POLITECNICO DI MILANO





I materiali a cambiamento di fase PCM (Phase Change Materials)

Luigi De Nardo
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Materials for innovation lab
People

POLITECNICO DI MILANO

MATERIALS for INNOVATION

Luigi De Nardo, PhD MSc
Assistant Professor

Materials Science and Eng.

Lina Altomare, PhD MSc
Post-Doc
Bioengineering

Ludovica Lattanzi
PhD student

Bioengineering

Virginia Melli
PhD student

Materials Science and Eng.

Elisabetta Bossi
PhD student

Chemistry

Permanent staff:

- Alberto Cigada
- Roberto Chiesa
- Maria Pia Pedeferri
- Barbara Del Curto
- Gabriele Candiani
- Carmen Giordano
- Luigi De Nardo
- Lorenza Draghi

Temporary staff:

- Lina Altomare (Post doc)
- Marta Tunesi (Post Doc)
- Daniele Pezzoli (Post Doc)
- Giulio Cotogno (PhD stud.)
- Cinzia Della Valle (PhD St.)
- Ludovica Lattanzi (PhD St)

- 20 master students
- 5 Assistant researchers

Materials Science

Biology

Industrial Design

Technical Staff:

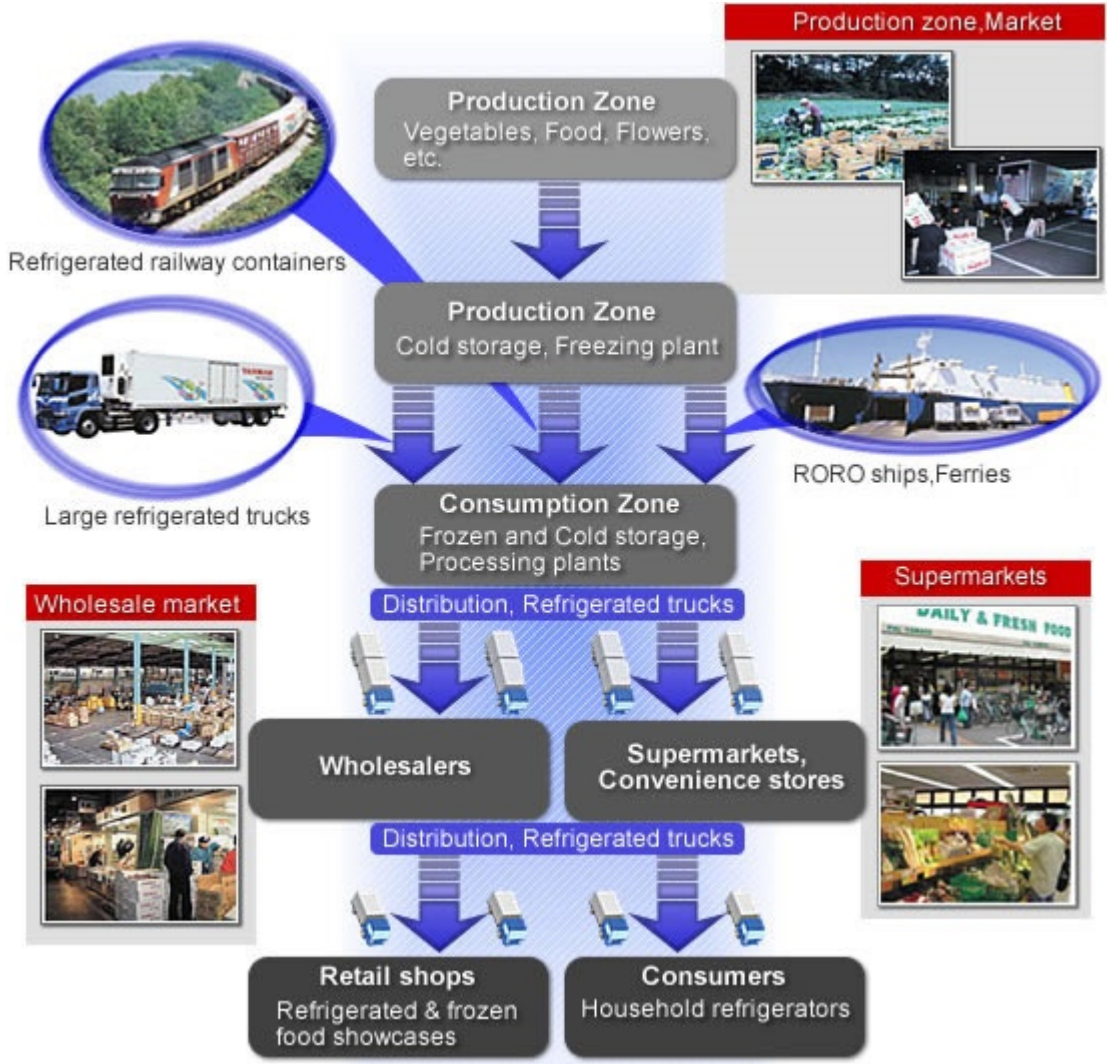
- Dr. Monica Moscatelli

- Lo studio di **materiali funzionali per applicazioni industriali**
  - Lo studio di **materiali a memoria di forma e intelligenti** finalizzato a realizzare **nuovi device medici e applicazioni nel packaging**
  - Lo sviluppo di **modifiche di superficie** basate su tecnologie chimiche ed elettrochimiche
  - Lo studio di **materiali gerarchici**
- **Sviluppare conoscenze e competenze nell'insegnamento**, al fine di fornire le migliori competenze ed educazione a studenti universitari

Outline

1. Scenario
   1. I problemi della logistica
   2. L'approccio TES (Thermal energy storage)
2. Aspetti teorici dei PCM
3. Applicazioni industriali
4. PCM know-how @ PoliMI per il packaging termico attivo

La catena logistica del freddo
Un cammino complesso



http://www.yanmar.co.jp/en/environment/coolcontainer/cold_chain/images/cold_chain_pict.jpg

Fattori non controllabili

- Condizioni Meteo
- Ritardi
- Handling
- Posizionamento dei beni trasportati

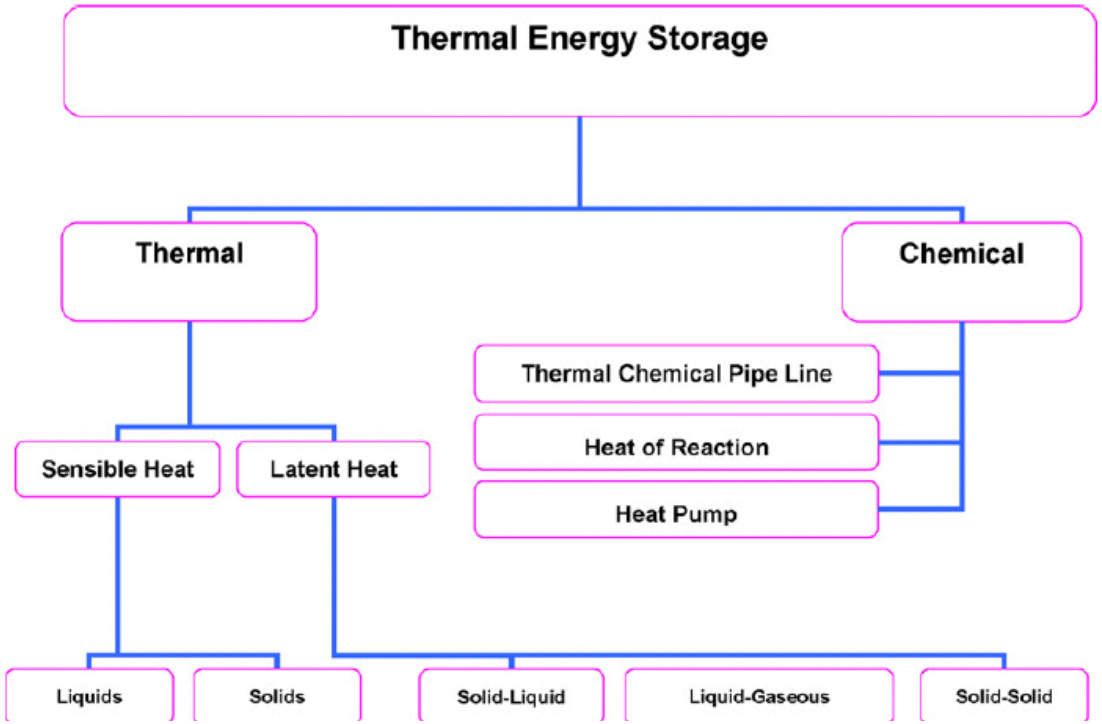
Fattori prevedibili

- Packaging
- Percorsi
- Carrier
- Delivery time

Approccio Thermal Energy Storage

- L'immagazinamento di energia termica (Thermal energy storage - TES) rappresenta l'accumulo temporaneo di energia termica a maggiore o minore temperatura, per un suo uso successivo

- Consente di colmare il divario temporale tra la richiesta di energia e il suo uso

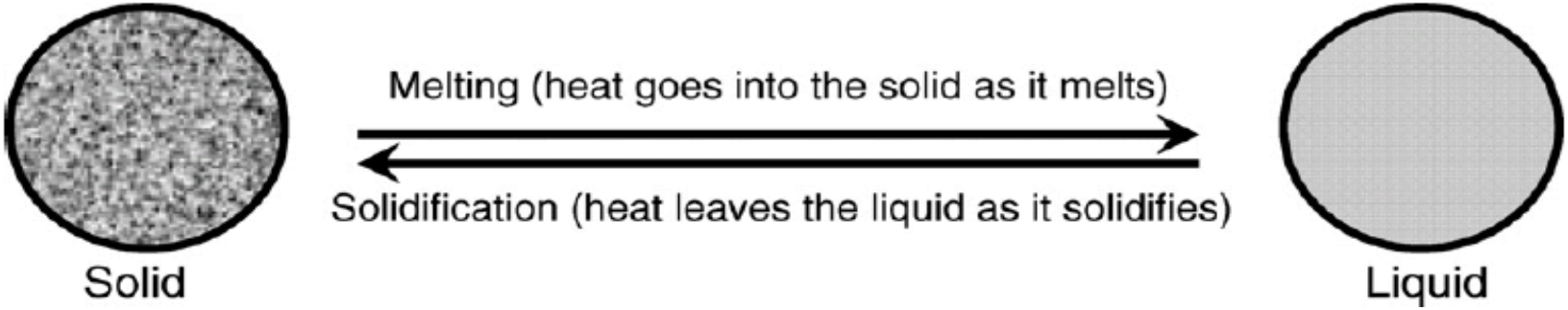


Renewable and Sustainable Energy Reviews 13 (2009) 318–345

I materiali a cambiamento di fase (PCM)

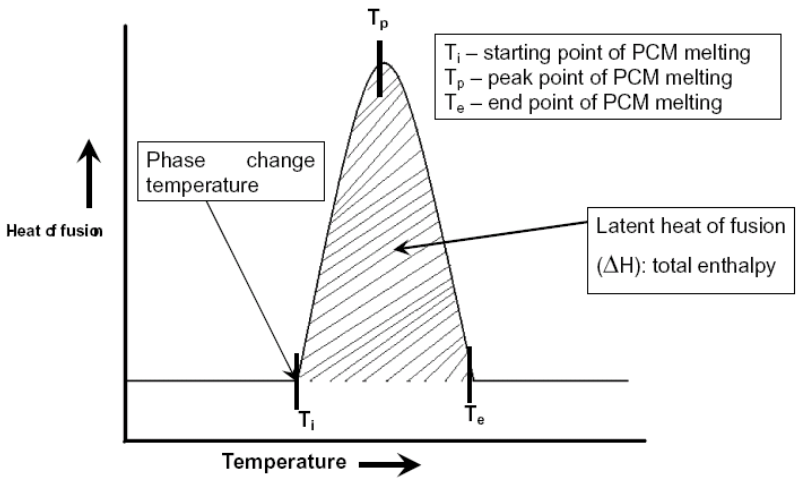
Principi fisici

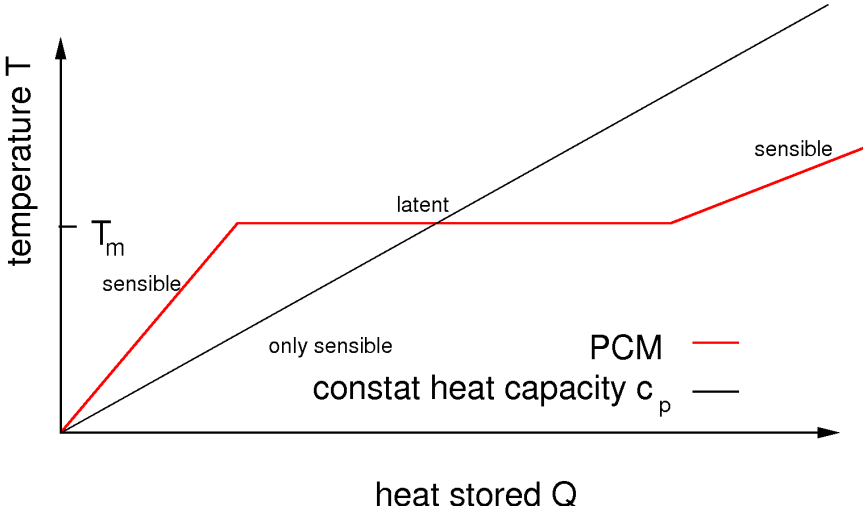
- Tra le varie tecniche di accumulo di calore di interesse, l'accumulo di calore latente è particolarmente interessante per la sua capacità di fornire un'alta densità di immagazzinamento a condizioni quasi isoterme ed è uno dei metodi più efficienti per la conservazione di energia



- Contrariamente ai metodi di immagazzinamento di energia basati sul calore sensibile, il calore latente consente di avere
  - → Una più alta densità di immgazzinamento
  - → Più basse differenze di temperatura tra l'immagazzinamento e il rilasiodifference between storing and releasing heat

I materiali a cambiamento di fase (PCM)
Principi fisici

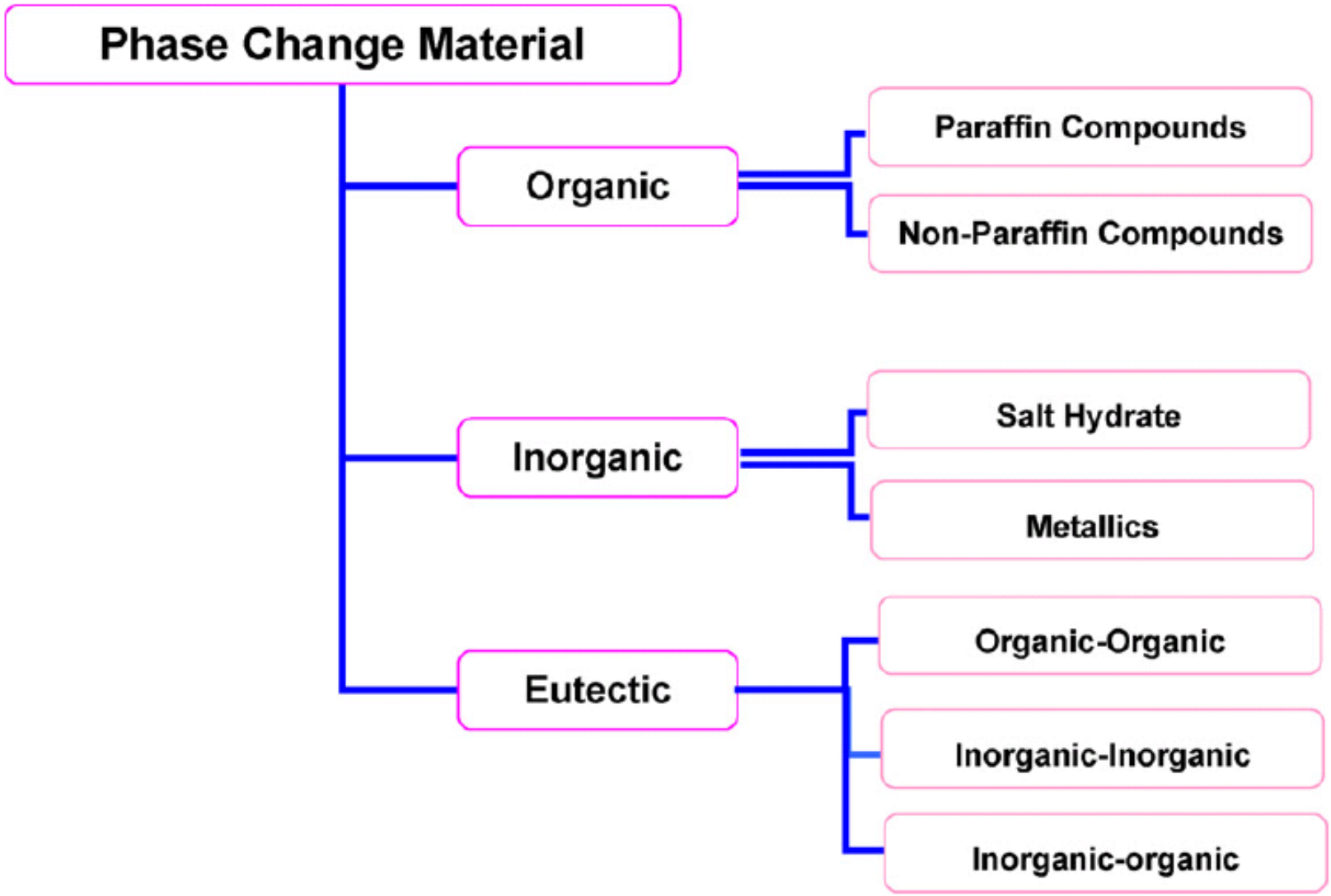




Applied Thermal Engineering 28 (2008) 1536–1550

- L'immagazzinamento di calore latente è basato sul calore assorbito o rilasciato quanto un PCM va incontro ad una trasformazione di fase
  - → da solido a liquido (e viceversa)
  - → Liquido a gas

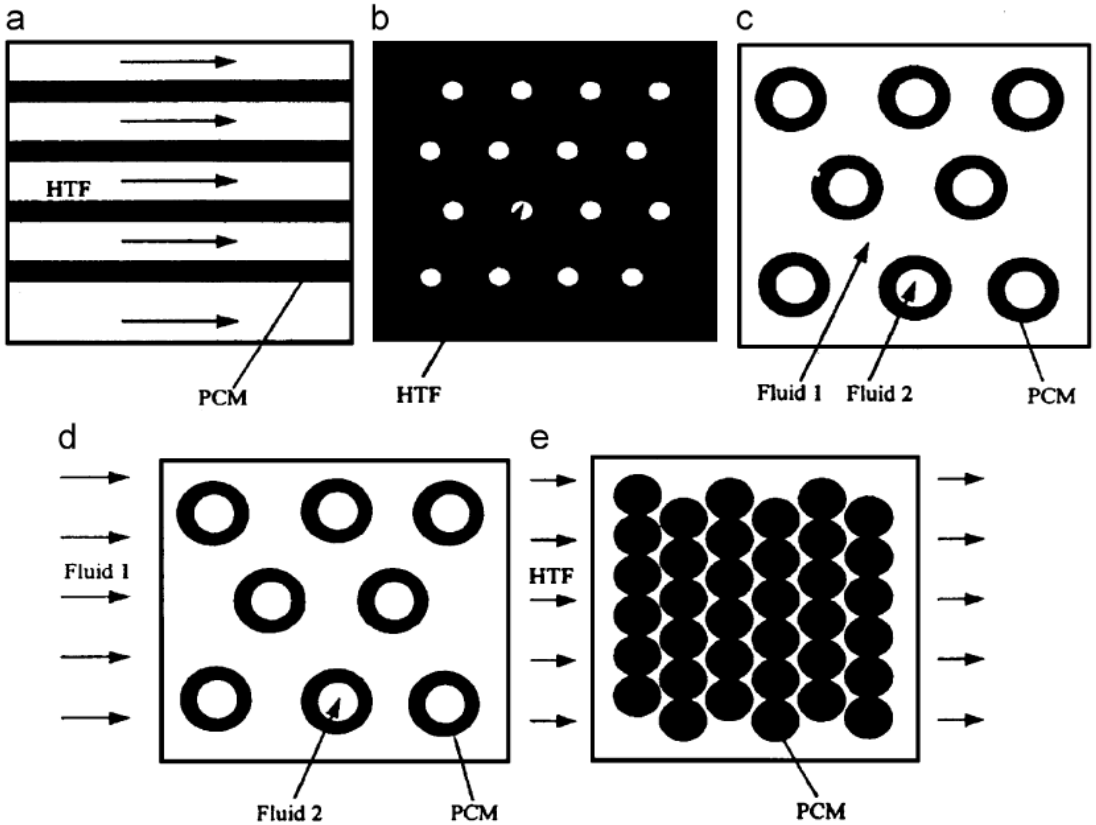
Phase Change Materials
Classificazione



Renewable and Sustainable Energy Reviews 13 (2009) 318–345

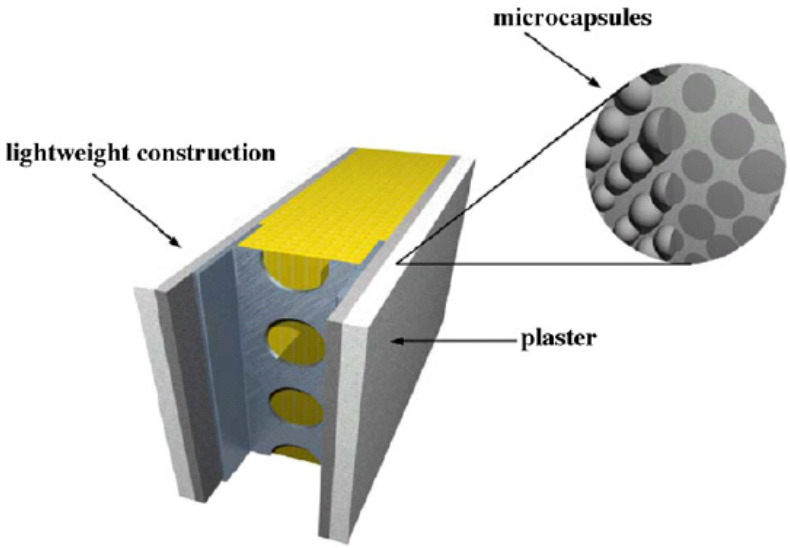
- I PCM possono essere usati in varie forme fisiche:
  - In ogni caso è necessario prevedere un involucro protettivo/contenitivo per i cambiamenti di fase

- **Microencapsulation**

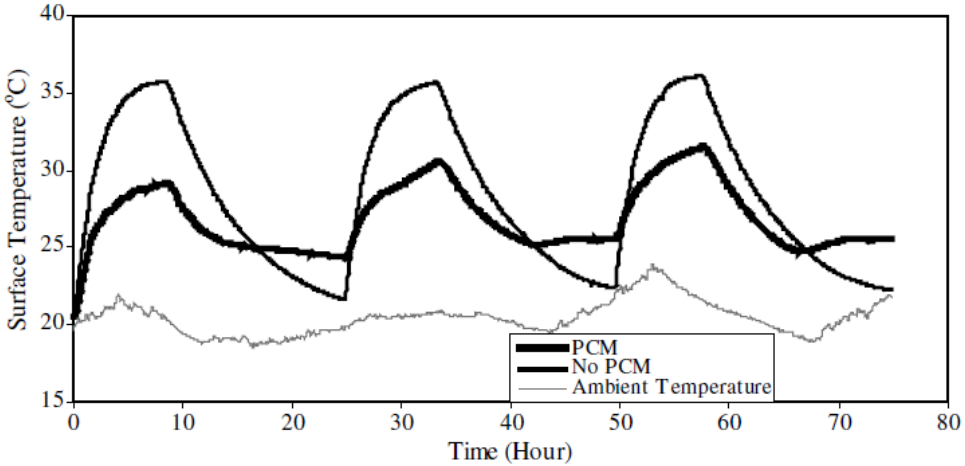


- I cartongessi sono economici e utilizzati in un ampio ventaglio di applicazioni

- Il calore latente e I principi di immagazzinamento dello stesso possono essere utilizzati in diversi tipi di materiali per l'edilizia



Renewable and Sustainable Energy Reviews 13 (2009) 318–345



Energy Conversion and Management 45 (2004) 263–275


Greenbox Systems :: Thermal Management System - Mozilla Firefox
File Modifica Visualizza Cronologia Segnalibri Strumenti Aiuto
http://www.greenboxsystems.com/
greenbox
Greenbox Systems :: Thermal Manag...
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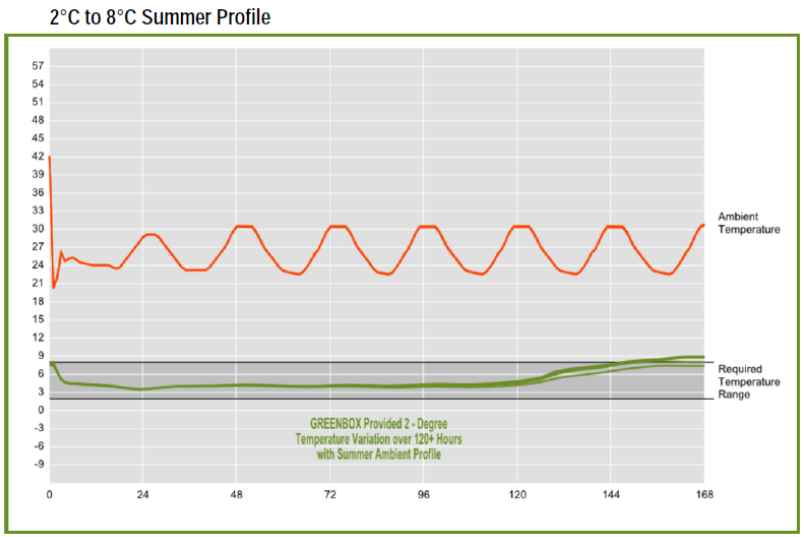
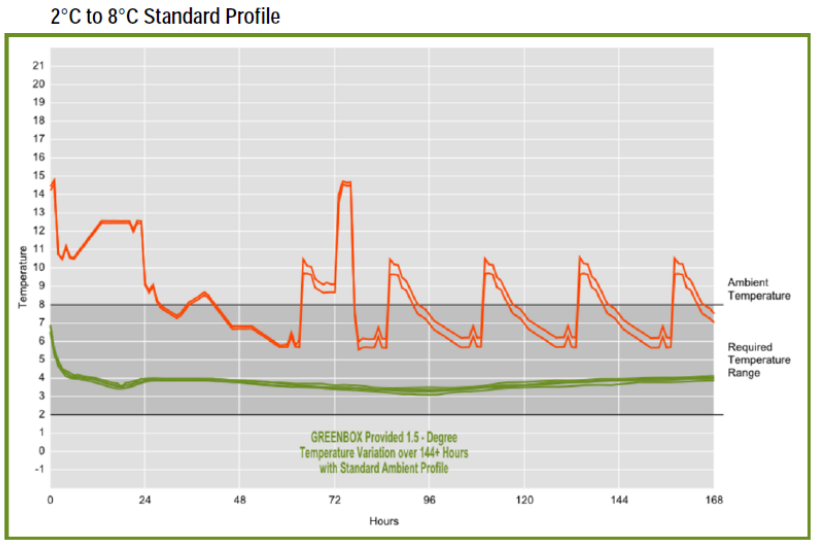
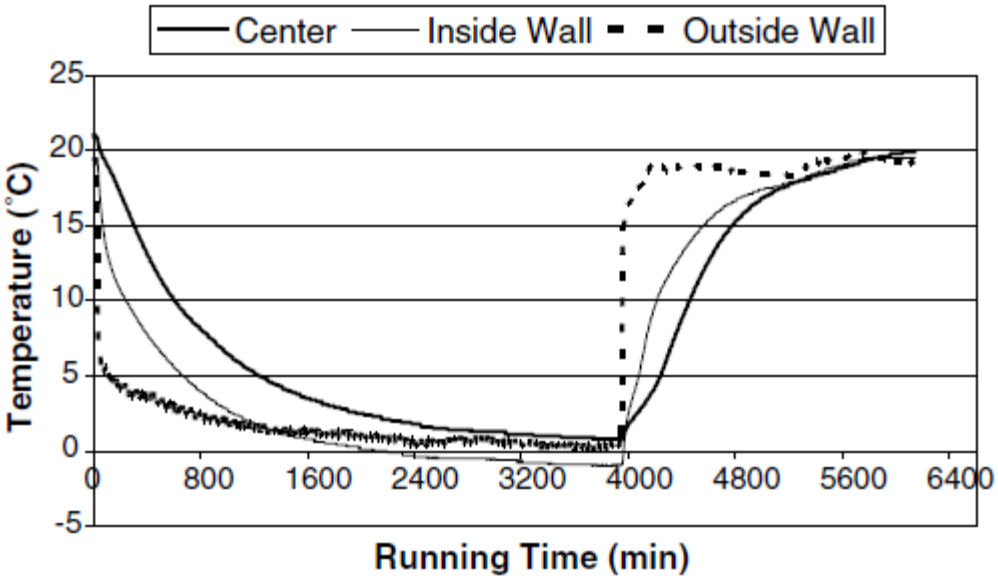
THERMAL MANAGEMENT SYSTEM
REDUCE DISTRIBUTION RELATED EXPENSES BY UP TO 65%...
spend your precious corporate dollars elsewhere, or heck, give yourself a raise.
PERISHABLE
REDUCE EXPENSE · 51% PAYLOAD EFFICIENCY · SHIP ANY DAY · SINGLE PACKING PROTOCOL · ENVIRONMENTALLY FRIENDLY
Pure Temp
Renewable Phase Change Technology
-40°C to + 70°C
120+ HOURS
CONTACT US BY PHONE: 1-877-4GRNBOX OR CLICK HERE
RETURN INFO CLICK HERE
PRESS/MEDIA:
April, 2010
Thermal shipper protects H1N1 vaccines for Chicago
March, 2010
Entropy Solutions Recognized for Pharma Cold Chain Excellence
NEWS:
February 5, 2010
Chicago Public Health Department Protects H1N1 Vaccine with GREENBOX
Renewable, reusable packaging protects temperature sensitive drugs and biologics - Chicago reports no vaccine spoilage since remote clinics began. >> More
February 5, 2010
Entropy awarded "Top Green" award by Pharma IQ
100 percent renewable, sustainable
EVENTS AND TRADE SHOWS:
Canadian Cold Chain Summit
Toronto, Canada
February 24-26 >>More
PDA Pharmaceutical Cold Chain Conference
Bethesda, MD
April 12-15 >>More
GSA Conference & Expo
Orlando, FL
May 4-6 >>More
North American Cold Chain Conference
Completato

- Greenbox technology
  - www.greenboxsystems.com
  - currently used for high-payload shippings
  - Modified Wal Mart chain perception



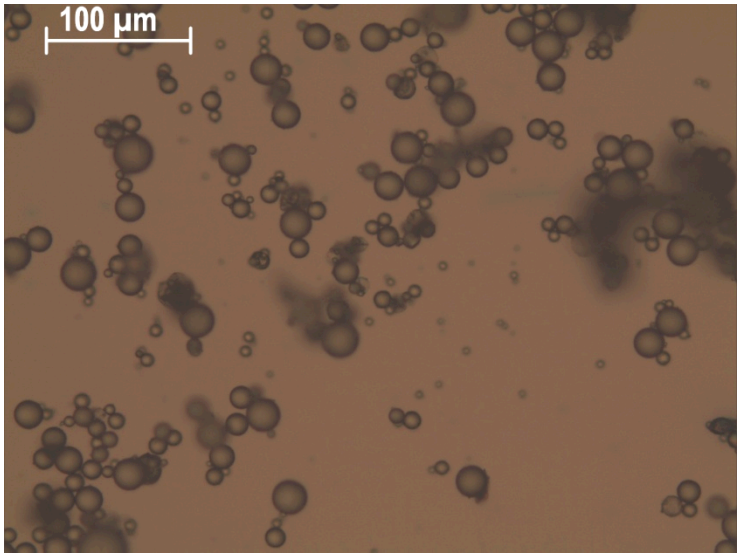


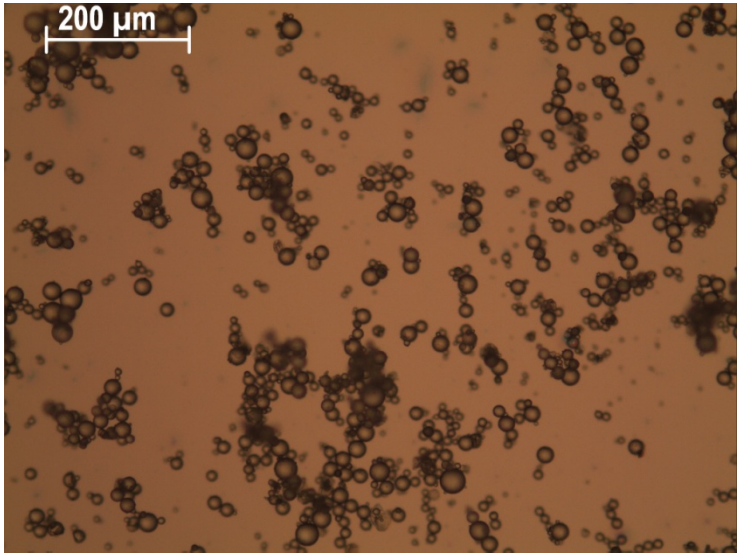
- Nanotechnology meets PCM in producing more effective systems for composite materials design
- **Incorporation in nanostructures**

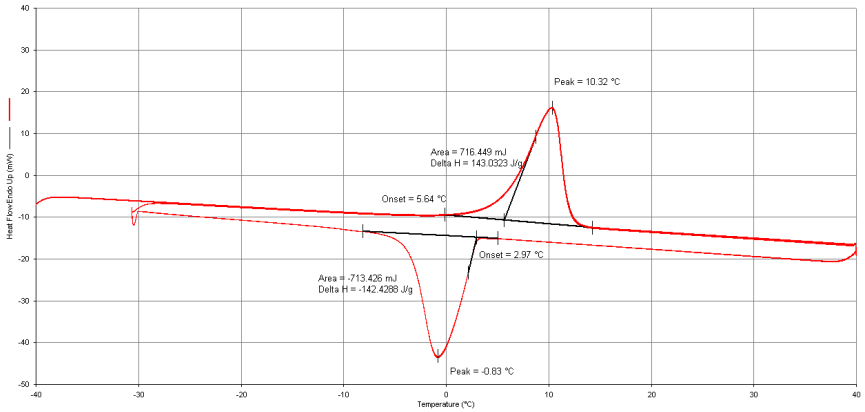


Current Applied Physics 8 (2008) 508–511

- PCM µparticles:
  - Tm = 6-10 °C
  - Easily suspended in common hydrophilic solvents
  - Good dimension dispersion







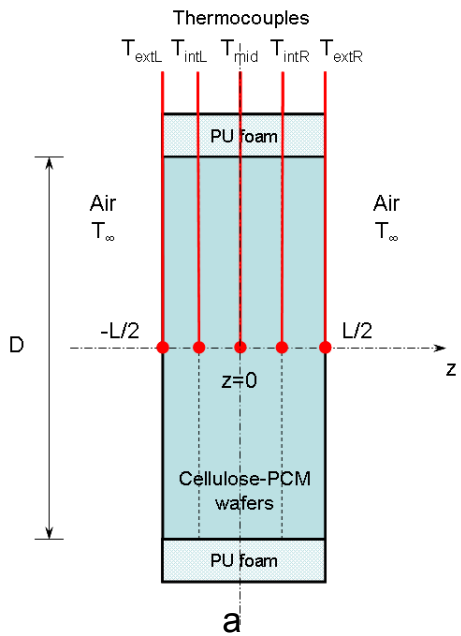
50 PCM panels and disks

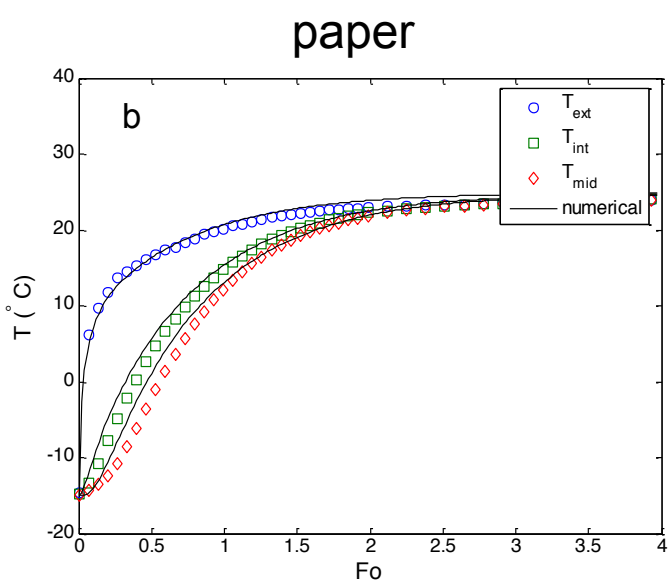
$$\rho \frac{\partial H}{\partial t} = k \frac{\partial^2 T}{\partial z^2} \quad \begin{cases} T(z,t=0) = T_0 & \forall z \in [0, L/2] \\ h_{ext}\left(T_\infty - T\left(z = \frac{L}{2}, t\right)\right) = k \left.\frac{\partial T}{\partial z}\right|_{z=\frac{L}{2}} & \forall t > 0 \\ \left.\frac{\partial T}{\partial z}\right|_{z=0} = 0 & \forall t > 0 \end{cases}$$

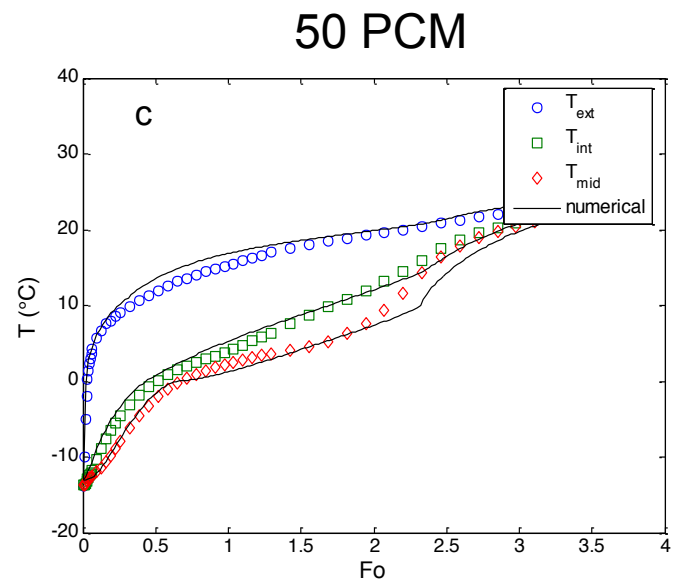
$$h_{ext} = 15 \div 20 \, W m^{-2} {}^\circ C^{-1}$$

Fourier number: $Fo = \frac{\alpha \cdot t}{(L/2)^2}$

Thermal diffusivity: $\alpha = \frac{k}{\rho \cdot C_P}$

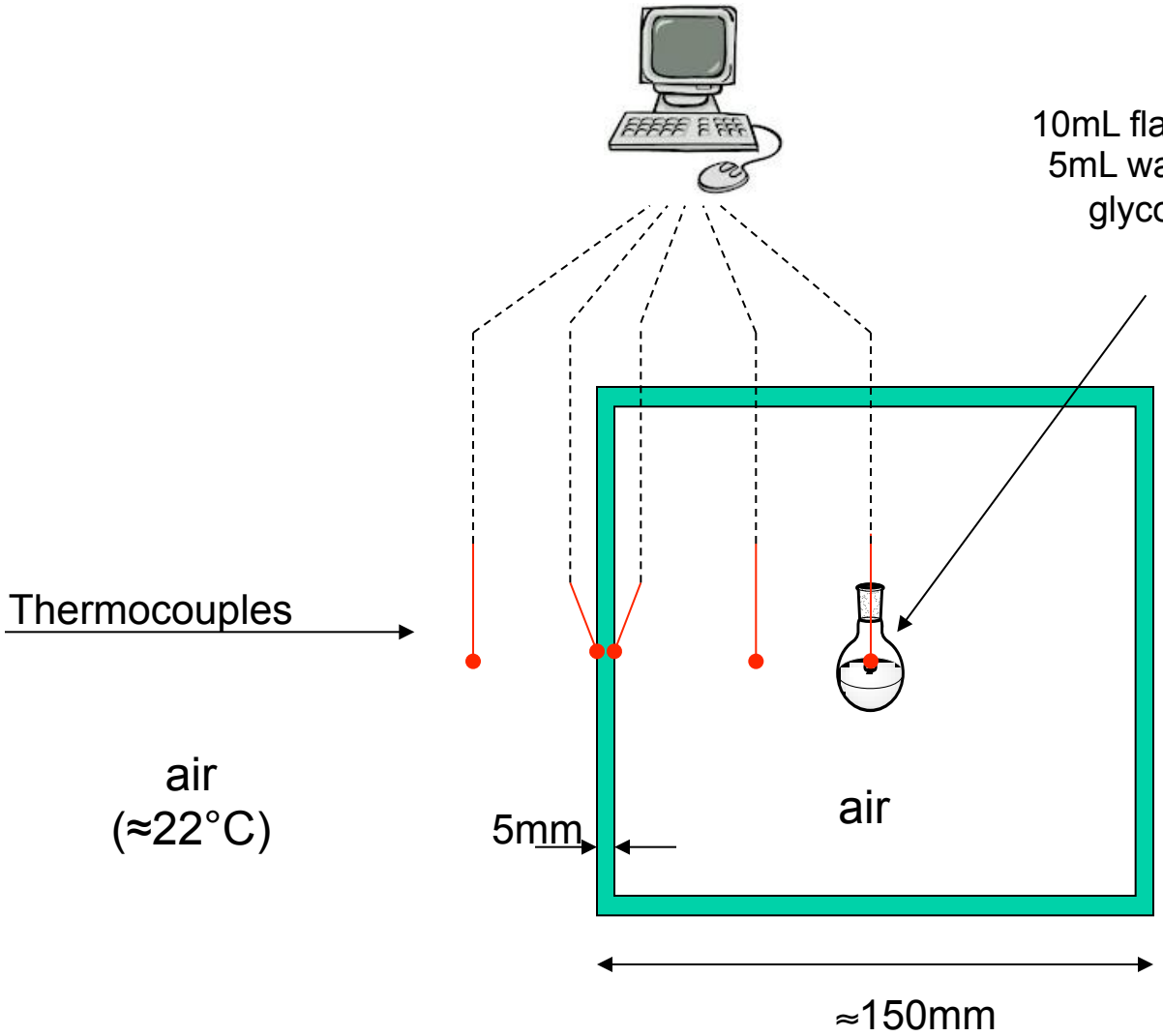






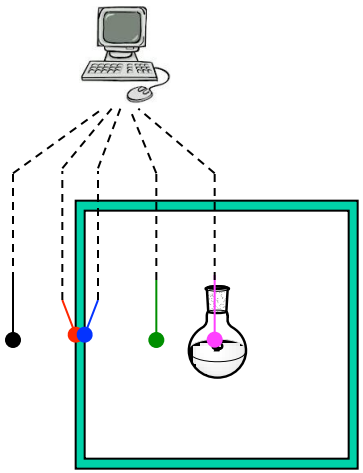
Markers: experimental data
Solid line: numerical calculations

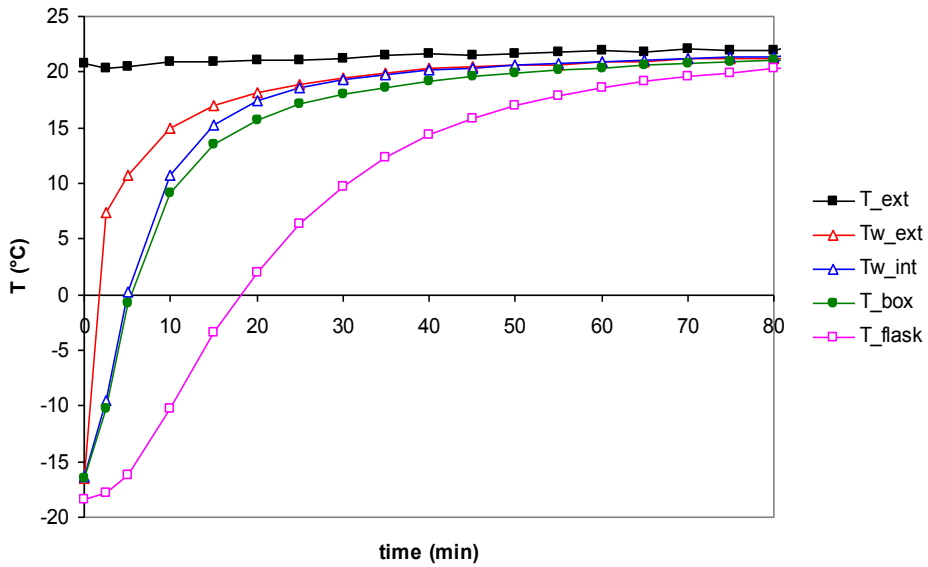
L. Melone, De Nardo et al., *Applied Energy* **2012**, 89, 339–346



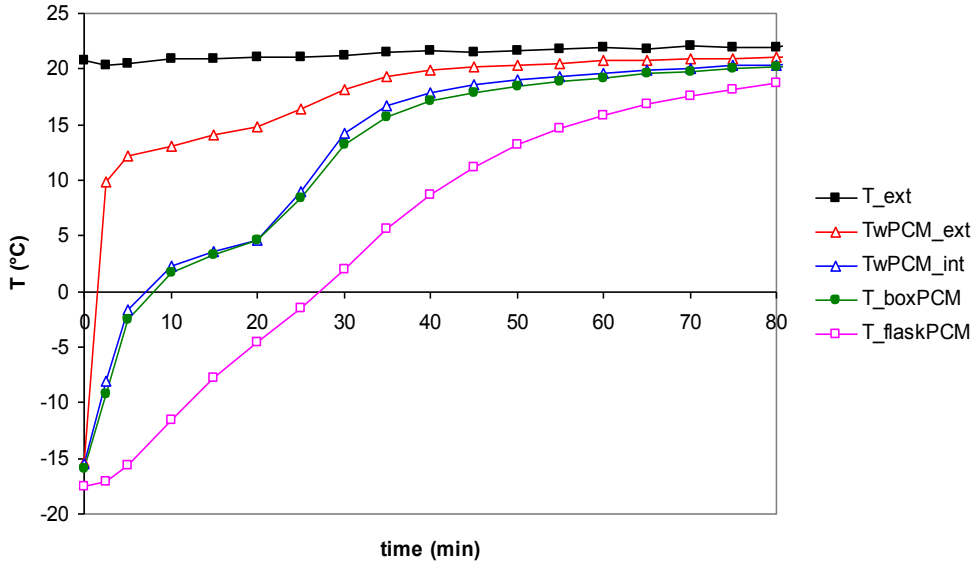
Experimental apparatus kept in deep freezer at **-15°C** for **12h** then
warming up to r.t. (≈**22°C**)

Phase Change Materials
Towards pratical applications





paperboard



50 PCM

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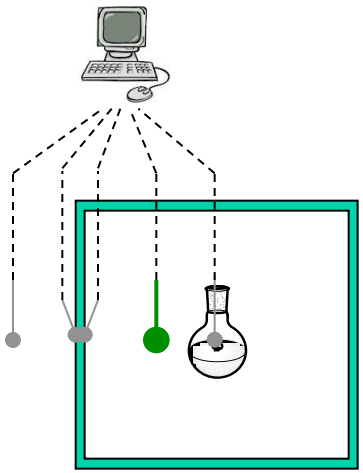
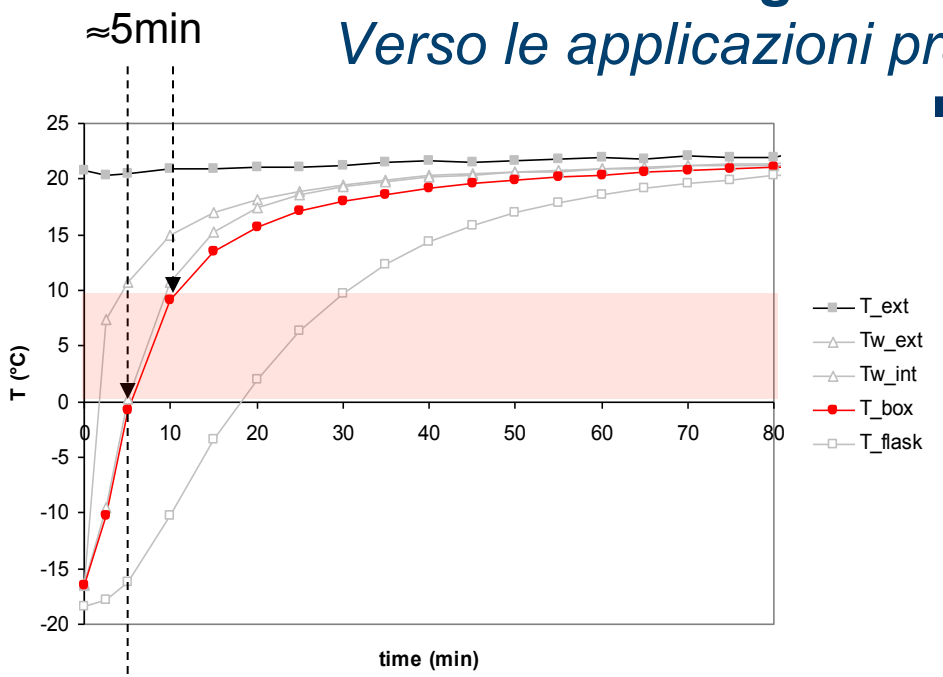
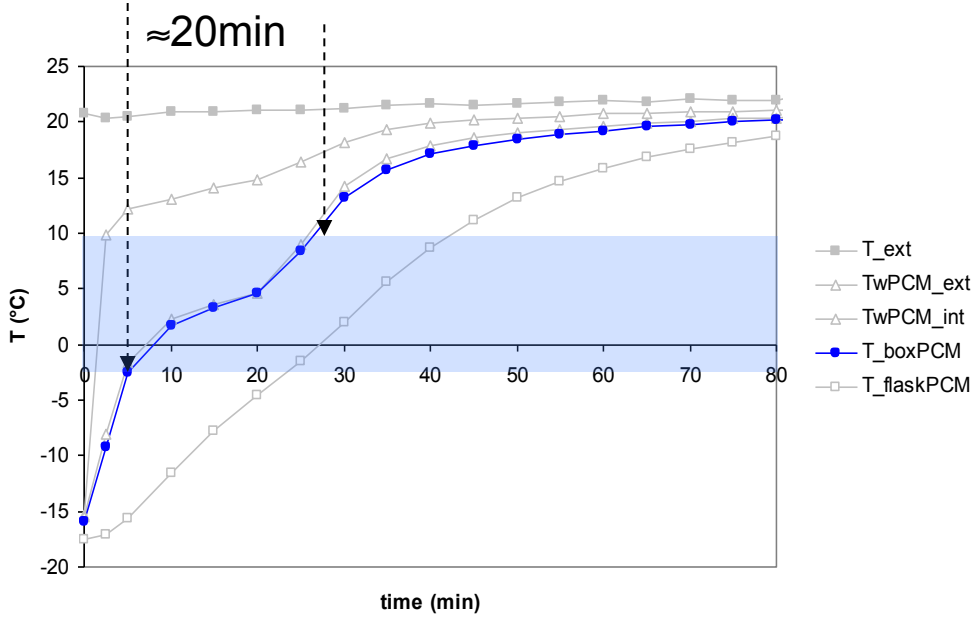
Phase Change Materials
Verso le applicazioni pratiche





paperboard



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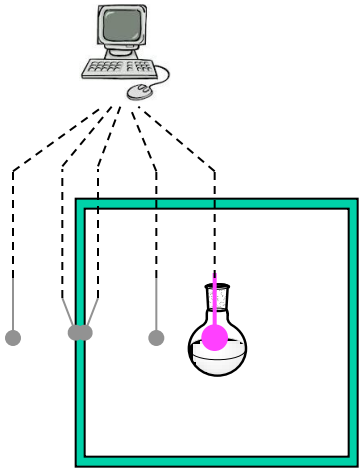
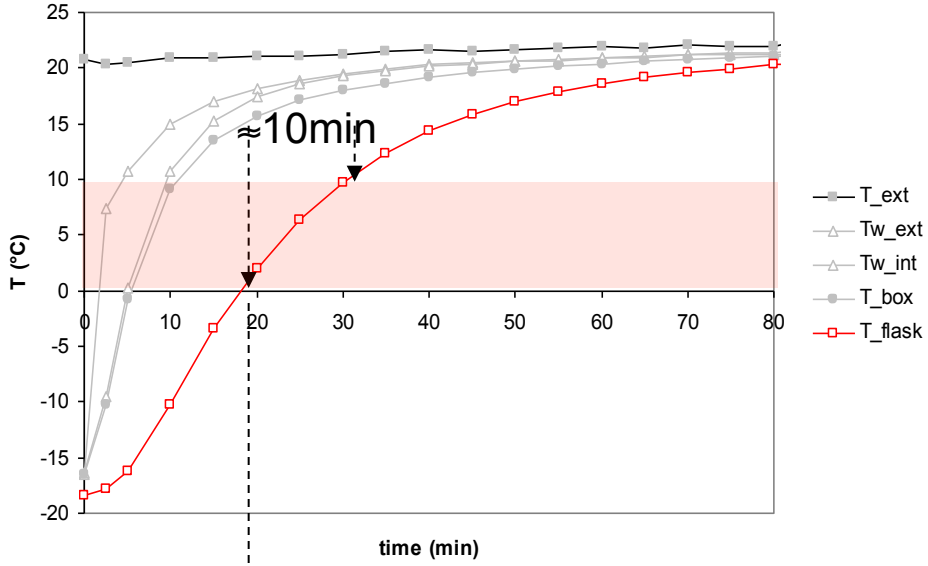
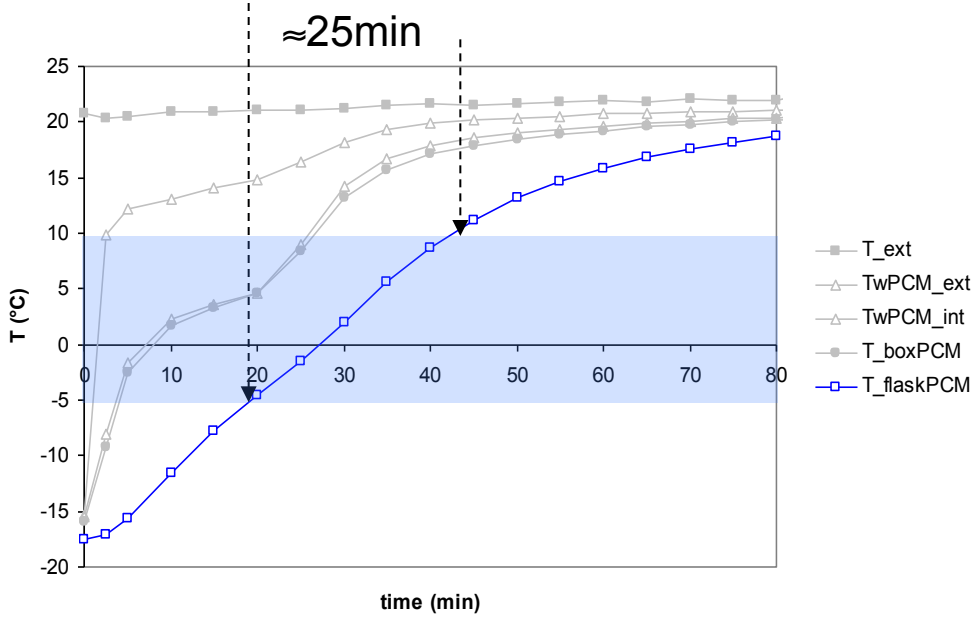
Phase Change Materials
Verso le applicazioni pratiche

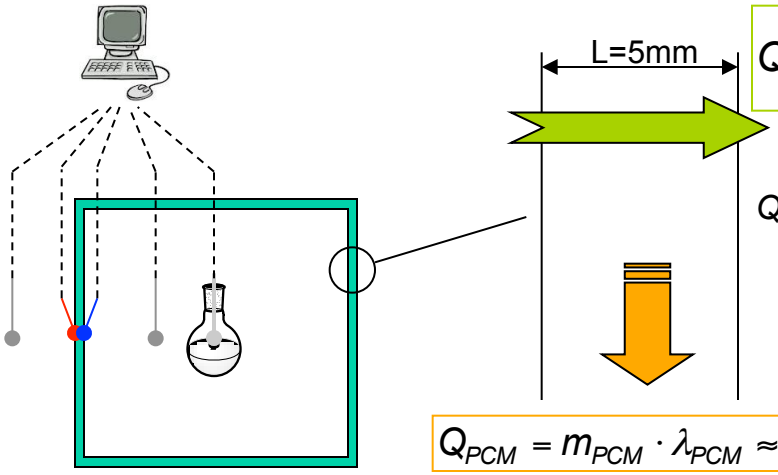




paperboard



50 PCM



$$Q_{COND} = \frac{k}{L} \cdot A \cdot \Delta T \cdot time \approx 26500J$$

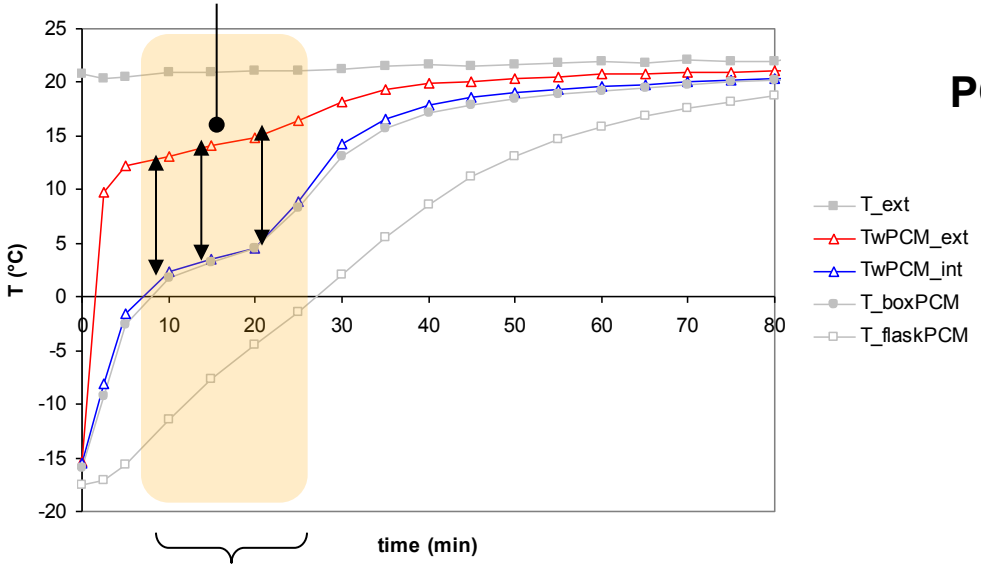
$$Q_{COND} = \left(\frac{0.082 Wm^{-1}°C^{-1}}{5 \cdot 10^{-3} m}\right) \cdot \left(0.135 m^2\right) \cdot \left(10°C\right) \cdot \left(20 \min\right) \cdot \left(60 s \min^{-1}\right) \approx 26500J$$

$$Q_{PCM} = m_{PCM} \cdot \lambda_{PCM} \approx 21500J$$

$$Q_{PCM} = \left(0.150 kg\right) \cdot \left(143{,}000 Jkg^{-1}\right) \approx 21500J$$

This is the max amount of thermal energy that can be absorbed by PCM (**≈150g**)

ΔT≈10÷15°C



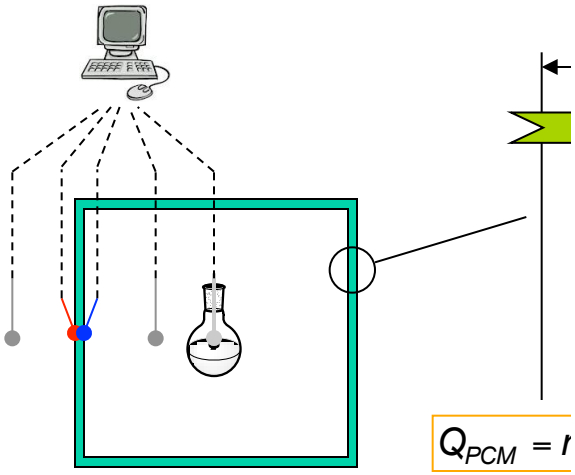
≈20min

PCM's really buffer the conductive heat flux

Prolunged buffering times can be obtained reducing the k/L ratio

- higher **L**
- lower **k**

1. **Materials**
2. **Packaging design**



$\Delta T \approx 10 \div 15°C$

Applied Energy 89 (2012) 339–346

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Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Phase change material cellulosic composites for the cold storage of perishable products: From material preparation to computational evaluation

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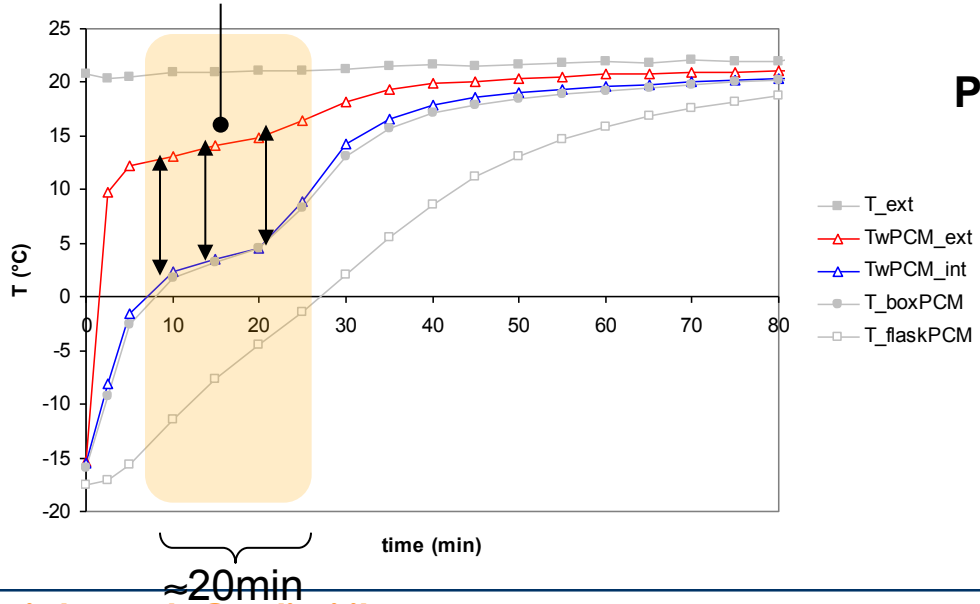
[b] Local Unit, Istituto Nazionale di Scienza e Tecnologia dei Materiali, INSTM, Firenze, Italy

$Q_{PCM} = r$

$Q_{PCM} = (0.$



PCM's really buffer the conductive heat flux

Prolunged buffering times can be obtained reducing the k/L ratio

- higher **L**
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1. **Materials**
2. **Packaging design**

Conclusioni

- I Materiali a cambiamento di fase:
  - Consentono di accumulare energia termica legata alle transizioni di fase
  - L'accumulo e il rilascio avvengono a temperatura controllata e quasi costante

- L'approccio di immagazzinamento termico consente di realizzare:
  - Prodotti industriali con maggiori performace
  - Costi contenuti

- Al Politecnico di Milano sono presenti competenze:
  - progettazione (legata alla selezione dei materiali)
  - Caratterizzazione teorica e sperimentale
  - Scale up industriale

Thanks for your attention

POLITECNICO DI MILANO

Warming up your ideas…

By cooling down your products!

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