Thermal Mass Effect of Solid Block Aerated Autoclaved Concrete

Bryan Urban, Diana Elliott, Nitin Shukla, Jan Kosny, Fraunhofer CSE
Michael McDonough, Architect P.C., New York, NY

Author Contacts:
Bryan Urban (Presenter) burban@fraunhofer.org
Dr. Jan Kosny (PI) jkosny@fraunhofer.org

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Background
Three Walls

pre-cast panels
$$$

cast in place
$$$

concrete block
$

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1 billion per yr

80 million m²

1 of these...
Aerated Autoclaved Concrete

- Invented in mid 1920s by Swedish Architect

Advantages
- Lighter weight
  - 20% the weight of concrete
  - Up to 80% air by volume
- Lower transport cost
- Easier to shape with tools onsite
- Insulating and energy savings?
Concrete Density vs Thermal Resistivity

Concrete Density (kg/m³) vs Thermal Resistivity (m·K/W)

- AAC
- Light concrete
- Concrete
- Mortar

Insulation threshold: 20 (m·K/W)

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Building Energy Codes
Provide thermal mass credit for certain weight classes of concrete. These may fail to represent the insulating benefits of lightweight concrete.
## Thermal Mass Credit in ASHRAE 90.1 and 90.2 & IECC

### IECC Insulation Requirement for a Mass Wall (From Table R402.1) (ICC 2012)

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>Mass Wall R-Value¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3/4</td>
</tr>
<tr>
<td>2</td>
<td>4/6</td>
</tr>
<tr>
<td>3</td>
<td>8/13</td>
</tr>
<tr>
<td>4 except Marine</td>
<td>8/13</td>
</tr>
<tr>
<td>5 &amp; Marine 4</td>
<td>13/17</td>
</tr>
<tr>
<td>6</td>
<td>15/20</td>
</tr>
<tr>
<td>7 &amp; 8</td>
<td>19/21</td>
</tr>
</tbody>
</table>

¹ Second R-value applies when more than half of the insulation is on the interior of the mass wall.
Data Gaps Exist
Thermal properties of some types of lightweight concrete were not well represented in the literature.
# AAC Concrete Strength Classes

<table>
<thead>
<tr>
<th>Concrete Class Strength (MPa)</th>
<th>Nominal Dry Bulk Density, kg/m³</th>
<th>Density Limits, kg/m³</th>
<th>Average Drying Shrinkage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AAC-2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td></td>
<td>350-450</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
<td>450-550</td>
<td></td>
</tr>
<tr>
<td><strong>AAC-4</strong></td>
<td>500</td>
<td>450-550</td>
<td>0.24</td>
</tr>
<tr>
<td>600</td>
<td></td>
<td>550-650</td>
<td></td>
</tr>
<tr>
<td>700</td>
<td></td>
<td>650-750</td>
<td></td>
</tr>
<tr>
<td><strong>AAC-6</strong></td>
<td>600</td>
<td>550-650</td>
<td>≤ 0.02</td>
</tr>
<tr>
<td>700</td>
<td></td>
<td>650-750</td>
<td></td>
</tr>
<tr>
<td>800</td>
<td></td>
<td>750-850</td>
<td></td>
</tr>
</tbody>
</table>

Thermal conductivity measurements missing from the literature
Experiment
Experimental Approach

- Receive batch of 14 samples from manufacturer
- Weigh samples (to measure density)
- Dry samples in thermal chamber until weight reaches equilibrium
  - ASTM D4442 says 103±2°C
  - We used 52.5 °C and 5% RH to prevent condensation on the isothermal plates during testing
- Measure thermal conductivity in Heat Flow Meter Apparatus
- Weigh samples to confirm moisture content has not changed
Thermal Conductivity of Concrete vs. Density

\[ k = 0.0425e^{0.0023\rho} \]

\[ R^2 = 0.9788 \]

\[ k = 0.026e^{0.0738\rho^{0.5}} \] (ASHRAE)
Simulation
Simulation Challenges
3D heat transfer not easily modeled in whole building simulation tools. Material descriptions must be 1D layers.
Importance of Thermal Bridging

Mortar Joint

Insulated Joint
Equivalent Wall Theory

- Represent 3D assemblies as a series of fictitious 1D material layers that produce the same thermal response
3D Simulation of Concrete with Mortar Joint

Detail of mortar joint used in numerical analysis

3-D model of 8-in CMU

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Simulation Cases

- DOE Reference Building for Mid-Rise apartment building

- ASHRAE Climate Zones 4 and 5
  - New York and New Jersey
  - Cold winters, warm summers

- 5 Wall Configurations
  - 3 CMU configurations
  - 2 AAC configurations
Exterior Wall Configurations

**Concrete Masonry Units**
- 200mm CMU + 63mm XPS
- 250mm CMU + 63mm XPS
- 300mm CMU with vermiculite core

**Aerated Autoclaved Concrete**
- 250mm AAC
- 300mm AAC
### Wall Configurations with Equivalent Layer Simulation Properties

<table>
<thead>
<tr>
<th>Wall Assembly</th>
<th>Thickness (mm)</th>
<th>Conductivity k (W/m·K)</th>
<th>Density (kg/m³)</th>
<th>Specific Heat (kJ/kg·K)</th>
<th>Surface-to-surface R-SI (R-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200mm CMU + 63mm XPS</td>
<td>25.4</td>
<td>0.15</td>
<td>1600</td>
<td>0.04</td>
<td>2.37</td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>0.43</td>
<td>1600</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>10.19</td>
<td>1600</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>1.75</td>
<td>1600</td>
<td>3.17</td>
<td></td>
</tr>
<tr>
<td>250mm CMU + 63mm XPS</td>
<td>25.4</td>
<td>0.15</td>
<td>1600</td>
<td>0.05</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>0.44</td>
<td>1600</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>10.03</td>
<td>1600</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>1.55</td>
<td>1600</td>
<td>4.27</td>
<td></td>
</tr>
<tr>
<td>300mm CMU with vermiculite core</td>
<td>25.4</td>
<td>2.59</td>
<td>1600</td>
<td>2.38</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>1.20</td>
<td>1600</td>
<td>1.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>1.30</td>
<td>1600</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25.4</td>
<td>2.25</td>
<td>1600</td>
<td>3.35</td>
<td></td>
</tr>
<tr>
<td>250mm AAC</td>
<td>250.8</td>
<td>1.14</td>
<td>450</td>
<td>0.84</td>
<td>2.09</td>
</tr>
<tr>
<td>300mm AAC</td>
<td>301.6</td>
<td>1.14</td>
<td>450</td>
<td>0.84</td>
<td>2.51</td>
</tr>
</tbody>
</table>

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Representative Summer and Winter Week Temperature Data

Ambient Air Temperature

°C

Summer
Boston

Winter
Boston

Time (hours)

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Interior South Wall Surface Temperatures on a Winter Day

°C

hour

© Fraunhofer USA
Interior South Wall Surface Temperatures on a Summer Day

°C

24 25 26 27

0 4 8 12 16 20 24

hour

© Fraunhofer USA
Interior South Wall Surface Heat Flux on a Winter Day

W/m²

0 10 20 30 40

0 4 8 12 16 20 24

hour

300-mm CMU R-0.6
200-mm CMU R-2.4
250-mm CMU R-2.4
250-mm AAC R-2.1
300-mm AAC R-2.5

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Interior South Wall Surface Heat Flux on a Summer Day

W/m²

-5 0 5 10 15 20 24

0 4 8 12 16 20 24

--- 300-mm CMU R-0.6
--- 200-mm CMU R-2.4
--- 250-mm CMU R-2.4
--- 250-mm AAC R-2.1
--- 300-mm AAC R-2.5

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Conclusions

- Data gaps in the thermal conductivity of AAC were identified
- This resulted in lack of acceptance of lightweight AAC in thermal mass credits
- We measured thermal conductivity of concrete samples to fill the data gap. Results matched theoretical expectation fairly well.
- We used the data to simulate thermal performance of AAC and CMU wall cases in several climates.
- Performance of AAC wall systems performed comparably to insulated CMUs, suggesting that thermal mass credit may be appropriate for lightweight AAC-4 blocks.
Thank You!

Author Contact: Jan Kosny
jkosny@fraunhofer.org
Ph: +1-865-607-6962

Presenter: Bryan Urban
burban@fraunhofer.org
Ph: +1-617-588-0618