BEST 5 CONFERENCE
Building Enclosure Science & Technology

VIRGINIA TECH

Taking Sides - Impact of Positioning PCMs at Different Sides of Enclosure Systems

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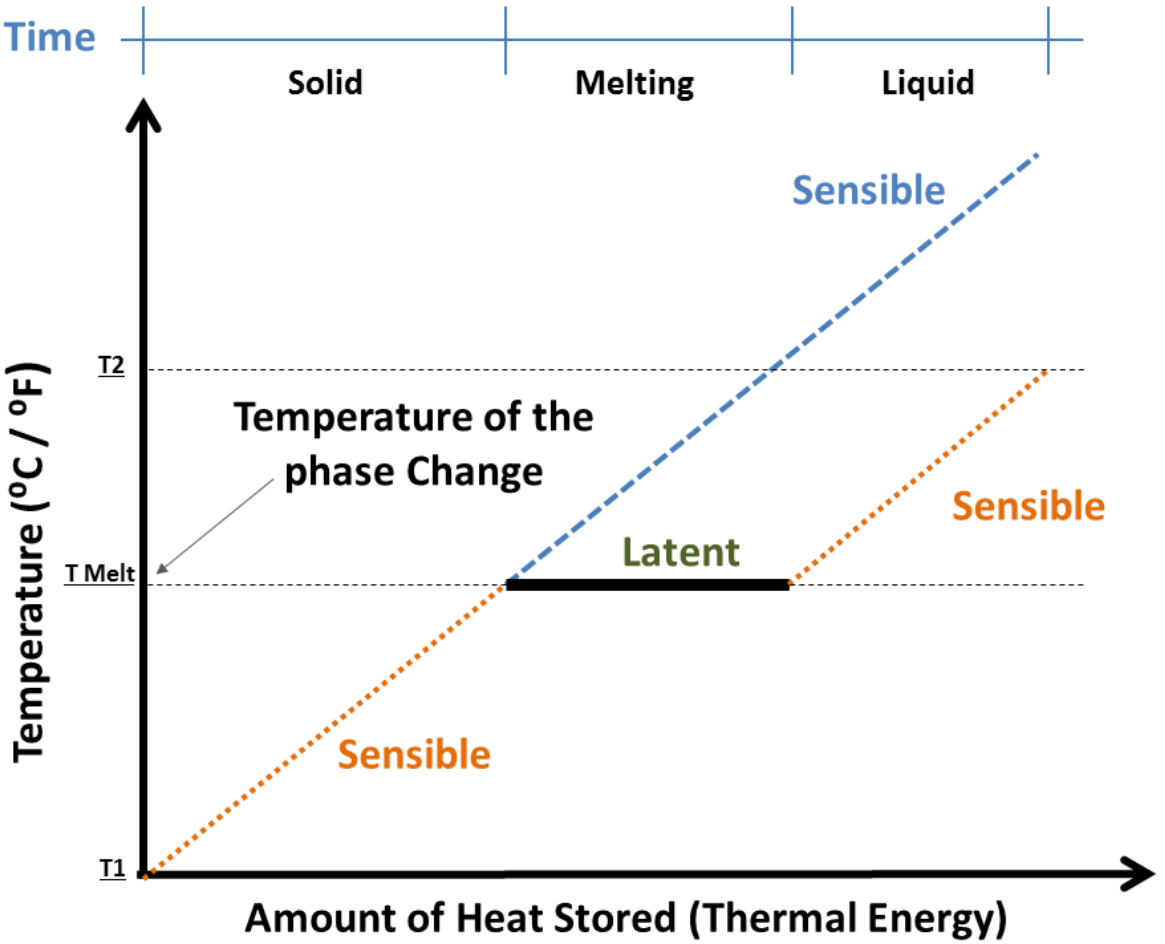
What are PCMs ?

PCMs Store and release great quantities of heat by using chemical bonds

- Absorb heat when materials melt
- Release heat when materials solidify



PCM Properties

- Thermo-physical
- Chemical
- Kinetic

- Specific Melting Temperature
- Specific Freezing Temperature
- Specific Latent Heat Storage Capacity
- High Thermal Storage Densities

Industry Applications

- Consumer Products

- Packaging

- Electronics

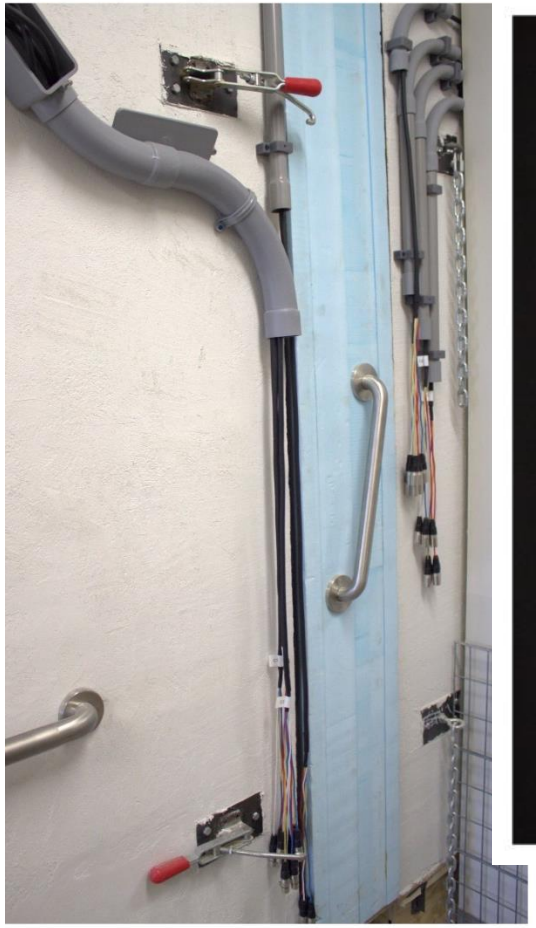
What is their role in Construction?

- They are suitable to be used in buildings for
  - Reducing building loads
  - Energy savings
  - Improving thermal comfort
  - Reducing peaks demand by shifting loads

Where is their place in Construction?

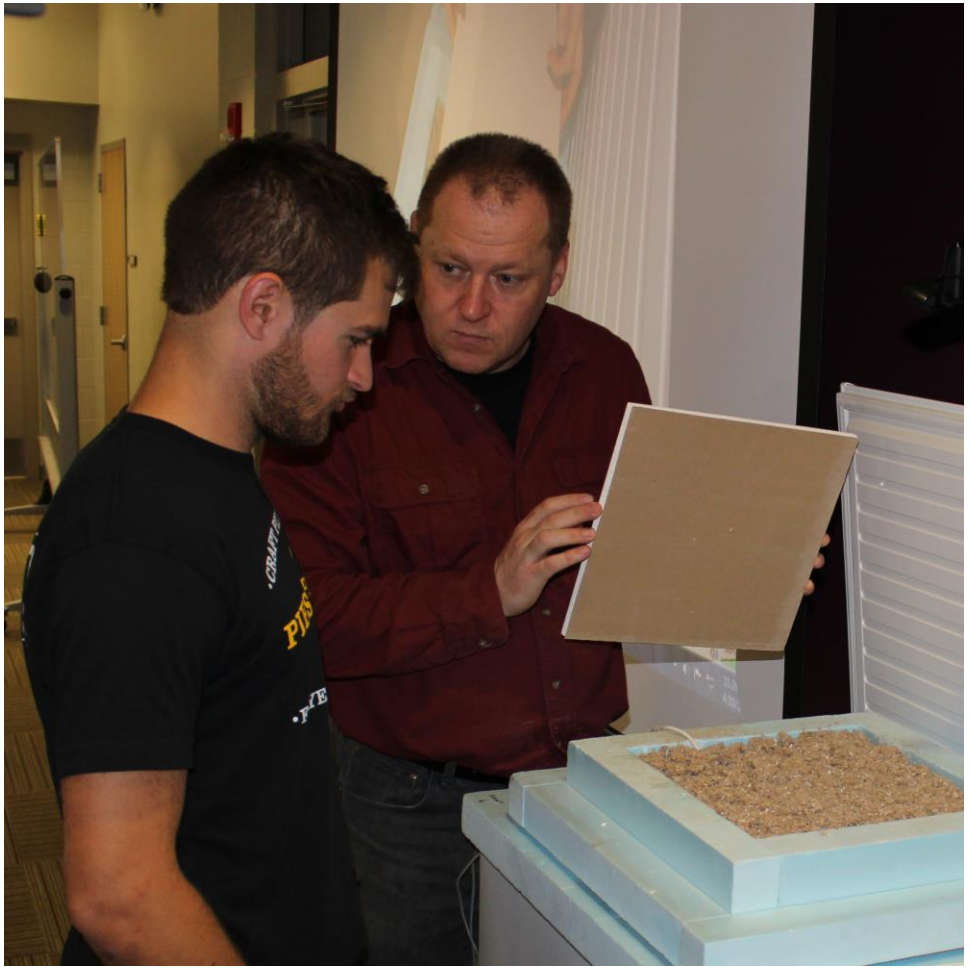
- Effects differ by position in building enclosures
- **Impact of position** on (thermal) performance
  - Thermal comfort
  - Load shifting time
  - Energy consumption

Environmental Test Chamber

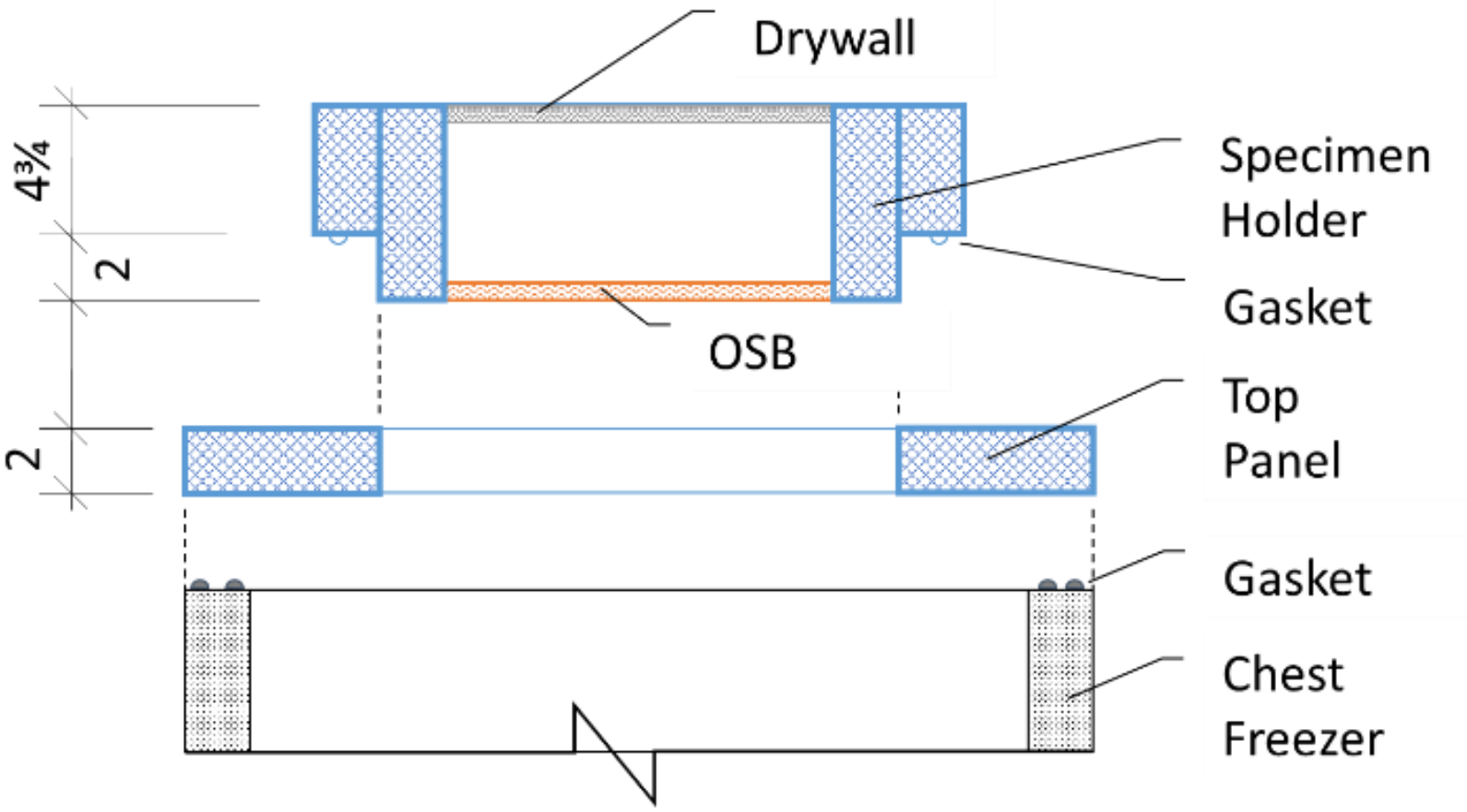


Meet the Little Brother

For In-Classroom Use



System Cross Section



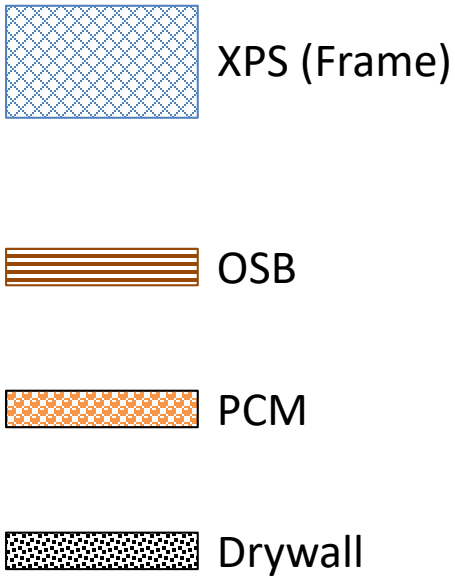
Methodology

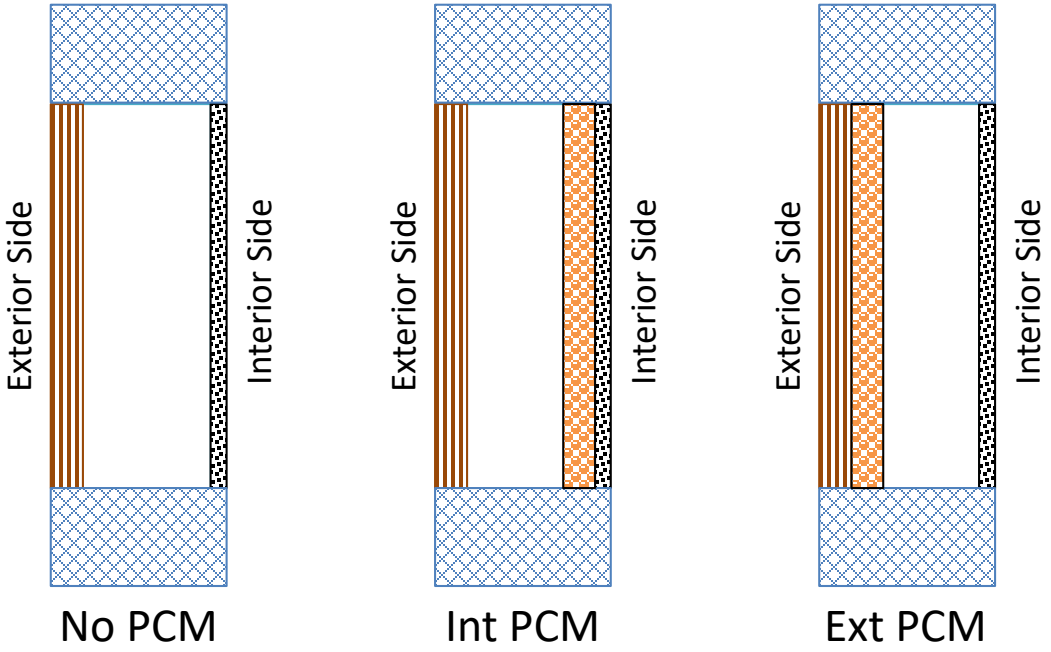
- Asynchronous experiment for **3 basic specimen variants**
  - A wall with a **PCM at exterior** side of the wall cavity
  - A wall with a **PCM at the interior** side of the wall cavity
  - A wall **without PCM** application

- **Semi-Steady State** Temperature Boundary Conditions
  - Exterior temperatures at 45 °C for the hot climate
  - Exterior temperatures at 0 °C for the cold climate
  - Room temperature kept between 22-23 °C

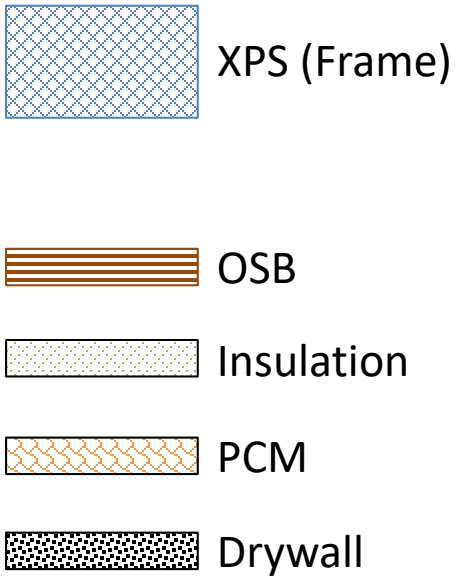
- Experiments were conducted for 72 hours
  - **Three cycles** of 12 hrs cool then 12 hrs of warm climate each

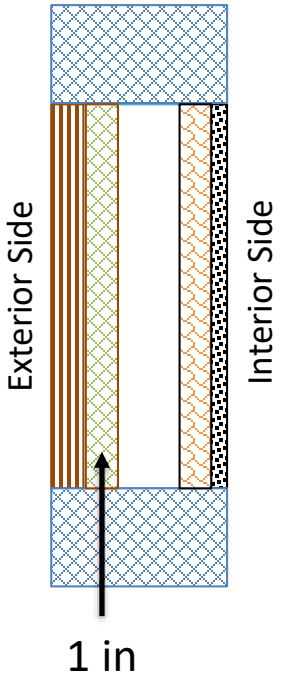
Specimen Variants - PCM Positions

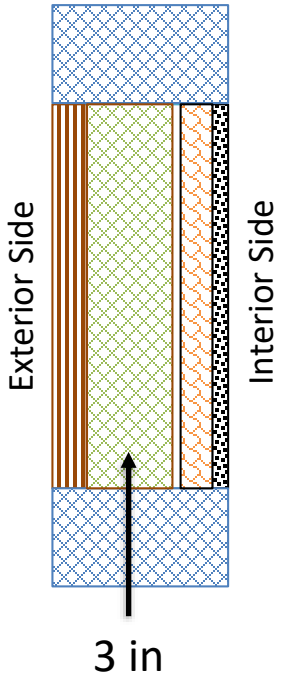




Specimen Variants – Insulation Level



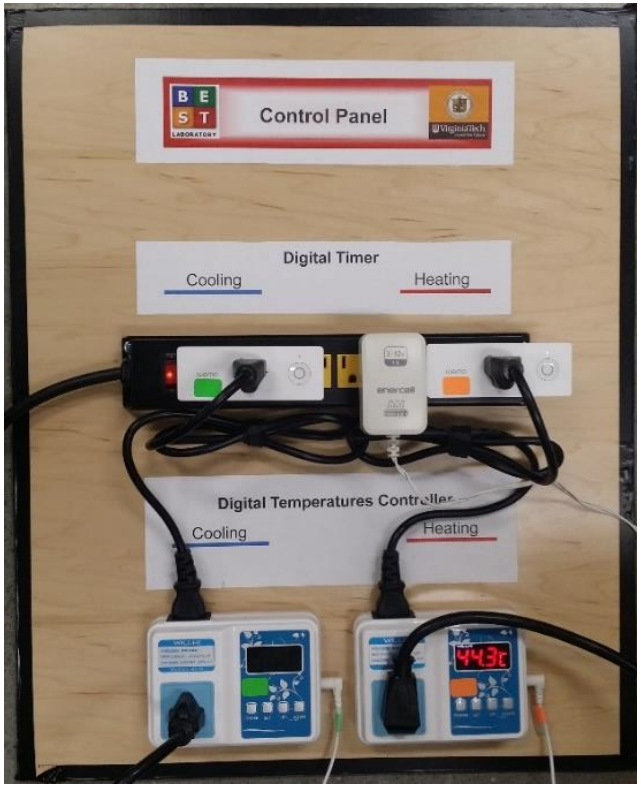




Experimental Limitations

- Focus limited to
  - Thermal aspects in building enclosures
  - Periodical steady state outdoor temperatures
  - Phase change processes limited to solid-liquid
  - One bio-based PCM with a melting point of 23 °C
  - Fixed temperature differential (+25 °C)

Control Components



Control panel assembly

Data logger node and receiver

Timer module

Temperature controller

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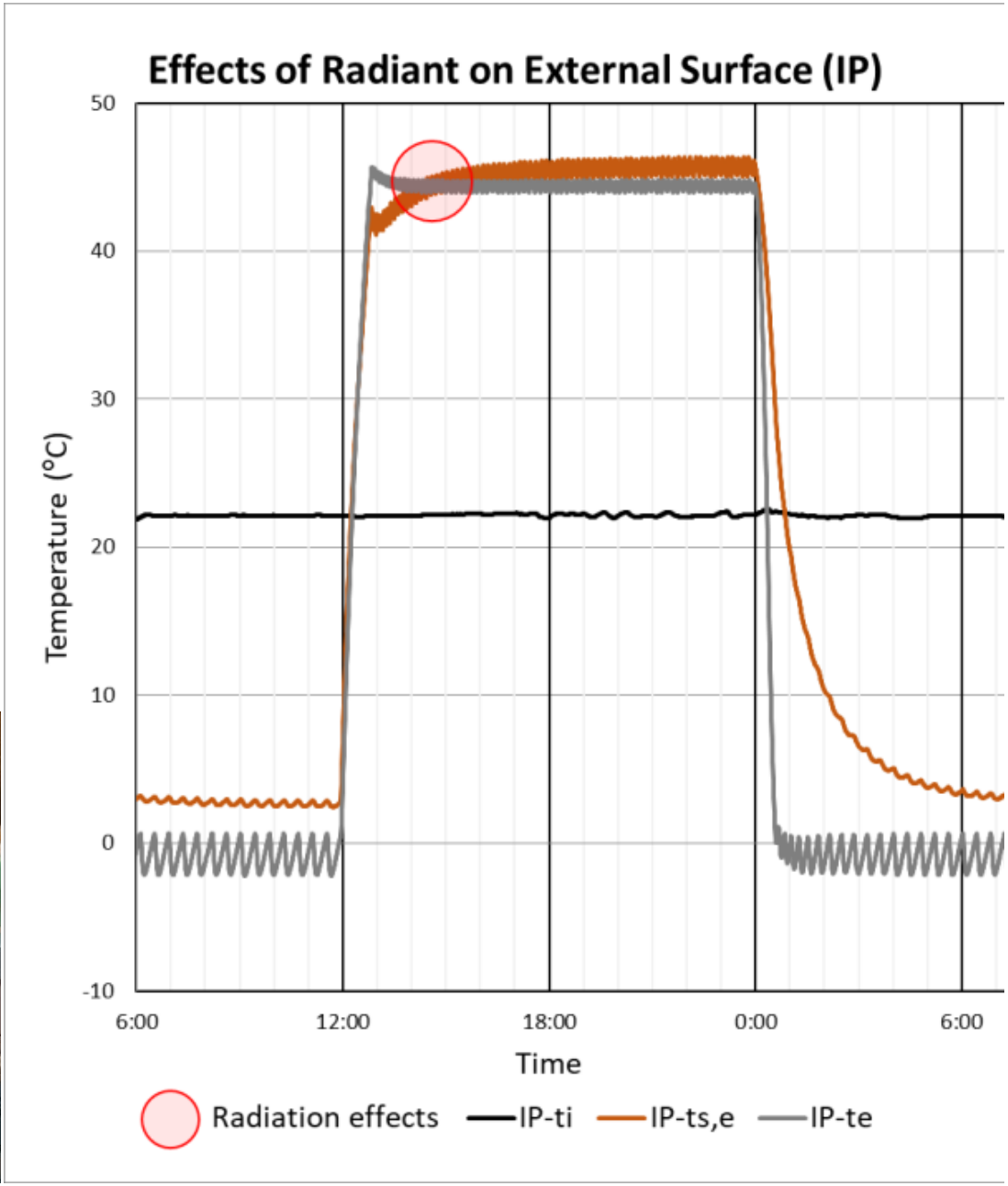
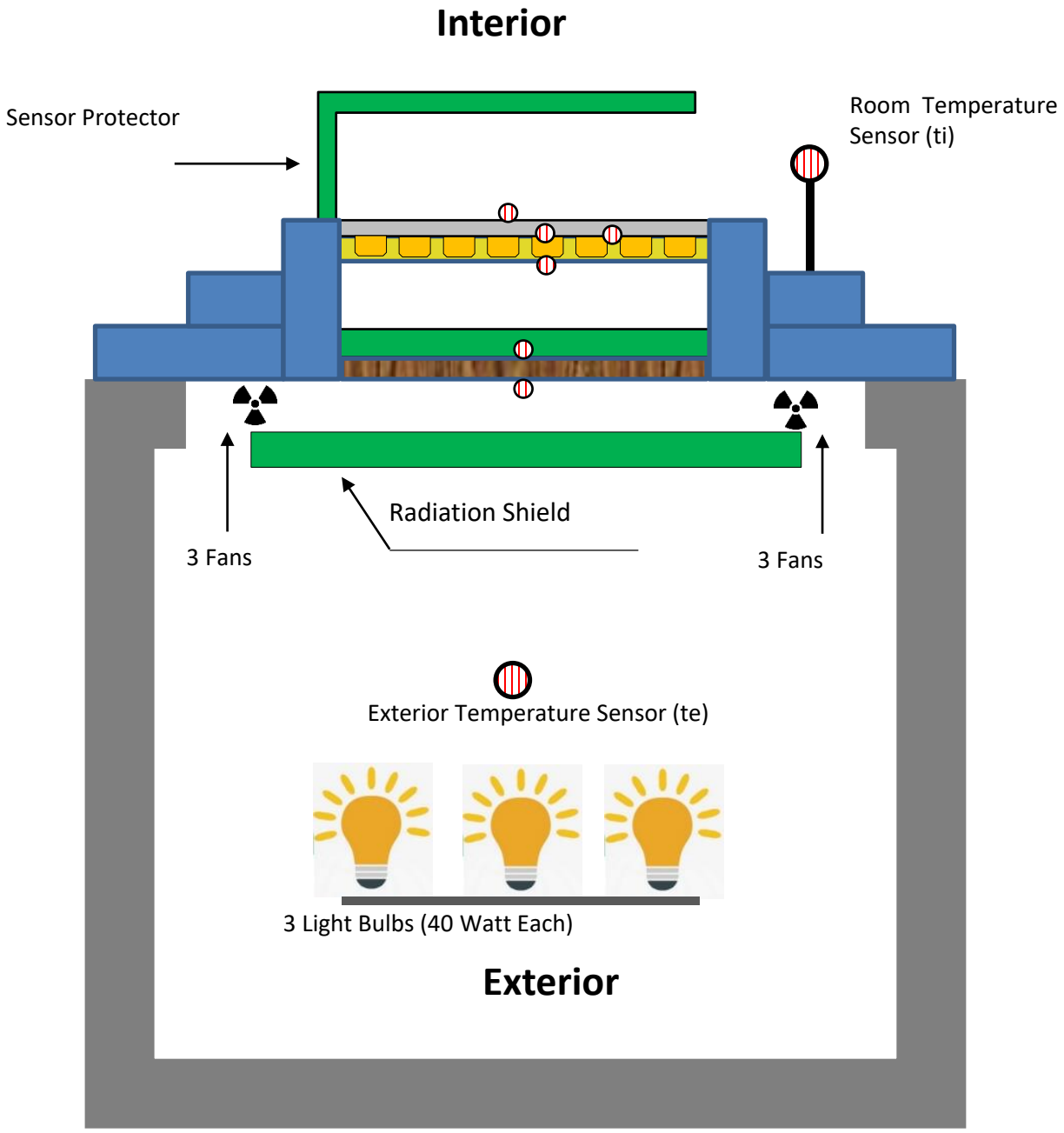
Experimental Issues

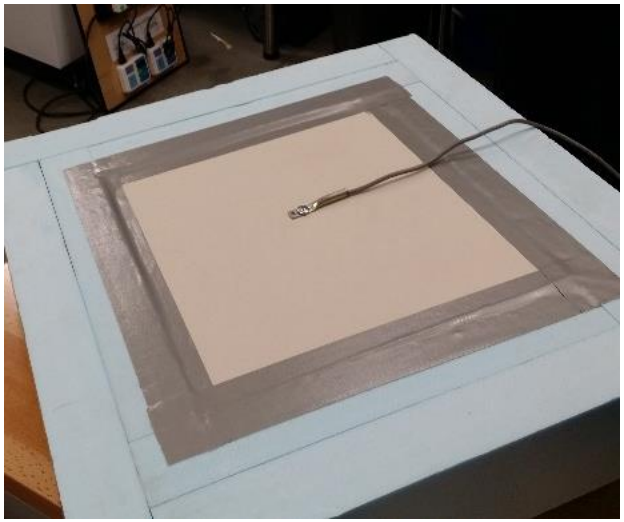
- Radiant impact of heat source




Interior
Sensor Protector
Room Temperature Sensor (ti)
Radiation Shield
3 Fans
3 Fans
Exterior Temperature Sensor (te)
3 Light Bulbs (40 Watt Each)
Exterior


biopcm
biopcm
biopcm


PHASECHANGE
ENERGY SOLUTIONS



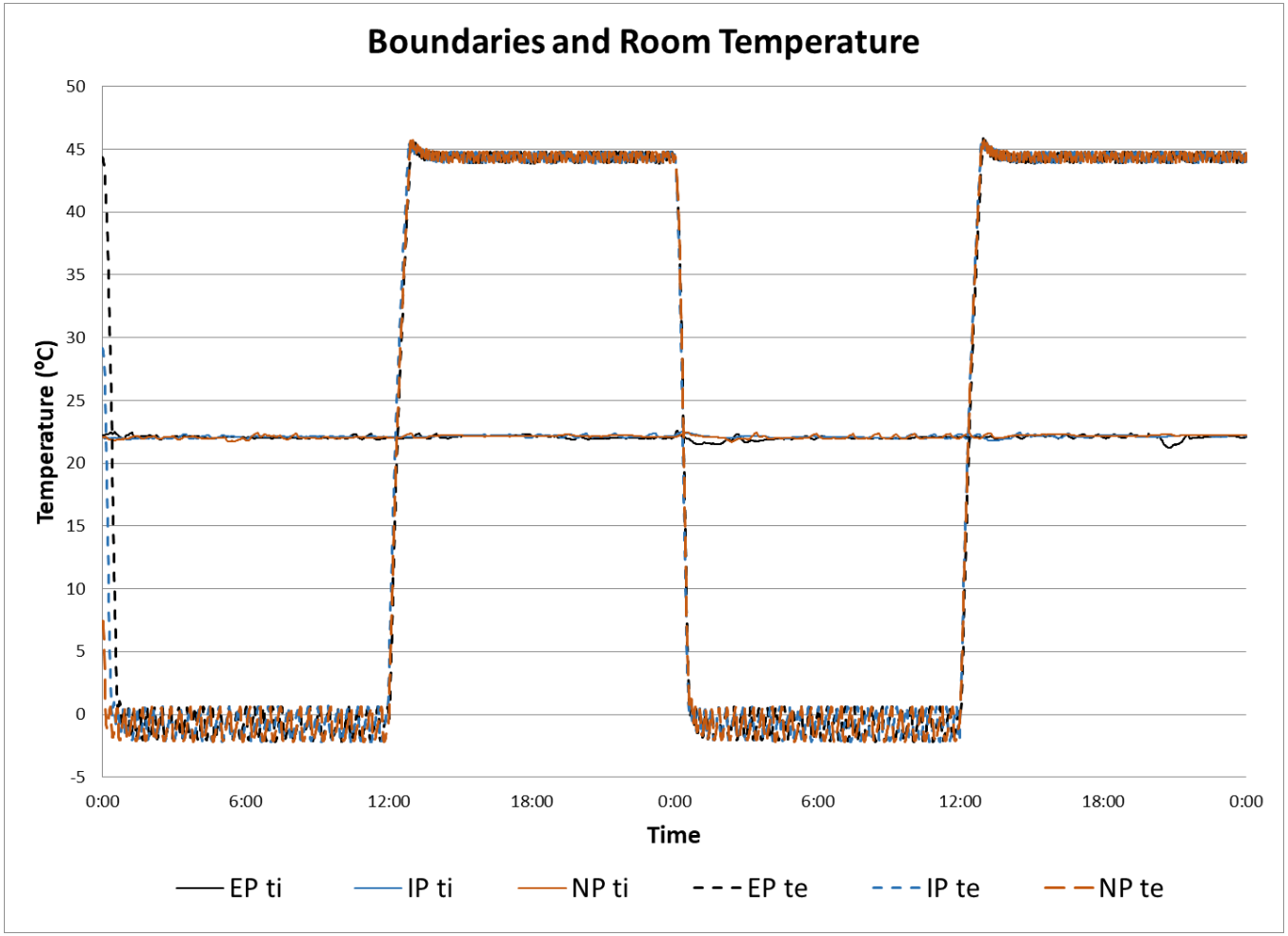
Surface Boundary Conditions

Interior

- 22.5°C

Exterior

- 45°C
- 0°C



Analysis Method: Comfort

- Analysis of impact of PCM positioning on thermal comfort through “Comfort Degree Minutes” for heating and cooling periods

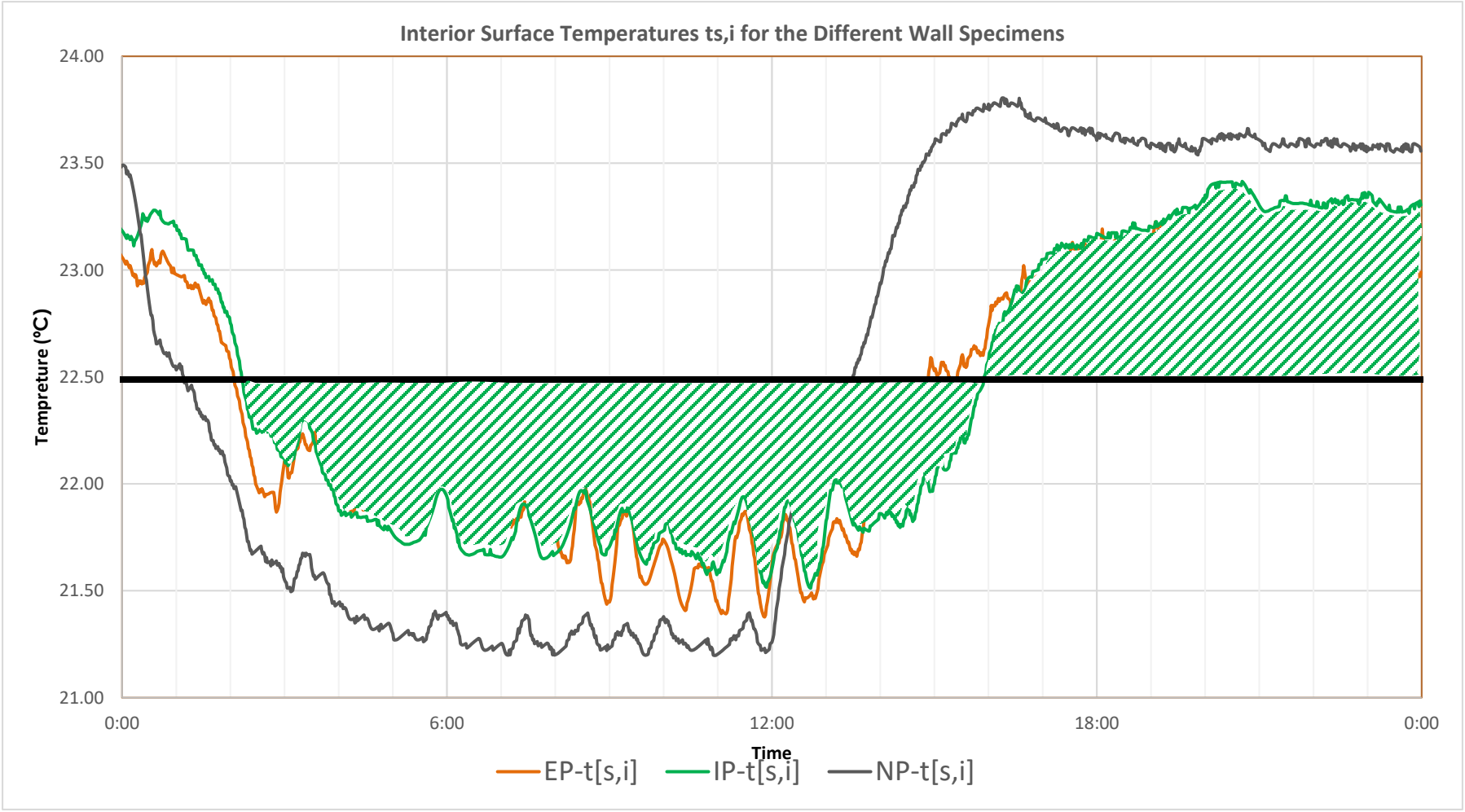
$$\mathrm{CCDM}_{th} = \sum \left| t_{s,i} - t_{th,c} \right| \cdot \Delta m \quad for\ all\ \ t_{s,i} \geq t_{th,c}$$

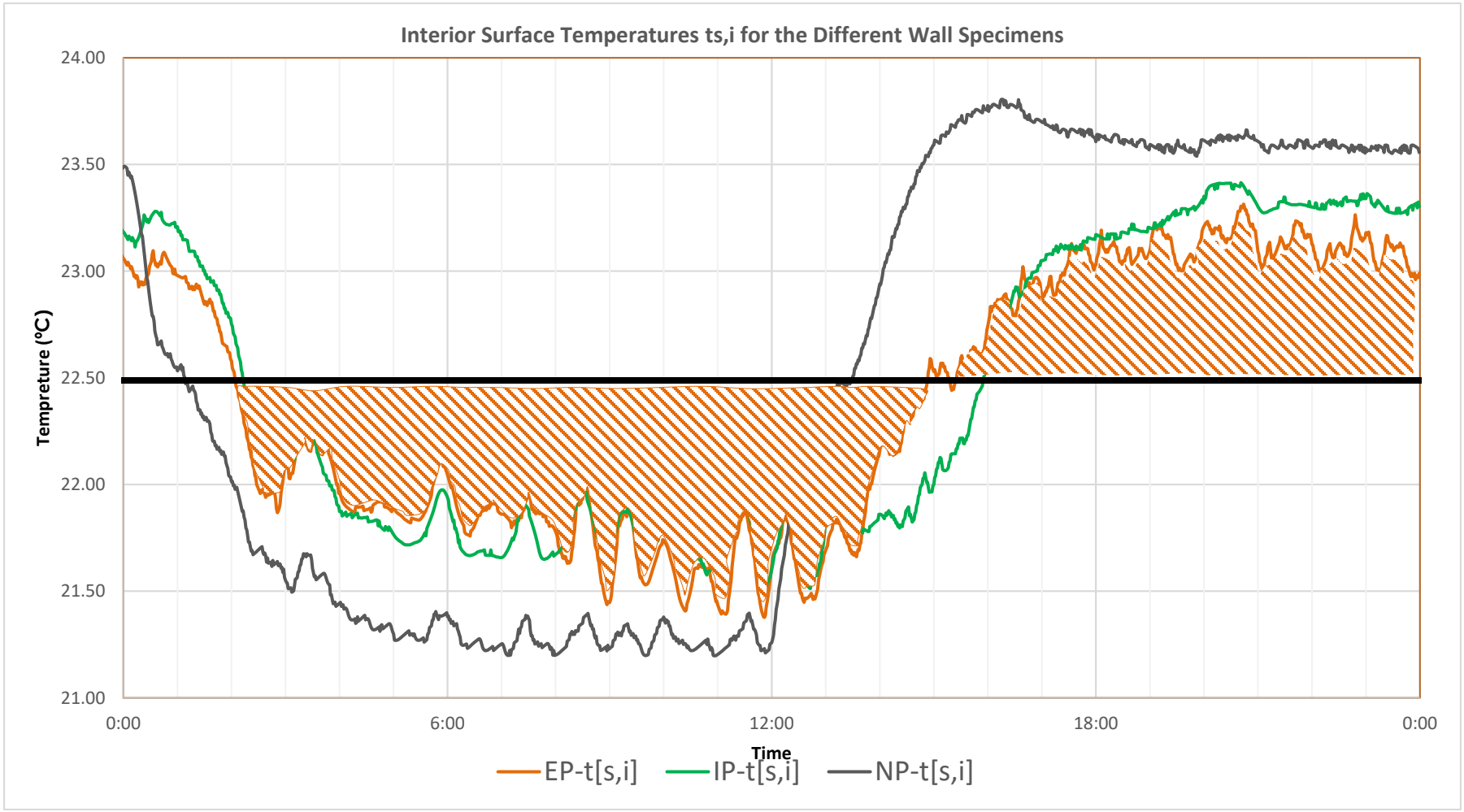
$$\mathrm{HCDM}_{th} = \sum \left| t_{s,i} - t_{th,h} \right| \cdot \Delta m \quad for\ all\ \ t_{s,i} \leq t_{th,h}$$

$t_{s,i}$ … interior surface temperature

$t_{tr,c}$ … threshold temperature cooling period

$t_{tr,h}$ … threshold temperature heating period


Interior Surface Temperatures ts,i for the Different Wall Specimens
24.00
23.50
23.00
22.50
22.00
21.50
21.00
Tempreture (°C)
0:00
6:00
12:00
18:00
0:00
Time
EP-t[s,i]
IP-t[s,i]
NP-t[s,i]


Interior Surface Temperatures ts,i for the Different Wall Specimens
24.00
23.50
23.00
22.50
22.00
21.50
21.00
Tempreture (°C)
0:00
6:00
12:00
18:00
0:00
Time
EP-t[s,i]
IP-t[s,i]
NP-t[s,i]

Comfort Degree Minutes - Results

Thermal Comfort								
	P1X1		P1X3		P2X1		P2X3	
	Cold period	Warm period	Cold period	Warm period	Cold period	Warm period	Cold period	Warm period
EP	521	316	289	440	660	838	419	207
IP	796	737	299	318	1049	1182	414	262

- In assemblies with less insulation in the cavity, exterior PCMs seem to be more effective in reducing the thermal comfort loads when moving into cold periods
- The effect disappears as the insulation amount increases

Analysis Method: Shift Time

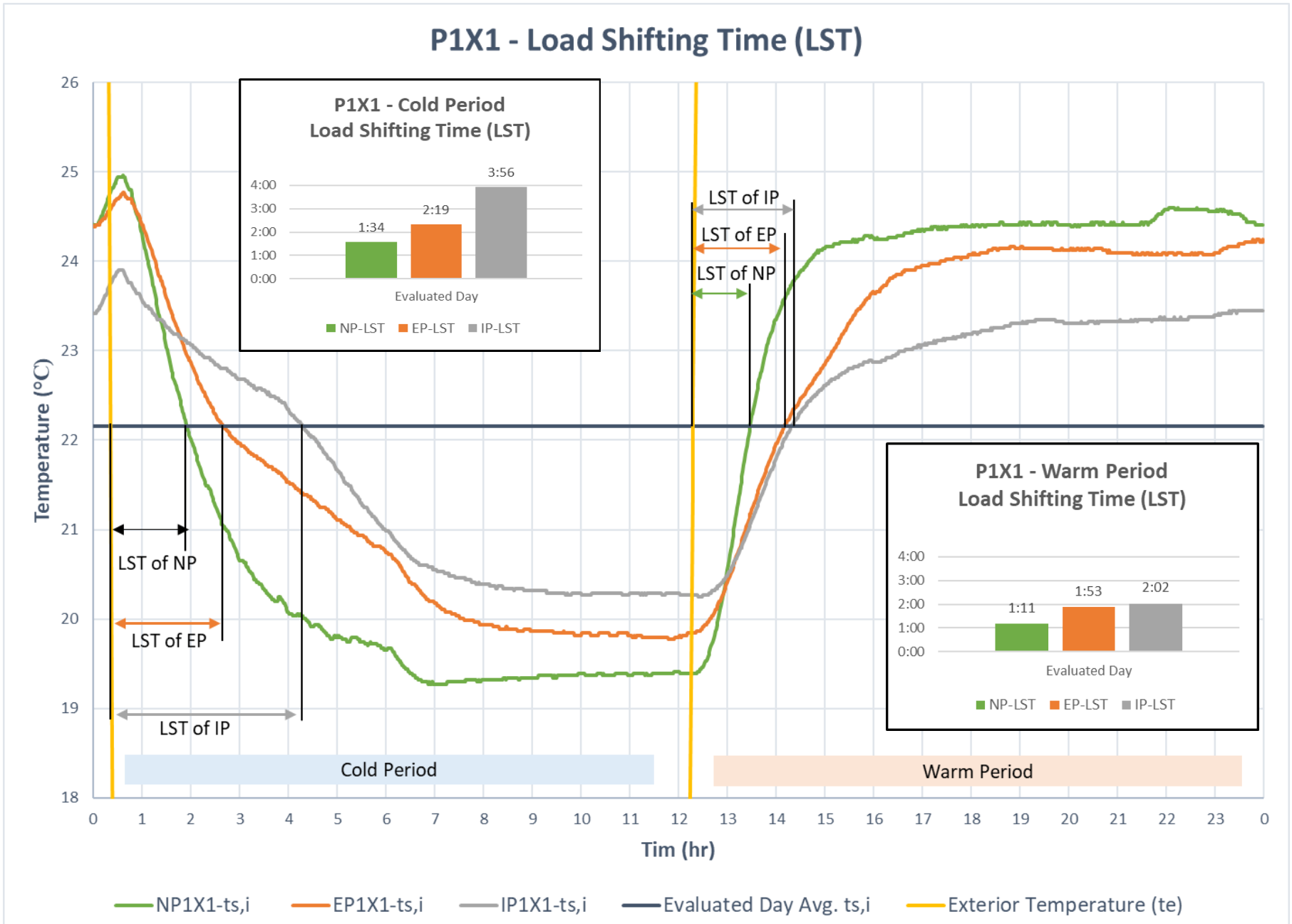
- Analysis of impact of PCM positioning on load shifting time

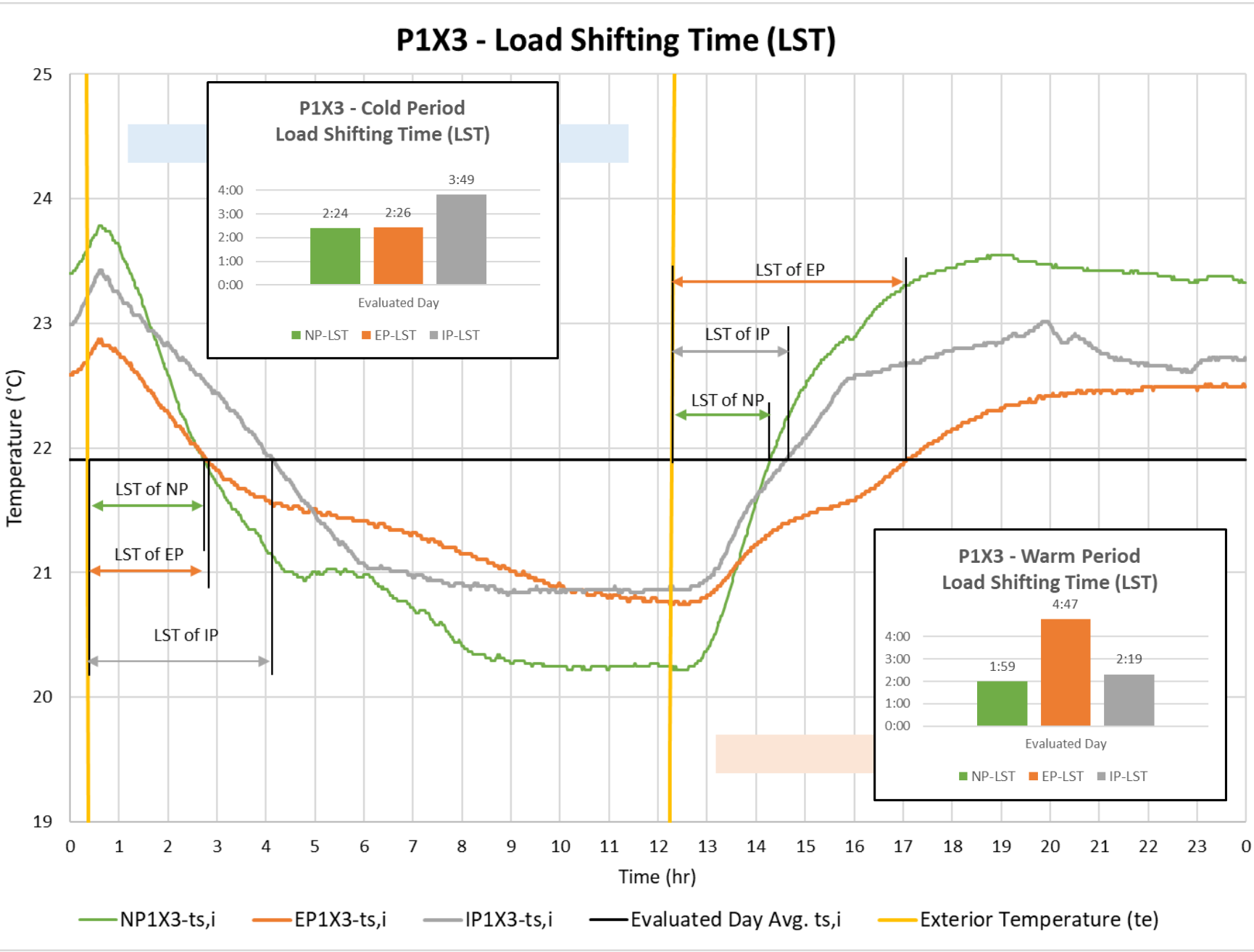
$$LST = T0_{tsi} - T0_{te}$$

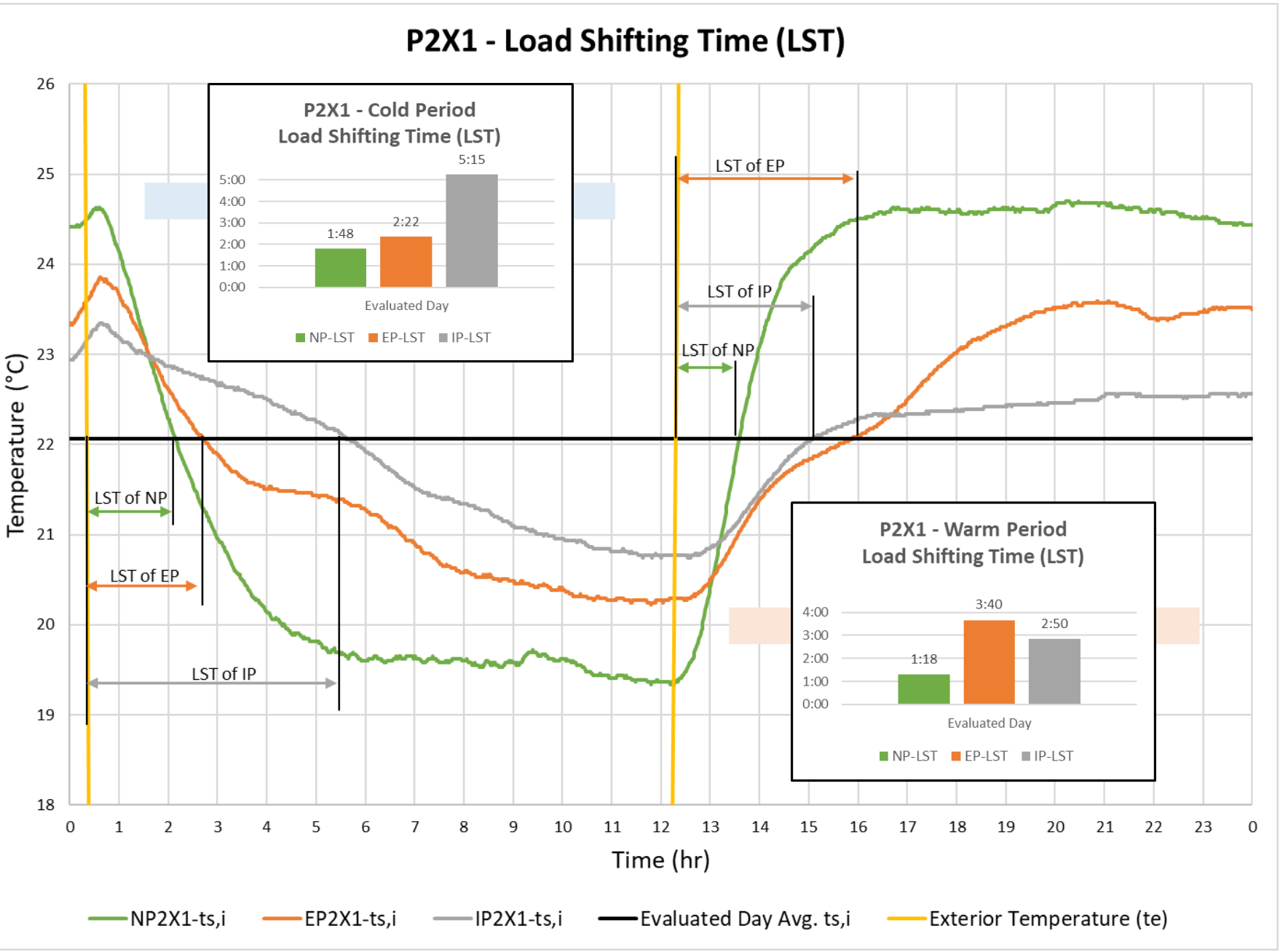
T0 … Timestamp when temperature curve crosses $t_{i,avrg}$

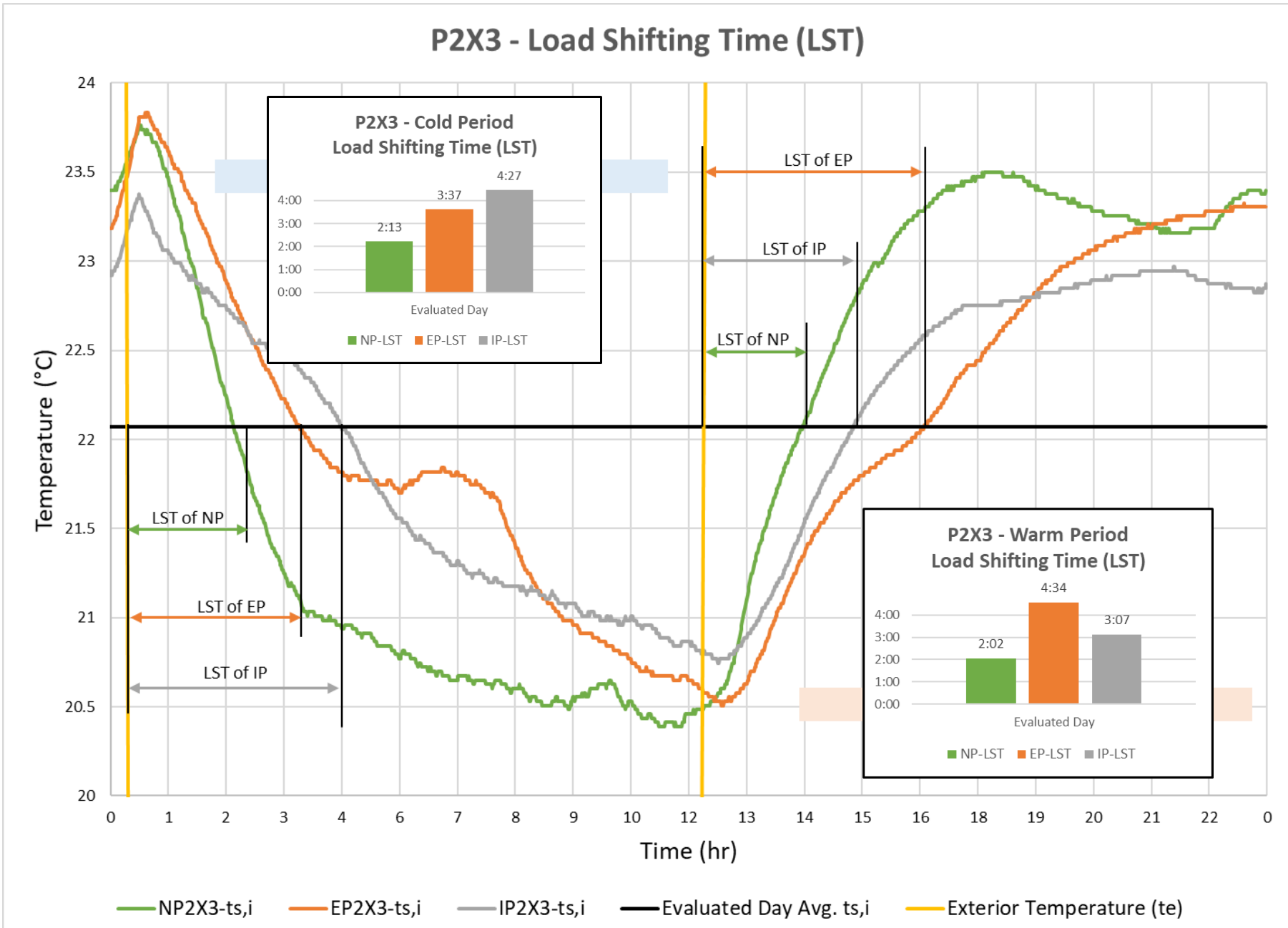
$T0_{tsi}$ … Timestamp when $t_{s,i}$ crosses $t_{i,avrg}$
$T0_{te}$ … Timestamp when t_e crosses $t_{i,avrg}$

where
$t_{i,avrg}$ … average interior temperature (const.)
$t_{s,i}$ … specimen interior surface temperature
t_e … experimental exterior temperature (chest temperature)


P1X1 - Load Shifting Time (LST)
P1X1 - Cold Period
Load Shifting Time (LST)
4:00
3:00
2:00
1:00
0:00
1:34
2:19
3:56
Evaluated Day
NP-LST
EP-LST
IP-LST
LST of IP
LST of EP
LST of NP
LST of NP
LST of EP
LST of IP
P1X1 - Warm Period
Load Shifting Time (LST)
4:00
3:00
2:00
1:00
0:00
1:11
1:53
2:02
Evaluated Day
NP-LST
EP-LST
IP-LST
Cold Period
Warm Period
Temperature (°C)
26
25
24
23
22
21
20
19
18
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 0
Tim (hr)
NP1X1-ts,i
EP1X1-ts,i
IP1X1-ts,i
Evaluated Day Avg. ts,i
Exterior Temperature (te)


P1X3 - Load Shifting Time (LST)
P1X3 - Cold Period
Load Shifting Time (LST)
4:00
3:00
2:00
1:00
0:00
2:24
2:26
3:49
Evaluated Day
NP-LST
EP-LST
IP-LST
LST of EP
LST of IP
LST of NP
LST of NP
LST of EP
LST of IP
P1X3 - Warm Period
Load Shifting Time (LST)
4:47
1:59
2:19
Evaluated Day
NP-LST
EP-LST
IP-LST
Temperature (°C)
Time (hr)
NP1X3-ts,i
EP1X3-ts,i
IP1X3-ts,i
Evaluated Day Avg. ts,i
Exterior Temperature (te)


P2X1 - Load Shifting Time (LST)
Temperature (°C)
Time (hr)
LST of NP
LST of EP
LST of IP
LST of EP
LST of IP
LST of NP
P2X1 - Cold Period
Load Shifting Time (LST)
5:15
2:22
1:48
Evaluated Day
NP-LST
EP-LST
IP-LST
P2X1 - Warm Period
Load Shifting Time (LST)
3:40
2:50
1:18
Evaluated Day
NP-LST
EP-LST
IP-LST
NP2X1-ts,i
EP2X1-ts,i
IP2X1-ts,i
Evaluated Day Avg. ts,i
Exterior Temperature (te)


P2X3 - Load Shifting Time (LST)
Temperature (°C)
Time (hr)
LST of NP
LST of EP
LST of IP
LST of EP
LST of IP
LST of NP
P2X3 - Cold Period
Load Shifting Time (LST)
2:13
3:37
4:27
Evaluated Day
NP-LST
EP-LST
IP-LST
P2X3 - Warm Period
Load Shifting Time (LST)
2:02
4:34
3:07
Evaluated Day
NP-LST
EP-LST
IP-LST
NP2X3-ts,i
EP2X3-ts,i
IP2X3-ts,i
Evaluated Day Avg. ts,i
Exterior Temperature (te)

Load Shift Impacts - Results

- In **low insulated assemblies**, **interior** positioning can achieve **longer lag times when moving from warm to cold** periods, but makes little difference when moving from cold to warm periods

- **Increasing the amount of PCMs extends this effects** for the cold period with interior positions, but also yields **better results in warm periods with exterior** positioned PCMs

- When the **insulation amount is increased** these **effects** and differences become **more pronounced**

CONCLUSIONS

- With surface temperatures as an indicator and contributor to thermal **comfort** the experiments suggest that in assemblies with lower thermal resistance **exterior** PCM positions yield better performance

- In terms of **load shift strategies**, PCMs create **longer time** lags when installed on the **warmer side** of the change-over climates (i.e. on the interior when outdoor temperatures drop and on the exterior when outdoor temperatures rise)


Any questions?