FIRE RESISTANCE LEVEL ASSESSMENTS AND DEVELOPMENT OF APPROPRIATE INPUT DATA

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INTRODUCTION

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CONTENTS

• Commonly adopted fire severity and time equivalence methods;
• Fire load density parameter, data collection & calculation;
• Fire load density survey of Australian primary and secondary school buildings;
• Comparison of findings to existing data;
• Future research and conclusion.
Equivalent fire severity may be defined as the time of exposure to the standard fire that would result in the same load-bearing capacity as the minimum which would occur in a complete burnout of a fire cell.
The severity of a fire is dependent on:

- Fuel type and load;
- Geometry and size of the room/compartment;
- Size of the ventilation openings.
Several approaches have been used to determine the equivalent severity of fire, and in that equal area and time equivalent concepts are commonly used.

With the time equivalence approach the performance of a structure exposed to a realistic fire is assessed in terms of an equivalent exposure time to a standard fire.
FIRE SEVERITY AND TIME EQUIVALENCE

- The time-equivalence method creates a relation between the effects of heating in structural members caused by natural fires and those caused by the ISO fire curve (BS ISO834, 2014).

\[ T = 345 \log(8t + 1) + 20 \]
Temperature-time curves represent gas temperature in the environment to which building elements are exposed as a function of time. They may be:

- **Nominal**: conventional curves, adopted for classification or verification of fire resistance, e.g. the standard temperature-time curve, external fire curve, hydrocarbon fire curve;
- **Parametric**: determined on the basis of fire models and the specific physical parameters defining the conditions in the fire compartment.
Equivalent fire severity on (a) equal area and (b) equal temperature basis
FIRE SEVERITY AND TIME EQUIVALENCE

Some commonly adopted methods:

• Law’s Method;
• Pettersson’s Method;
• CIB W14;
• Harmathy’s Normalised Heat Load Distribution method;
• Eurocode.
Limitations of time equivalent formulae:

1. They have been developed for a certain range of structural steel sizes and thicknesses of insulation, but may not be appropriate beyond this range;

2. They may be not applicable to unprotected steel;

3. The time equivalent formulae are often used for other materials such as concrete or wood structures, but very little is known about their accuracy for these materials;
Limitations of time equivalent formulae:

4. A major shortcoming of these methods is that they ignore the effect of applied load on the structural member;

5. There is considerable debate about the ventilation factor. The ventilation factor in the CIB formula was based on many tests on very small compartments, but did not allow for horizontal openings in the ceiling;

6. These formulae have not been verified for large or tall compartments.
Impact of Input Variations on the Results:

• The challenge is not to the methodology but to the end user as how to select the appropriate method and the **appropriate input data** to deal with the problem in hand.

• The parameters for fire resistance design and fire severity evaluation such as **fire loads** and ventilation factors, have a direct impact on the outcomes of the analysis.
Both with the Eurocode equation and Law’s equation the fire load \((e_f)\) is a direct multiplier and hence, any modification of the fire load input can increase or reduce the equivalent time severity proportionally.

\[
t_e = e_f \times k_b \times w_f
\]

\[
t_e = (A_f \times e_f) / (H_c \sqrt{A_v (A_t - A_v)})
\]

An understanding of the likely nature and extent of fire loads within specific building classifications is required to analyse the potential impact of a compartment fire.
SIGNIFICANCE OF FIRE LOAD DATA

• Fire load values are generally extracted from guideline documents or research papers.
• Many of which may be outdated or may not be applicable to countries other than the country of origin.
• Fire load as the building content is related to building occupant’s lifestyle which evolved with time.
• Fire load can also be dependent on geographic location or climate.
• These factors, however, are not reflected in many of the fire load data sources.
SIGNIFICANCE OF FIRE LOAD DATA

• One way of ensuring the appropriateness and accuracy of the input data for fire severity calculation is to collect contemporary fire load data from the relevant building classes in the relevant geographic regions.

• In the following sections a study involving the collection and analysis of fire load data relevant to Australian primary and secondary schools is presented.
DATA COLLECTION METHODS

• Fire load survey’s are typically utilised in collecting the raw data required to determine fire load density.

• There are a number of survey methods including the following:
  • **Inventory:** A list of typical combustibles with corresponding characteristics used to calculate the equivalent mass and fire load contribution.
  • **Direct weight:** Mass of combustible content measured directly to calculate fire load contribution.
  • **Combination:** incorporates both aspects of inventory & direct weight methods.
  • **Questionnaire:** Indirect measurement through tabular look ups.
  • **Website review:** Relies on photographs that depict fire load arrangements.
DATA COLLECTION METHODS

• Fire load by locality:
  • **Fixed:** Combustible content that bounds, is permanently fixed to or is infrequently moved within a room/enclosure.
  • **Moveable:** Combustible content (e.g. furniture) used by occupants that can be moved into or out of a room/enclosure.
  • **Protected:** Combustible content which may be protected from direct fire exposure (e.g. metallic container, shelves, draws).
  • **Localised:** Combustible content which may be concentrated within a specific location.
DATA COLLECTION METHODS

- Fire load by material:
  - Cellulosic (e.g. paper, cardboard, wood), plastic, textile/fabric);
  - Corresponding characteristics (e.g. calorific value, density, specific weight) determined from literature.

<table>
<thead>
<tr>
<th>Material</th>
<th>Calorific Value</th>
<th>Reference</th>
<th>Density</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood</td>
<td>18.6 MJ/kg</td>
<td>Hadjisophocleous and Chen (2010)</td>
<td>450 kg/m³</td>
<td>Zalok (2011)</td>
</tr>
<tr>
<td>Paper</td>
<td>17.0 MJ/kg</td>
<td></td>
<td>450 kg/m³</td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td>22.1 MJ/kg</td>
<td></td>
<td>1500 kg/m³</td>
<td>Gao et al (2012)</td>
</tr>
<tr>
<td>Textile</td>
<td>19.0 MJ/kg</td>
<td></td>
<td>2.6 kg/m²</td>
<td></td>
</tr>
</tbody>
</table>
CALCULATION OF FIRE LOAD DENSITY

- Fire load density random variable.
- Differs with building classification and room/enclosure use.
- Described using two (2) parameters:
  - Total fire load \((Q)\) corresponds to the potential energy release of materials within a room/enclosure
  - Fire load density \((e_f)\) corresponds to the fire load per unit floor area

\[
e_f = \frac{Q}{A_f} = \frac{1}{A_f} \sum k_i m_i h_{ci}
\]

where,

\(e_f\) = Fire load density \((\text{MJ/m}^2)\)
\(Q\) = total fire load in compartment \((\text{MJ})\)
\(k_i\) = Proportion of the \(i^{th}\) item than can burn
\(m_i\) = Mass of the \(i^{th}\) item \((\text{kg})\)
\(h_{ci}\) = Calorific value of the \(i^{th}\) item \((\text{MJ/kg})\)
\(A_f\) = Floor area of room/enclosure \((\text{m}^2)\)
FIRE LOAD SURVEY

- Three (3) schools surveyed in the school holiday periods of January 2015 and April 2015.
- Total of 85 rooms/enclosures surveyed adopting the combination method (i.e. inventory-weight).
- Total 6313.94m² surveyed.

<table>
<thead>
<tr>
<th>Surveyed Rooms</th>
<th>School-1</th>
<th>School-2</th>
<th>School-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL-P</td>
<td>19</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>CL-S</td>
<td>-</td>
<td>13</td>
<td>7</td>
</tr>
<tr>
<td>SC</td>
<td>-</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>VA</td>
<td>-</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>IT</td>
<td>1</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>LIB</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>ST</td>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>OTHER</td>
<td>1</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>School Type</th>
<th>Primary</th>
<th>Secondary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>31</td>
<td>5</td>
</tr>
<tr>
<td>Secondary</td>
<td>-</td>
<td>24</td>
</tr>
</tbody>
</table>
FIRE LOAD SURVEY

• Combination method (inventory-weight):
  • Mass based off direct measurement;
  • Equivalent mass (i.e. product of volume and material density);

• Survey form developed for data collection.

• Equipment – 4 x digital scales, standard metric tape measure and electronic distance measuring device.
**FIRE LOAD SURVEY**

**Modular Fire Load**

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Length (m)</th>
<th>Width (m)</th>
<th>Thickness (mm)</th>
<th>Material</th>
<th>Usage</th>
<th>Weight (kg)</th>
<th>Weight Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>5</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2.5 x 2.5</td>
<td>2.5</td>
<td>2.5</td>
<td></td>
<td></td>
<td>255.15</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>7.5 x 1.8</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>22.16</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>2.5 x 2.5</td>
<td>2.5</td>
<td>2.5</td>
<td></td>
<td></td>
<td>255.15</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>3 x 3</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>2 x 2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>22.16</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>1.5 x 1.5</td>
<td>1.5</td>
<td>1.5</td>
<td></td>
<td></td>
<td>26.25</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1 x 1</td>
<td>1</td>
<td>1</td>
<td></td>
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<td>10</td>
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<tr>
<td>10</td>
<td>1</td>
<td>0.5 x 0.5</td>
<td>0.5</td>
<td>0.5</td>
<td></td>
<td></td>
<td>2.5</td>
<td></td>
</tr>
</tbody>
</table>

**Floor Area (m²)**

<table>
<thead>
<tr>
<th>Type</th>
<th>Wall</th>
<th>Ceiling</th>
<th>Floor</th>
<th>Door</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceiling</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Door</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Other Comments**

- 6.25 m² (6.25 m x 1 m)
- 5.5 m² (5.5 m x 1 m)
- 4.25 m² (4.25 m x 1 m)
- 3 m² (3 m x 1 m)
- 2.5 m² (2.5 m x 1 m)
- 2 m² (2 m x 1 m)
- 1.5 m² (1.5 m x 1 m)
- 1 m² (1 m x 1 m)
- 0.5 m² (0.5 m x 1 m)
FIRE LOAD SURVEY

- Room geometry & floor plan sketch
- Vertical opening dimensions
- Bounding construction type
- Moveable fire load
  - Large contents measured using inventory approach (e.g. cabinets, teacher desks, bookcases, storage units);
  - Small contents directly weighed using digital scales (e.g. plastic bins, tubs, baskets, toys, books, chairs).
- Identical contents added to inventory
FIRE LOAD DENSITY ACCORDING TO ROOM USE

• Room/enclosure use found to have significant impact on moveable fire load density.

• Primary classrooms observed to contain approximately 1.5 times more fire load density than secondary classrooms.

• Storage enclosures comprised greatest fire load due to stacked storage arrangements coupled with small floor area (i.e. <11m²)

• For every room/enclosure surveyed:
  • Mean of 316MJ/m²
  • 90th Percentile of 525MJ/m²
FIRE LOAD DENSITY ACCORDING TO SCHOOL TYPE

- School type found to have a significant impact on moveable fire load density
- Primary school rooms/enclosures surveyed:
  - Mean of 473MJ/m²
  - 90th percentile of 746MJ/m²
  - Excluding storage rooms, the 90th percentile value for primary schools (260MJ/m²) is approximately 1.5 more than the 90th percentile for secondary schools (174MJ/m²)
• Secondary school rooms and enclosures surveyed:
  • Mean of 138 MJ/m²
  • 90th percentile of 173 MJ/m²
  • Secondary schools were observed to contain less moveable fire load density in comparison to primary schools.
COMPARISON TO EXISTING DATA

International Fire Engineering Guidelines (ABCB, 2005)

• Data for school buildings based off studies undertaken in Switzerland (1967-69) and Netherlands (1983)

• Fire load density comparable only for the overall mean fire load density value in the current study.

• Fire load density is not comparable for the 80th, 90th & 95th percentile values in the current study.

<table>
<thead>
<tr>
<th>Source</th>
<th>Fire Load Density (MJ/m²)</th>
<th>Mean</th>
<th>Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>80th</td>
<td>90th</td>
</tr>
<tr>
<td>Netherlands (IFEG)</td>
<td></td>
<td>285</td>
<td>360</td>
</tr>
<tr>
<td>Switzerland (IFEG)</td>
<td></td>
<td>300</td>
<td>-</td>
</tr>
<tr>
<td>Current study</td>
<td></td>
<td>316</td>
<td>232</td>
</tr>
</tbody>
</table>
Canadian data (Hadjisophocleous and Chen 2010)

- Fire load density comparable for computer rooms and libraries.
- Fire load density for classrooms, science & art rooms generally of a greater magnitude.
- Hadjisophocleous and Chen (2010) observed fire load density to be approximately 2 times greater in elementary schools than in high schools.

<table>
<thead>
<tr>
<th>Surveyed Rooms</th>
<th>Mean Fire Load Density (MJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hadjisophocleous and Chen (2010)</td>
</tr>
<tr>
<td><strong>Elementary Schools</strong></td>
<td></td>
</tr>
<tr>
<td>Classrooms</td>
<td>303.9</td>
</tr>
<tr>
<td>Computer rooms</td>
<td>211.4</td>
</tr>
<tr>
<td>Libraries</td>
<td>545.8</td>
</tr>
<tr>
<td>All elementary schools</td>
<td>329.5</td>
</tr>
<tr>
<td><strong>High Schools</strong></td>
<td></td>
</tr>
<tr>
<td>Classrooms</td>
<td>137.2</td>
</tr>
<tr>
<td>Computer rooms</td>
<td>201.0</td>
</tr>
<tr>
<td>Science rooms</td>
<td>336.0</td>
</tr>
<tr>
<td>Art rooms</td>
<td>490.7</td>
</tr>
<tr>
<td>Libraries</td>
<td>537.8</td>
</tr>
<tr>
<td>All high schools</td>
<td>265.1</td>
</tr>
</tbody>
</table>
COMPARISON TO EXISTING DATA

German data (Thomas, 1986)

- Fire load density associated libraries up to 3 times greater than the current study.
- Fire load density of store rooms significantly less than the current study.
- No differentiation between classroom types, however the mean and 90th percentile values are comparable to secondary classrooms in the current study.
CONCLUSION

• Fire severity and time equivalence assessments require a clear understanding of limitations and inputs.

• Fire loads are a key input parameter and impact significantly on the outcome.

• The study presented has shown some similarities and some discrepancies with commonly referenced documents such as IFEG with respect to fuel loads.

• Holistic fire load density values don’t account for subtle differences (e.g. school type and room use) which can have an impact on the outcomes of fire safety engineering assessments.
FUTURE RESEARCH

• The data presented is a sample of rooms/enclosures associated with the school building classification.

• Further studies required to enhance the reliability of the data presented.

• Future research to establish fire loads within other building classifications and within the context of Australian buildings.
Thankyou for Listening