Quantifying the Hazards of Green Building Construction for Fire Investigation Analysis

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and

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• Introduction to the green building movement
• Risk associated with green materials
• Use of the Cone Calorimeter
• Green materials testing data
• Impact of green materials
• Method for assessing risk of green materials
• Fire damage patterns in green materials
Introduction to the Green Building Movement
Modern green building movement roots in 1970 U.S. oil crisis

Research into energy efficient building development
- Increased funding
- New construction methods
- Energy efficient devices
- Green materials
Green building materials have become more commonplace

Little research has been conducted on their impact from a fire safety and fire investigation perspective

Concerns
- Easier ignition of materials
- More rapid fire growth and spread
- Significant release of carbon dioxide (sustainability)
- Fire department personnel safety
- Fire damage pattern analysis
Introduction

• Insulation
• Vegetative roofing systems
• Specialty glazings
• Skylights/solar tubes
• Solar collectors
• Construction & building materials
• High Volume Low Speed (HVLS) fan systems
Figure 1: Contribution of risk factors to total lifecycle carbon emissions.

Factory Mutual, 2010
Risk Associated with Green Materials
What is Risk?

- Risk is inherent to life
- Covers a broad range of potential events that are “bad”
- Insurance companies analyze risk in order to set premiums
- Risk analyses in engineering provide a cost-benefit between the potential loss and a modification prior to a failure that can prevent the loss
Calculating Risk

Risk = (Consequence of Incident) \times (Frequency at which Incident Occurs)
Assessing Risk

- Identify the hazards associated with the process or product
- Use the Risk equation to evaluate the magnitude of the risk (Risk Assessment)
- Manage the risk
- How do we assess the risk for green materials?
Cone Calorimeter
• One of the most prevalent bench-scale test apparatus
• Determines ignition and flammability parameters of materials
• Test samples are small
  – 4 inch square
  – Radiant cone heating element provides 1 – 50 kWm$^2$ of energy on sample
Cone Calorimeter Theory

- Ignition of liquids is expanded to combustible solids with several assumptions

  - Decomposition of the solid does not vary the surface temperature
  - Surface temperature is sufficient to generate flammable vapors
  - Lower flammable limit of gas and air will be reached and allow for piloted ignition
Cone Calorimeter Theory

\[ t_{ig} = \frac{(\pi / 4)k\rho c(T_{ig} - T_0)^2}{q''^2} \]

\[ t_{ig} < t^* . \]

- Time to ignition is a function of:
  - The thermal properties of the material
  - Temperature of the sample
  - Incident radiation on the sample
Cone Calorimeter Theory

\[ k \rho c = \frac{4}{\pi} \left( \frac{h_t}{b} \right)^2, \]

- Thermal inertia, \( krc \):
  - The convective coefficient
  - Slope of the line, \( b \)-parameter
\[
\left( \frac{\dot{q}''_{0,ig}}{\dot{q}''}, t^{-0.5} \right)
\]

- Slope is calculated with a best fit line approximation

\[q''_{0,ig} / q'' = 0.0385 \cdot t^{1/2} \]
Using this analysis and test data, thermophysical properties can be determined for any green or non-green material.

Data on the left is an example for ABS (Acrylonitrile Butadiene Styrene).
Cone Calorimeter – Surface T vs. Flux

Temperature (°C)

Heat Flux (kW/m²)

Sutula and Ryder: Green Building Construction and Fire
Green Material Data from Literature
Common Green Materials

- Bamboo
- Straw
- Linoleum
- Sheep wool
- Paper flake panels
- Seagrass
- Cork
- Coconut
- Lignin
- Wood fiber plates
• Byproduct of paper production
• Deemed natural, renewable, biodegradable
• Used in hybrid materials due to charring ability
• When mixed with ABS
  – Reduced peak HRR by 42%
  – Peak HRR “only” 526 kW/m²
Bamboo Flooring

- Critical flux for ignition
  - 13 kW/m²
- Increasing use due to ability to be rapidly grown
- Deemed a sustainable material
- Comparable to oak flooring
• Commonly used in building construction due to ease of application
• Can be fire retardant treated
• Three different foams were tested
• Critical heat flux for ignition did not vary between the three samples, even the FR treated
Comparison of Small-Scale Testing on Full-Scale Results
• Can be cost prohibitive
• Larger amount of materials needed
  – For example, Li-Ion batteries
• Greater support staff needed
• Results may not provide more information or better results
Several studies have concluded that small-scale can be linked to large-scale testing:
- Hansen and Hovde
- Quintiere and Lian

Strong analytical evidence linking results of cone testing to ISO 9705 Room Corner Test.
Potential Impact of Green Building Materials
Risk of Green Materials

• In the fire setting, determining the risk of green materials is the same as standard materials
  – Time to ignition
  – Thermal inertia
  – Peak heat release rate
  – Total heat release rate
  – Products of combustion
Risk to Occupants

- Occupants must have sufficient notice of the presence of a fire
- Occupants must have sufficient time to egress safely
- What toxicants are produced by a green material involved in the fire?
- Presence of green building materials can influence fire department personnel’s decisions to perform search and rescue
Risk to First Responders

• Insulation building products
  – Potential to create more rapid fire growth and spread

• Lightweight building products
  – Elevated risk to fire service personnel
  – Structure fails more rapidly
  – Several case studies have shown increase in injury and death risk to fire service with these materials
Recent fires in Michigan resulting in deaths of fire service personnel
  – Failure of flooring from lightweight green construction

Similar incidents in Pennsylvania
  – Has resulted in legislation to require gypsum board barrier below lightweight flooring construction
The green initiative has resulted in energy efficient buildings

- Tight building construction
- Well-sealed

Ideal conditions for trapping heat during a fire
## Suppressed vs. Non-Suppressed

<table>
<thead>
<tr>
<th>Criteria Pollutants</th>
<th>Emissions (lbs/burn)</th>
<th>Ratio of Emissions, No Sprinkler vs. Sprinkler</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 September</td>
<td>1 October</td>
</tr>
<tr>
<td></td>
<td>No Sprinkler</td>
<td>Sprinkler</td>
</tr>
<tr>
<td>CO</td>
<td>26.42</td>
<td>0.23</td>
</tr>
<tr>
<td>NO₂</td>
<td>0.14</td>
<td>0.14</td>
</tr>
<tr>
<td>SO₂</td>
<td>0.48</td>
<td>0.20</td>
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<tr>
<td>Total VOC - THC (as CH₄)</td>
<td>3.77</td>
<td>0.02</td>
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<tr>
<td>Particulate</td>
<td>17.76</td>
<td>1.39</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Greenhouse Gases</th>
<th>Emissions (lbs/burn)</th>
<th>Ratio of Emissions, No Sprinkler vs. Sprinkler</th>
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<tr>
<td></td>
<td>No Sprinkler</td>
<td>Sprinkler</td>
</tr>
<tr>
<td>CO₂</td>
<td>793.95</td>
<td>12.98</td>
</tr>
<tr>
<td>Methane</td>
<td>1.80</td>
<td>0.01</td>
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<tr>
<td>Nitrous Oxide (N₂O)</td>
<td>0.17</td>
<td>0.02</td>
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</table>

<table>
<thead>
<tr>
<th>Metals</th>
<th>Emissions (lbs/burn)</th>
<th>Ratio of Emissions, No Sprinkler vs. Sprinkler</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td></td>
<td>No Sprinkler</td>
<td>Sprinkler</td>
</tr>
<tr>
<td>Antimony (Sb)</td>
<td>0.017</td>
<td>0.00056</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>0.00056</td>
<td>0.00023</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>0.012</td>
<td>0.012</td>
</tr>
<tr>
<td>Beryllium (Be)</td>
<td>0.0014</td>
<td>0.000056</td>
</tr>
</tbody>
</table>
High Profile Examples

- 2009 Monte Carlo Fire, Las Vegas
- 2007 Borgata Water Club Fire, Atlantic City
- 2009 Mandarin Oriental Hotel Fire, Beijing
Risk to the Structure Examples

- Structural Insulated Panels (SIPs)
  - More frequent use
  - Increased fire load
  - Increased ease of ignition

- Spray-on foam insulation
  - Spontaneous ignition
  - Curing process is exothermic
  - Fuel load contribution and ignition source
Method for Assessing Risk
• Quintiere and Lian
  – Developed a method of using scaled data to characterize risk
  – Data from cone calorimeter used to predict flashover time in ISO 9705
  – Study examined data from 54 different materials
Methodology Parameters

- Methodology relies on four parameters:
  - Heat release parameter
  - Thermal response parameter
  - Critical heat flux
  - Available energy parameter
<table>
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<tr>
<th>Parameter</th>
<th>Physical meaning</th>
<th>Measurement means</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRP, heat release parameter</td>
<td>$\Delta h_c/L$</td>
<td>Slope of peak HRR and flux</td>
</tr>
<tr>
<td>TRP, thermal response parameter</td>
<td>$\sqrt{\frac{\pi}{4} k \rho c (T_{ig} - T_0)}$</td>
<td>Slope of $(\text{time to ignition})^{-1/2}$ and flux</td>
</tr>
<tr>
<td>CHF, critical heat flux</td>
<td>$h_t(T_{ig} - T_\infty)$, $h_t = h_r + h_c$</td>
<td>Lowest flux for piloted ignition</td>
</tr>
<tr>
<td>AEP, available energy parameter</td>
<td>Total energy per unit surface area</td>
<td>Area under HRR and flux curve</td>
</tr>
</tbody>
</table>
Flashover Prediction

- The parameters are used to generate a curve to predict the measured time to flashover

\[ t_{\text{FO}} = 0.06533 \cdot \text{AEP}^{0.1297} \cdot \text{HRP}^{-0.2208} \cdot \text{TRP}^{1.3293} \quad \text{in seconds} \]
Flashover Prediction

- Result indicate that flashover can be predicted using the equation.
- Flashover propensity is a quantified measure for assessing the risk of a particular material:
  - Green
  - Standard
Fire Damage Patterns In Green Materials
• Some green building materials can produce rapid flame spread and burn to completion quickly
  – Straw
  – Seagrass
  – Untreated cellulosic insulation
  – Lightweight building elements

• Could mimic the results of accelerant-based fire growth
Unusual Patterns

• Composite materials can result in unusual fire damage patterns
• Understanding and quantifying the risk associated with green materials will allow for better understanding of the resulting damage patterns at a fire scene when green materials have been involved
Ongoing Research

• WPI awarded $1 million DHS grant to investigate: *Quantification of Green Building Features on Firefighter Safety*
Questions?