Performance-Based Codes and Fire Safety Design: An International Perspective

Handout Material – Selected Presentation Slides

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Worcester Polytechnic Institute

Overview

• Acknowledgements
• Background & Introduction
• Situation in Selected Countries
  — Australia, New Zealand, Scotland, the Netherlands, Sweden, Spain and Japan (order of visits)
• Selected Survey Outcomes
  — Australia, England, New Zealand, Scotland, Spain and USA (largest sample sizes)
• Summary and Conclusions
Acknowledgements

- I sincerely thank the following organizations
  - Australian Building Codes Board
  - Ministry of Business, Innovation and Employment, Building Performance Group (New Zealand)
  - Scottish Government, Building Standards Division
  - TNO (Netherlands)
  - Fulbright Foundation
    - Lund University and Boverket (Sweden)
    - University of Navarra, Ministry of Infrastructure (Spain)
    - Tokyo University of Science, Building Research Institute Ministry of Land, Infrastructure, Transport & Tourism, (Japan)
  - Worcester Polytechnic Institute (USA)

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Background & Introduction

- Investigation into situation with performance-based building regulations and fire safety engineering, with a look at how to make regulations and design more ‘risk-informed’
- Research approach for each country
  - Review legislation
  - Speak with people who develop building regulations, practice in FSE community, and enforce building regulations
  - Use questionnaire to supplement in-person discussions

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• Each country visited has a performance-based (functional) building code, built largely on the NKB structure from 1976
• In most cases, the initial code structure did not include quantified performance measures (loads, criteria)
• Engineers were given significant flexibility

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• By the year 2006, we had a large number of ‘first generation’ PB FSE design guides and standards, but largely ‘frameworks’ and not detailed
  — NFPA FSCT (1985)
  — Australia FEG (1996)
  — SFPE (1997)
  — ISO (1999)
  — BSI 7974 (1999)
  — IFEG (2005)
  — BSI 9999 (2008)
  — Germany (2009)

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Australia

- PB Building Code implemented in 1996
- Australian Fire Engineering Guidelines (FEG) introduced in 1996
- Broad, framework type document, with six subsystems: fire initiation and development, smoke control, control of fire spread, detection and suppression, egress and fire brigade response

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Australia

- The FEG has some ‘suggested’ criteria (e.g., tenability) and calculation methods, but not required
- Criteria removed when became International Fire Engineering Guidelines (IFEG) in 2005
- Australia has private certification
- Requirements for professional registration by state

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Australia

• Private certifiers are supposed to be separate from the design / design contract (independent)
• In practice, to save time and cost, clients ask private certifiers what they will accept, and the private certifier looks for designer who will prepare documents – takes independent designer out of the system
• Government authorities concerned with variability in performance and gaps in design
  — No ‘agreed’ common criteria, analysis, verification...

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Australia

• In 2014, fire in Lacrosse Building in the Docklands area of Melbourne
• Combustible exterior façade
• Subsequent investigation by Victoria Building Commission audited 151 buildings, and found that 51% had non-compliance issues
• Performance in use is uncertain, and likely variable

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Perspectives from FSEs in Australia

- There is a major lack of proper inspections in construction, and often inadequate commissioning.
- In general, maintenance and preparation of fire safety management plans are not fully and properly implemented, but there seems to be no auditing or enforcement regime to ensure compliance.
- State governments and state regulatory bodies need to be held to account for the perilous state in Australia on many of these fire safety matters before we have some catastrophic fires.

Perspectives from FSEs in Australia

- There is no proper set of annual Australian fire statistics, which makes fire risk assessments nearly impossible and inhibits proper justification of regulatory changes.
- More action and agitation is required from SFS/Engineers Australia and/or FPA Australia to bring these matters and regulatory and control weaknesses to the attention of those who can effect change for the better.
Australia

- Australian Building Codes Board (ABCB), which is responsible for building code, has 3-year effort underway to quantify performance in building code, including fire performance
- ABCB has decided to use risk to life as a basis of performance across all areas of safety in the building code, including structural, fire, safety in use and maybe indoor air quality
- Will require new guidance and education for engineers, code officials and others
- Also developing a ‘verification method’ for ‘simple’ PB designs

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Australia

- Performance requirements represent the tolerable levels of health and safety in new buildings.
- Quantifying at this level means health and safety can be clearly represented in terms of individual and societal risk and allow ultimate flexibility in achieving these goals.
- Addressing both societal and individual risk allows building regulation to be proactive in its approach to multi-fatality events. Frequency (F), versus Number (N) of fatalities plots supports a quantitative risk assessment (QRA).

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New Zealand

• Implemented PB Building Code in 1992
• Leaky building issue in early 2000s – caused change of Building Act and Building Code in 2004
• Response by government
  — Better quantification of performance, licensing of practitioners, audits of local authorities and more

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New Zealand

• 2012: Fire verification method (C/VM2) and quantified criteria in code
  — Initial opposition from FSEs, but opinions changing
• Open issues
  — Qualification of engineers (or lack thereof)
  — Acceptance of PB design

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New Zealand

- New Zealand – C/VM2 Fire Compliance / Verification Method
- For use by design professionals with specific fire engineering expertise, such as a Chartered Professional Engineer
- Based on Risk Groups
- 10 standard design scenarios
- Design fires specified
- Parameters affecting the movement of people specified

http://www.dbh.govt.nz/compliance-documents#C

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New Zealand

- Significant ‘push-back’ (opposition) to C/VM2 verification method by FSEs between 2013-2015
  — Many complaints: too restrictive, many gaps, not enough assumptions, costly to designs, etc.
- Most significant issue was that full PB design, which did not use C/VM2, was discouraged

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New Zealand

- Cost for small alteration to existing buildings could therefore be very costly
  - For example, a $1500 upgrade for seismic retrofit could trigger a fire safety engineering analysis of $7,500
- Also, government concern – very tall buildings – 20 minute FRR for 50-story building?

New Zealand

- Perspectives from FSEs in NZ
  - State of FSE in NZ
  - What is working well?
    - Key thing is that VM takes away the unproductive debate about input values, which shouldn’t be the focus of the design. Focus more on design and important issues.

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• Perspectives from FSEs in NZ
  — What is not working well
    • Working under expectation that VM2 only being used by qualified and competent engineer, but no requirements for client to employ competent engineer
    • Market does not have enough qualified engineers
    • Issues with Code - some things too prescribed, i.e., material numbers for surface rating, while others too loose, without quantitative measures, need to use qualitative assessment
    • Peer review not working well - some good engineers, but real potential for people being too friendly with peer reviewer – playing the system

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• Perspectives from FSEs in NZ
  — Major issues: qualifications and review of designs
    • There is a perceived shortage of adequately qualified and competent fire engineers in New Zealand.
    • There is a clear lack of enforced, minimum competency and qualifications criteria, for use in determining which engineers have the appropriate knowledge, expertise and skill set to undertake fire solutions – or sit in review of fire solutions as ‘peers’ – across a wide spectrum of needs, from ‘simple’ adherence to Acceptable Solutions, to the more challenging C/VM2, to specific designs
    • Peer reviewers, while paid by the Client, are generally selected by the fire engineer. This creates conflict concerns.

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New Zealand

- Review of fire provisions in building code, and C/VM2, was undertaken in 2014 and 2015
- 11 new projects underway, ranging from revising the criteria in the building code, to revising the C/VM2 verification method, to development of new guidance for very tall buildings
- Issue of qualification system for fire engineers being discussed (not required now)
- Possibility of a centralized peer-review mechanism for PB designs is being considered

Scotland

- The functional (performance-based) building code was implemented in Scotland in May 2005.
- The structure is functional specifications (mandatory) and Technical Handbooks with ‘deemed to satisfy’ solutions (non-mandatory)
- Building control is via 32 Local Authority Verifiers (LAV)
- Scottish Fire & Rescue Services (SFRS) involved too

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**Scotland**

- Most fire engineers follow BS 7974 and BS 9999 – in principle (but often not in detail)
- Authorities concerned about details and design documentation – often benchmark to the Technical Handbook requirements
- Several situations in which fire engineering was applied, but rejected by LAV or SFRS (in some cases, accepted by LAV and rejected by SFRS, even though SFRS does not technically have the authority under the Building Act)

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**Scotland**

- Perspectives from FEs (FSEs) in Scotland
  - Three general themes emerged from interviews
    - The environment is not really functional based, but is ‘prescriptive with functional (performance) alternatives.’
    - There is a wide range of capability amongst LAVs, with most local authorities not having any FE staff, and the approval process being driven by comparison against the TH-Fire provisions.
    - There is a wide range of policies, practices and expertise applied to review and approval of FE designs.
  - Inconsistency in the review of FE designs imposes impacts on the market: uncertainty exists in approval from project-to-project & jurisdiction-to-jurisdiction.

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**Scotland**

- **Perspectives from FEs (FSEs) in Scotland**
  - It was generally desired that some type of qualifications / registration system be applied to both engineers and reviewers, such that those undertaking reviews have the required competencies to look for the right issues, ask the right questions, and understand and appropriately act on the answers.
  - Most attendees felt that Chartered Engineer (CEng) level is needed for FE practitioners.
  - It was also noted that Chartership is not itself enough. The practitioners need to have an understanding of the local regulatory environment as well.

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**Scotland**

- **Perspectives from Authorities in Scotland**
  - Inadequately developed, supported, documented
  - When there are complicated issues, the approach seems to be that volumes of material are provided, but often includes insufficient justification
  - When LAVs question assumptions, analysis, etc., they sometimes get accused of being unqualified and/or problematic
  - While fire engineers often refer to BS 7974, which cites the need for a QDR at the start of the project to agree key factors, QDRs are often missing, and/or significant variations end up in later reports

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**Netherlands**

- Performance-based building code (Building Decree) since 1992
- Follows NKB hierarchy: functional and performance requirements
- For innovative solutions it should be possible to prove performance by scientific means
- Building Decree administered by the Ministry of the Interior and Kingdom Relations (BZK)

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**Netherlands**

- Looking to develop and promulgate risk-based fire safety engineering approach (not scenario-based approach like NZ)
- Looking to set risk to life from fire target in building regulation and/or guidance
- Looking to develop probabilistic approach to fire safety verification based on IRCC Hierarchy and Eurocode for Structures approach

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**Netherlands**

- **Structural reliability approach of Eurocodes**

<table>
<thead>
<tr>
<th>Risk Group (IV)</th>
<th>Risk Level (V)</th>
<th>Risk Criteria (VI)</th>
<th>Matching probability per 50 year</th>
<th>Matching probability per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of Life</td>
<td>CC3 - High</td>
<td>$\beta &gt; 4.3$</td>
<td>&lt; $0.09 \cdot 10^{-4}$</td>
<td>&lt; $0.17 \cdot 10^{-4}$</td>
</tr>
<tr>
<td></td>
<td>CC2 - Medium</td>
<td>$\beta &gt; 3.8$</td>
<td>&lt; $0.7 \cdot 10^{-4}$</td>
<td>&lt; $1.3 \cdot 10^{-6}$</td>
</tr>
<tr>
<td></td>
<td>CC1 - Low</td>
<td>$\beta &gt; 3.3$</td>
<td>&lt; $4.8 \cdot 10^{-4}$</td>
<td>&lt; $10 \cdot 10^{-6}$</td>
</tr>
</tbody>
</table>

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**Netherlands**

- **Perspectives from ‘FSEs’ in Netherlands**
  - What is the situation with FSE
    - Not good – FSE not well known
  - What is working well
    - Large projects with FSEs from international firms
  - What is not working well
    - No FSE locally – mostly compliance with code
    - No dedicated FSE university program
  - Ready for a risk-based approach in the Netherlands?
    - No – need to understand basic FSE approach first

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Sweden

- Performance-based building regulatory system
- PB building regulations (code) first introduced in 1994
- No specific guidance for FSE – some criteria
- Significant variability in the market
- Changed the regulations in 2011, adding three compliance routes and providing guidance (general recommendations) on fire safety engineering approach (similar to NZ)

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Sweden

- General recommendations verification options
  — qualitative assessment (including expert judgment),
  — scenario-based analysis, or
  — quantitative risk analysis (QRA)
- Scenario-based analysis has defined scenarios, fires and parameters like NZ C/VM2
- Unlike NZ, optional from start
- Feedback from FSE community is that is has been helpful – sets baseline – helps reduce number of unqualified practitioners.

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Sweden

• Perspectives from FSEs in Sweden
  — What is the general situation with FSE in Sweden?
    • Generally the situation is good. There is a lot of work, and projects are going rather well.
  — What is working well?
    • Current FSE approach as in the general recommendations works quite well, for qualified firms
    • System now allows PB design in a structured manner

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Sweden

• Perspectives from FSEs in Sweden
  — What is not working so well?
    • Concerns with the designs from some firms. While solutions are theoretically (technically) feasible, they are not always practical to install, and long term operation is suspect.
    • There is a concern that quality of education is going down (universities are forced to admit less qualified students).
    • Graduates and young engineers are often focused on modeling without understanding the value of output in the context of design.
    • Too much complex technology being used, without good controls and knowledge of reliability and availability when needed in fire.
Sweden

• Perspectives from FSEs in Sweden
  — What is not working so well?
    • The FSE guidance / general recommendations have created a focus on solving the stated problem, not necessarily the correct problem. Engineers are not asking as many questions as they used to, and are more often solving the problem the client wants without exploring whether it is the right (or complete) question / problem.
    • Comparative analyses difficult, especially how to define ‘reference building.’ One can take the worst possible code-compliant building – and then ‘stretch’ the comparative part, so the basis is a very poor performing building.

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Spain

• The 1999 Building Act (Ley 38/1999 de Ordenacion de la Edificacion, LOE) established a performance-based building regulatory system.
• The performance-based Technical Building Code (Código Técnico de la Edificación, CTE) was approved in 2006.

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Spain

<table>
<thead>
<tr>
<th>LOE</th>
<th>CTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Requirements</td>
<td>Basic Exigencies</td>
</tr>
<tr>
<td>Involving Functionality</td>
<td>Basic Documents</td>
</tr>
<tr>
<td>Utility</td>
<td></td>
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<td>Accessibility</td>
<td></td>
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<td>Access to telecommunications</td>
<td></td>
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<tr>
<td>Relating to security</td>
<td></td>
</tr>
<tr>
<td>Structural safety</td>
<td>Structural Safety</td>
</tr>
<tr>
<td>Safety in case of fire</td>
<td>Safety in case of fire</td>
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<tr>
<td>Safety in use</td>
<td>Safety in use and accessibility</td>
</tr>
<tr>
<td>Involving habitability</td>
<td></td>
</tr>
<tr>
<td>Hygiene health and environmental protection</td>
<td>Healthiness</td>
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<tr>
<td>Protectin against noise</td>
<td>Noise Protection</td>
</tr>
<tr>
<td>Energy saving and thermal insulation</td>
<td>Energy Saving</td>
</tr>
<tr>
<td>Other functional aspects</td>
<td></td>
</tr>
</tbody>
</table>

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• The way building control is performed in Spain differs from other European or western countries. It relies in the qualification of professionals, normally architects, who are responsible.
• Once a project is finished, it is checked by the local architect association (Colegio), which performs a control of the formal content of the project documents according to the applicable regulations (zoning code, building code...).
• The fire service also has a review role for fire safety issues.

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Spain

- FSE is not a ‘recognized’ discipline like Architect or Civil Engineer - there is no ‘Colegio’ for FSE
- No solid educational programs in FSE
- No requirement to use FSE
- Unclear level of safety delivered in PB designs by non-FSEs...

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Japan

- The Building Standards Law (BSL) is developed and promulgated at national level by the Ministry of Land, Infrastructure, Transportation and Tourism.

<table>
<thead>
<tr>
<th>Official documents</th>
<th>Number of documents</th>
<th>Person to determine</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Building Standard Law (BSL)</td>
<td>One</td>
<td>National Government (National Congress)</td>
</tr>
<tr>
<td>(2) Cabinet Order for Enforcement of BSL</td>
<td>One</td>
<td>National Government (Cabinet)</td>
</tr>
<tr>
<td>(3) Ministerial Notifications</td>
<td>219 as of 2014</td>
<td>National Government (Minister)</td>
</tr>
<tr>
<td></td>
<td>82 of structural safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>57 of fire safety</td>
<td></td>
</tr>
<tr>
<td></td>
<td>56 of building equipment</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 of other fields of building code</td>
<td></td>
</tr>
<tr>
<td>(4) Ordinances</td>
<td>Around 400</td>
<td>Local governments (Prefectural/City Councils)</td>
</tr>
</tbody>
</table>

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In addition to BSL, there is Fire Service Law (FSL), Barrier-Free Law, Energy Law and others.

<table>
<thead>
<tr>
<th>Building codes items and related fields</th>
<th>Restrictive laws (Requirements are mandatory.)</th>
<th>Promotional laws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire safety</td>
<td>Fire extinguishing equipment, etc.</td>
<td>Fire Service Law</td>
</tr>
<tr>
<td></td>
<td>Fire-resistance, evacuation, etc.</td>
<td></td>
</tr>
<tr>
<td>Structural safety</td>
<td>Building Standard Law</td>
<td>Seismic Retrofitting Law</td>
</tr>
<tr>
<td>Hygienic safety</td>
<td></td>
<td>Building Management Law</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Barrier-free Law</td>
<td></td>
</tr>
<tr>
<td>Energy saving</td>
<td>Energy Saving Law (*)</td>
<td></td>
</tr>
</tbody>
</table>

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Examples of technical requirements:

<table>
<thead>
<tr>
<th>Fire safety measures</th>
<th>The BSL (Regulates the basic structure and facilities of buildings)</th>
<th>The Fire Service Law (Regulates facilities and equipment from a fire safety viewpoint)</th>
</tr>
</thead>
</table>
| Prevention of the spread of fire from adjacent buildings | - Fire-resistance of roofing materials  
- Fire-resistance of external walls | - Flame retardant curtains  
- Restrictions on appliances that operate with a flame |
| Prevention of outbreak of fire          | - Fire-resistance of interior finishing materials                  | - Escape facilities, such as escape ladders |
| Fire detection                         |                                                                    | - Fire alarms |
| Evacuation                              | - Evacuation facilities, such as escape stairs  
- Smoke control systems                  | - Emergency elevators  
- Rescue access |
| Fire extinguishment and rescue          | - Emergency elevators  
- Rescue access | - Fire extinguishing equipment, such as automatic sprinkler systems and standpipe systems |
| Prevention of spread of fire within a building | - Fire compartments | |
| Prevention of structural collapse      | - Fire-resistance of principal building parts | |

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As part of the 1998 revision of the BSL (enforced in June 2000), performance-based provisions were included so as to facilitate:

- Increased flexibility of performance-based design according to the BSL, and
- The smoother introduction of technical innovations and materials from overseas.

In addition, a new evaluation system was set up:

- Three compliance routes
- Private sector designated evaluation bodies in addition to local government
Japan

• Ordinary verification methods (prescribed)
• Fire-Resistance Verification Method
  — Calculation of fire duration
  — Calculation of heat-withstanding periods for principal building parts
  — Comparison of (a) and (b)
• Verification Method for Evacuation Safety
  — Calculation of time until completion of evacuation
  — Calculation of time required for smoke and gas to become a hazard
  — Comparison of (a) and (b)

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Japan

• Several challenges for fire safety engineers
  — Have performance-based code, but also have very limited verification method, using simplified equations and 2-zone models
  — Can take the Ministerial Approval route, but must gain approval from expert panel, many of whom developed the simplified methods and are wary of advanced engineering
  — Must comply with BSL and FSL, but BSL does not recognize sprinklers to reduce fire load as a strategy to reduce fire resistance requirements, and experts wary of CFD and evacuation models

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Feedback from fire protection engineers includes few approvals of engineered designs which use CFD (FDS) analysis and evacuation analysis

Long time to get approval, and uncertainty of approval, has impact on jobs

Working on getting fire protection engineering to be recognized

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International Situation with PB Codes & Design

Survey approaches to performance-based design for fire safety which you apply most often:

- ASET vs. RSET analysis
- Structural stability in case of fire
- Fire brigade operations
- Operational continuity
- Other

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Survey of approaches to performance-based design for fire safety in Australia, New Zealand, and Scotland:

- International Fire Engineering Guidelines (IFEG)
- SFPE Engineering Guide to Performance-Based Fire Protection
- CIBSE guidelines
- NFPA standards
- NZ C/V/M2
- BS7974
- ISO standards on fire safety engineering
- BS5999

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Do you think there are enough qualified fire safety engineers in your country - across all areas (design, review and approval, peer review, enforcement, etc.)?

- Yes
- No

Survey

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Survey

Do you think there are enough qualified fire safety engineers in your country?

<table>
<thead>
<tr>
<th>Country</th>
<th>No</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td>England</td>
<td>22</td>
<td>3</td>
</tr>
<tr>
<td>New Zealand</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Scotland</td>
<td>27</td>
<td>4</td>
</tr>
<tr>
<td>Spain</td>
<td>19</td>
<td>2</td>
</tr>
<tr>
<td>USA</td>
<td>22</td>
<td>6</td>
</tr>
</tbody>
</table>

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Do you think that only qualified fire safety engineers are undertaking fire engineering designs?

- Yes
- No

Survey

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<table>
<thead>
<tr>
<th></th>
<th>Australia</th>
<th>England</th>
<th>New Zealand</th>
<th>Scotland</th>
<th>Spain</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>41</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>Yes</td>
<td>11</td>
<td>8</td>
<td>6</td>
<td>11</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>
Do you think specialist certification would be helpful, such as CFD modeling competency, evacuation modeling competency, or risk assessment competency?

- Yes
- No

Each country visited has a performance-based building code.

Expected to see significant amount of performance-based design, but found that focus is still on ‘deemed to satisfy’ rather than engineering.

Several concerns with competence.
Summary Observations

• Many similarities
  — Only 5-10% ‘full’ PB FSE designs
  — About 5-20% are FSE deviations from prescriptive (DTS)
  — Remaining 80-90% strictly prescriptive (DTS) compliance
  — Lack of confidence in PBD by authorities – significant variation in design possible
    • Inadequate quantification of performance (criteria, loads)
    • Inadequate verification methods
    • Inadequate number of qualified engineers & reviewers
    • Inadequate qualifications system

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• Future changes
  — To respond to confidence issue and lack of criteria, governments including more criteria in code (e.g., NZ and Sweden, and Australia in near future) and/or providing more specific guidance, with scenarios, design fires, etc. (Sweden, NZ and Australia in the future, as well as potentially Scotland and Spain)
• Future changes
  — There is desire to be more risk-informed or risk-based, but system and practitioners not ready (if not functioning well now, little confidence for more involved analysis...)
  — However, governments want a unifying base for quantifying performance, and that can be risk (Australia, Sweden and Netherlands working in this area)

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• Where do we go from here?
  — More university programs
  — Better definition of qualifications and appropriate recognition of qualified & competent FSEs
  — More definition of key components, for now
  — Slow transition to risk-informed approach

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Thank you for your attention!

Questions?

bmeacham@wpi.edu

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