Fraunhofer Center for Sustainable Energy Systems

# Energy Performance Analysis of Building Envelopes Utilizing Blown Fiber Insulation with Microencapsulated Phase Change Material (PCM).


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# Agenda

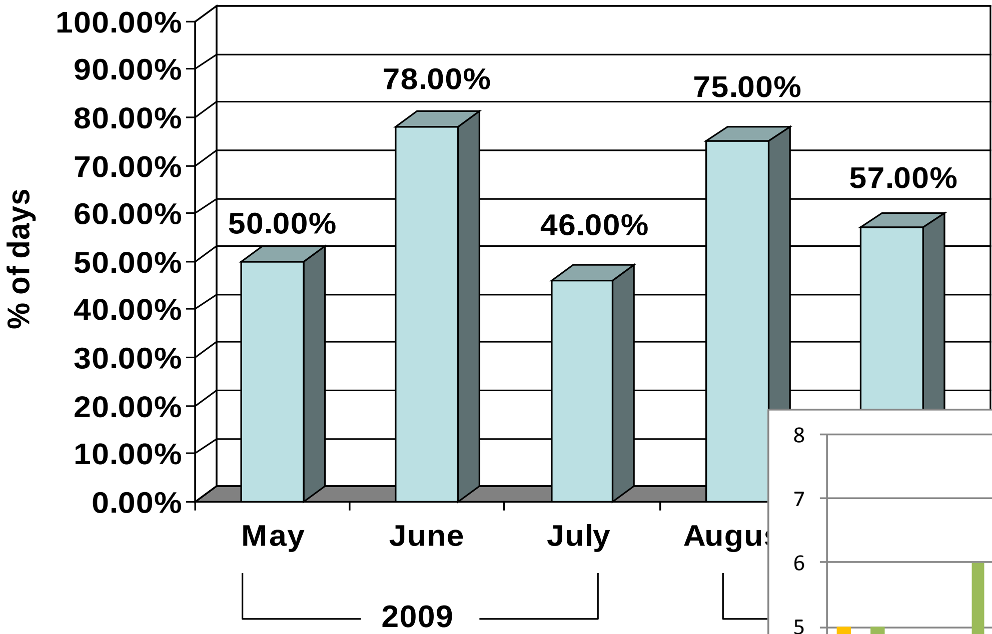

- Available PCM performance data – testing, validated simulations
- Theoretical analysis of performance limits for basic PCM applications
- Cost competitiveness of PCMs comparing to conventional insulations
- Progress on development of the PCM database for U.S. building applications

# Existing Performance Data on PCM Applications

# Available PCM performance data – testing, validated simulations

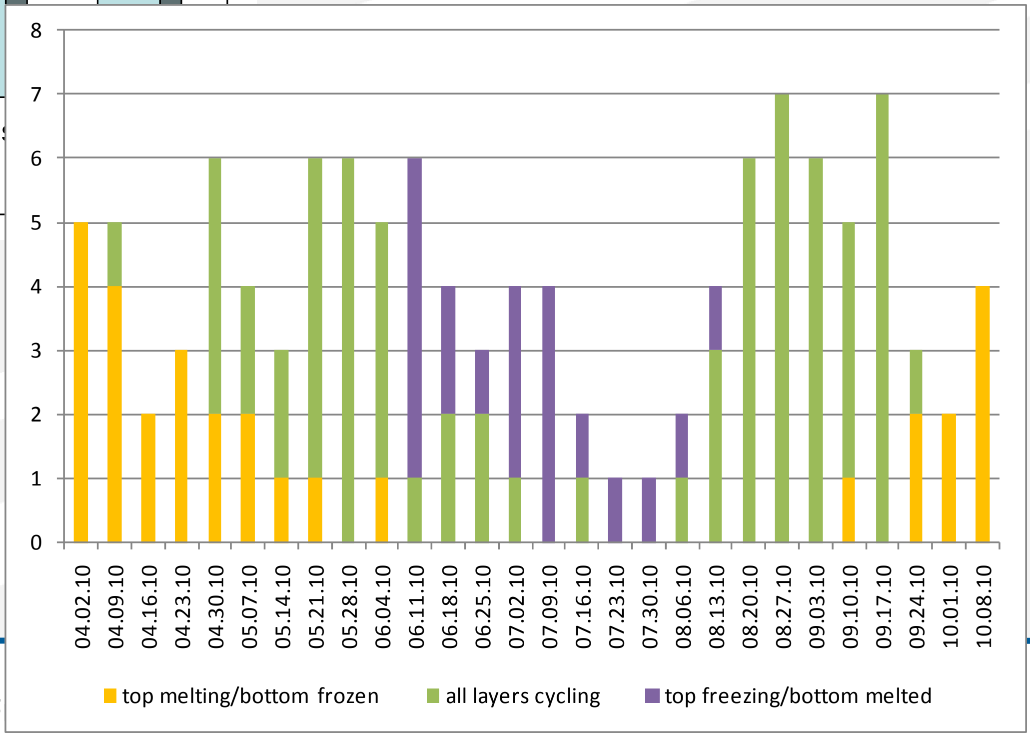
| Authors - reference | PCM location | PCM enthalpy | PCM loading | Appr. cooling load savings |
|---|---|---|---|---|
| Stovall, Tomlinson – 1997 | Wall – gypsum board | 140 kJ/kg (64 Btu/lb), | 30% - 32-Btu/ft$^2$ - 0.5 lb/ft$^2$ | 7% - Miami, FL<br>15% - Nashville, TN |
| Zhang, Medina - 2005 | Wall core - containers | 123.7 kJ/kg (52 Btu/lb) | 10% - ~10 - Btu/ft$^2$ - 0.2 lb/ft$^2$ | 9% - Lawrence, KS |
| Zhang, Medina - 2005 | Wall core - pipes | 123.7 kJ/kg (52 Btu/lb) | 20% - ~21 - Btu/ft$^2$ - 0.4 lb/ft$^2$ | 11% - Lawrence, KS |
| Kissock, Limas - 2006 | Wall – gypsum board | 143 kJ/kg (65 Btu/lb) | 30% - ~32 - Btu/ft$^2$ - 0.5 lb/ft$^2$ | 16% - Dayton, OH |
| Willson - 2010 | Wall – gypsum board | 110 kJ/kg (48 Btu/lb) | 22-Btu/ft$^2$ ~ 0.4 lb/ft$^2$ | 13.5% - Dynamic HFMA testing |
| Murugananthama et al. – 2010 | Wall, Celilng, Floor – PCM containers | 178 kJ.Kg (81 Btu/lb) | Walls; 45-Btu/ft$^2$ ~ 0.56 lb/ft$^2$ | 16% - whole building – Tempe, AZ |
| Kosny - 2007 | Wall Cavity – PCM enhanced cellulose | 120 kJ/kg (50 Btu/lb) | 22% - ~10 - Btu/ft$^2$ - 0.2 lb/ft$^2$ | 7% - Charleston, SC<br>40% - Oak Ridge, TN |
| Kissock - 2007 | Metal roof–polyisocyanurate board | 143 kJ/kg (65 Btu/lb) | 30 - Btu/ft$^2$ - 0.5 lb/ft$^2$ | 14% - Dayton, OH |
| Kosny et al. - 2011 | Roof deck – PCM containers | 178 kJ.Kg (81 Btu/lb) | 27-Btu/ft$^2$ ~ 0.3 lb/ft$^2$ | 25% - PCM - Oak Ridge, TN |

# Two tests; ~ 60% with days with PCM melting-freezing




ORNL – cellulose
Kosny - 2008

ORNL – metal roof
Kosny et al. -2012

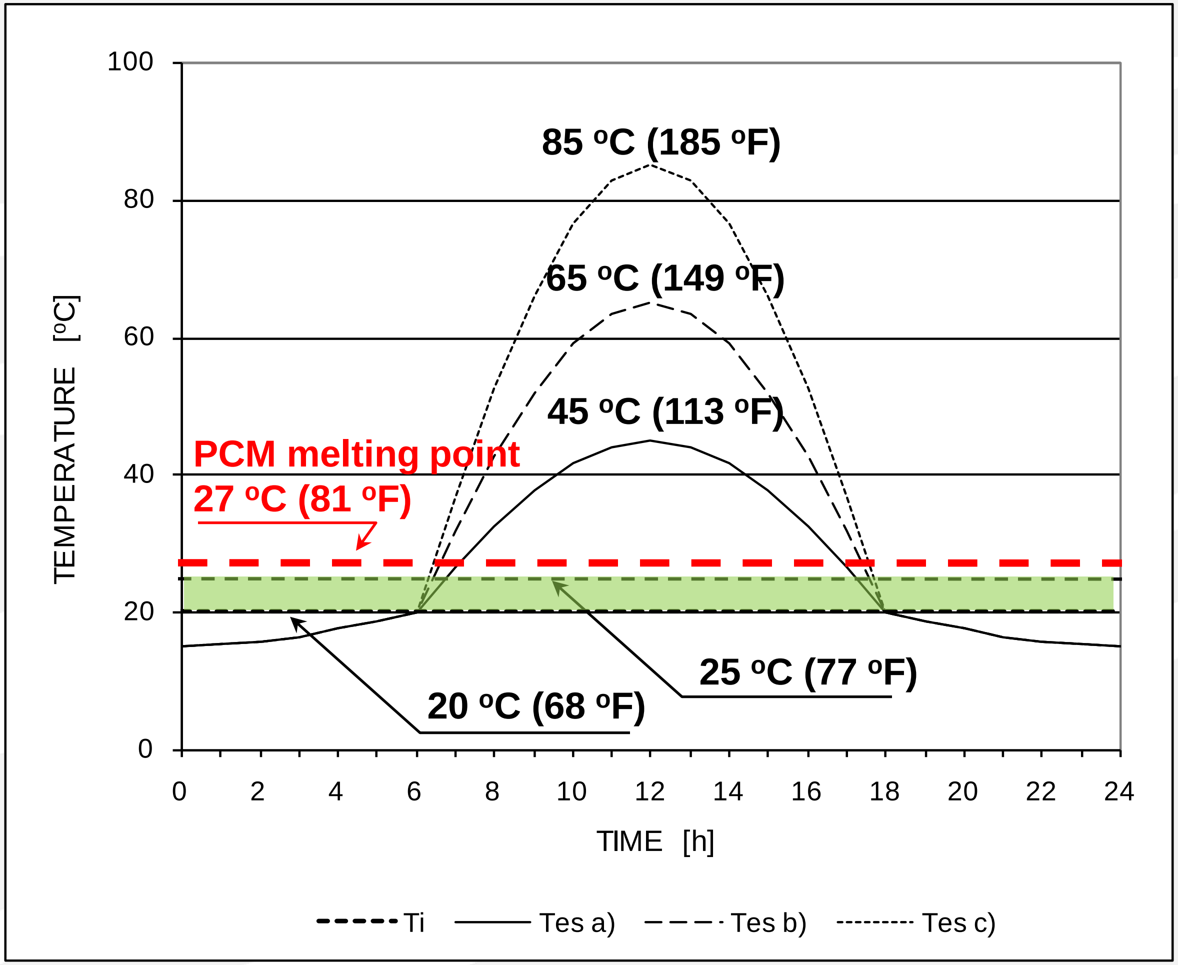


# Theoretical Analysis of Performance Limits for Basic PCM Applications

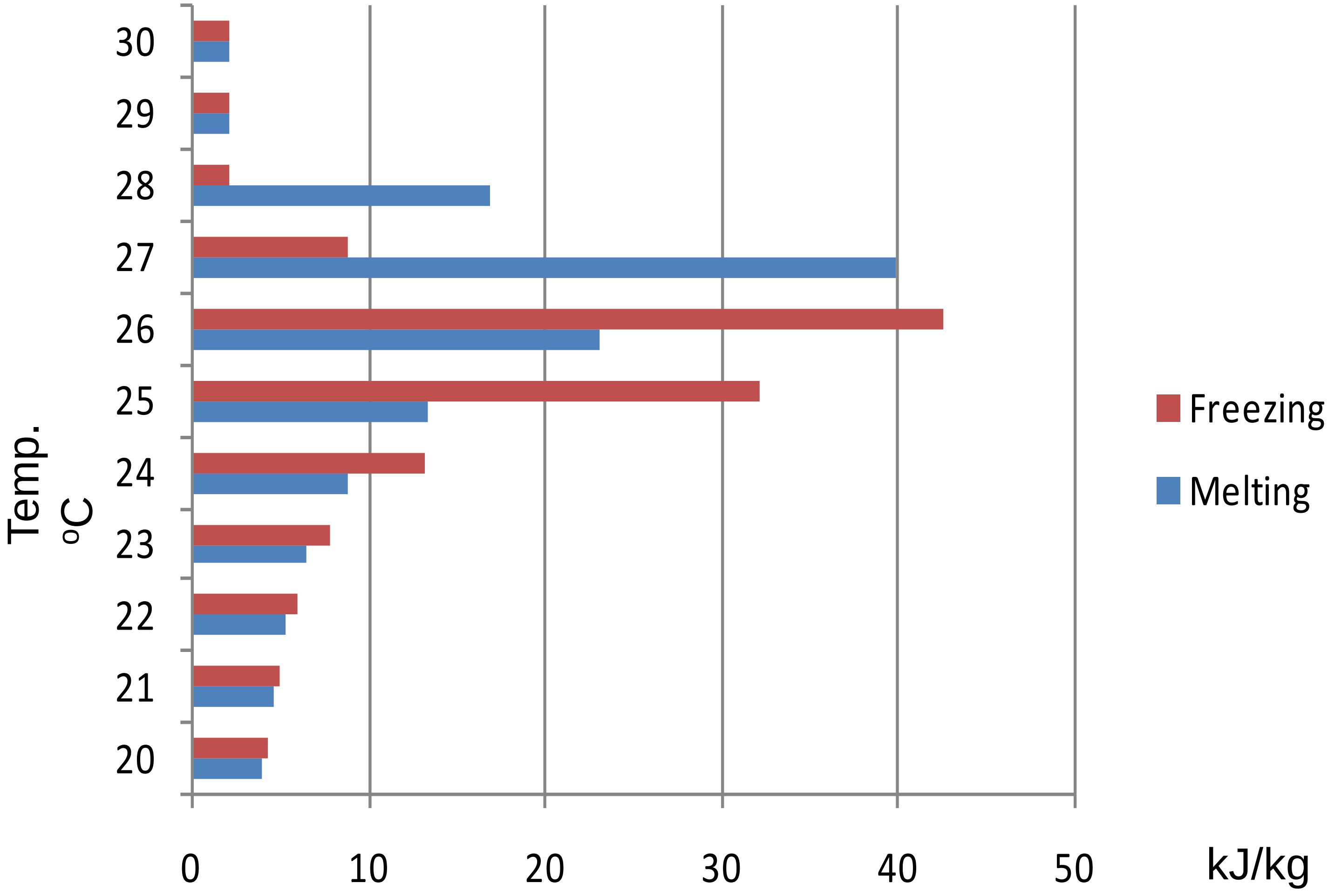
# Theoretical analysis of performance limits for basic PCM applications

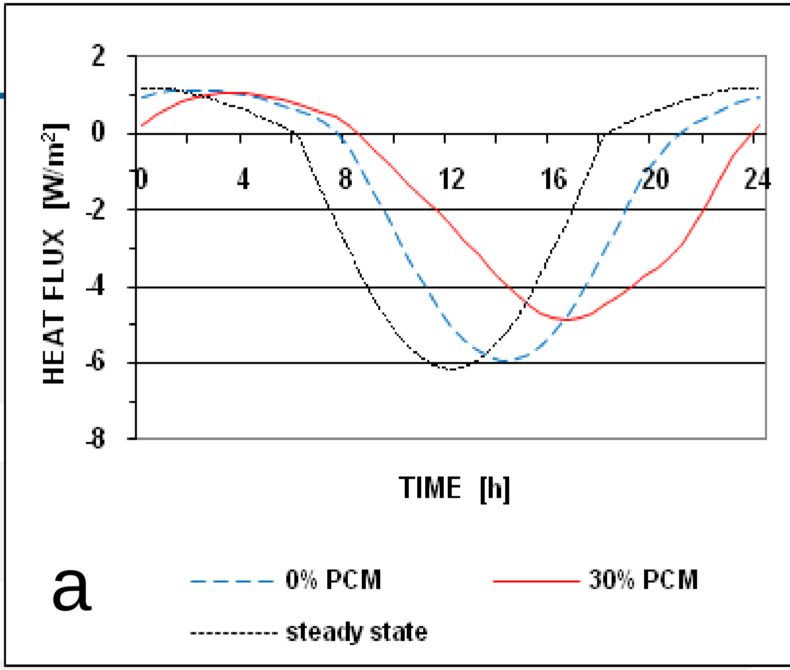
- Two thicknesses representing wall and attic applications were used in modeling;
  - 14 cm (5.5 in) representing walls and vaulted ceiling applications, and
  - 30 cm. (11.8 in.) representing attic floor insulations.
- Numerical program developed for this purpose used the control volume heat balance method, explicit scheme, with temperature dependent effective heat capacity and experimentally determined thermal conductivity.
- Distance between nodes within insulation was 0.01 – 0.02 m (0.39 and 0.79-in.), and time step was 30 s.
- To visualize dynamic effects, heat fluxes for steady state, which represent the “zero mass” wall, were calculated, taking into account dependence of insulation conductivity on temperature.
- An accurate elementary solution of the non-linear steady state heat transfer problem, in the case of linear dependence of conductivity on temperature, may be obtained using the Kirchoff transform method; see Kossecka (1999).

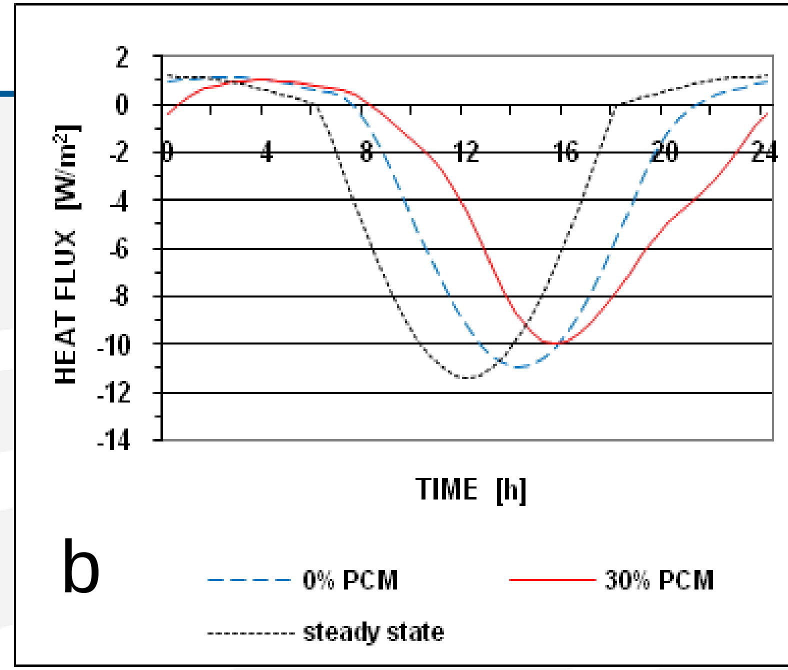
# Thermal Excitations Used in Analysis

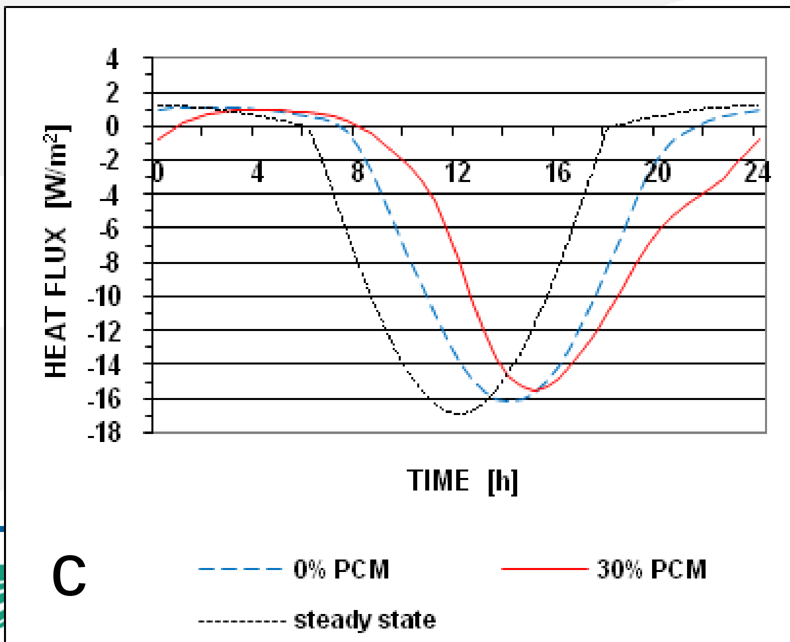


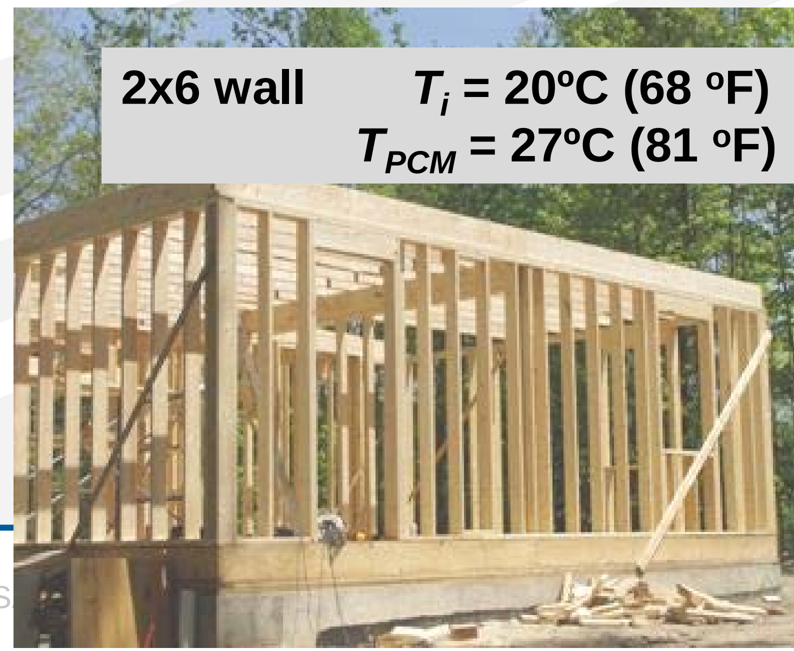
# PCM Enthalpy Profile Used in Analysis




a
HEAT FLUX [W/m²]
2
0
-2
-4
-6
-8
0 4 8 12 16 20 24
TIME [h]
0% PCM
30% PCM
steady state

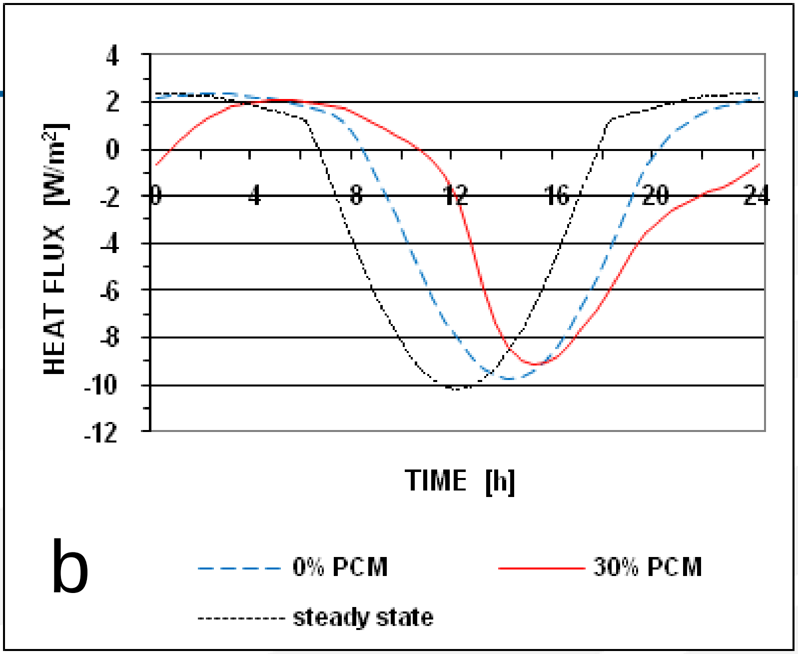

b
HEAT FLUX [W/m²]
2
0
-2
-4
-6
-8
-10
-12
-14
0 4 8 12 16 20 24
TIME [h]
0% PCM
30% PCM
steady state

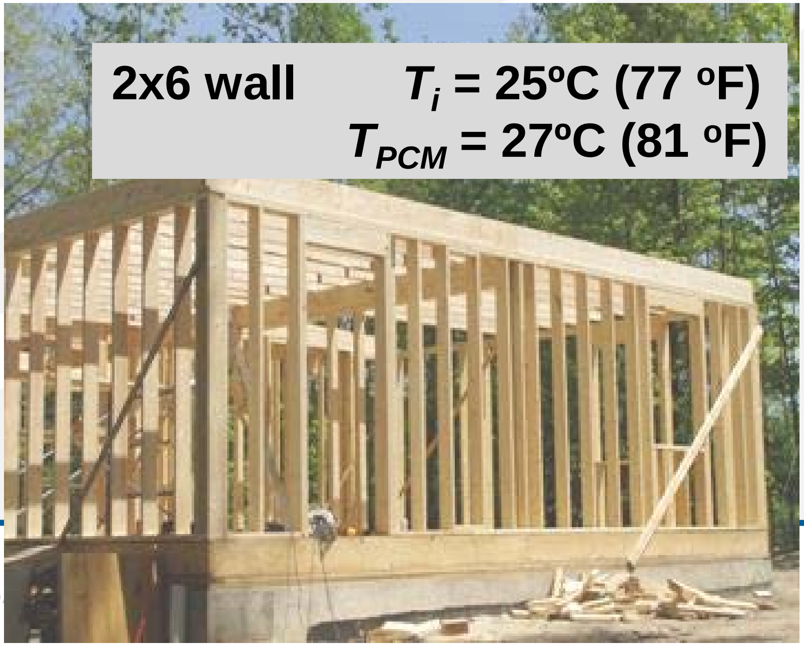

c
HEAT FLUX [W/m²]
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0 4 8 12 16 20 24
TIME [h]
0% PCM
30% PCM
steady state

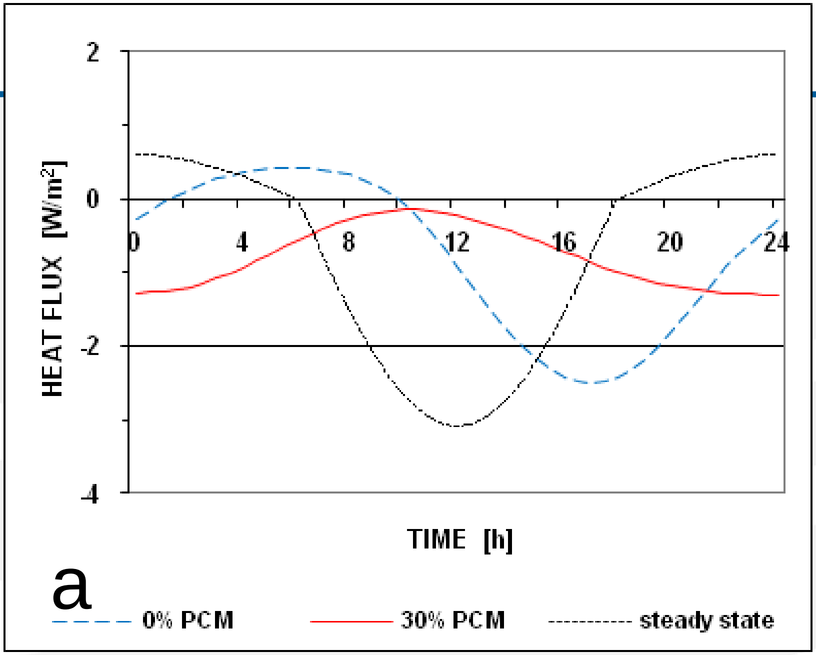

2x6 wall
Ti = 20ºC (68 ºF)
TPCM = 27ºC (81 ºF)

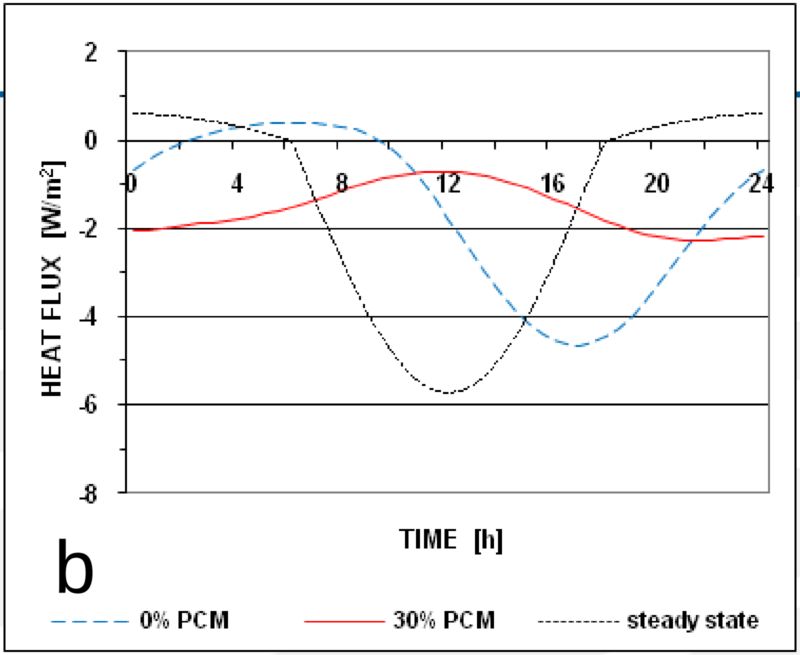
a

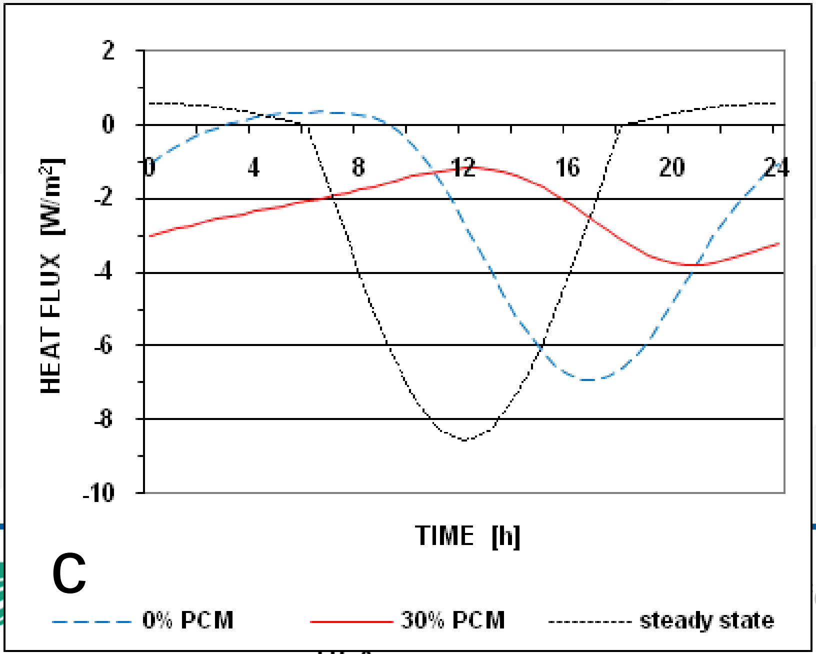
b

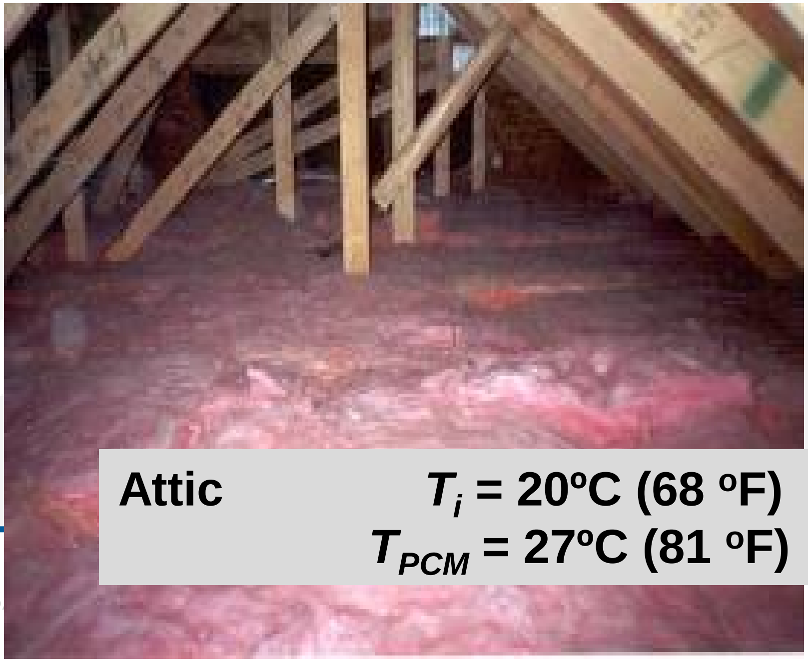

HEAT FLUX [W/m²]
TIME [h]
0% PCM
30% PCM
steady state


2x6 wall
$T_i$ = 25ºC (77 ºF)
$T_{PCM}$ = 27ºC (81 ºF)

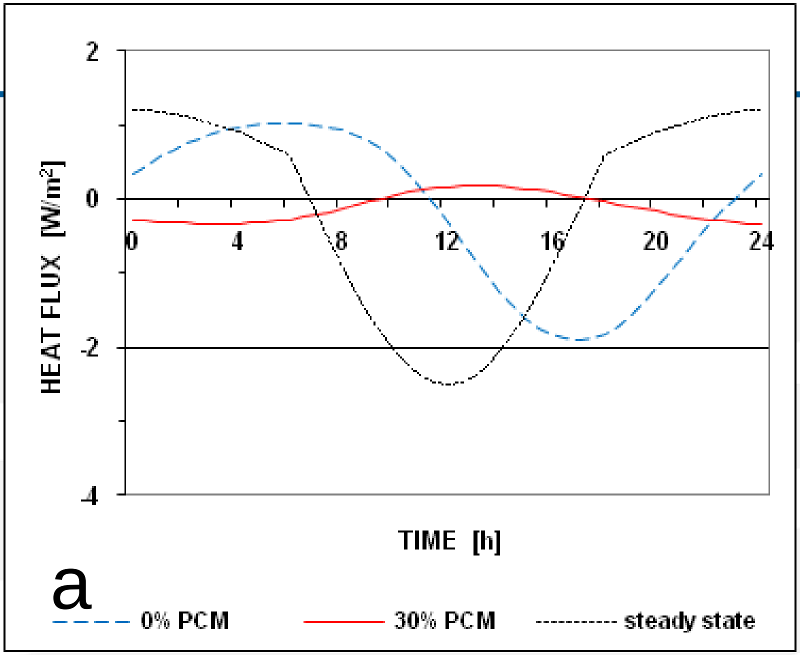

2
0
-2
-4
HEAT FLUX [W/m²]
0
4
8
12
16
20
24
TIME [h]
a
0% PCM
30% PCM
steady state

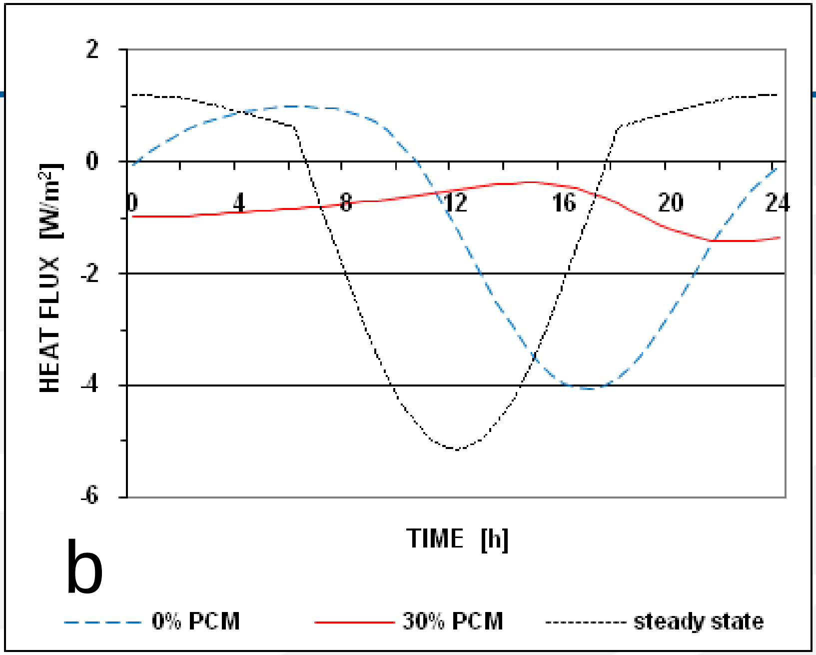

2
0
-2
-4
-6
-8
HEAT FLUX [W/m²]
0
4
8
12
16
20
24
TIME [h]
b
0% PCM
30% PCM
steady state

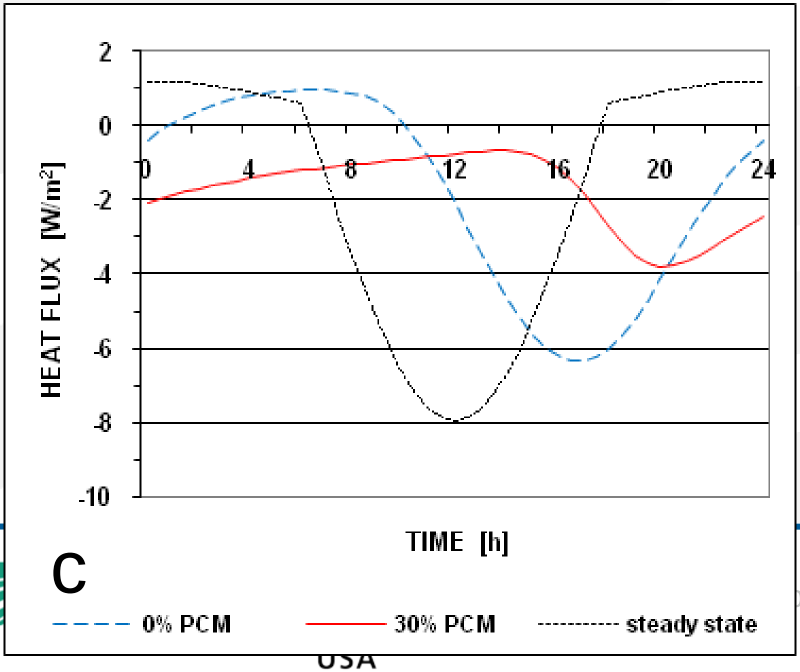

2
0
-2
-4
-6
-8
-10
HEAT FLUX [W/m²]
0
4
8
12
16
20
24
TIME [h]
c
0% PCM
30% PCM
steady state

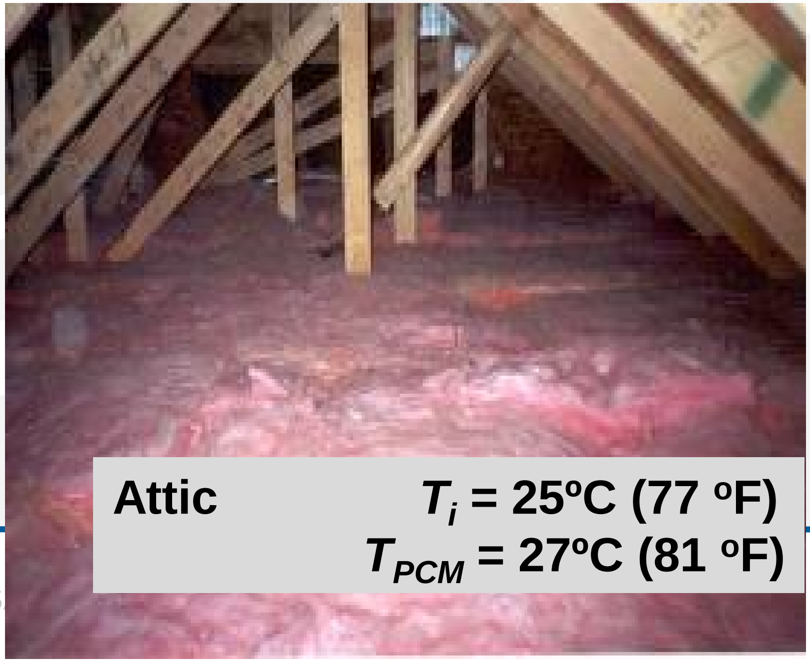

Attic
$T_i$ = 20ºC (68 ºF)
$T_{PCM}$ = 27ºC (81 ºF)

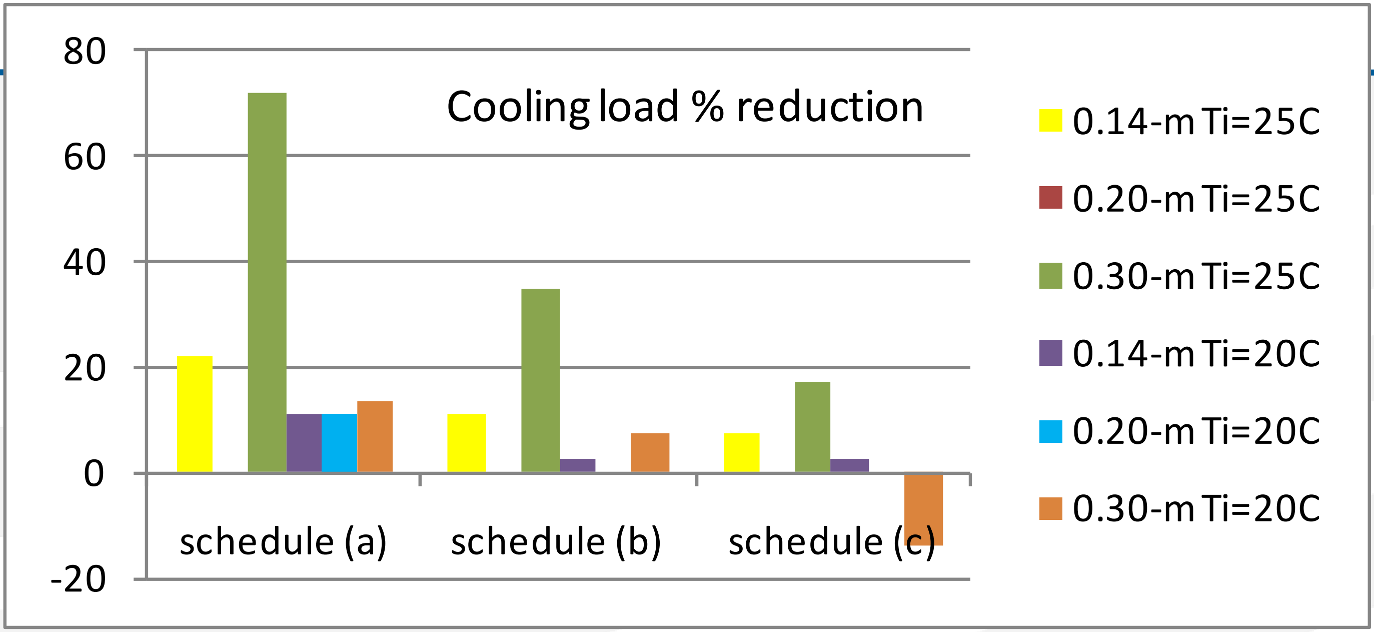
USA


HEAT FLUX [W/m²]
TIME [h]
a
0% PCM
30% PCM
steady state

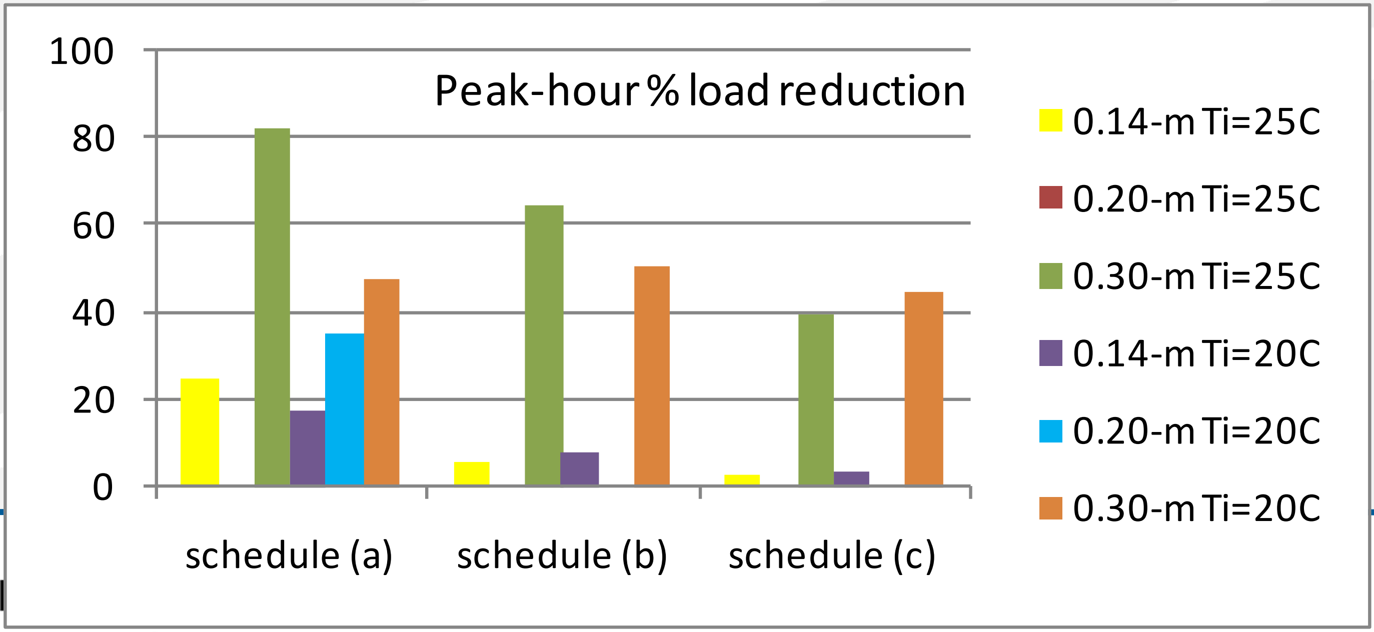

HEAT FLUX [W/m²]
TIME [h]
b
0% PCM
30% PCM
steady state


HEAT FLUX [W/m²]
TIME [h]
c
0% PCM
30% PCM
steady state


Attic
$T_i$ = 25ºC (77 ºF)
$T_{PCM}$ = 27ºC (81 ºF)

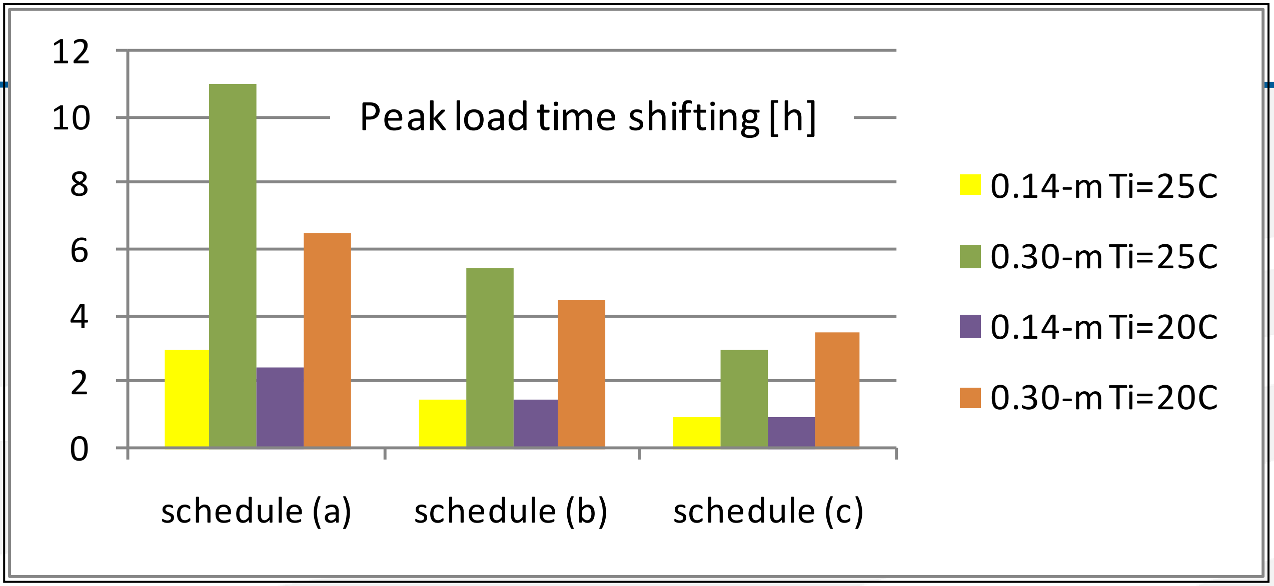


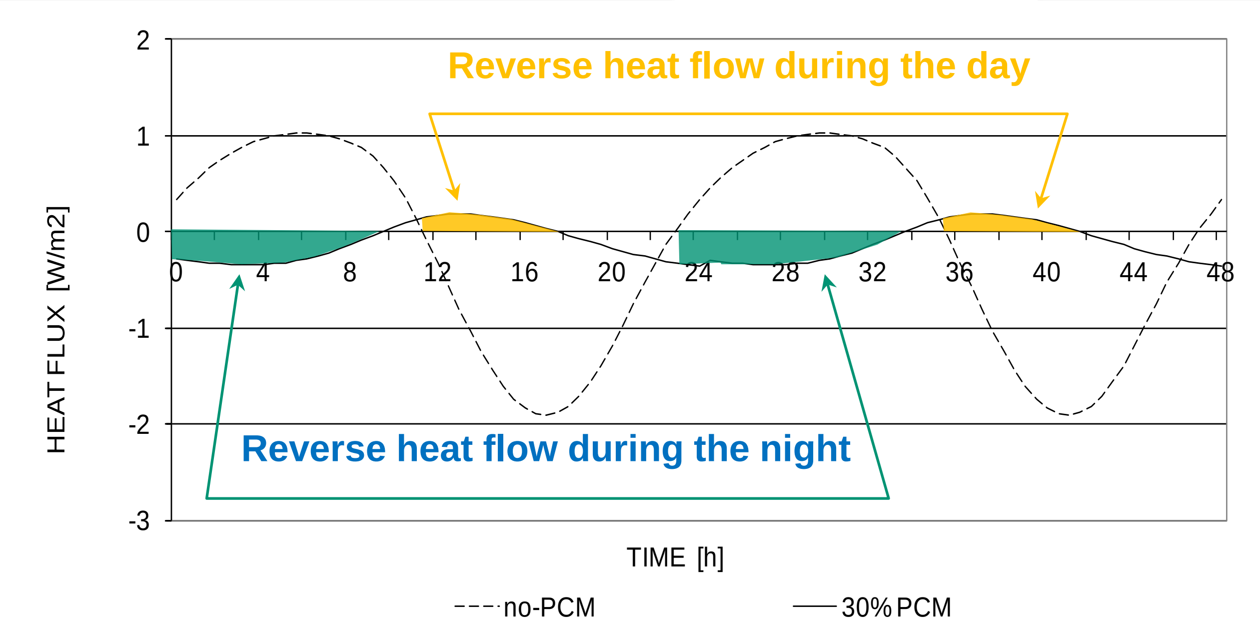

$T_{PCM}$ = 27°C (81 °F)




Frau

USA

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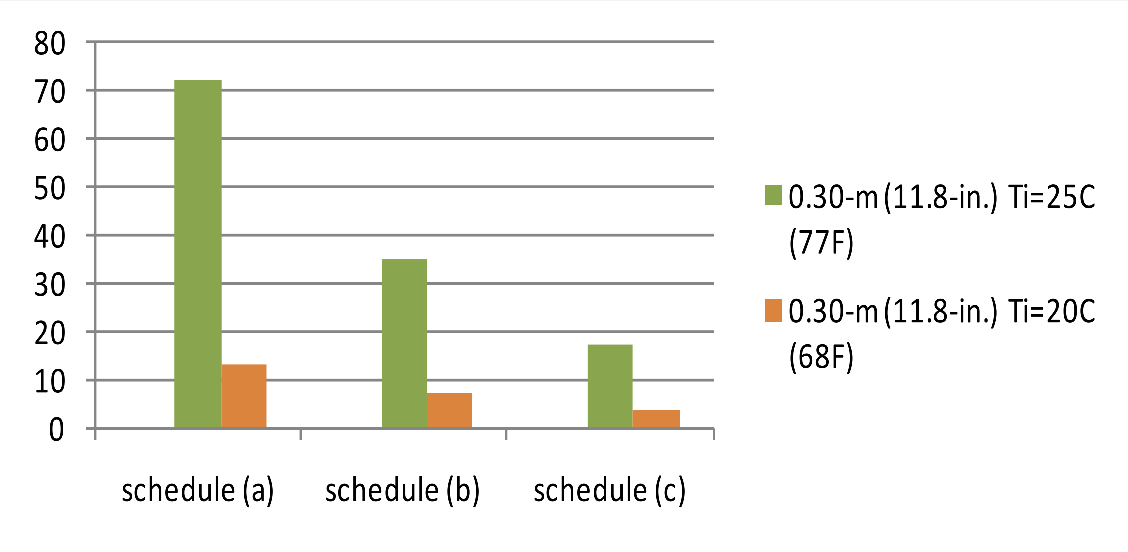
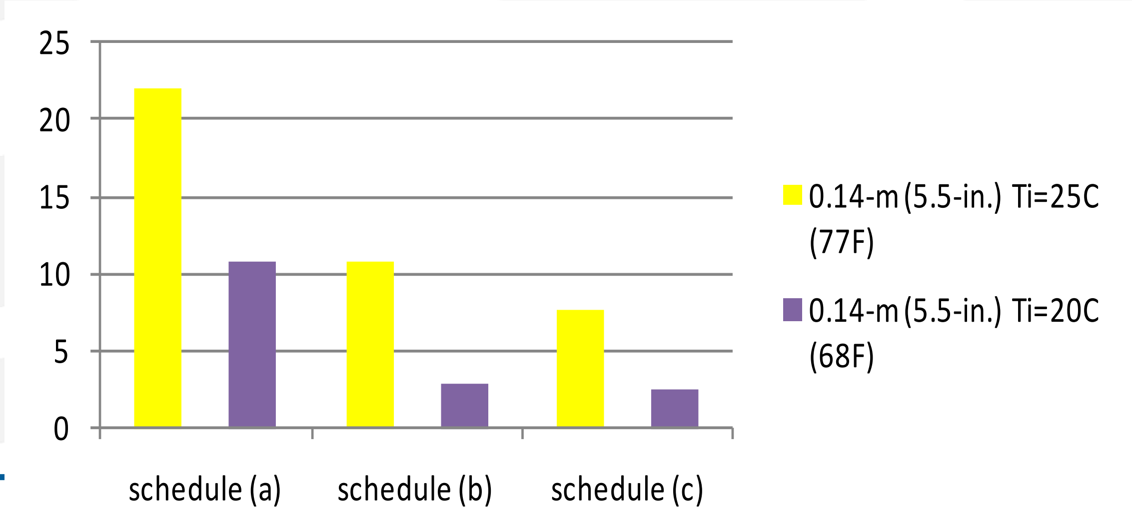
# Effect of PCM Temp. Range on % Cooling Load Reductions

Attics




***$T_{PCM}$* = 27ºC (81 ºF)**

Walls
Vaulted ceilings

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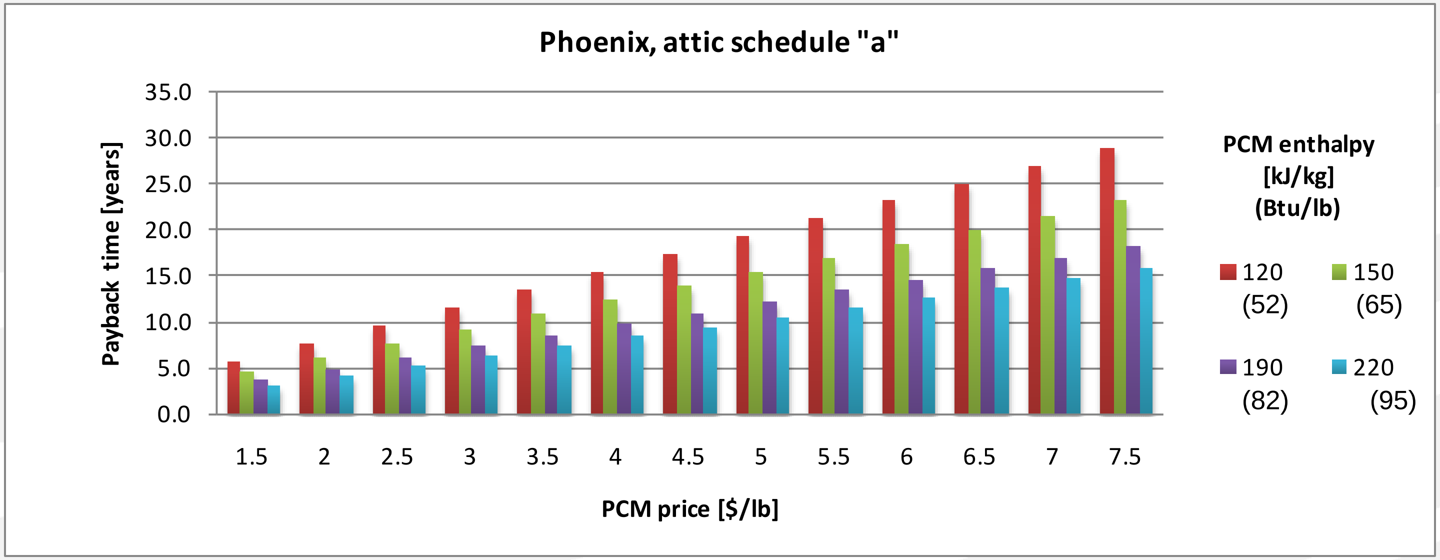
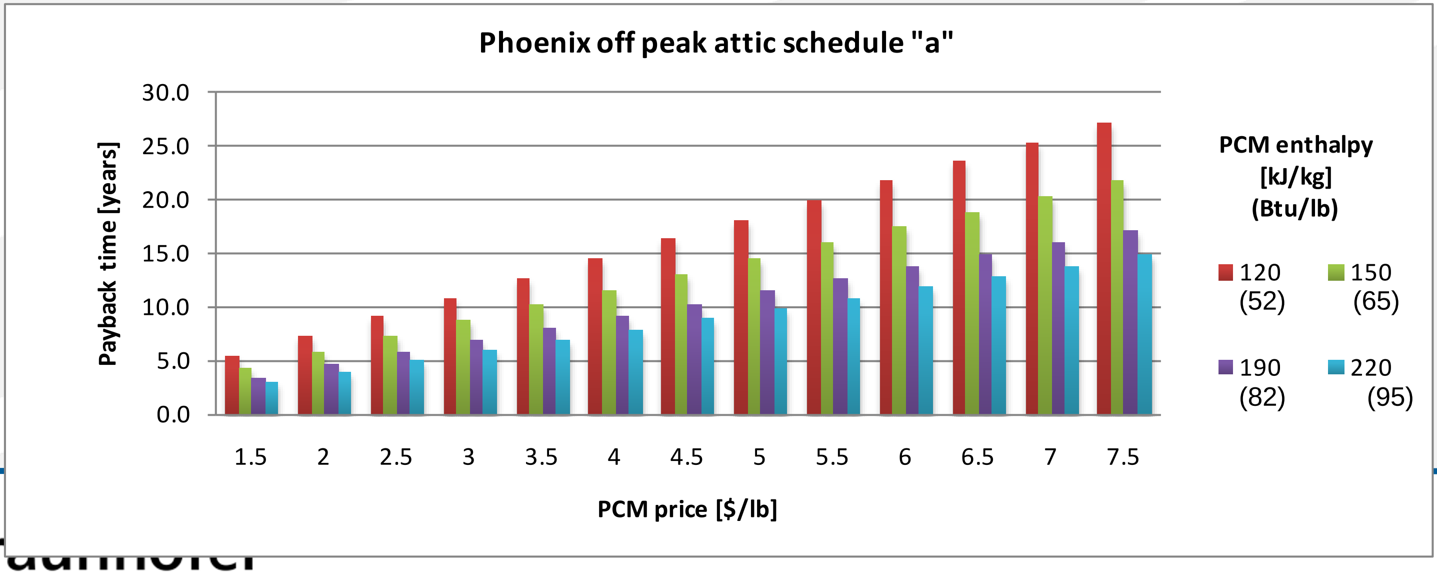
# Example of Payback Time Analysis for PCM Cellulose Blend



## Cost comparisons with conventional insulations:

1. Microencapsulated PCMs 110 J/g - $7.00/lb
2. Macroencapsulated PCMs 110 J/g - $2.50/lb
3. Microencapsulated PCMs 170 J/g - $3.50/lb
4. Packaged bio PCM – 188 J/g - $3.50/lb
5. Packaged inorganic PCM – 134 J/g - $1.50/lb

# Potential savings in annual costs of cooling electric energy generated by the attic calculated for a single-story ranch house and for five southern U.S. climates.

| Cities: | Attic-generated cooling energy consumption [kWh] | Annual cost of electricity used for cooling (attic-generated) [$] | Annual cost savings of electricity used for cooling (attic-generated) [$] | | |
|---|---|---|---|---|---|
| | | | Installation R-19 insulation over existing R-30 *(level of savings for each location)* | Addition of microencapsulated PCM to the existing R-30 (savings level for schedule “a”) | Addition of microencapsulated PCM to the existing R-30 (savings level for schedule “b”) |
| Atlanta | 269.3 | 30.43 | 2.74 *(9%)* | 21.91 | 10.65 |
| Bakersfield | 456.4 | 155.18 | 15.52 (*10%*) | 111.73 | 54.31 |
| Fort Worth | 458.0 | 43.05 | 3.87 *(9%)* | 31.00 | 15.07 |
| Miami | 911.4 | 105.72 | 9.52 *(9%)* | 76.12 | 37.00 |
| Phoenix | 870.8 | 188.09 | 16.93 *(9%)* | 135.43 | 65.83 |

# Comparisons of energy cost savings and material costs calculated for a single-story ranch house for five southern U.S. climates

| Cities | Annual cost savings of electricity used for cooling (attic-generated) [$] | | Approximate cost of materials Assuming net attic floor area of 1108 $ft^2$ [$] | |
|---|---|---|---|---|
| | Installation R-19 insulation over existing R-30 *(level of savings for each location)* | Adding 30% by weight of PCM to the existing R-30, savings levels for schedules "a" and "(b)" | R-19 insulations – based on US RS Means Fiberglass - $0.77/$ft^2$ (Cellulose - $0.55/$ft^2$) | Addition of microencapsulated PCM at $3.50/lb Assuming enthalpy of 190 kJ/kg (82 Btu/lb) |
| Atlanta | 2.74 *(9%)* | 21.91 (10.65) | 853.16 (609.40) | 1151 |
| Bakersfield | 15.52 (*10%*) | 111.73 (54.31) | 853.16 (609.40) | 1151 |
| Fort Worth | 3.87 *(9%)* | 31.00 (15.07) | 853.16 (609.40) | 1151 |
| Miami | 9.52 *(9%)* | 76.12 (37.00) | 853.16 (609.40) | 1151 |
| Phoenix | 16.93 *(9%)* | 135.43 (65.83) | 853.16 (609.40) | 1151 |

# PCM database update:

# Review process and approvals by individual PCM companies

# PCM Cost Components: **THERMAL PEROFRMANCE**

## ❑Maximum Enthalpy

- **Uniform performance labels for PCMs**
- **Dependable Test Data for PCMs and PCM products**
- **Durability standards**

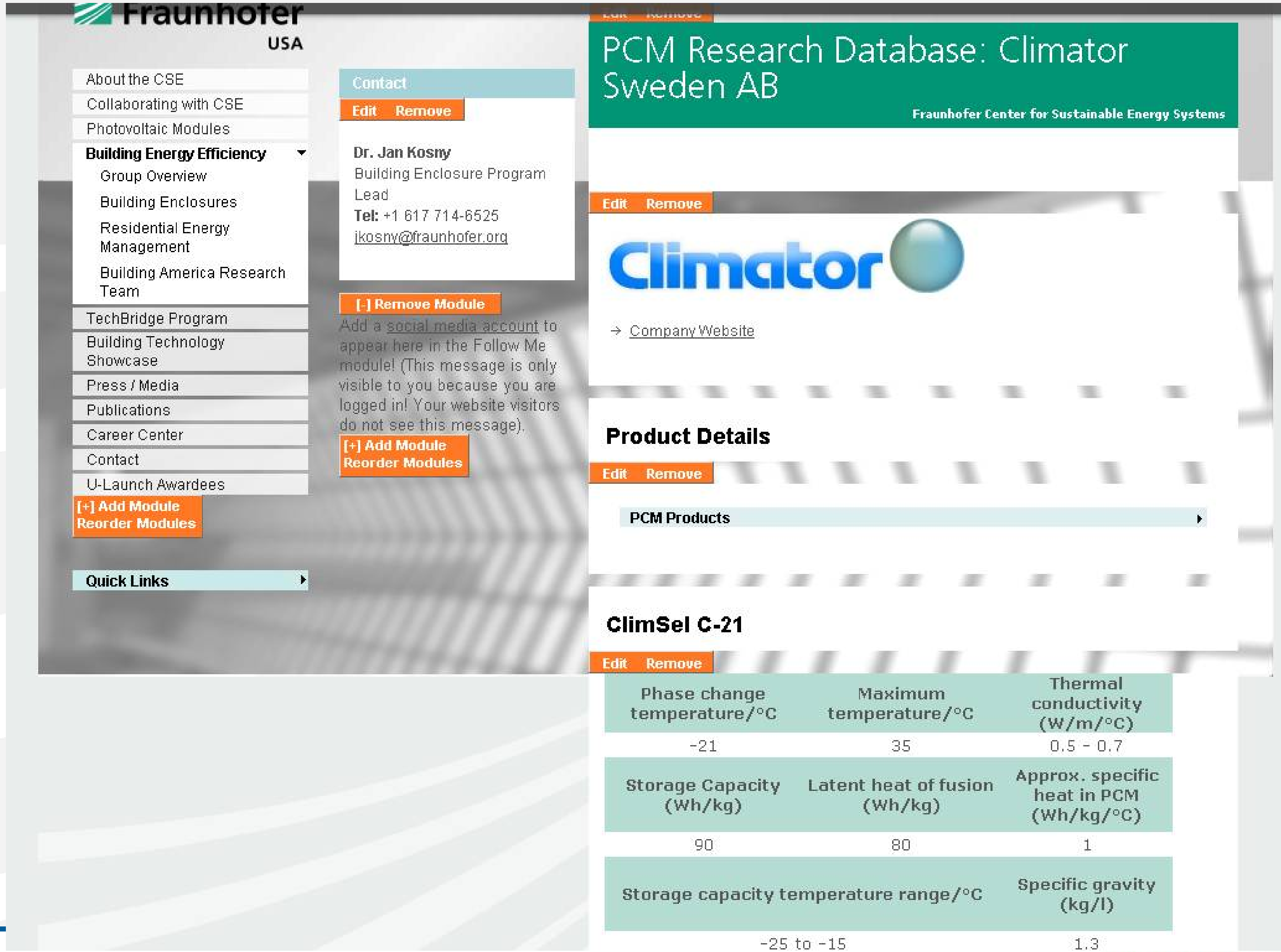
**Fraunhofer CSE PCM Database**

**As of March. 2012 305 PCM products with detailed energy performance data**

**~ 200 with no test data**

| Company | Location | Product amount | Temp. Range (℃) | Raw Data | Downloaded Flyers | Testing Method |
|---|---|---|---|---|---|---|
| Micro. Labs | USA | 17 | -30~52 | Yes (5) | 16 | DSC |
| PCES | USA | 4 | 23~29 | Yes (4) | No | DSC |
| BASF | Germany/ USA | 9 | 21~26 | Yes (1) | 6 | DSC |
| PCM | UK | 127 | -114~885 | No | 5 tables | - |
| RGEES | USA | 16 | -27~88 | Yes (16) | 16 | T-history |
| PLUSS | India | 18 | -37~89 | No | 1 table | T-history (In) |
| ESI | USA | 32 | -37~151 | Yes (8) | 1 table | DSC |
| Climator | Sweden | 11 | -21~70 | No | 11 | - |
| JCXT | China | 18 | 5~110 | No | No | - |
| SGL | Germany/ USA | 4 | 22~58°C | | | DSC |
| Rubitherm | Germany | 49 | -10~86°C | No | | 3-layer Calorimeter |

# Fraunhofer CSE PCM Database – Example Input



# Conclusions

- Comparison of calculated daily heat flow values indicates that for cyclic processes the effect of PCM in an insulation layer results in time shifting of the heat flux maxima and in reduction of the peak-hour heat flow.
- For insulation thickness of 0.14 m reduction of the heat gains maxima, compared to plain cellulose fiber insulation, is significant only when the external sol-air temperature amplitude if not too high (up to 25ºC); for very high external temperature peaks its rather small.
- The situation is much better for very thick PCM enhanced insulation layer. In this case, reduction of the heat gains maxima, compared to plain cellulose fiber insulation, may reach 80% with 11 hours long peak-hour load shift.
- The presented above results indicate that a thick layer of the attic floor insulation may be one of the best-performing immediate applications of the PCM-enhanced insulation, today.

# Thank You!

# Any questions ?