Current and future modelling of the burning of exposed timber internal surfaces using B-RISK

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Desire to use more timber in buildings, examples include the use of cross-laminated timber (CLT) and similar engineered timber products in tall timber buildings throughout the world.

Timber is a combustible material - additional fuel changes the fire dynamics and severity of the compartment fire.

Temperatures in compartments for fully developed fires do not consider the additional fuel contributed by the timber and its effect on the fire dynamics.
Zone model developed in New Zealand by BRANZ and University of Canterbury
- Many applications for performance-based design built around the core governing equations of mass/energy conservation
- Recently modified to include effects on fire severity due to CLT bounding construction
- [http://www.b-risk.com](http://www.b-risk.com)
Charred mass added to contents fuel load – total fuel load updated each time step

Char depth based on 300 °C isotherm position
Post flashover fire model

- Contents fuel burns as wood cribs considering
  - ventilation-control
  - fuel-control
  - crib porosity control
- Charred timber linings added to contents (fire load updated each time step)

- User-defined factor representing an excess fuel fraction (global equivalence ratio / GER)
  - 1.0 all the fuel burns inside compartment (no external burning)
  - 1.3 default ~ wood cribs (Babrauskas, SFPE hdbk)
  - 2.0 half of the fuel burns inside and half outside
Delamination of CLT

- Delamination of CLT layers not currently modelled
- Temperature at the glue-line is calculated
- Adhesive type important – temperature sensitive adhesives (e.g. PU) allow delamination at about 200 °C
- Temperature resistant adhesives (e.g. melamine urea formaldehyde, phenol-resorcinol formaldehyde) prevent delamination
- Design choice could be to avoid delamination by specifying minimum CLT layer thickness
References


<table>
<thead>
<tr>
<th>Config.</th>
<th>Room geometry L × W × H (m)</th>
<th>Opening W × H (m)</th>
<th>Timber configuration on walls and ceiling</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.5 × 3.5 × 2.5</td>
<td>1.069 × 2.0</td>
<td>No exposed timber Two experiments conducted</td>
<td>[1, 2]</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td>100% exposed timber</td>
<td>[1, 2]</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td>Two adjacent walls exposed (52.8% of the wall area) and ceiling protected</td>
<td>[3]</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td></td>
<td>Two opposite walls exposed (59.4% of the wall area) and ceiling protected</td>
<td>[3]</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td></td>
<td>One wall with exposed (29.7% of the wall area) and ceiling protected</td>
<td>[3]</td>
</tr>
<tr>
<td>F</td>
<td>2.72 × 2.72 × 2.77</td>
<td>0.76 × 1.84</td>
<td>Back wall and side wall (50%) exposed</td>
<td>[4]</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td>Back wall (25%) and ceiling (100%) exposed</td>
<td>[4]</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td></td>
<td>Back wall and side wall (50%) and ceiling (100%) exposed</td>
<td>[4]</td>
</tr>
</tbody>
</table>
University of Carleton experiments by McGregor, Li and Medina

- CLT panels 105 mm thick and comprising 3 layers
- The layers were adhered with a PU-based adhesive
- The fuel load was 30 kg/m² (as wood equivalent excluding the CLT panels)
Config A – Fully protected

![Graphs showing Total HRR (MW) and Temperature (°C) over Time (min) for Experiment A and Prediction GER 1.3]
Config B – Fully exposed

- Total HRR (MW)
  - Measured
  - Prediction GER 2.0
  - Prediction GER 3.1

- Temperature (°C)
  - Measured
  - Prediction GER 2.0
  - Prediction GER 3.1
Config C – Two adjacent walls exposed
Config D – Two opposite walls exposed

**Graph 1:**
- **Total rate of heat release (MW)**
- **Time (min)**
- **Experiment D**
- **Model prediction GER 1.3**
- **Model prediction GER 2.0**

**Graph 2:**
- **Gas temperature (°C)**
- **Time (min)**
- **Experiment D**
- **Model prediction GER 1.3**
- **Model prediction GER 2.0**
Config E – One wall exposed

- Total rate of heat release (MW)
- Gas temperature (°C)

Experiment E
- Model prediction
  - GER 1.3
  - GER 2.0

Time (min)
0 10 20 30 40 50 60 70 80 90
0 1 2 3 4 5 6 7 8
0 200 400 600 800 1000 1200 1400
University of Edinburgh experiments by Hadden et al.

Room dimensions $2.72 \times 2.72 \times 2.77$ m high with an opening $1.84$ m high and $0.76$ m wide

CLT panels $100$ mm thick and comprising $5$ layers

The layers were adhered with a polyurethane-based adhesive

The fuel load was $7.5$ kg/m$^2$ (wood excluding the CLT panels)
Config F – Rear and one side wall exposed

[Graph 1: Total rate of heat release (MW) vs. Time (min)
- Experiment F, Alpha-1
- Experiment F, Alpha-2
- Model prediction GER 1.3
- Model prediction GER 2.0]

[Graph 2: Gas temperature (°C) vs. Time (min)
- Experiment F, Alpha-1
- Experiment F, Alpha-2
- Model prediction GER 1.3
- Model prediction GER 2.0]
Config G – Ceiling and rear wall exposed

Total rate of heat release (MW)

- - - - Experiment G, Beta-1
- - - Experiment G, Beta-2
- - - Model prediction GER 1.3
- - Model prediction GER 2.0

Time (min)

Gas temperature (°C)

- - - - Experiment G, Beta-1
- - - Experiment G, Beta-2
- - - Model prediction GER 1.3
- - Model prediction GER 2.0

Time (min)
No clear outcome in regard to which GER to use

Value no greater than 1.3 recommended where a conservative prediction for the gas temperatures and fire severity is desired

Excess fuel factor of 2.0 is recommended where timber surfaces are unprotected, and where a conservative prediction for the external flaming environment is desired
- Crielaard* found smouldering CLT self-extinguishes when the externally applied heat flux falls below 5 to 6 kW/m²
- Model calculates position of the char interface – maximum depth (plateau) can be determined
- However, ‘erosion’ of char is not accounted for – could be important for thick layers in the absence of delamination

Minimum thickness of CLT layer (to avoid delamination) with regard to unprotected wall area for a given compartment size and ventilation condition.
Parallel developments

- Parallel to B-RISK developments, Hopkin et al.* also been developing a one-zone model to examine effect of CLT linings
- Similar assumptions with regard to 1D heat transfer, 300 C isotherm tracking, delamination not included
- Benchmarked against Carlton work with similar results although maximum temperatures generally higher

*Hopkin D, Anastasov S, Brandon D. Reviewing the veracity of a zone-model-based-approach for the assessment of enclosures formed of exposed CLT, Applications of Structural Fire Engineering, 2017
Future developments?

- Further development of B-RISK implementation
  - Hopkin et al. have a multiple wall heat transfer model to calculate separate loss components to encapsulated vs. exposed surfaces
  - Add Hopkin et al. heating rate dependant material properties
  - Define thermal properties according to finite rate chemistry and the relative fractions of differing components as a function of time*

*Hopkin D, Spearpoint M. Implementation of Arrhenius combustion reactions to estimate timber charring rates in realistic fires, in progress


Model limitations

- Include delamination of CLT layers
  - Delamination has significant influence on the fire duration and the ability of a structure to withstand burnout
  - Predicting is challenging, numerical implementation has difficulties e.g. sudden increase in fire load, staged wall heat transfer analyses

![Graph showing temperature over time with delamination levels]

- Four exposed walls
- Two exposed walls
- One exposed wall
- Fully protected
Future developments?

- Consider potential for charring with encapsulation in place
  - Carleton experiments observed charring behind the gypsum lining
  - Heat release rate component is currently neglected

- Consider encapsulation failure to include pre- and post-protection behaviours
  - Lining failure may lead to the sudden exposure of pre-heated timber, increase in char formation, increase in HRR and a change in fire duration

- Radiative heat transfer between exposed surfaces during cooling after variable fire load consumed
  - Surface flaming during cooling can result in significant radiative exchange between surfaces, perpetuating charring and prolonging fire duration