Fire safety of EPS ETICS

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Fire Safety of EPS ETICS in Residential Suburb Multi-Storey Buildings

Goals and scope

- To work out the effect of EPS insulation used in external wall to the fire safety of the building
- Concerns residential suburb multi-storey buildings
  - Max 8 floors + possible basement floor (which can be aboveground)
  - New buildings and renovation
  - Loadbearing structures: Stone based (concrete, bricks, etc.)
- Main emphasis in safety of people in completed/occupied houses + assessments on fire safety during building/renovation
External ignitions

- Concerning fire spread on facades and to upper floors of the building, fires ignited externally in the vicinity of facades are a smaller hazard compared to flashover room fires.
- The main hazards of external fires are related to the ground floor.
  - However, even in this case the fire exposures by external fires are not more severe than those from flashover room fires.

Distance between buildings

- Assumed to be at least 5-8 m and thus effects from possible fires in neighbouring buildings are not considered.
EPS insulation in facades

Types/qualities

- **White** EPS and **grey** EPS with and without flame retardant
- Thicknesses – max 300 mm, minimum 50 mm
- Density 15 – 22 kg/m$^3$

Protection of insulation

- Internal – at least EI 30 (at least A2-s1, d0 materials)
- External
  - EI 30 (at least A2-s1, d0) - EPS sandwich: No further analysis needed
  - Reinforced rendering system – approved systems - ETICS
  - Fire stops
    - 200 mm high mineral wool (A2-s1, d0) above each window, or continuous 300 mm high mineral wool (A2-s1, d0) at every second floor
Fire stops – two alternatives

Fire stops (at least A2-s1, d0 class mineral wool): 200 mm above each window, or continuous 300 mm barrier at every second floor
Statistics – buildings

Finland

- Multi-storey dwelling buildings: Average size of apartments is about 57 m² (about 80 m² for all apartments)
- In Helsinki average floor area of new apartments in multi-storey buildings is above 70 m² and about 10% of new buildings have floor area of at least 100 m²
- Floor area of rooms (with reasonable sized windows) varies typically between 7 and 30 m²

Sweden

- Average floor about 93 m² for all apartments, thus for multi-storey dwelling buildings the average size of apartments can be assumed to be around 70 m²
Statistics – fires

Finland
- Statistics system of the Finnish rescue services (PRONTO)
  - Years 2004 – 2012 covered in this study

Sweden
- Statistics database of the Swedish Civil Contingencies Agency (IDA)
  - Years 2004 – 2011 covered in this study
Proportions of external and internal ignitions in residential multi-storey buildings of different fire classes during 2004–2012 in Finland

<table>
<thead>
<tr>
<th>Fire class</th>
<th>External ignitions</th>
<th>Internal ignitions</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number</td>
<td>percent-age</td>
<td>number</td>
<td>percent-age</td>
</tr>
<tr>
<td>P1</td>
<td>318</td>
<td>8 %</td>
<td>3412</td>
<td>91 %</td>
</tr>
<tr>
<td>P2</td>
<td>28</td>
<td>9 %</td>
<td>265</td>
<td>89 %</td>
</tr>
<tr>
<td>P3</td>
<td>51</td>
<td>10 %</td>
<td>479</td>
<td>90 %</td>
</tr>
<tr>
<td>Total</td>
<td>397</td>
<td>9 %</td>
<td>4156</td>
<td>91 %</td>
</tr>
</tbody>
</table>

Note: Only P1 and P2 class buildings can have more than 2 floors.

Proportions of external and internal ignitions in residential multi-storey buildings during 2004–2011 in Sweden

<table>
<thead>
<tr>
<th>Room or space of ignition</th>
<th>Number of cases</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal ignition</td>
<td>19548</td>
<td>89 %</td>
</tr>
<tr>
<td>External ignition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>other than balcony</td>
<td>615</td>
<td>3 %</td>
</tr>
<tr>
<td>balcony</td>
<td>1297</td>
<td>6 %</td>
</tr>
<tr>
<td>Unknown</td>
<td>454</td>
<td>2 %</td>
</tr>
<tr>
<td>Total number of fires</td>
<td>21914</td>
<td></td>
</tr>
</tbody>
</table>

Note the differences in accident data basis. Definitions are different and also within country these change by years, like in Finland (factor >2 in total numbers/year).
Fire development and spread according to statistics

Situation of fire development at arrival of fire brigade

Fire spread out of fire compartment:
- Finland: 3 - 4 % of fires
- Sweden: 1 % of fires

Fires breaking compartment window

Information on fire spread due to window breaking was available only in the Finnish statistics
- The separating element which failed was a window in 26 cases (0,7 % of fires)
- Upper limit not more than 2 % (earlier study for wooden facades*)
  - Compare with ‘Fire spread to several rooms or out of fire compartment’: 1 – 4 %
  - All of these fires do not spread via window

EPS – ignitability and heat release

- 2013 results for grey and white EPS compared with earlier results for white EPS at 50 kW/m² exposure level

<table>
<thead>
<tr>
<th>EPS without flame retardant</th>
<th>White EPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey EPS</td>
<td>[1]</td>
</tr>
<tr>
<td>ρ (kg/m³)</td>
<td>18</td>
</tr>
<tr>
<td>d (mm)</td>
<td>25</td>
</tr>
<tr>
<td>Time to ignition (s)</td>
<td>40.5</td>
</tr>
<tr>
<td>RHRmax (kW/m²)</td>
<td>411</td>
</tr>
<tr>
<td>RHR60s (kW/m²)</td>
<td>218</td>
</tr>
<tr>
<td>THR (MJ/m²)</td>
<td>13.3</td>
</tr>
<tr>
<td>Smoke; SEA (m²/kg)</td>
<td>-</td>
</tr>
</tbody>
</table>

* No protection
** Steel sheet (0.6 mm) protection

### EPS with flame retardant

<table>
<thead>
<tr>
<th></th>
<th>Grey EPS</th>
<th>[1]</th>
<th>[2]</th>
<th>[3,4]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ρ (kg/m³)</strong></td>
<td>19</td>
<td>19</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td><strong>d (mm)</strong></td>
<td>25</td>
<td>50</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td><strong>Time to ignition (s)</strong></td>
<td>48</td>
<td>46</td>
<td>56</td>
<td>46</td>
</tr>
<tr>
<td><strong>RHR_{max} (kW/m²)</strong></td>
<td><strong>325</strong></td>
<td><strong>329</strong></td>
<td><strong>265</strong></td>
<td><strong>330</strong></td>
</tr>
<tr>
<td><strong>RHR_{60s} (kW/m²)</strong></td>
<td><strong>172</strong></td>
<td><strong>290</strong></td>
<td><strong>202</strong></td>
<td><strong>293</strong></td>
</tr>
<tr>
<td><strong>THR (MJ/m²)</strong></td>
<td>13.9</td>
<td>27.6</td>
<td>16.5</td>
<td>32.7</td>
</tr>
<tr>
<td><strong>Smoke; SEA (m²/kg)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* No protection
** Steel sheet (0.6 mm) protection
*** Steel sheet (0.6 mm) + 4.5 mm fibre-cement board protection

Ignition and burning of rendering protected EPS insulation

- The EPS insulation is protected with rendering (5-8 mm) which does not ignite or the contribution to fire is limited (because of small amount of organic substances)
- Only when the heat flux level is at least 30 kW/m$^2$ ignition of rendering protected EPS is estimated to occur (takes about 15 minutes at 30 kW/m$^2$ and more than 3 minutes at 50 kW/m$^2$)* and EPS will start contributing to fire development
- The maximum rate of heat release (RHR) will be below 100 kW/m$^2$ (average about 50 kW/m$^2$)
  - This is lower than typical RHR for wood based products
- Large scale evidence from facade testing
  - Height of test specimen (above fire room) 5 – 6 m, fire loads 300 – 600 MJ/m$^2$
  - Experiments have shown that the burnt area is limited to the lower edge of the window two floors above

Analysis of fires spreading - Event tree method

Early detection  First-aid extinguish  Self-extinct  Fire brigade extinguishes before spread via window  Spread via window outside  Breakage of window one floor above  Breakage of window two floors above

Ignition of fire

Yes

No
Room fires spreading to façade - simulations

- The simulations were done using Fire Dynamics Simulator (FDS) and statistical study was made using Monte Carlo simulations
- 200 random cases were simulated using the parameters and distributions listed in the following table:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Distribution</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room area (m²)</td>
<td>Uniform</td>
<td>7, 30</td>
</tr>
<tr>
<td>Window wall length (proportional)</td>
<td>Uniform</td>
<td>0.25, 0.75</td>
</tr>
<tr>
<td>Window height (m)</td>
<td>Uniform</td>
<td>1.2, 1.4</td>
</tr>
<tr>
<td>Window width (m)</td>
<td>Uniform</td>
<td>1, 3</td>
</tr>
<tr>
<td>Fire load (MJ/m²)</td>
<td>Triangular</td>
<td>200, 600, 1000</td>
</tr>
<tr>
<td>Time delay to window break (min)</td>
<td>Log-normal</td>
<td>1.099, 0.610</td>
</tr>
<tr>
<td>Time to fire peak (s)</td>
<td>Uniform</td>
<td>300, 2700</td>
</tr>
</tbody>
</table>
Fire loads

- Finland: Assumed maximum 600 MJ/m² for residential buildings
- Sweden: Residential buildings 800 MJ/m² (80 % fractal) as a design value

Assumed fire loads for the analysis:
- 200 – 1000 MJ/m² with mean value at 600 MJ/m²
- Compare with Eurocode 1: the Gumbel distribution with the mean value equal to 780 MJ/m² and the 80 % fractal value equal to 948 MJ/m² (50 % fractal 740 MJ/m²)

Room size distribution: 7 – 30 m²
+ variation of width and length

Windows: Height 1.2-1.4 m + up to 1.8 m
Width 1-3 m
Spreading of fire

Conditions for window breaking

- The window breaks in the fire room after the temperature at any point of the window exceeds 500 °C during a time defined by a random variable which has average of 3 minutes and 80% fractal at 5 minutes.
- The window above the flashover fire will break in a short time (within 3 minutes) when the heat flux level is 35 kW/m².
  - Note that EPS can be ignited if the exposure level is 30 kW/m² for about 15 minutes, or 40 kW/m² for about 4 minutes.
- Heat fluxes at windows of 2nd and 3rd floor
  - Simulations: See figure
  - Lund measurements: max 70 kW/m²
  - SP Fire 105 tests: over 30 kW/m²
  - Room fire tests at VTT: max 75 kW/m²
    - Fire load 920-1200 MJ/m² & large window
  - Experimental evidence indicates that there will be no window breaking on 4th floor because heat fluxes are low (< 10 kW/m²).
Cumulative probabilities for time of window break (room-of-fire-origin)

A flash-over room fire on facade
Cumulative probabilities for times of upper floor window breaks (of all the cases when fire spread through window to the facade) for at least A2-s1, d0 facade
Until about 25 minutes from the start of the fire the window breaking time probabilities for both façade types are very close to each other (within one minute difference)
Effects of contribution of EPS to fire development

- Simulation result examples of heat flux for at least A2-s1, d0 facade, and for EPS/rendering systems with rate of heat release of 50 kW/m² and 100 kW/m².
  - a) Heat flux at 2nd window.
  - b) Heat flux at 3rd window.

- Not sensitive whether 50 kW/m² or 100 kW/m² is the contribution from EPS
It is unlikely that the rendering protected EPS ignites if the window edge is located at least 1 m from the corner wall.
In case of external balconies flames are usually directed further off from façade plane and thus the fire exposure on the façade surface will be lower than for normal window cases.

For recessed balconies the heat exposures to walls and ceiling can be as high as in room fires. Higher heat fluxes will mean an increased contribution of EPS to fire development. Thus fire safety requirements for internal walls and ceilings should be applied.

For corridor type exits the situation is similar to recessed balconies and potential for flaming droplets should be taken into account. For these cases fire safety requirements for exits should be applied.
Fire stops/barriers – different window layouts
## Data used and probabilities of fire spread to floors above

<table>
<thead>
<tr>
<th>Probabilities in the branches of event tree and overall probabilities</th>
<th>Statistical data At least/nearly A2-s1, d0 facade</th>
<th>Data used and results of simulations At least A2-s1, d0 facade</th>
<th>Data used and results of simulations Rendering + EPS insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early detection of fire</td>
<td></td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>First-aid extinguishing successful</td>
<td>0.15 – 0.25</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Self-extinction of fire</td>
<td>0.1 – 0.15</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Fire brigade extinguishes before spread via window</td>
<td>0.8 – 0.95</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Fire spreads via window</td>
<td></td>
<td>0.73</td>
<td>0.73</td>
</tr>
<tr>
<td>Breakage of window 1 floor above of fires spreading via window</td>
<td></td>
<td>0.31</td>
<td>0.36</td>
</tr>
<tr>
<td>Breakage of window 2 floors above of fires breaking window 1 floor above</td>
<td></td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Overall probabilities</strong></td>
<td></td>
<td><strong>1.66 %</strong></td>
<td><strong>1.95 %</strong></td>
</tr>
<tr>
<td>Breakage of window 1 floor above</td>
<td></td>
<td><strong>0.26 %</strong></td>
<td><strong>0.31 %</strong></td>
</tr>
<tr>
<td>Breakage of window 1 or 2 floors above</td>
<td>&lt; 0.7 % - 2 %</td>
<td><strong>1.9 %</strong></td>
<td><strong>2.3 %</strong></td>
</tr>
</tbody>
</table>
Probabilistic criteria – acceptable safety levels

Ignition frequency (apartment buildings/Finland)
\(< 7.5 \cdot 10^{-6} \text{ 1/m}^2\text{a}\)
+ average size of apartment 70 m\(^2\)
→ \(5 \cdot 10^{-4}\) probability per apartment per year

**All at least A2-s1, d0 materials:**
Maximum 1 - 2 % of fires will spread upper floors:
\(< 1 \cdot 10^{-5}\) probability per window to spread floors above
If max large 4 windows per apartment:
\(< 4 \cdot 10^{-5}\) probability to spread floors above

EPS insulation:
\(< 4.8 \cdot 10^{-5}\) probability to spread floors above

Fatalities in multi-storey building fires: 1-2 \(\cdot 10^{-2}\) per fire


F-N plot – Frequency of events (F) as a function of fatalities (N)
Field of application of the results

Influence of general building characteristics

- Fire load: High fire loads covered (up to 1000 MJ/m²)
- Room dimensions: Normal apartment rooms covered (when at the same floor)
- Windows: Can be least 3 m wide and 1.8 high

Influence of specific building characteristics and rescue

- Windows close to inner corners: 1 m distance recommended
- Balconies: External balconies usually OK; For recessed balconies or corridor shaped exits use of relevant fire safety requirements (for internal walls and ceilings or exits) recommended
- Fire barriers: Possible to use different layouts in different parts of building
- Number of floors: Maximum 8
- Distance between buildings: Minimum 5 – 8 m
- EPS ETICS: Approved system (fulfilling component and system requirements)
- Fire brigade intervention: Normal urban area resources
Fire safety during building and renovation

Uncovered EPS

- Small ignition sources – effects of flame retardant
  - EPS with flame retardant (class E) can resist small ignition sources and needs higher heat flux (about 25 kW/m²) to ignite than without flame retardant
  - RHR for EPS with flame retardant is close to zero and for EPS without flame retardant 330 kW/m² at 25 kW/m² heat flux level

- High heat flux ignition sources – 50 kW/m² (or even more)
  - Differences between flame retardant and without flame retardant EPS are not very significant
  - Mean RHR is about 350 kW/m²
  - Fire may spread mainly upwards to an area covering up to approximately 100 m² in building with maximum 8 floors
  - This possibility must be minimised by on site instructions
Guidance for building and renovation

- CFPA Guideline No21: 2012F. Fire prevention on construction sites
  - Use of combustible construction materials:
- CFPA Guideline No12: 2012F. Fire safety basics for hot work operatives
  - Alternative working methods recommended for hot works
  - Detailed safety precautions
  - Hot work licences required
- SPEK (Finland) – as above + check lists etc.
- Sweden
  - Bygg säkert med cellplast. EPS-bygg.
Recommendations – installation phase

- Construction sites: A general need to reduce the risks of ignition by minimizing the use of flammable liquids and gases and the amount of fire load (including waste material).
- Compliance with hot work instructions is of primary importance, and the construction site needs to be non-smoking area.
- Understanding of all fire safety instructions should be ensured by language versions whenever necessary.
- If apartments are occupied during the installation process, the time EPS insulation is uncovered should be limited and proper safety instructions and means for escape need to be provided. Otherwise it is recommended that the apartments should not be occupied.
Main conclusions

- The estimated maximum overall probabilities for window breaking at floors above the fire room were about 2% which is in agreement with statistical data. About 85% of these window breaking cases occur one floor above the fire room and only about 15% two floors above.
- The overall window break probability in the floors above for EPS ETICS façade is 2.3% and for at least A2-s1, d0 façade 1.9% per ignited fire.
- Fire death probability is not more than $10^{-6}$ per building fire ($0.8 \times 10^{-6}$ for at least A2-s1, d0 façade and $1.0 \times 10^{-6}$ for EPS ETICS systems). This is tolerable compared with F-N-curves.
- Structural detailing of the façade system and the associated constructions are of essential importance in decreasing fire hazards.
- If the apartments are occupied during the installation process, limit the time EPS insulation is uncovered and provide proper safety instructions and means for escape.