COMSOL Modeling of Temperature Changes in Building Materials Incorporating Phase Change Materials

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1- PCMs

2- COMSOL Modeling

\[ \frac{d}{dt} \rho C_p \frac{\partial T}{\partial t} + \nabla \cdot (\rho C_p \mathbf{u} \cdot \nabla T) = \nabla \cdot (\lambda \nabla T) + Q_v + Q_l + Q_{\text{coop}} \]

\[ \rho = \theta \rho_{\text{phase1}} + (1 - \theta) \rho_{\text{phase2}} \]

\[ C_p = \frac{1}{\rho} \left( \theta C_{p \text{phase1}} + (1 - \theta) C_{p \text{phase2}} \right) + \frac{L_{\text{melt}}}{\rho_{\text{melt}}} \]

\[ k = \theta k_{\text{phase1}} + (1 - \theta) k_{\text{phase2}} \]

\[ \alpha_m = \frac{1}{2} \frac{(1 - \theta) \rho_{\text{phase2}} - \theta \rho_{\text{phase1}}}{\rho_{\text{phase1}} + (1 - \theta) \rho_{\text{phase2}}} \]

3- Model Validating

4- Actual Results

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1- Phase Change Materials

- Phase Change Materials:
  - Specific melting point
  - High latent heat of fusion

http://www.pcmproducts.net
http://www.thomasnet.com
Absorbs heat; Temperature remains constant
• PCMs are passive interior heat energy storage units

<table>
<thead>
<tr>
<th>Material</th>
<th>Melting Point</th>
<th>Latent Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C (°F)</td>
<td>kJ/kg (cal/g)</td>
</tr>
<tr>
<td>SN26</td>
<td>-26 (-14.8)</td>
<td>268 (64.0)</td>
</tr>
<tr>
<td>SN15</td>
<td>-11 (12.2)</td>
<td>311 (74.3)</td>
</tr>
<tr>
<td>SN06</td>
<td>-6 (21.2)</td>
<td>286 (68.3)</td>
</tr>
<tr>
<td>RT5</td>
<td>9 (48.2)</td>
<td>205 (48.9)</td>
</tr>
<tr>
<td>RT25</td>
<td>26 (78.8)</td>
<td>232 (55.4)</td>
</tr>
<tr>
<td>RT50</td>
<td>54 (129.2)</td>
<td>195 (46.6)</td>
</tr>
<tr>
<td>RT90</td>
<td>90 (194.0)</td>
<td>197 (47.1)</td>
</tr>
</tbody>
</table>
1- Phase Change Materials

- Desire for more energy efficient buildings
- Increase occupant comfort
- Environmentally friendly construction

http://www.drlanguell.com
The question is:

- What is the best Melting Temperature for buildings that are located in different cities?
- What is the optimum PCM percentage?
- How effective is the PCM?
- How much energy of HVAC system will be saved?
Using COMSOL to model temperature changes in structural elements

Step 1: Modeling porous media and PCM

Step 2: Validating the Model

Step 3: Using real temperature profiles of different cities

Equation

Show equation assuming:

Study 1, Time Dependent

\[ \frac{\partial T}{\partial t} = \alpha (T - T_i) \]

\[ \alpha = \frac{\varepsilon \rho \lambda}{\rho c_p \varepsilon} \]

\[ \frac{\partial T}{\partial t} = \alpha (T - T_i) \]

\[ \frac{\partial T}{\partial t} = \alpha (T - T_i) \]

\[ \frac{\partial T}{\partial t} = \alpha (T - T_i) \]
\[ \lambda_{\text{eff}} = \lambda_m \theta_m + \lambda_{\text{PCM}} (1 - \theta_m) \]

\[ (\rho C_p)_{\text{eff}} = \rho_m C_{p,m} \theta_m + \rho_{\text{PCM}} C_{p,\text{PCM}} (1 - \theta_m) \]

\( \theta_m \): Volume fraction of mortar

\( 1 \) \( - \) \( \theta_m \): Volume fraction of the porosity (the volume fraction filled with PCM)
\( \rho_{PCM} = \rho_{phase1}\beta + \rho_{phase2}(1 - \beta) \)

\( \lambda_{PCM} = \lambda_{phase1}\beta + \lambda_{phase2}(1 - \beta) \)

\( C_{p,PCM} = \frac{1}{\rho_{PCM}} (\rho_{phase1} C_{p,phase1}\beta + \rho_{phase2} C_{p,phase2}(1 - \beta)) + L \frac{\partial \alpha_m}{\partial T} \)

\( \beta \): Volume fraction of PCM at phase 1

\( (1-\beta) \): Volume fraction of PCM at phase 2
2- COMSOL Modeling

Conduction Heat Transfer:

\[
\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{\rho C_p}{\lambda} \frac{\partial T}{\partial t}
\]

Boundary Condition:

\[
\begin{align*}
-\lambda \frac{\partial T}{\partial x} &= h[T_\infty - T_s] \\
-\lambda \frac{\partial T}{\partial y} &= h[T_\infty - T_s]
\end{align*}
\]

Initial Condition: \( T(x, t = 0) = T_R \)

Applying Temp.: \( T(y = 0, t) = T_{input} \)
Guardsed Longitudinal Calorimeter

- Cold Plate
- Sample Stack
- Insolation
- Thermocouples
- Data Acquisition
- Computer
3- Model Validating

Applied Temperature Profiles

Number 1 for sample with PCM 6
Number 2 for sample with PCM 28
Comparing COMSOL simulation and laboratory experiment

PCM 6

Changing in Phase

Temperature (°C)

Time (Hours)

--- Top of the specimen-COMSOL Modeling
--- Top of the specimen-Laboratory Setup

PCM 28

Changing in Phase

Temperature (°C)

Time (Hours)

--- Top of the Specimen-COMSOL Modeling
--- Top of the Specimen-Laboratory Setup
Effect of different PCM percentages on the:

1) Time Lag    2) Decrement Factor (f)

\[ f = \frac{A_{x=0}}{A_{sa}} \]
3) Duration of being in comfort zone

Comfort Zone:

22 °C to 26 °C (71.6 °F to 78.8 °F)

4) Energy required by HVAC

\[
\frac{dQ}{dt} = hA(T_R - T_S) \rightarrow
\]

\[
Q = hA \int_{t_1}^{t_2} (T_R - T_S) dt
\]

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4- Actual Results

Sine Functions

- **T10**
  - Temperature (°C) vs. Time (h)
  - Input

- **T20**
  - Temperature (°C) vs. Time (h)
  - 0% PCM, 10% PCM, 30% PCM, 50% PCM

- **T30**
  - Temperature (°C) vs. Time (h)
  - 0% PCM, 10% PCM, 30% PCM, 50% PCM

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### 4- Actual Results

**Comfort duration and the area out of the comfort zone for Sine functions**

<table>
<thead>
<tr>
<th>Input</th>
<th>PCM %</th>
<th>Percentage increase in the comfort time duration</th>
<th>Percentage decrease in the area out of comfort zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>22 ± 1.5 °C</td>
<td>22 ± 3.0 °C</td>
</tr>
<tr>
<td>T10</td>
<td>10</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>T20</td>
<td>10</td>
<td>69</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>181</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>202</td>
<td>33</td>
</tr>
<tr>
<td>T30</td>
<td>10</td>
<td>75</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>208</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>323</td>
<td>118</td>
</tr>
</tbody>
</table>
## Real Temperature Changes of Different Cities

<table>
<thead>
<tr>
<th>City</th>
<th>Time</th>
<th>PCM %</th>
<th>Percentage increase in the comfort time duration</th>
<th>Percentage decrease in the area out of comfort zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle, Washington</td>
<td>Second week Aug. 1996</td>
<td>10</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>18</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>32</td>
<td>39</td>
</tr>
<tr>
<td>San Diego, California</td>
<td>Second week Sep. 2004</td>
<td>10</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>31</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>38</td>
<td>42</td>
</tr>
<tr>
<td>San Antonio, Texas</td>
<td>Second week Aug. 1990</td>
<td>10</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Miami, Florida</td>
<td>Third week May 2000</td>
<td>10</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Minot, North Dakota</td>
<td>Second week Jun. 1980</td>
<td>10</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>23</td>
<td>39</td>
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<tr>
<td></td>
<td></td>
<td>50</td>
<td>28</td>
<td>43</td>
</tr>
<tr>
<td>Denver, Colorado</td>
<td>Second week Jul. 2004</td>
<td>10</td>
<td>15</td>
<td>28</td>
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<tr>
<td></td>
<td></td>
<td>30</td>
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<td></td>
<td></td>
<td>50</td>
<td>27</td>
<td>48</td>
</tr>
</tbody>
</table>
- COMSOL Multiphysics® software can accurately simulate changes in temperature in porous media, such as gypsum boards, and can accurately take the effects of phase transition of PCMs into account.

- Under sine function inputs, depending on the percentage of the PCM, the inside peak temperature can be delayed by up to 7 hours and be decremented by up to 80%.

- For the real changes in temperature of different cities, the comfort duration was increased by up to 40% and almost half of the energy required by HVAC systems was reduced.

- **Future Works:**

  More studies should be conducted to find the optimum percentage and melting temperature of PCM for different cities. Furthermore, cost analysis should also be conducted to compare the efficiency of PCMs to alternative methods.

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THANKS FOR YOUR ATTENTION!

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