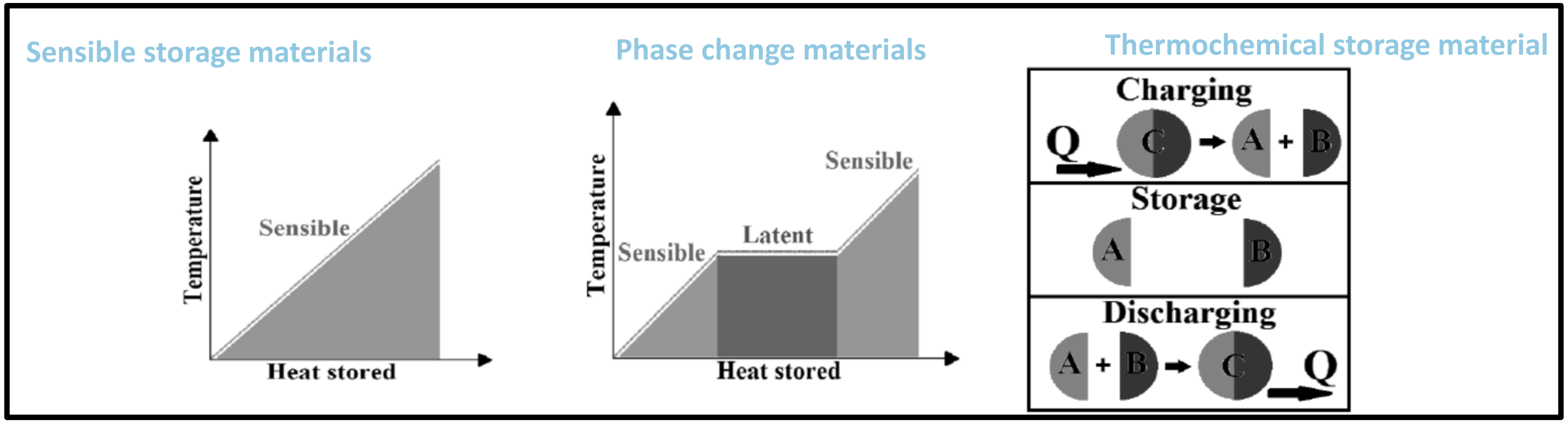
Ding, Y et al. **UK TES** (2015).

TES technologies – Classification



Energy and Buildings 2015;15:414-419

Sensible – in use Latent TRL 4-6 Thermochemical TRL 3-4

Technological potential

Modelling challenges

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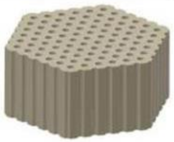
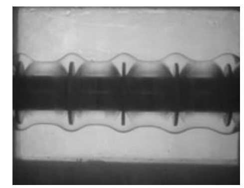
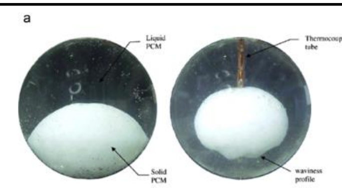
TES technologies – Classification

Checker bricks		
Honeycomb bricks		
Saddles, Shperes		
Natural stones		

Paraffin, sugar alcohols	
Salt hydrates, water-salt solutions	
Macro-encapsulated materials	
Composites	

AB + heat (ΔH) ↔ A + B
Zeolites
Salt hydrates
Hydro-oxides
Metal Oxides

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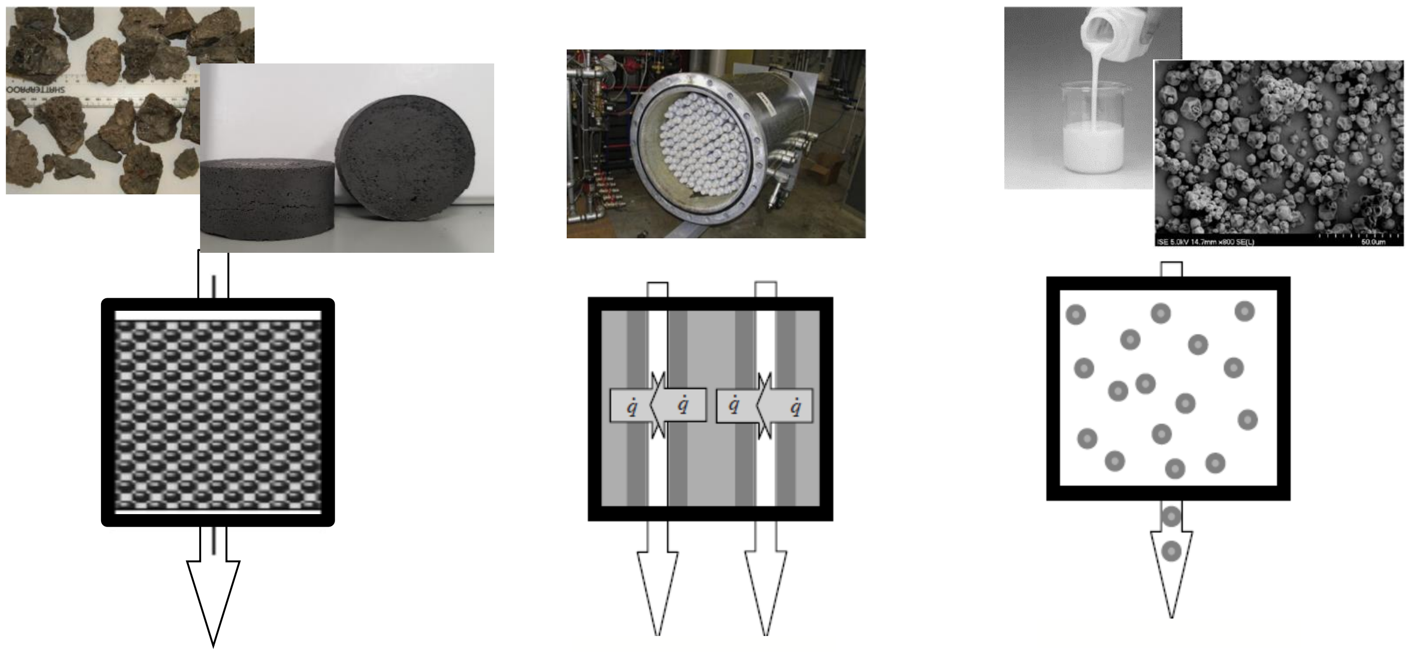
Cabeza, L.F. et al. **Advances in Thermal storage** (2015).

TES - common features across technologies



Heat transfer fluid (direct)

Heat transfer fluid (indirect)

Integrate heat transfer & storage fluid

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Mehling, H. et al. **Heat and cold storage with PCM An up to date introduction** (2008)

Physical modelling similarities/distinct features

	Sensible	Latent	Thermochemical
Single phase flow	✓		✓
Conduction/convection heat transfer	✓	✓	✓
Phase change		✓	
Multi species			✓
Multiphase flow		✓	(✓)
reactions			✓

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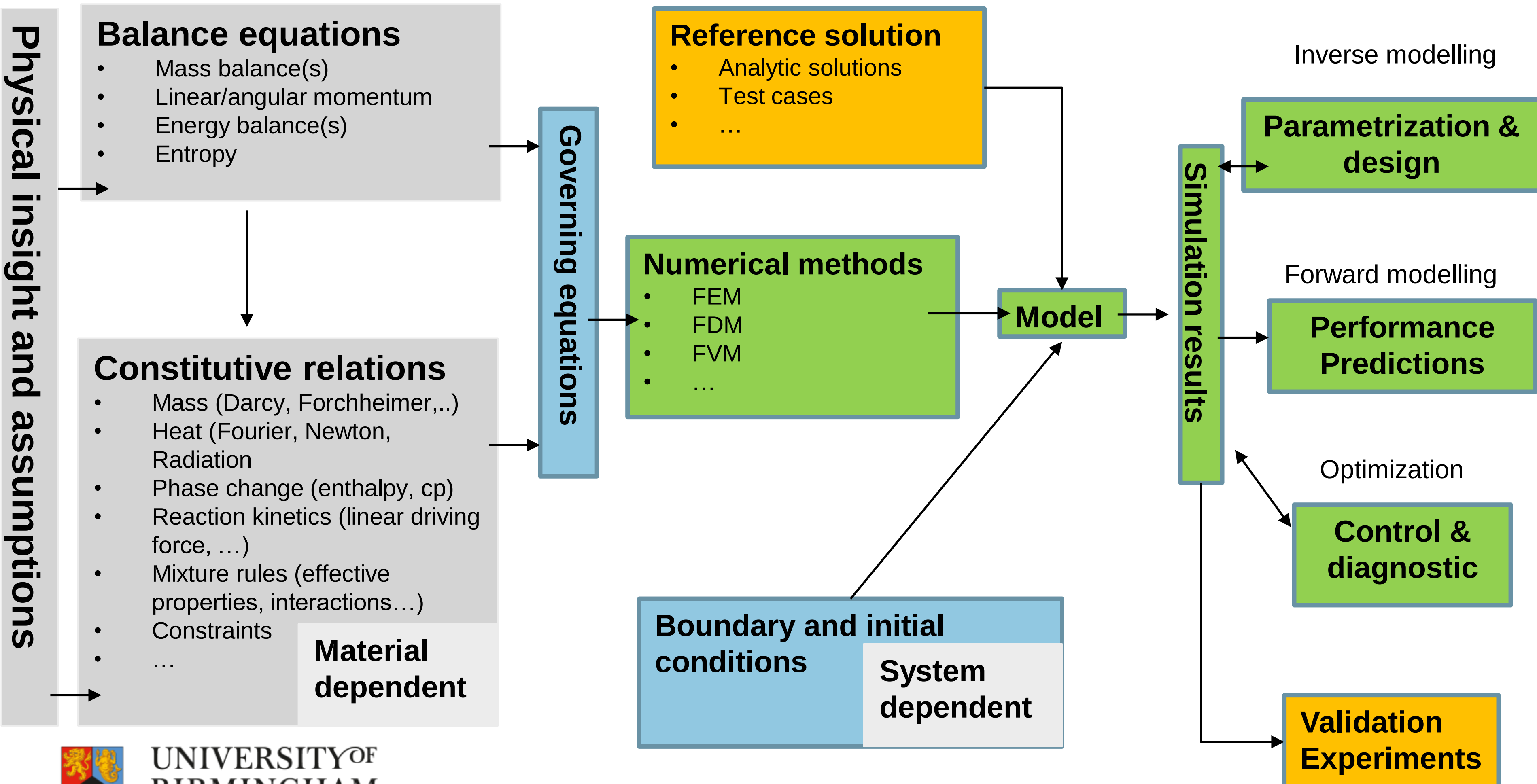
Physical modelling similarities/distinct features



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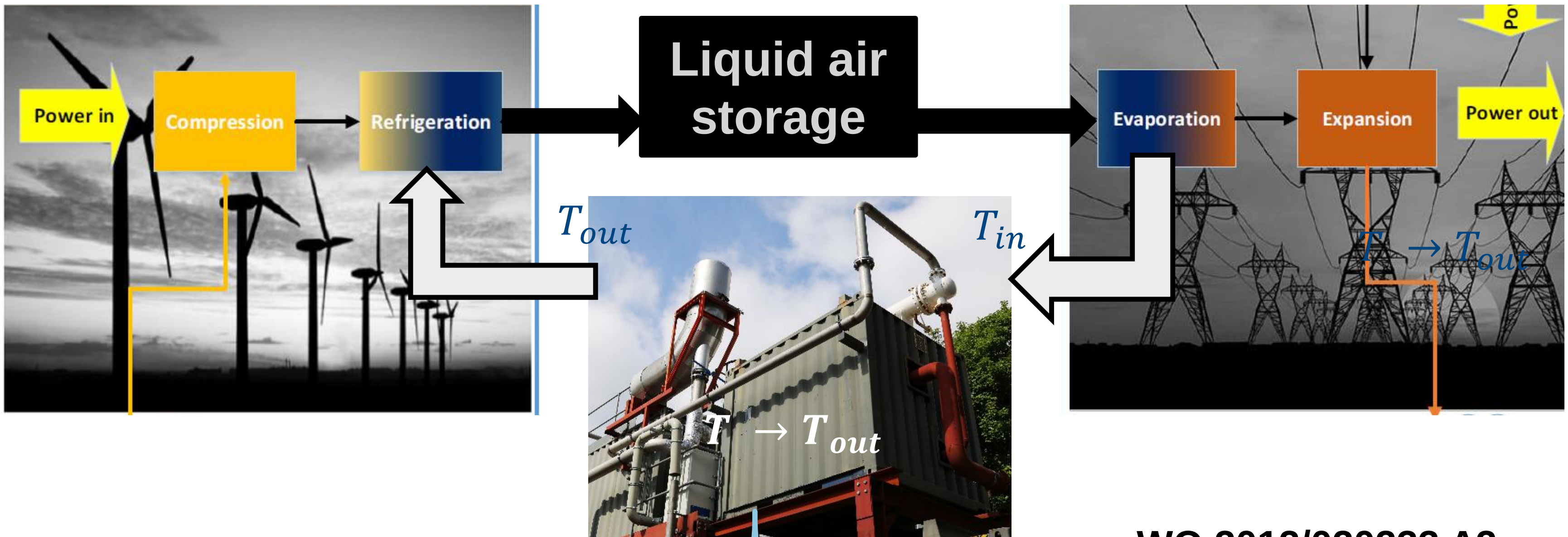
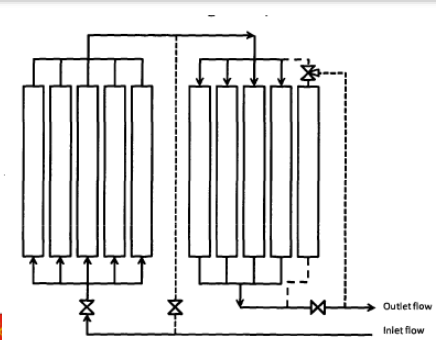
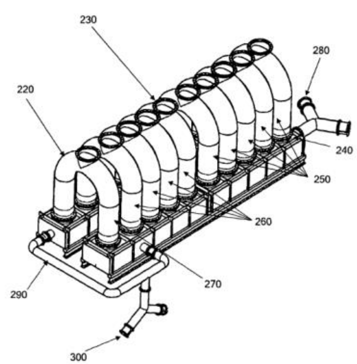
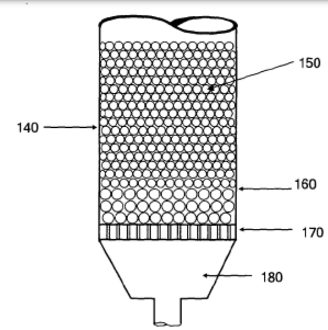
Sensible thermal energy storage



WO 2012/020233 A2







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Sciacovelli, A. et al. *Appl. Energy* 190, 84–98, 2017.
Sciacovelli, A. et al. *J. Energy Resour. Technol.* 140, 22001, 2017.

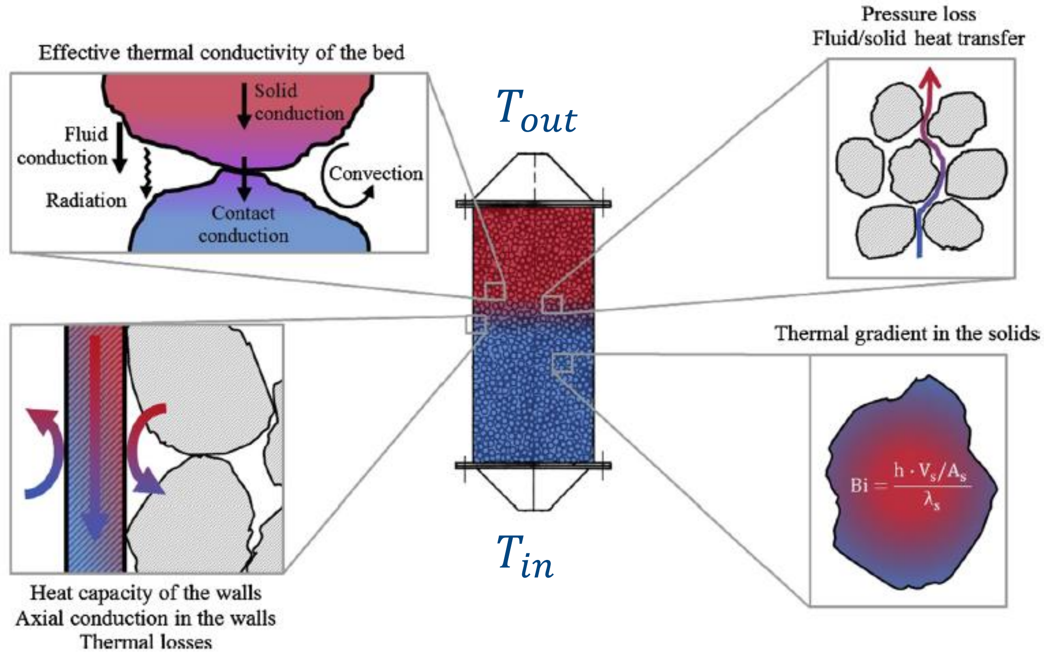
Sensible thermal energy storage

Continuity:

$$\frac{\partial v_i}{\partial x_i} = 0$$

Momentum:

$$\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j} = \frac{\partial \theta_{ij}}{\partial x_j} + F_L$$



Energy (fluid/solid):

$$\frac{\partial T_s}{\partial t} + v_j \frac{\partial T_s}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\frac{\partial T_s}{\partial x_j}\right) - St\left(\frac{T_f - T_s}{\varepsilon}\right) - Nu\left(T_f - T_s\right)$$

$$\frac{\partial T_s}{\partial t} + = \frac{1}{Pe}\frac{\partial}{\partial x_j}\left(\frac{\partial T_s}{\partial x_j}\right) + St\left(T_f - T_s\right)$$

$$Pe_p \frac{\partial T_p}{\partial t} + = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial T_p}{\partial r}\right)$$

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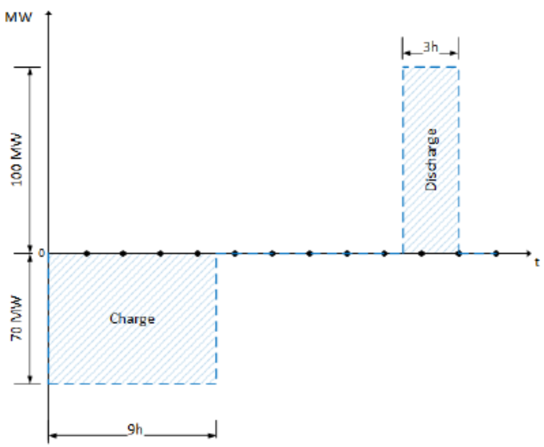
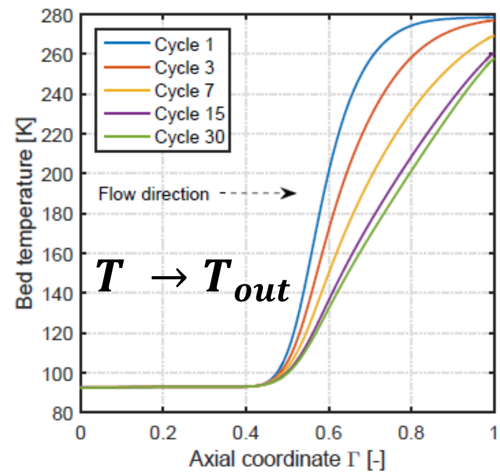
Esence, T. et al. *Sol. Energy* 153, 628–654, 2017
Sciacovelli, A. et al. *Appl. Energy* 190, 84–98, 2017.

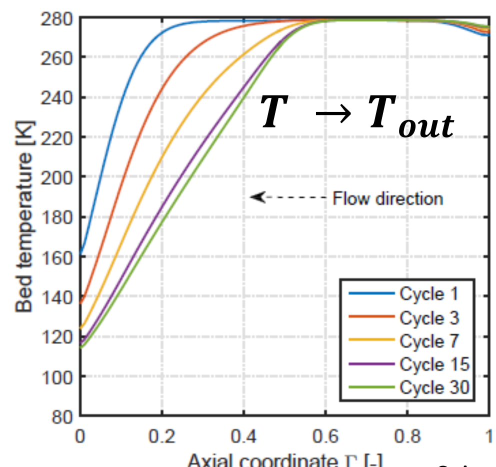
Sensible thermal energy storage

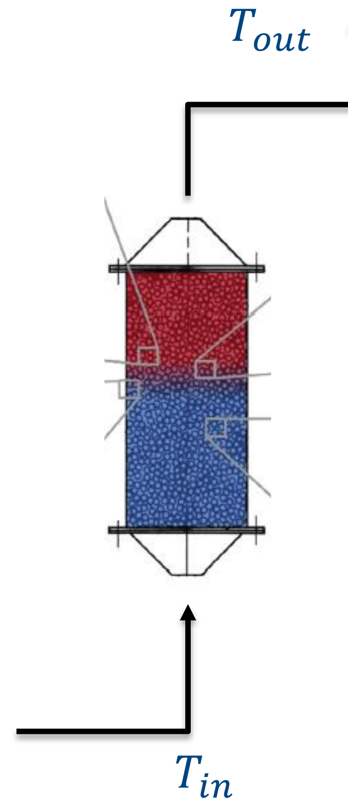
LAES cycles





TES cycles





Sciacovelli, A. et al. *Appl. Energy* 190, 84–98, 2017.

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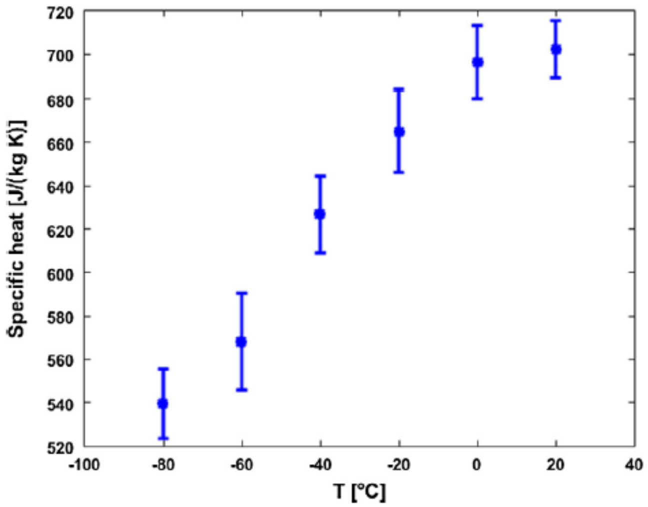
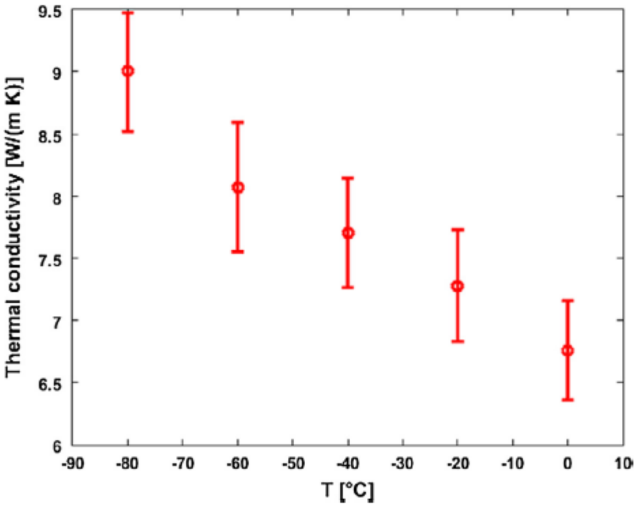
Sensible thermal energy storage

- Material-device coupling plays a role even for conventional materials

Quartzite rocks





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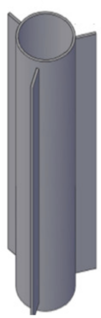
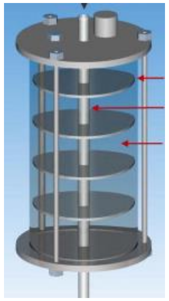
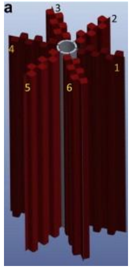
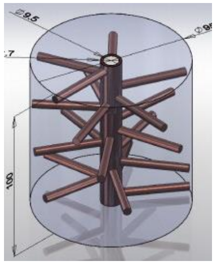
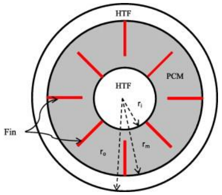
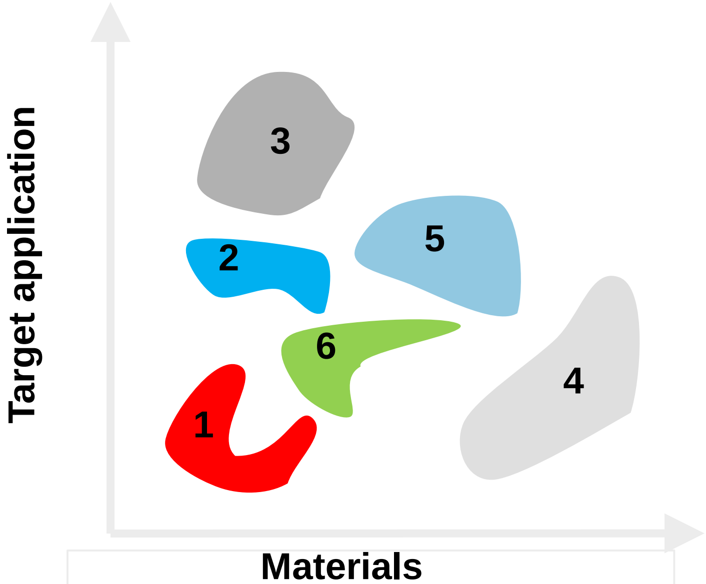
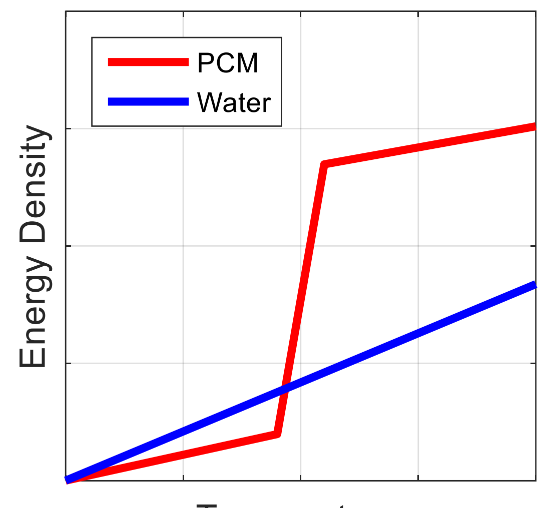
Sciacovelli, A. et al. *Appl. Energy* 190, 84–98, 2017.

Latent heat thermal storage

[1] Axial fins	[2] Y fins	[3] Radial fins
		
[4] Corrugated fins	[5] Pin fins	[6] Triple tube
		

$$[7], [8], \ldots, \infty$$





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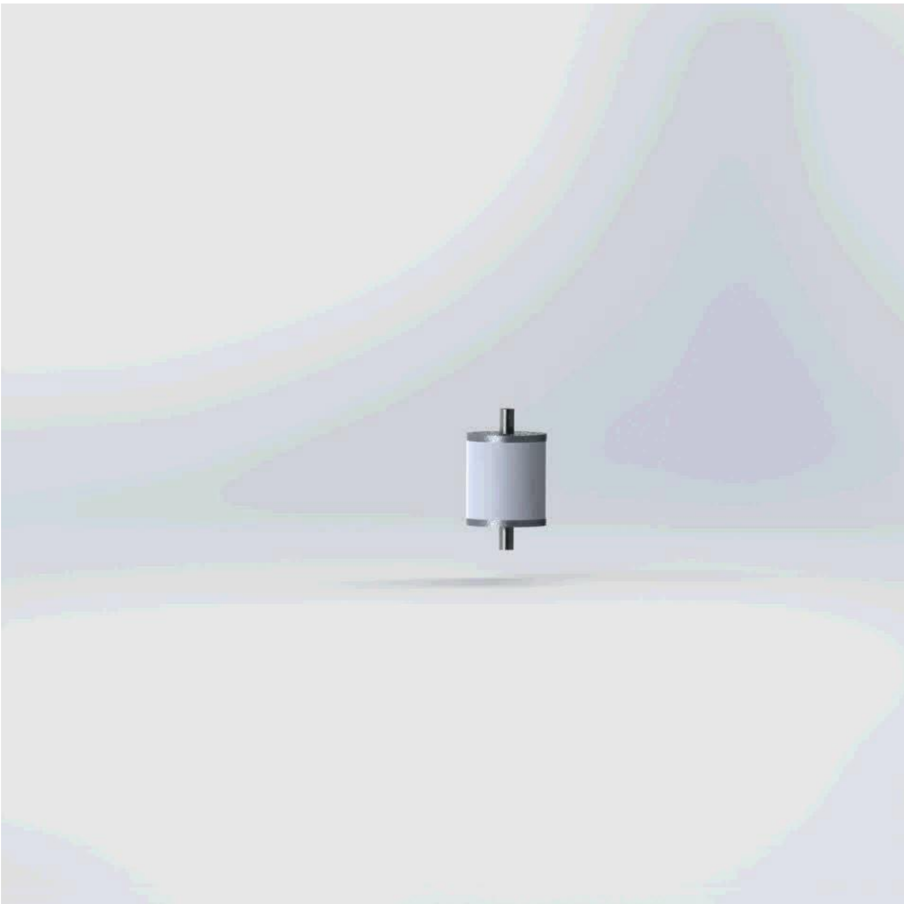
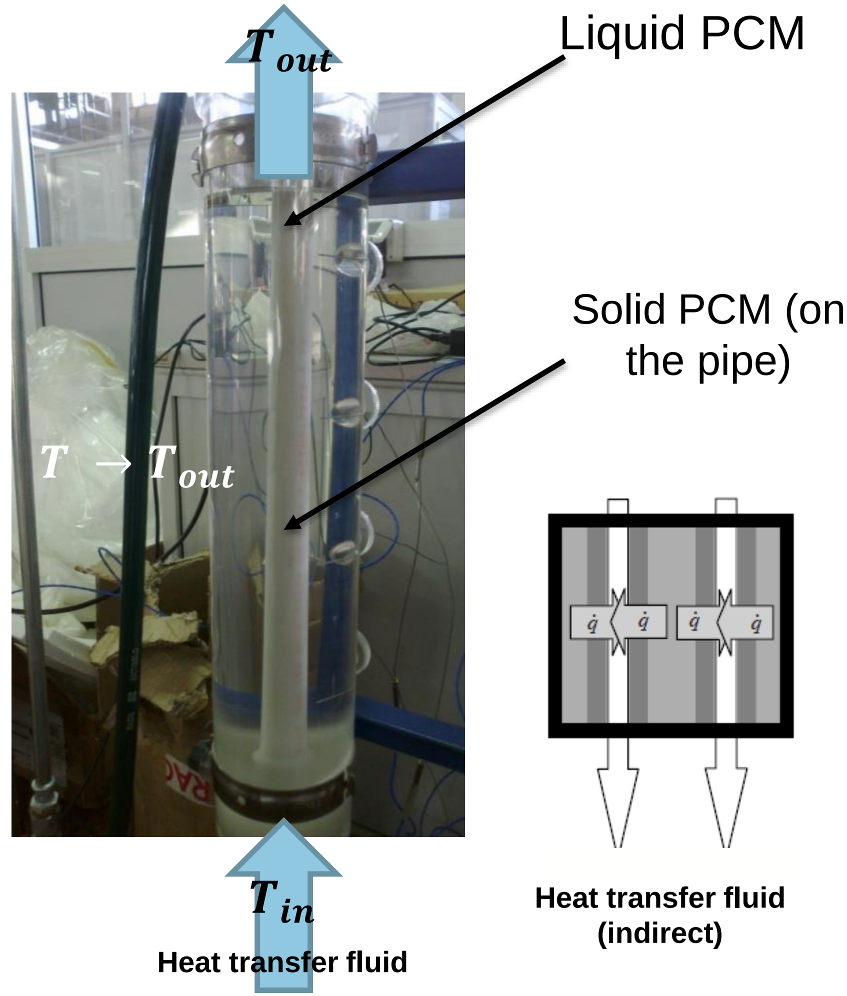
Latent heat thermal storage





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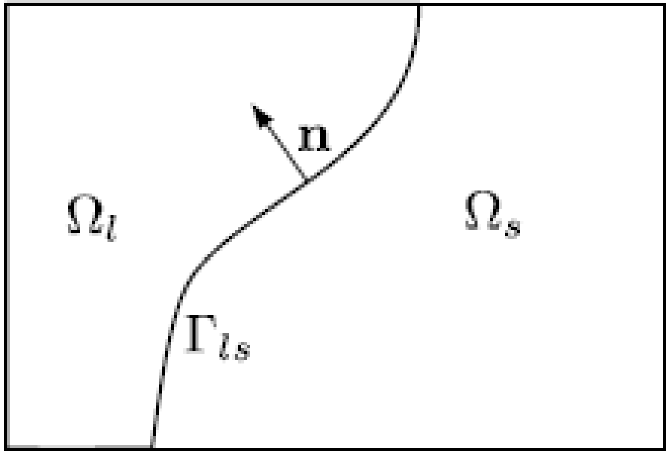
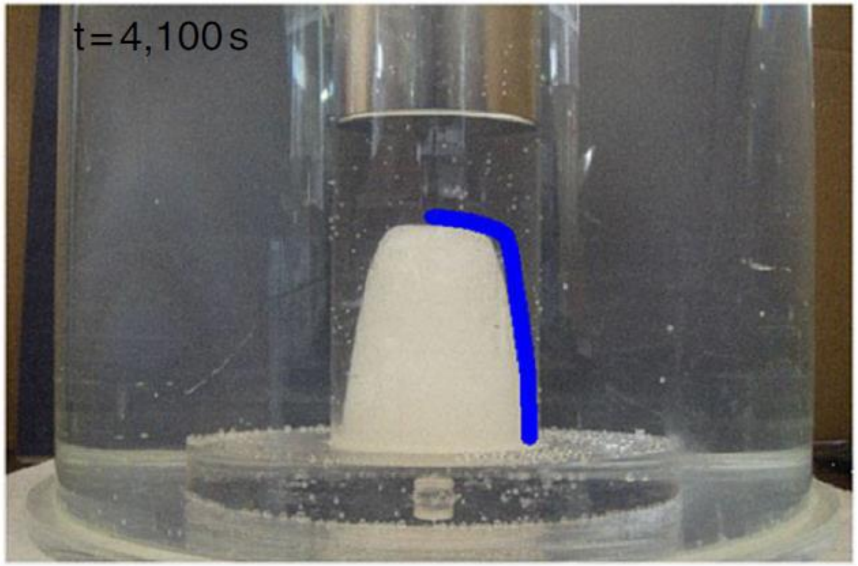
Sciacovelli, A. et al. *Int. J. energy Res.* 73, 1610–1623, 2013.
Sciacovelli, A. et al. *Int. J. Numer. Methods Heat Fluid Flow* 26, 489–503, 2016

Latent heat thermal storage

- phase change (energy) → enthalpy method
- co-existence of solid/liquid (fluid flow) → liquid fraction/darcy term
- Natural convection → Boussinesq approximation





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Sciacovelli, A. et al. *Int. J. Numer. Methods Heat Fluid Flow* 26, 489–503, 2016

Latent thermal energy storage

Continuity:

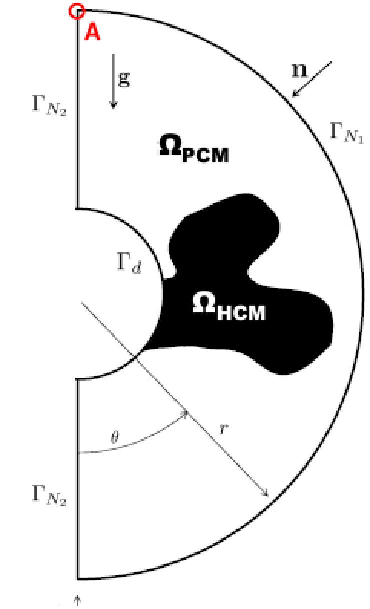
$$\frac{\partial v_i}{\partial x_i} = 0$$

Momentum:

$$\frac{\partial v_i}{\partial t} + v_j \frac{\partial v_i}{\partial x_j} = \frac{\partial \theta_{ij}}{\partial x_j} + Ra \Pr e_i^g T - \alpha_\beta(s) v_i + F_L$$

Energy (solid/liquid PCM):

$$\left(1 + L\frac{\partial f}{\partial T}\right)\frac{\partial T}{\partial t} + v_j\left(1 + L\frac{\partial f}{\partial T}\right)\frac{\partial T_s}{\partial x_j} = \frac{\partial}{\partial x_j}\left(k(f)\frac{\partial T_s}{\partial x_j}\right)$$



- **Flow-energy coupling**
- **Intrinsically non linear**
- **Need to track melting front**
- **Strong property-process coupling**

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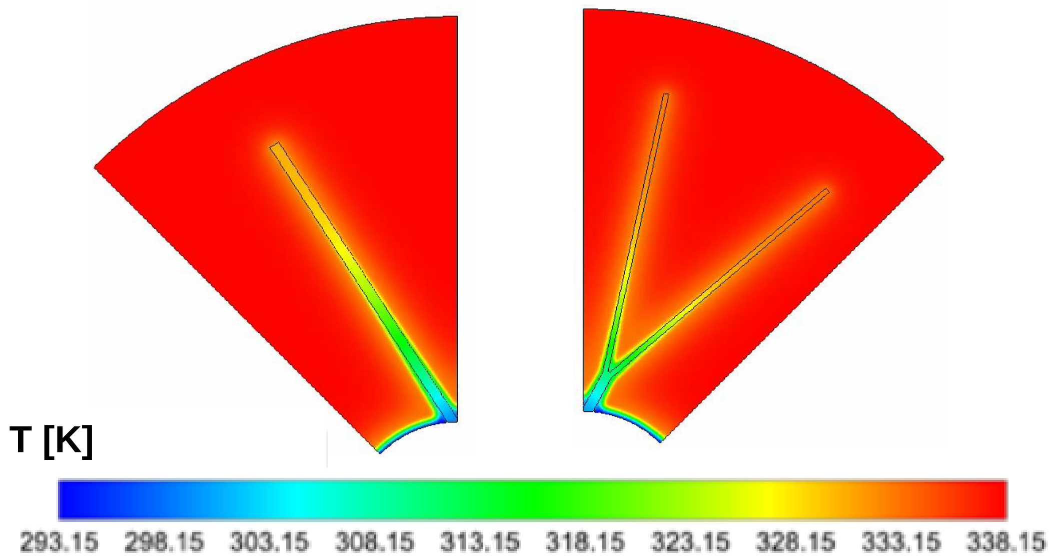
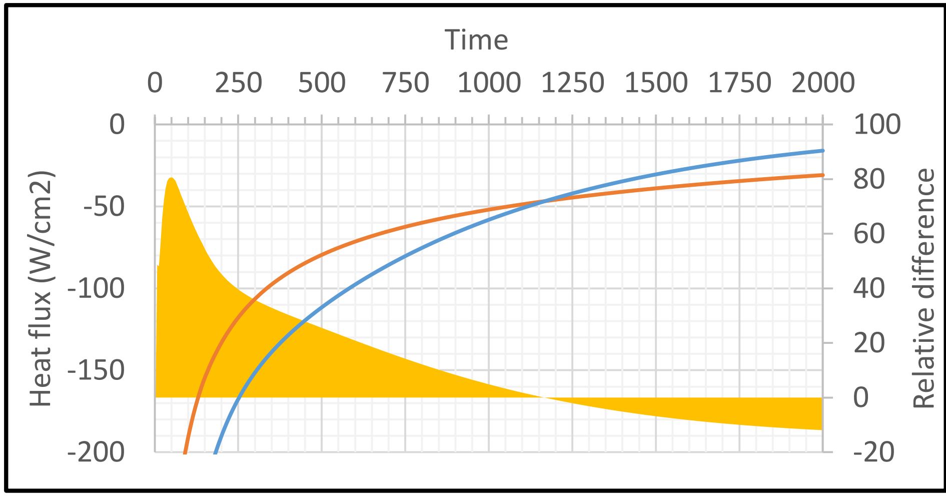
Sciacovelli, a et al. *Appl. Energy* 137, 707–715, 2015

Latent thermal energy storage



Extracted energy	1000s	2000s
Initial configuration	46.3%	63.9%
Single bifurcation	52.2%	71.8%
Double bifurcation	58.5%	88.0%



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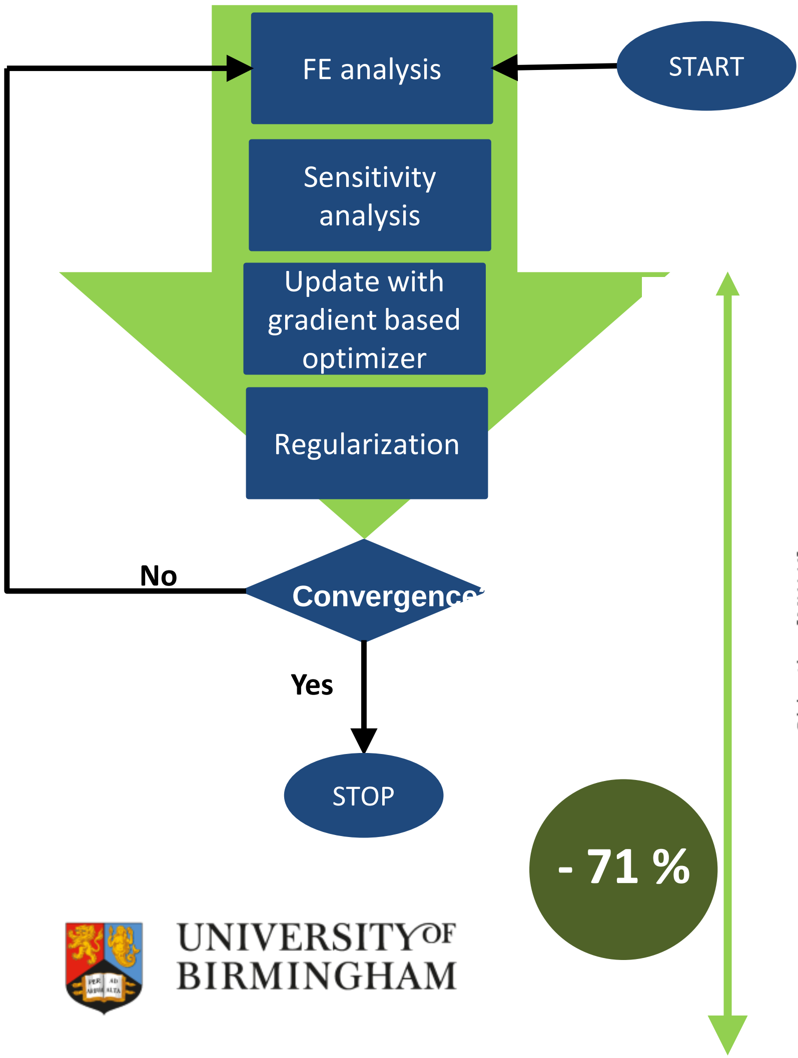
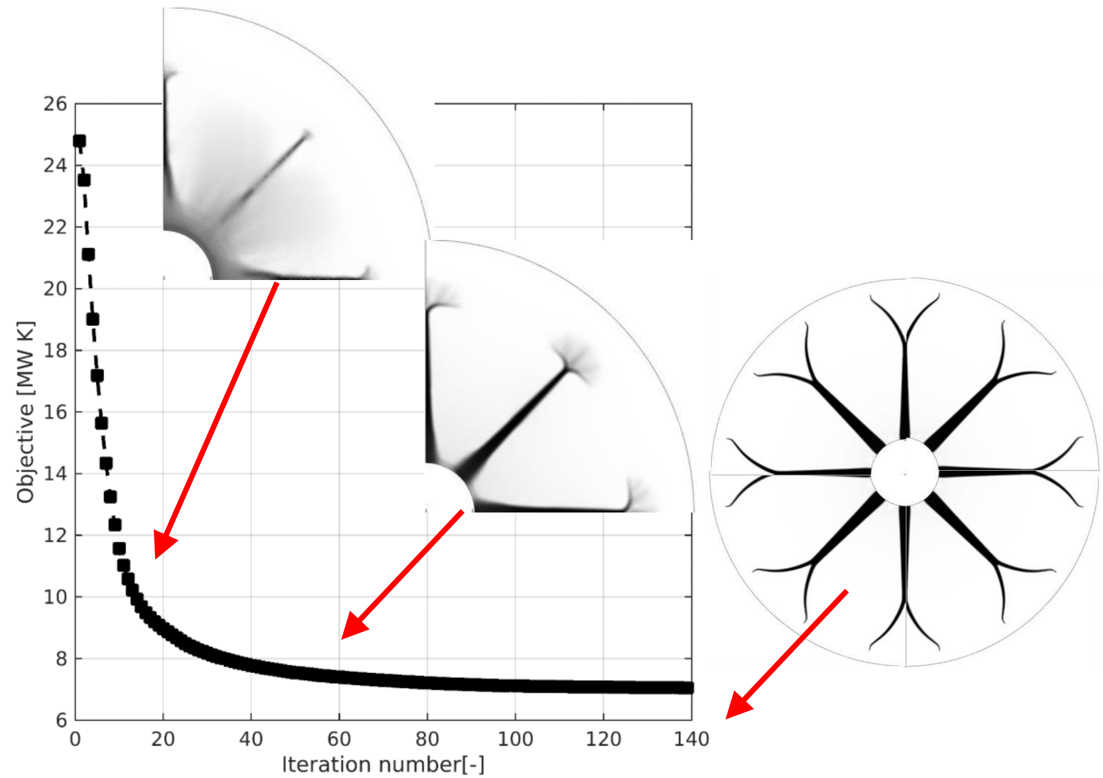
Sciacovelli, a et al. *Appl. Energy* 137, 707–715, 2015

Latent TES – optimization coupling





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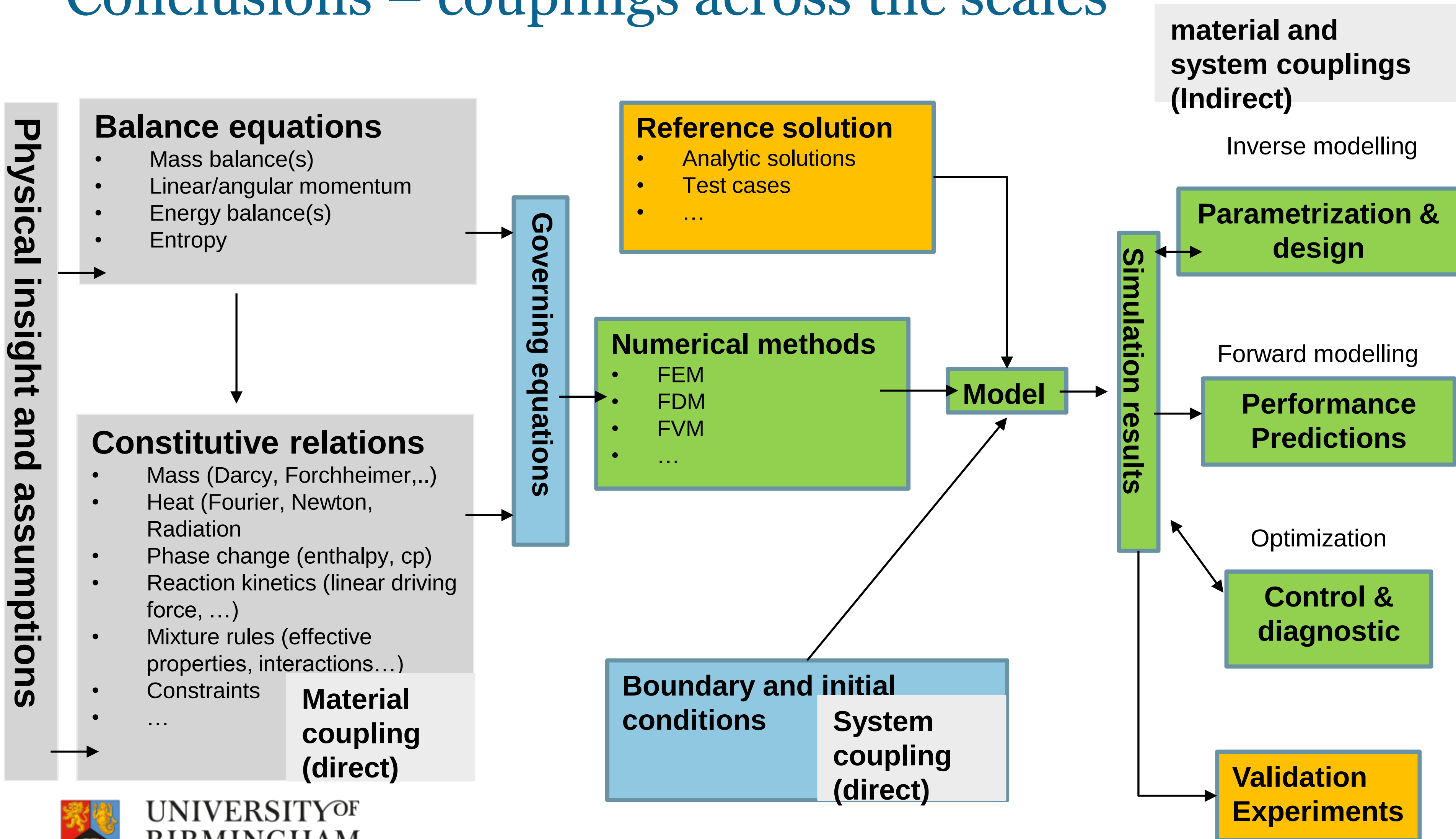
Pizzolato, A. Sciacovelli A et al. *Int. J. Heat Mass Transf.* 113, 875–888, 2017

Conclusions – couplings across the scales



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Thank you!

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