INTRODUCTION TO FIRE SAFETY SCIENCE AND ENGINEERING

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Overview

- Short presentation
- Historical overview
- PBD and connection to fire science and other presentations
- White paper on fire research
- Challenges for PBD and need for more fire science
- Conclusions

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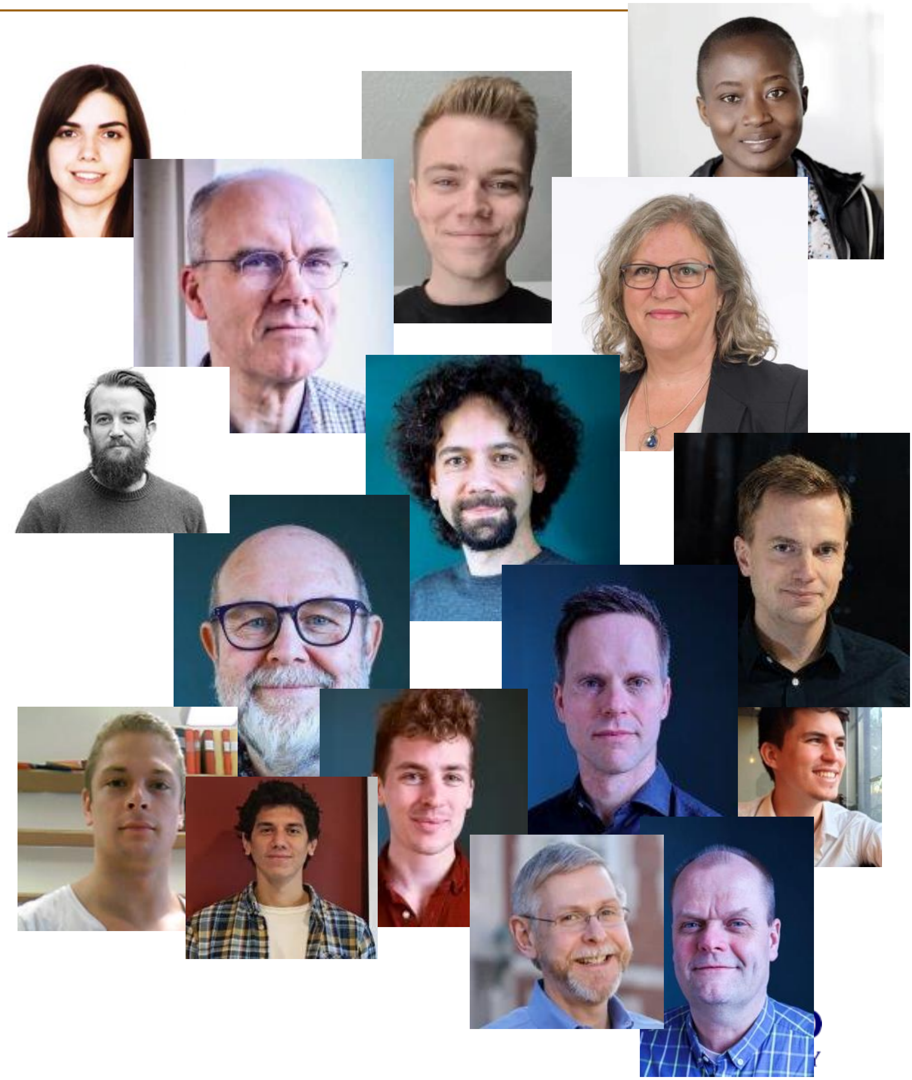
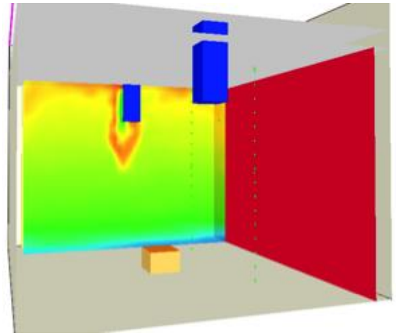
Division of Fire Safety Engineering

- Part of the Department of Building and Environmental Technology of LTH, Lund University
- 14 members of research staff and 12+ PhD (5 internal and 8+ industrial at the moment)
- More than 40 years of research experience
  - One of the firsts to start FSE education in Europe 1986
- IAFSS and ISO/TC92 Fire safety activity



Research at FSE, LTH

- Overview of some research areas:
  - » Fire performance-based design of buildings – Risk Analysis
  - » Fire modelling and experimental validation
  - » Fire development
  - » Human behaviour in fire
  - » Fire rescue services
  - » Sustainability and resilience
- Numerous national and international projects
- Research visits are possible.



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The historical perspective

- Performance based requirements in King Hammurabi code from Babylon, around 3700 years ago (On an obelisk in the Louvre in Paris)
- *“Article 229: If a builder builds a house, and does not construct it properly, and the house which he built falls in and kills its owner, then the builder shall be slain.”*

The historical perspective

- Despite this long tradition and demands on fire safety
  - Many towns and villages suffered serious fires during the 18th and 19th centuries
  - Often destroying whole villages or towns
  - Examples: next slide
- The development of fire protection regulations has been governed almost exclusively by experience of earlier fires
  - ➢ Development has been slow

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London fire 1666

Oulo fire 1822

Town of Oulu in flames 1822. Jacob Wacklin´s watercolor of the Oulu´s most destructive town fire in which total of 330 houses burnt down.

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Big city fires in Sweden (1850-1900)

Söderhamn 1876

Strömstad 1876

Hudiksvall 1878

Sala 1880

Luleå 1887

Umeå 1888

Sundsvall 1888

Köping 1889

Kristinehamn 1893

Lindesberg 1894

Mariestad 1895

- Jönköping 1854
- Örebro 1854
- Eksjö 1856
- Karlstad 1865
- Varberg 1863
- Ronneby 1864
- Gävle 1869
- Båstad 1870
- Uddevalla 1859 1871
- Söderhamn 1860
- Strängnäs 1871

Recent town fire (January 2014)

- Fire in Lærdal in Norway
- 42 buildings burned down
  - 17 residential houses
    - »13 of them inhabited the time of fire
  - 5 garages
  - 10 sheds
  - 10 other buildings

Ref: http://no.wikipedia.org/wiki/Brannen_i_L%C3%A6rdal_2014
Photo: Sogn Avis

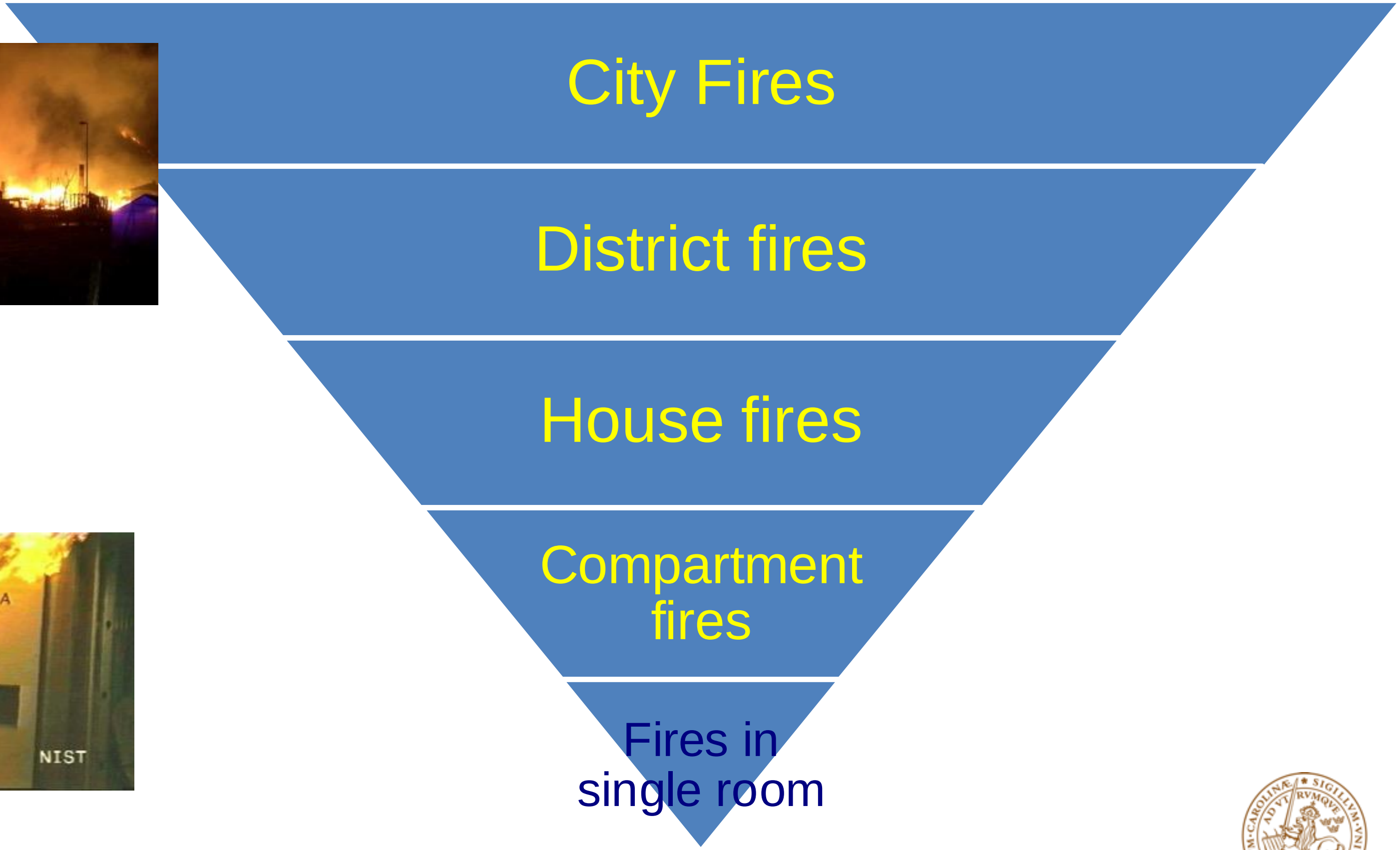
The historical perspective

Fire regulations have progressed from protecting whole cities, whole districts, whole buildings, whole compartments.

Fire safety regulations regarding buildings have traditionally been formulated in terms of detailed requirements concerning technical solutions and have left little scope for innovations.

Towards the end of the 20th century the need for revision of these regulations became increasingly apparent.

Research: Fire Safety in buildings – Historical



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Fire Regulations

Different Fire regulations

Based on detailed requirements

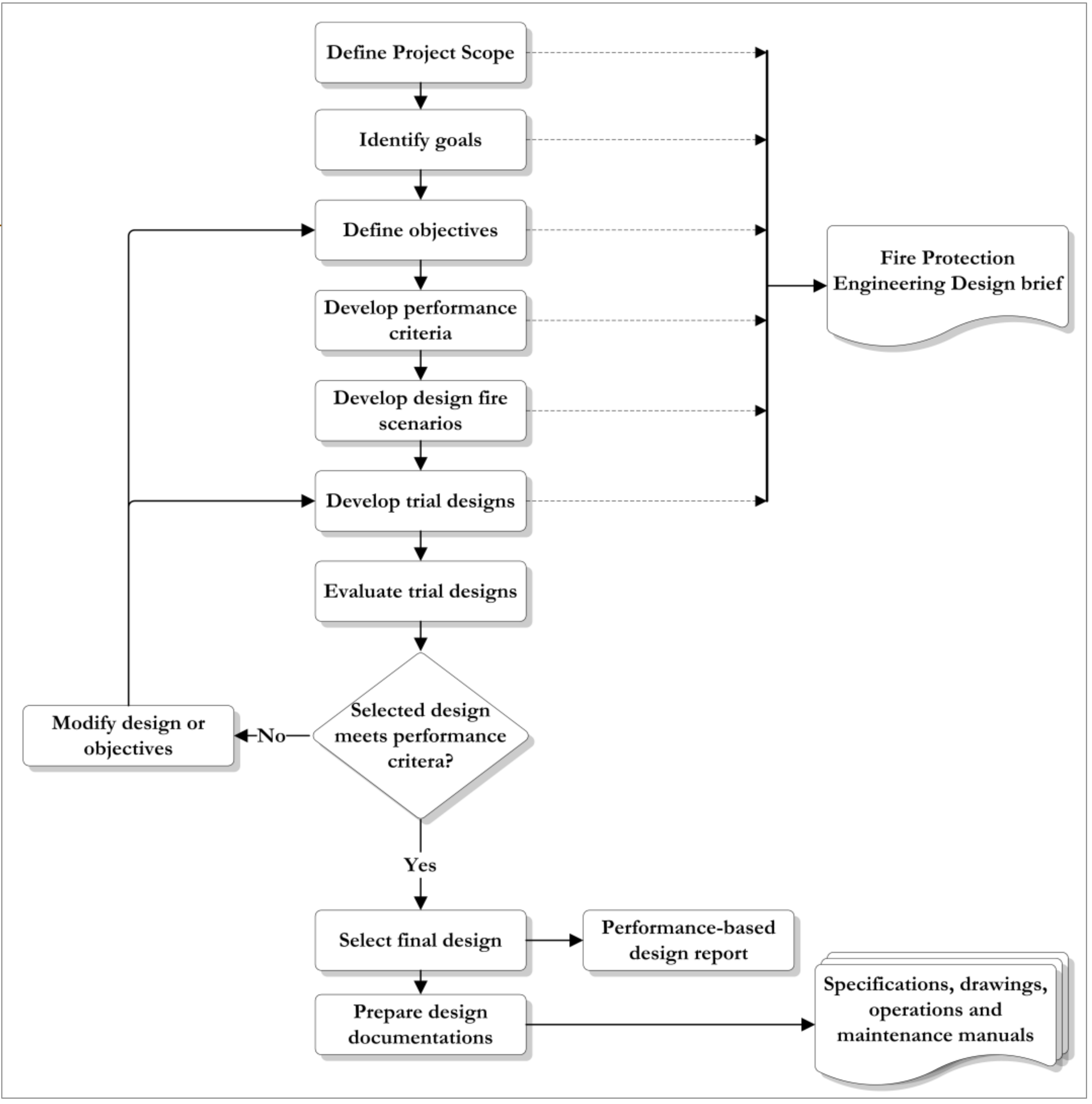
Detailed rules
↓
Product classification
↓
Accept, yes or no

Based on performance requirements

Functional demands, for instance people safety
↓
Risk analysis
↓
Statistics, fire scenario
↓
Consequence modeling
↓
Demands fulfilled?

System thinking

Overview



Define Project Scope
Identify goals
Define objectives
Develop performance criteria
Develop design fire scenarios
Develop trial designs
Evaluate trial designs
Selected design meets performance critera?
No
Modify design or objectives
Yes
Select final design
Prepare design documentations
Fire Protection Engineering Design brief
Performance-based design report
Specifications, drawings, operations and maintenance manuals

PB design – Overall overview

Define Scope, Goals and Objectives

↓

Define Performance Criteria

↓

Define Design Fire Scenario

↓

Run Trial Designs

↓

Check with performance criteria

↓

Choice of Design

PB design

Define Scope, Goals and Objectives

Define Performance Criteria

Define Design Fire Scenario

Run Trial Designs

Check with performance criteria

Choice of Design

Identify goals

- Those of interest for the stakeholders
- Prioritize those goals
- Which ones are fundamental
  - Life safety
  - Property protection
  - Continuity of operation
  - Environmental protection.
- Related goals e.g. historic preservation, cost effectiveness.
- Be aware that conflicting goals can occur e.g. if construction cost is included

PB design

Define Scope, Goals and Objectives

Define Performance Criteria

Define Design Fire Scenario

Run Trial Designs

Check with performance criteria

Choice of Design

Life safety

No loss of life

Safe evacuation before critical conditions

Thermal effect, Toxicity, Visibility
Smoke layer height

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PB design

Define Scope, Goals and Objectives

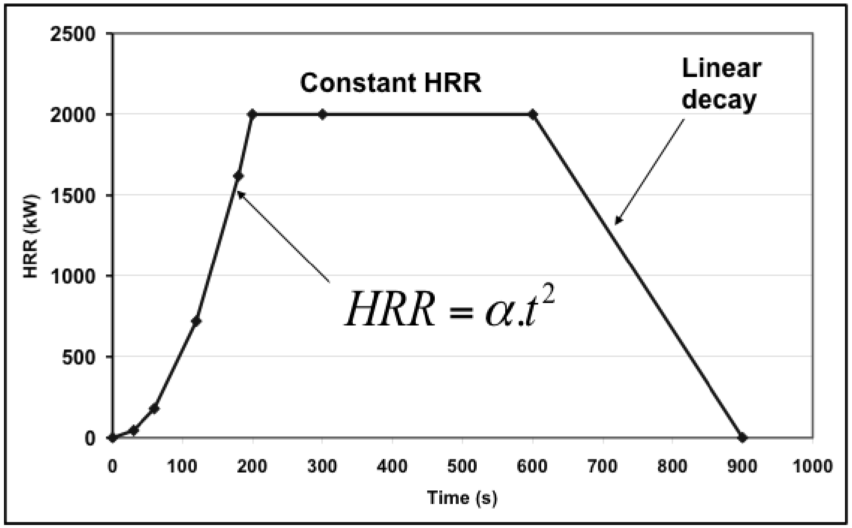
Define Performance Criteria

Define Design Fire Scenario

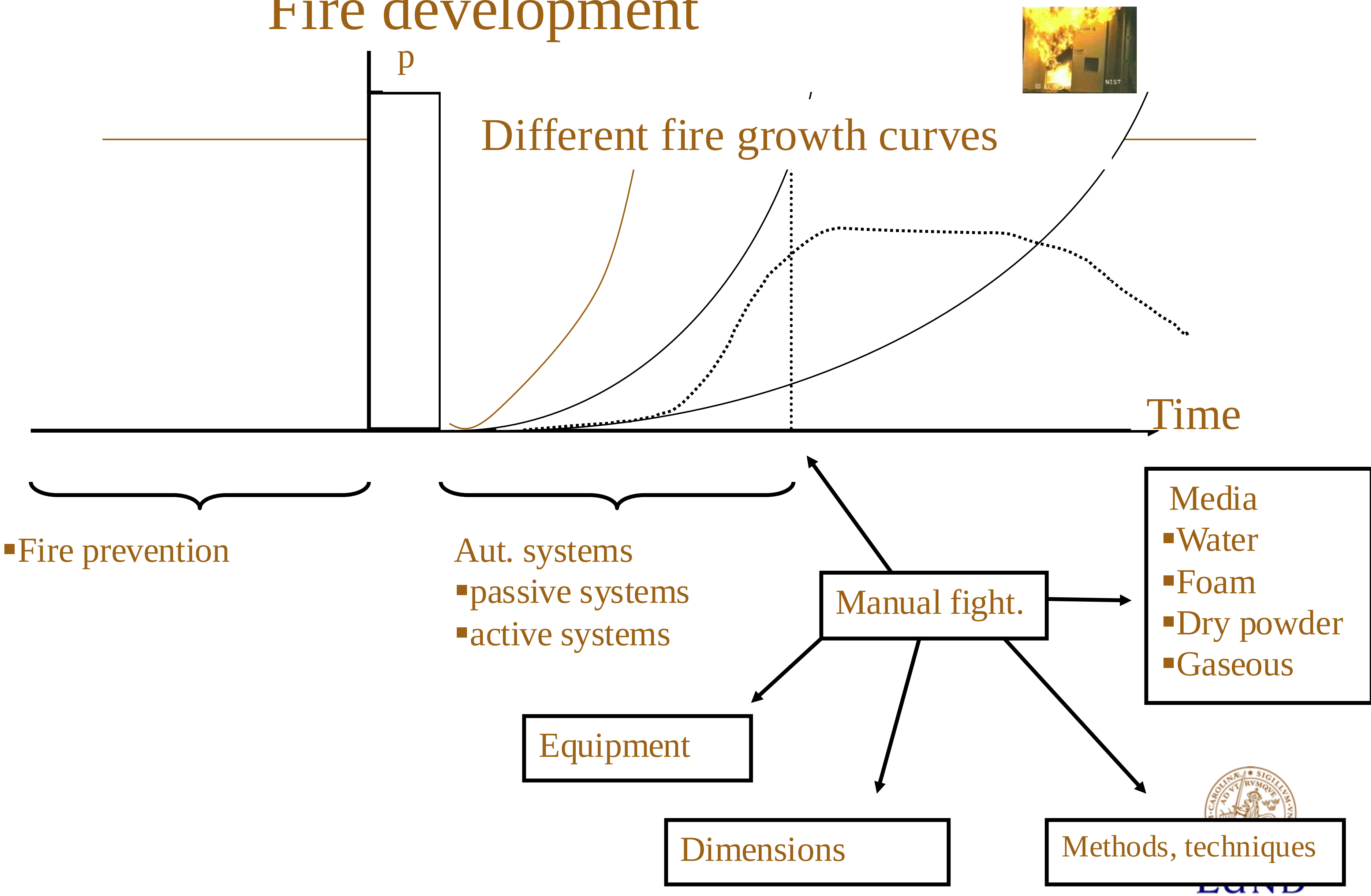
Run Trial Designs

Check with performance criteria

Choice of Design



Fire development



Factors influencing fire development in an enclosure

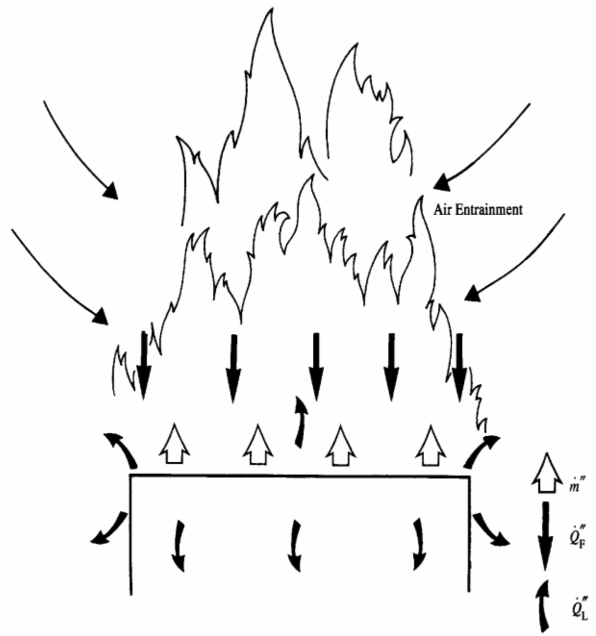
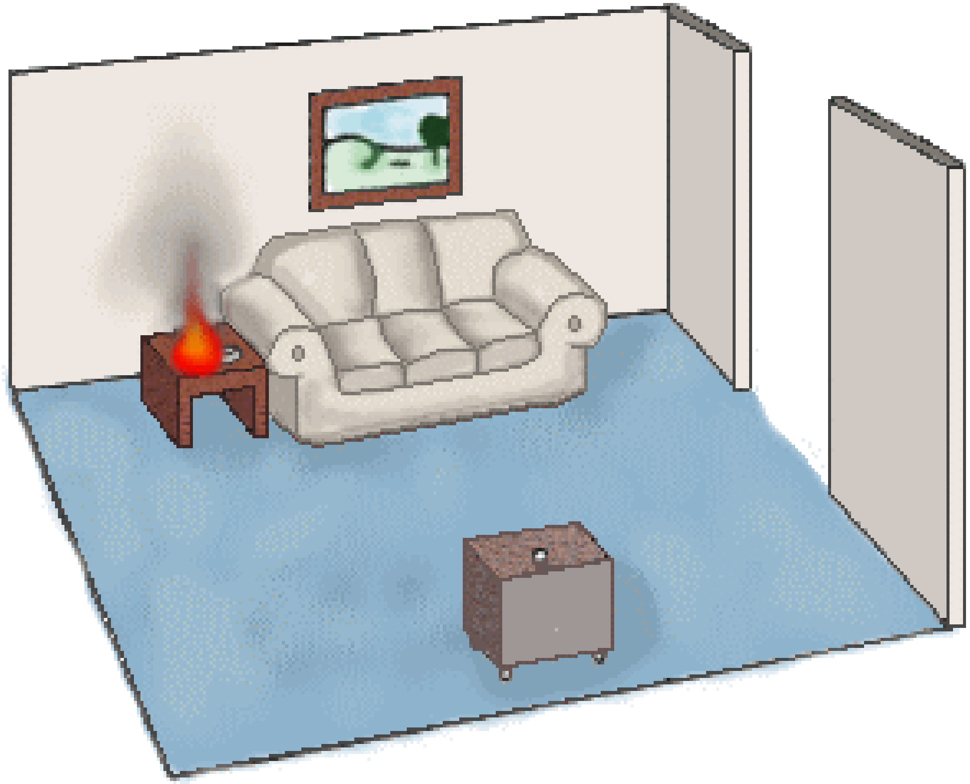


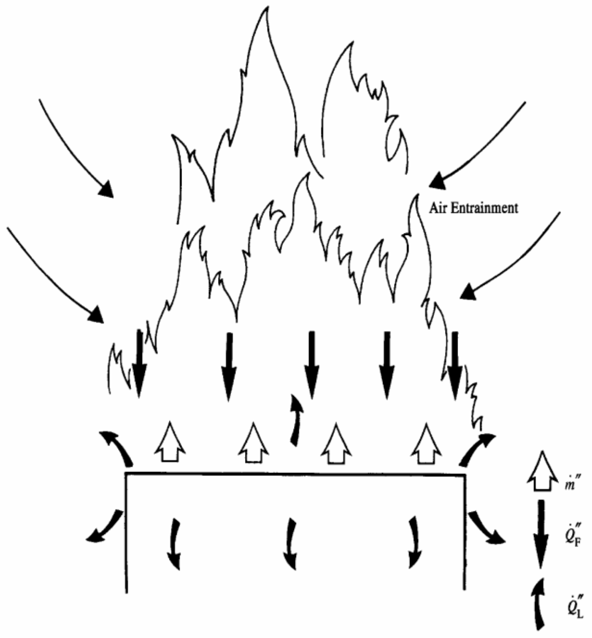
Figure 1.4 Schematic representation of a burning surface, showing the heat and mass transfer processes. $\dot{m}''$, mass flux from the surface: $\dot{Q}''_F$, heat flux from the flame to the surface; $\dot{Q}''_L$, heat losses (expressed as a flux from the surface)

- Ignition source
- Fuel
- Enclosure geometry
- Compartment openings
- Bounding surface

Ignition



Heat Balance//Pyrolysis//Combustion//Flow patterns



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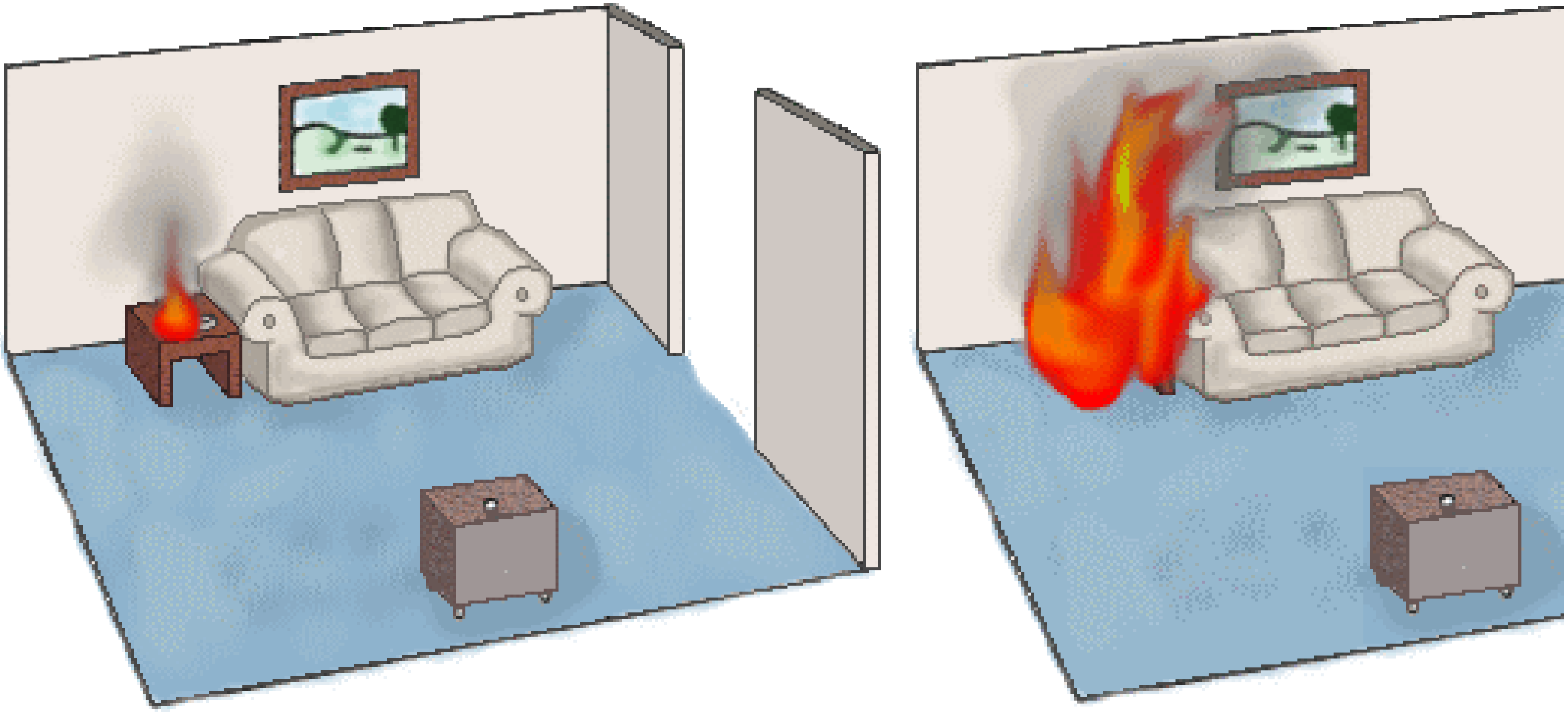
Spread to additional fuel



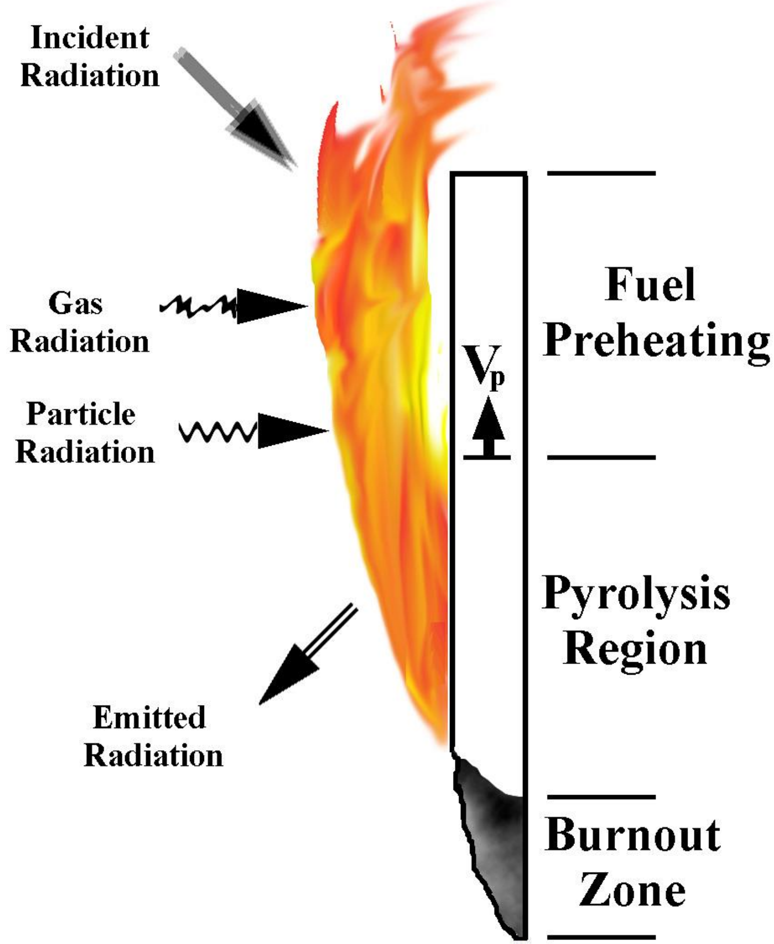
Flame spread

- After ignition, flame spread is the next step in fire growth
  - To grow, flame must spread beyond point of ignition
- Flame spread can be thought of as a series of piloted ignitions
- May include remote ignition
  - Spread from chair to table

Vertical Flame Spread

- Preheating of fuel increases spread
  - Forward heat flux approximately

    25-50+ kW/m^2
- Downward and lateral spread are usually much slower



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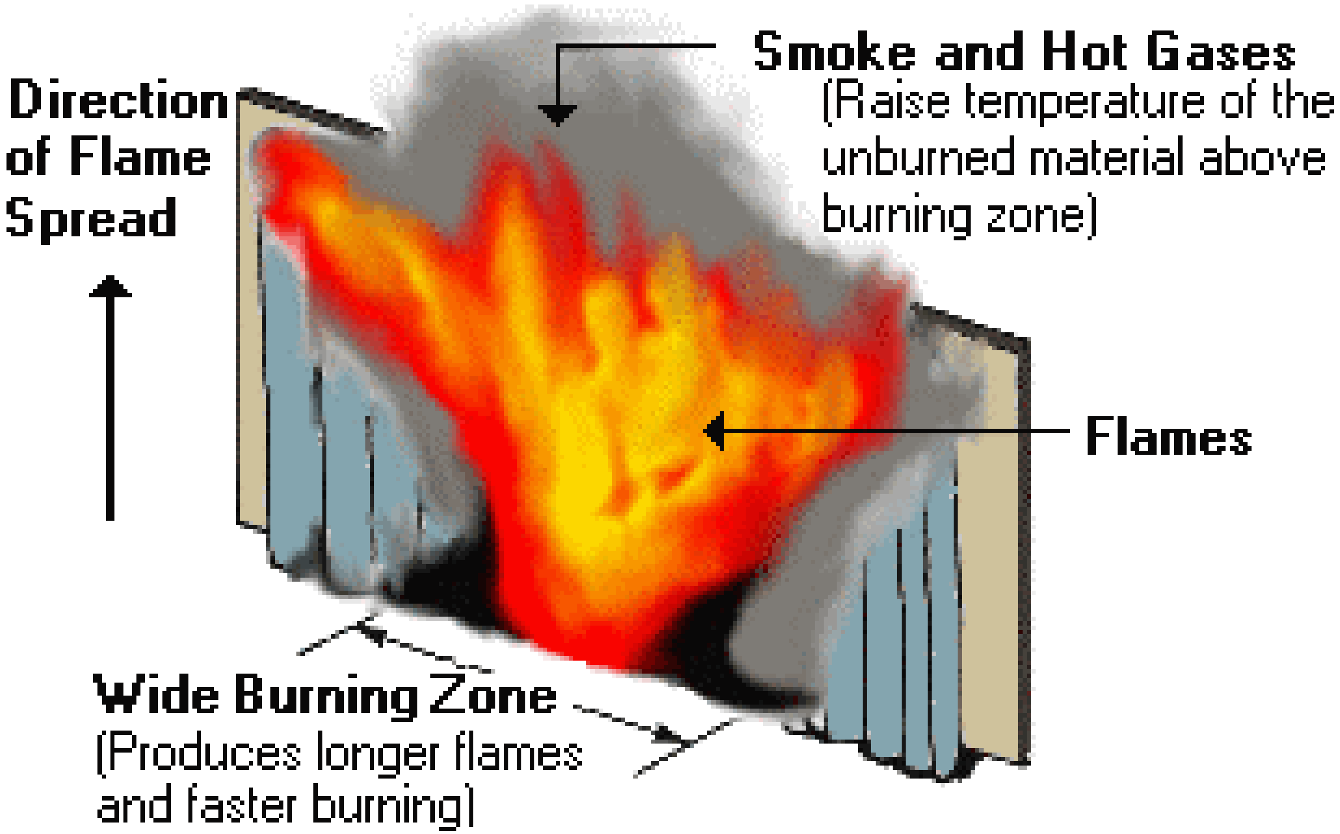
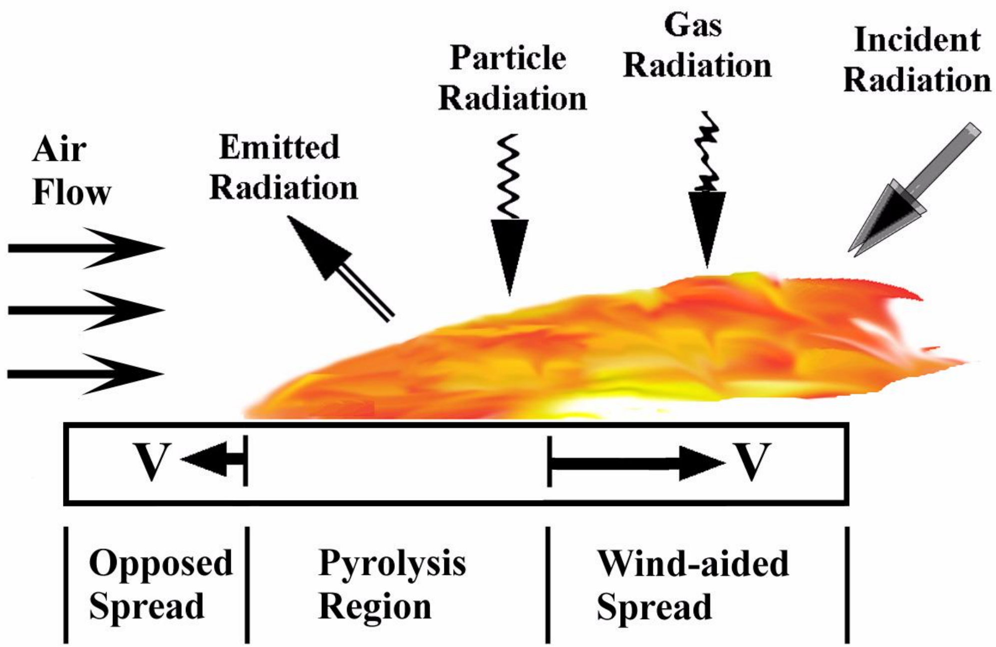
Vertical Flame Spread

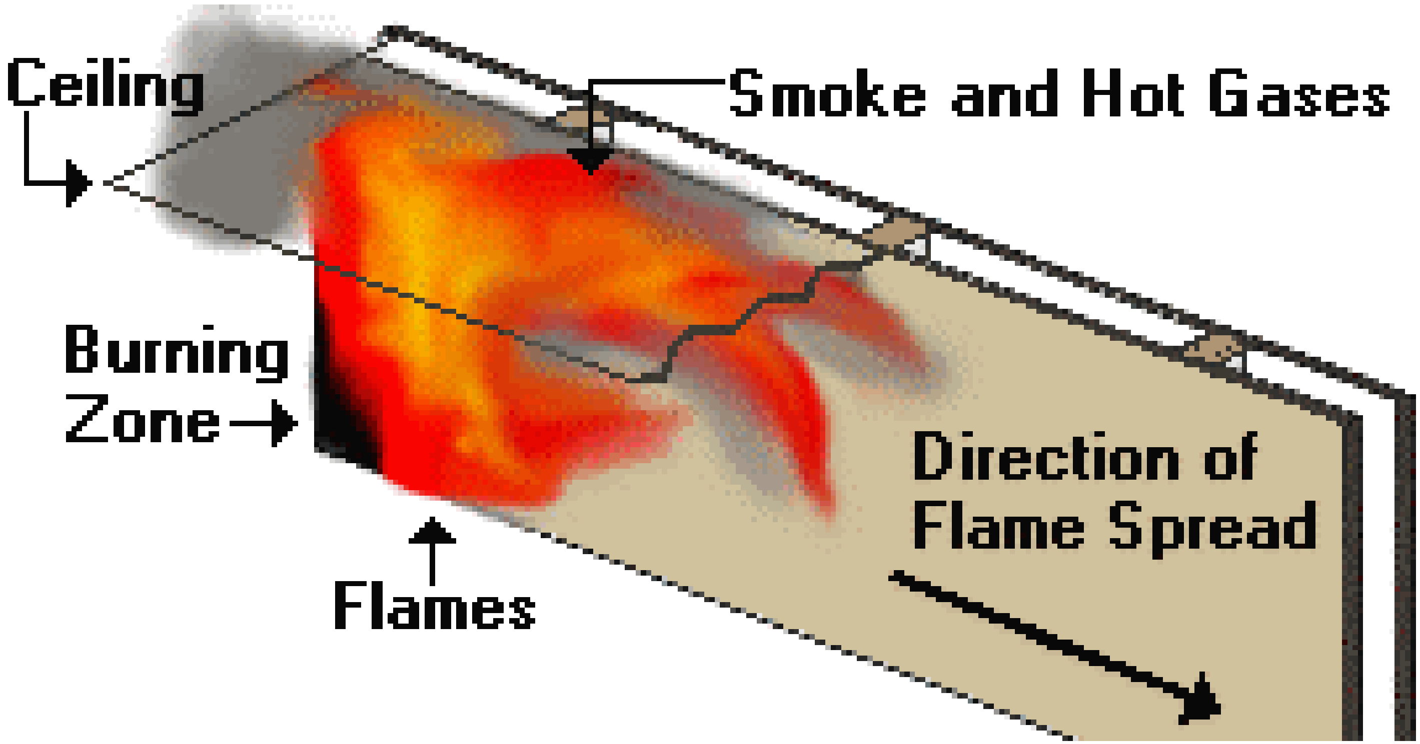


Horizontal flame spread

- External flux (from the ceiling, for example) critical for horizontal spread
- Important closer toward flashover

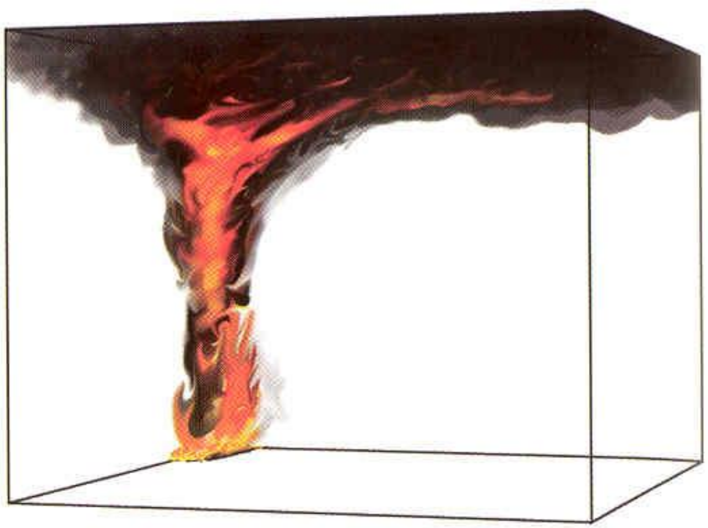


Horizontal flame spread

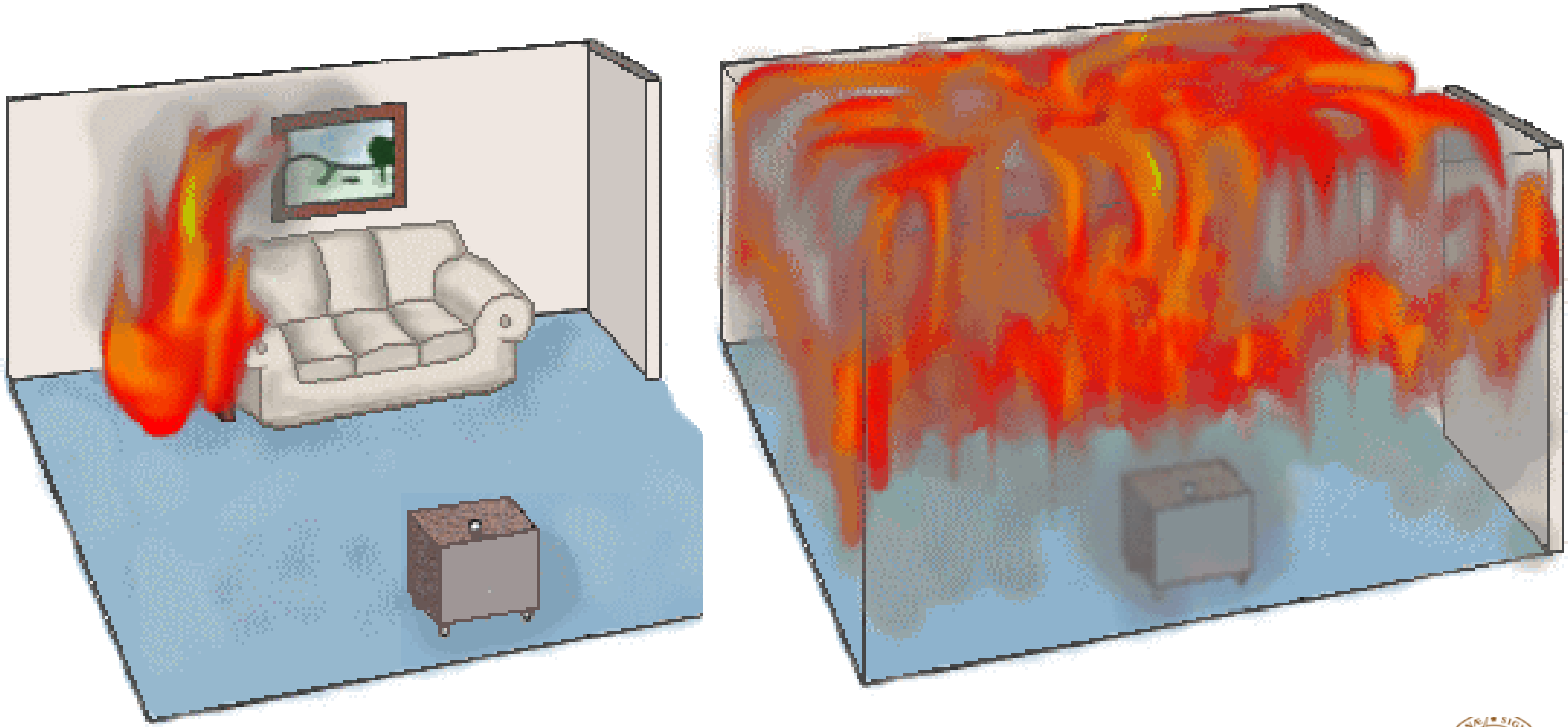


Fire along a wall or in a corner

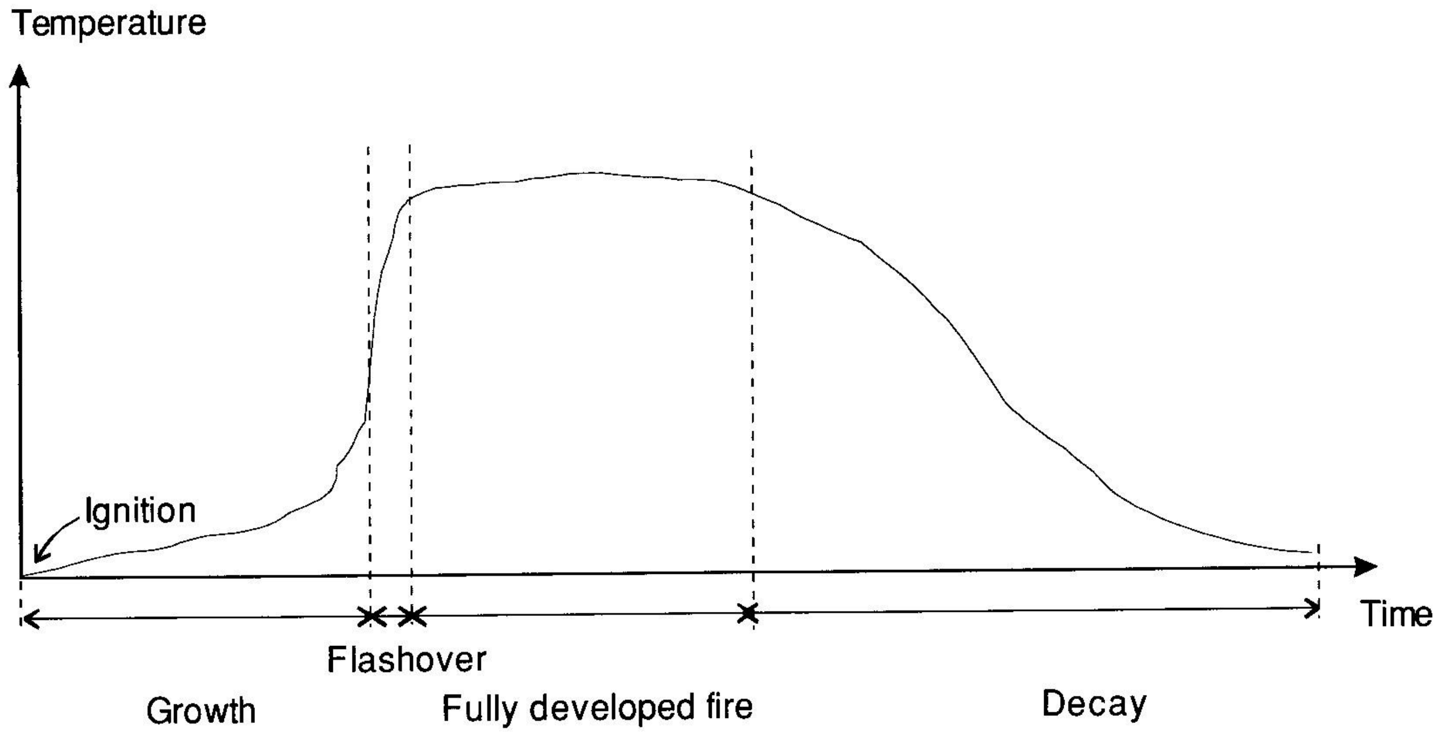
- Flames must travel further to entrain sufficient air to burn
- Represents corner test used to evaluate lining materials



Flashover



Temperature history during the course of a compartment fire



PB design

Define Scope, Goals and Objectives

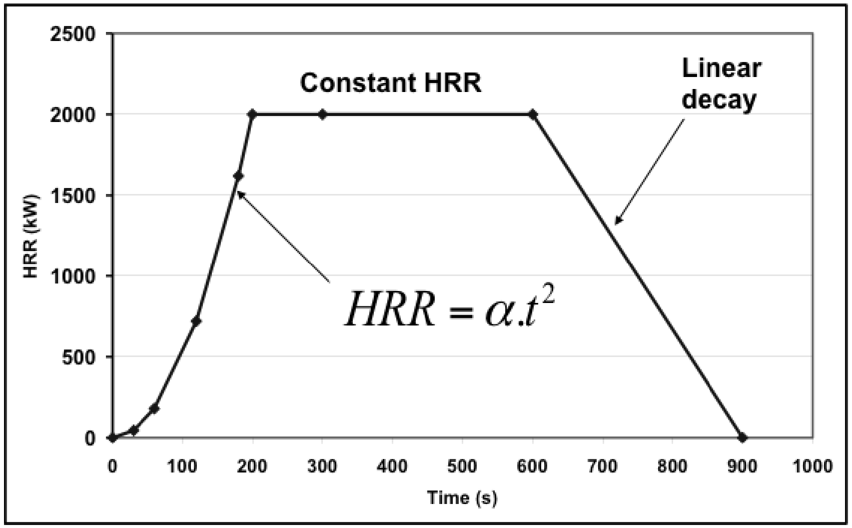
Define Performance Criteria

Define Design Fire Scenario

Run Trial Designs

Check with performance criteria

Choice of Design



Fuel packages

Heat release rate (HRR)

$$\dot{Q}(t) = A_f(t) \cdot \dot{m}''(t) \cdot \Delta H_{effective}$$

- Time dependence for most fuels
  - Both area and mass loss rate change with time
  - Are these a function of only the fuel?
- Combustion efficiency

$$\chi = \frac{\Delta H_{effective}}{\Delta H_{chemical}}$$

It is important to gain a feeling for the size of typical fires

- Light bulb 60 W
- Wastebasket 50-100 kW
- Wood chair with foam seat 200–500 kW
- Upholstered chair 500 – 1500 kW
- Upholstered couch 1000 – 3000 kW
- 1 m^2 pool of gasoline 2.5 MW
- 3m high stack of wood pallets 7 MW
- 2 m^2 plastic commodity 4.9 m high 30-40 MW

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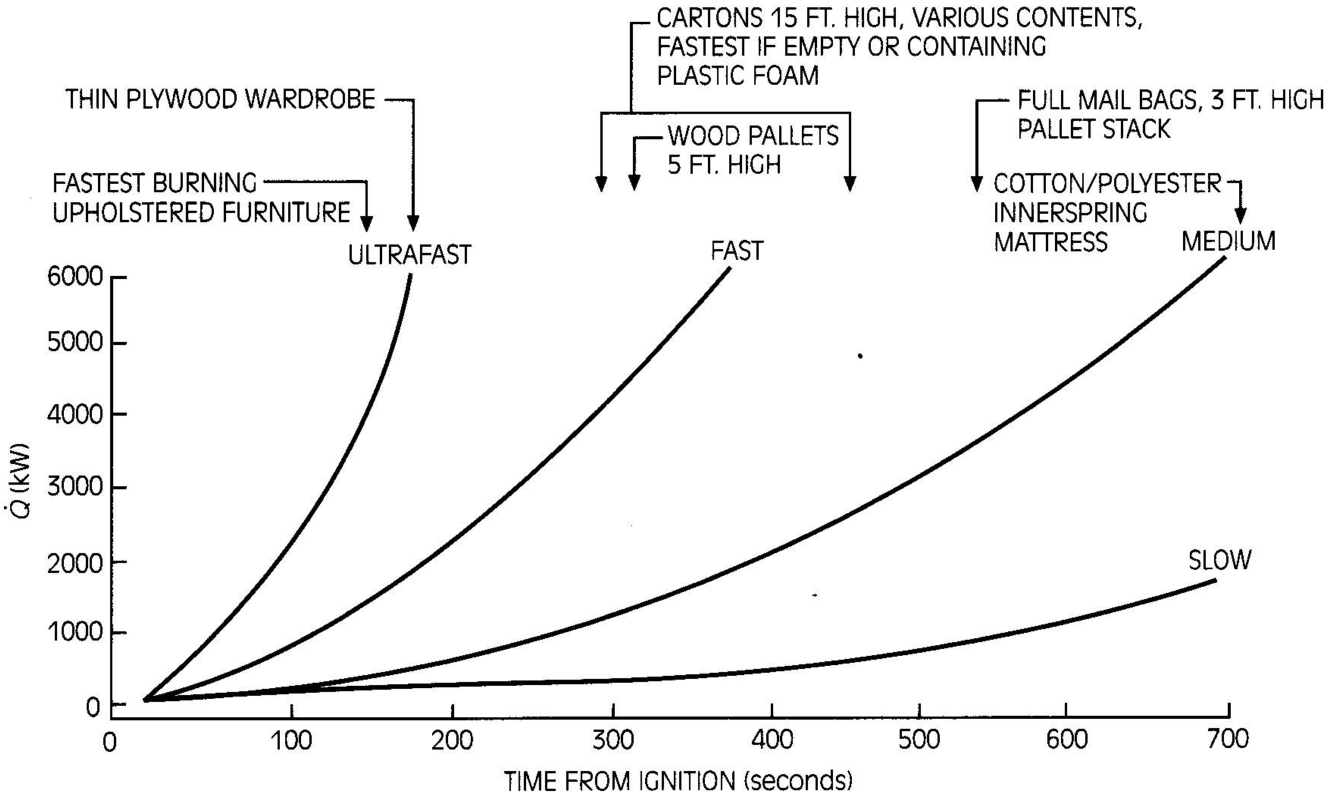
Fire Growth Rates $Q=\alpha t^2$

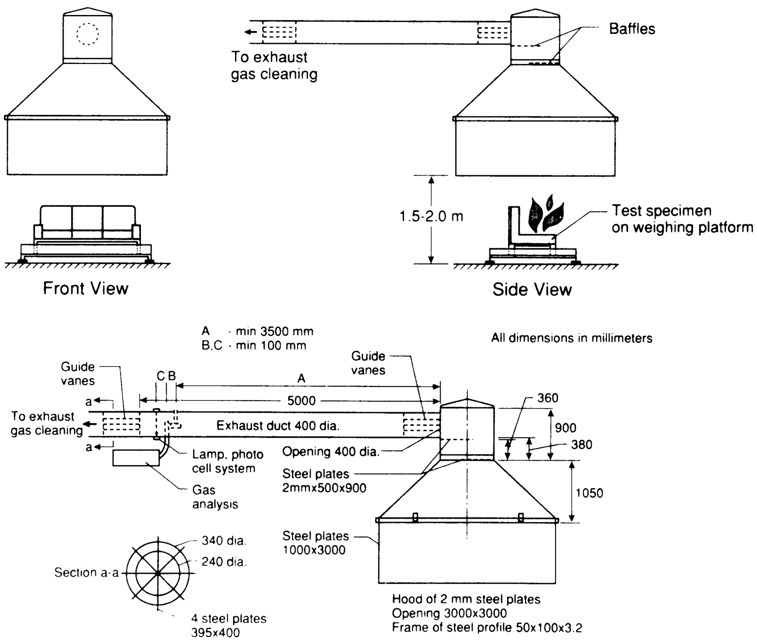


Use of t^2 fires

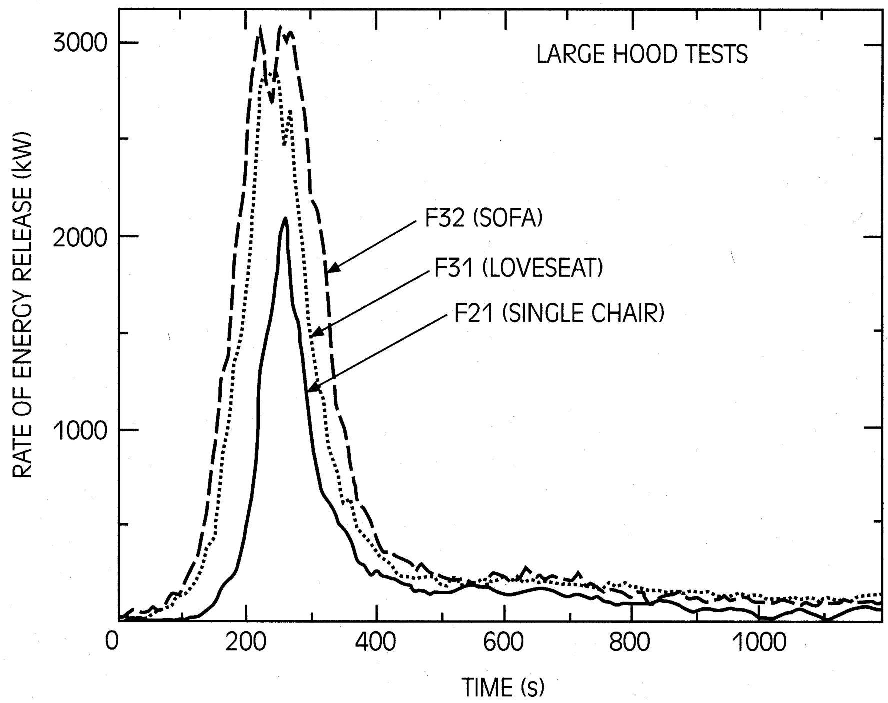
- Simplification to a complicated problem
- Appear to match some test results
- Used for design of:
  - Detection
  - Suppression
- The rate of heat release per unit area is constant over the entire ignited surface
- Represents a constant flame spread velocity
  - Increase in area of a circle with radius

Furniture calorimeter

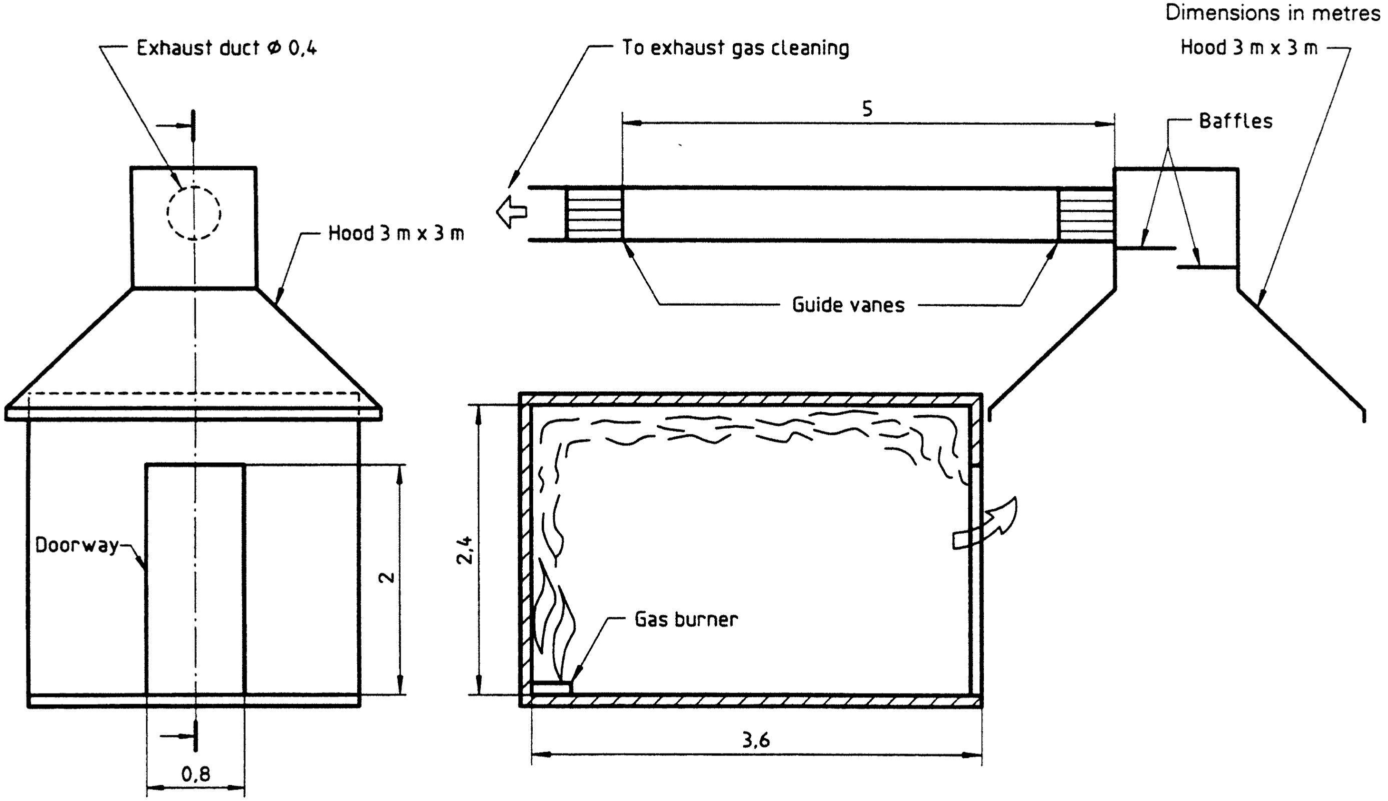
- Full-scale test
  - NT Fire 032
  - Wood crib used as ignition source
- Results represent burning in open
- Cone calorimeter data can be used to predict performance



HRR for furniture



Room Calorimeter



Storage fire growth measurements with calorimeter

- Possible to measure up to 15 MW at SP in Borås, Sweden
- The largest calorimeter (larger than20 MW) in the world is at FM global, USA

Creating a design fire

Simply add HRR curves based on ignition time of each item

- Neglects interaction between items
- May not be conservative
- Closer to flashover when multiple items are burning in small compartments
- FPEtool etc. uses this
  http://www.bfrl.nist.gov/866/fmabbs.html

Multiple fire model runs

- Run with 1 item first, evaluate ignition
- Add next item to ignite and run again

Resources for design fire information

- Initial Fires, Stefan Särdqvist, 1998
- Selecting design fires, Leif Staffansson, 2010
- SFPE Handbook
- Heat Release in Fires [Babrauskas]
- NIST web site: fire.nist.gov
- Design Fires for Pre-flashover Fires, Höglander and Sundström
- NFPA Standards [72, 204]

Link Smoke spread – Escape time

Define Scope, Goals and Objectives

Define Performance Criteria

Define Design Fire Scenario

Run Trial Designs

Check with performance criteria

Choice of Design

Choice of Fire Scenario and Design Fire

Calculation of smoke and fire spread by means of a zone model or CFD code

Calculation of the available evacuation time by means of evacuation models

What kind of models do we need?

- There is only need for one fire model if that model includes the entire building, with the expected loads and content, the people and their behaviour, the fire sources and causes, all being described in a probabilistic way changing over time. That would do it.

What should the models simulate?

- Spread of flames models
- Spread of toxic gases
- Active fire protection systems
- Structural behavior
- Evacuation of people
- Probabilistic behavior

What demands should we put on the models?

- » Accuracy

- The accuracy of models that produce a lot of information can be hard to describe in an over-all form. This is probably the biggest problem since models then are hard to compare and to validate to tests or other models.

What demands should we put on the models?

- » Field of application

- Most models are developed and tested only on a smaller number of scenarios and on a limited type of scenarios. This means that, although the models could work also for other scenarios, we cannot assume that they do.

How do today´s models fulfill these demands?

Complex fuel	▪ Often mixed
Complex geometry	▪ Rack storage etc.
Complex ventilation	▪ Uncontrolled
Low fuel velocity	▪ Low Froude nr
Varying fuel amount	▪ Time dependent
Radiation feedback	▪ Very important
Low combustion eff.	▪ Varying with vent.etc
Sensitive to bound.co.	▪ Experimental difficult

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How do today´s models fulfill these demands?

» Different kinds of models

- Empirical correlations (back of envelope calculations)
- Zone Models
- Computational fluid dynamics (CFD)
- Evacuation

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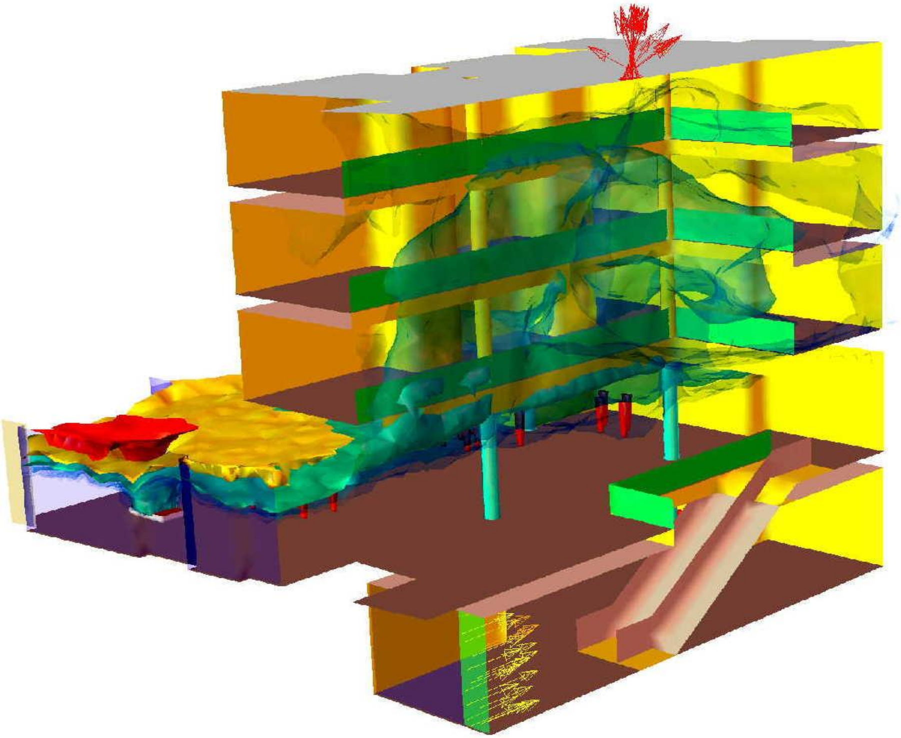
Smoke filling in a complex building



Problems

What is CFD ?

- Colour For Directors
- Confusion For Dummies
- Computational Fluid Dynamics

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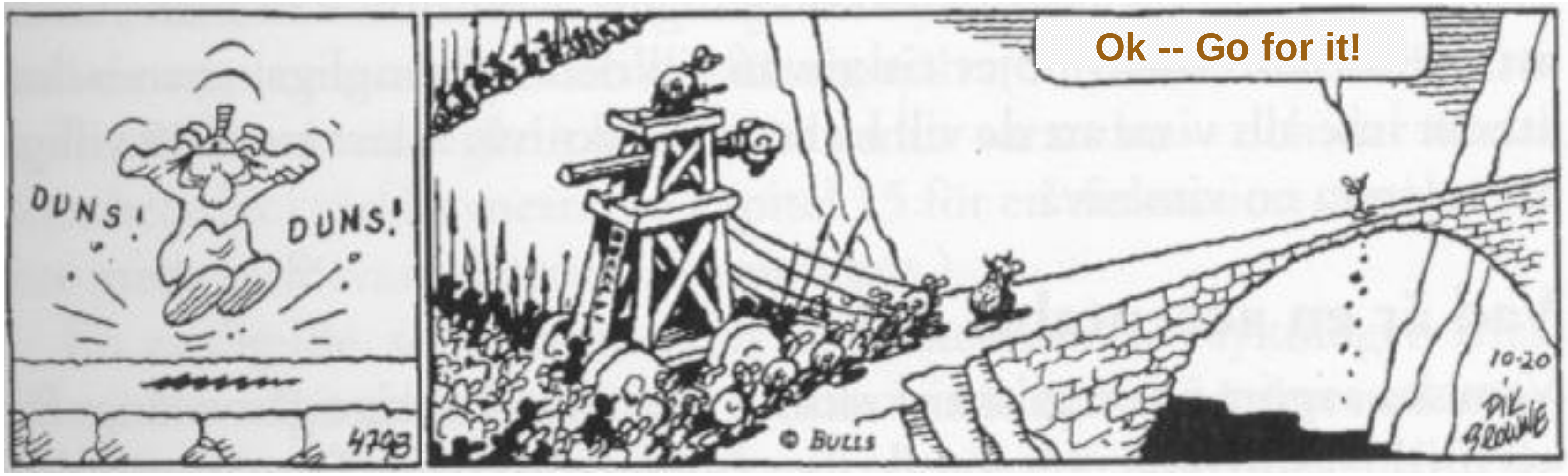
The concept of verification/validation



The public safety should not rely on the designer's "gut-feeling".

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Reflections

Fire is a complex phenomenon with a combination of heat transfer, combustion, fluid dynamics, etc.

Diffusion flames are the most typical type of flames

Models are available but do not cover all advanced physics and chemistry such as in other disciplines

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IAFSS Agenda 2030 for a Fire Safe World

https://www.sciencedirect.com/science/article/pii/S0379711219303509

WHITE PAPER FROM THE INTERNATIONAL ASSOCIATION OF FIRE SAFETY SCIENCE

The Fire Problem…

- **WHO** – 180 000 burn deaths annually, vast majority in low and middle-income countries but situation in developed countries is also troubling
- **Europe** – 3 500 killed in fires annually, at least 70 000 injured
- **Developed countries** – cost of fire >1% GDP
- **US** – <u>total</u> annual cost of fire close to 2% GDP
- **SwissRe** – cost of wildfires 2017 US$14 billion
- **Allianz** – fires and explosions in the built environment account for 59% of annual business interruptions globally

- … in September 2018 IAFSS called stakeholders to dialogue which ultimately resulted in the IAFSS Agenda 2030 for a Fire Safe World, published in Fire Safety Journal !
- Reference: https://www.sciencedirect.com/science/article/pii/S0379711219303509

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Societal Challenges
- that fire research can help address

- ✓ Climate change, resiliency and sustainability
- ✓ Population growth, urbanization and globalization

Climate change, resiliency and sustainability

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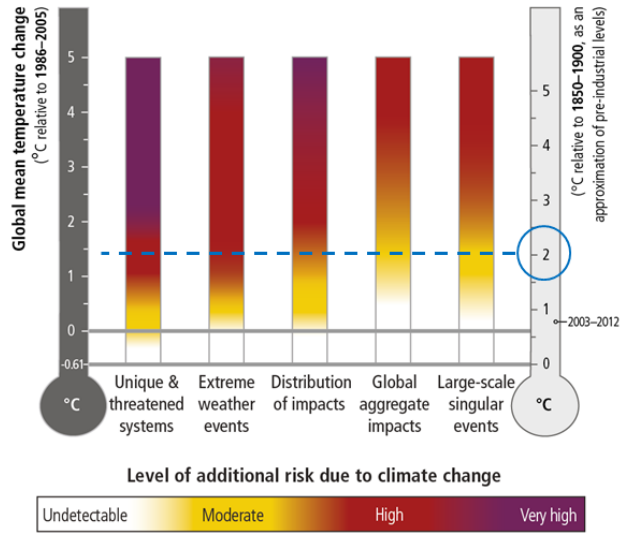
Intergovernmental Panel on Climate Change (IPCC)

Panel of the United Nations, leading global authority on Climate Change

Key messages IPCC Fifth Assessment Report:

- Human influence on the climate system is clear
- The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts
- We have the means to limit climate change and build a more prosperous, sustainable future

The impact has already begun to be visible



Source: IPCC 5th Assessment Report, 2014

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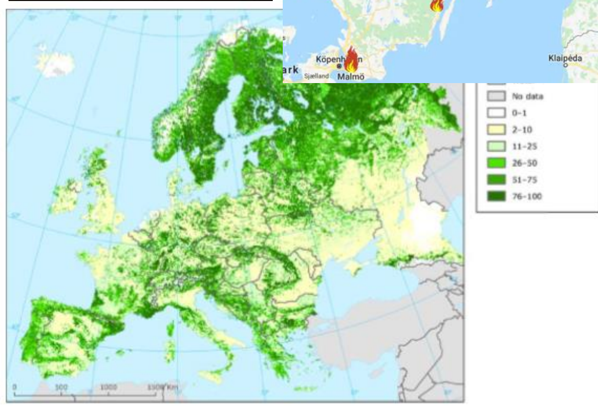
Forest fires

- Increasing weather volitility increased risk for large forest fires
- Global losses 2017 US$14 billion, 2018 expected to be higher
- The Swedish example 2018:
  - Sweden has the highest forest density in Europe
  - July 2018 there were approximately 50 forest fires requiring first responder attention at one time
  - International assistance was given for air response



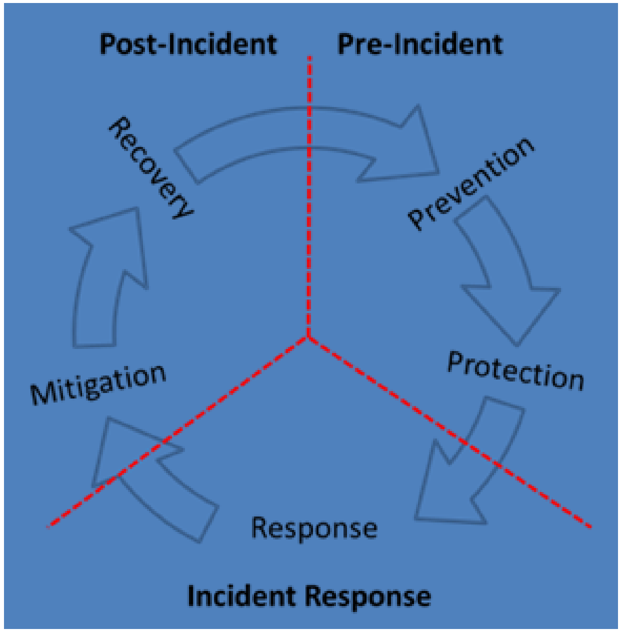
Resiliency

The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events

Larger and more complex incidents

Risk for multihazard events, e.g. cascading events, proximate but unrelated

Need for improved incident management, larger exercises, multifaceted incidents



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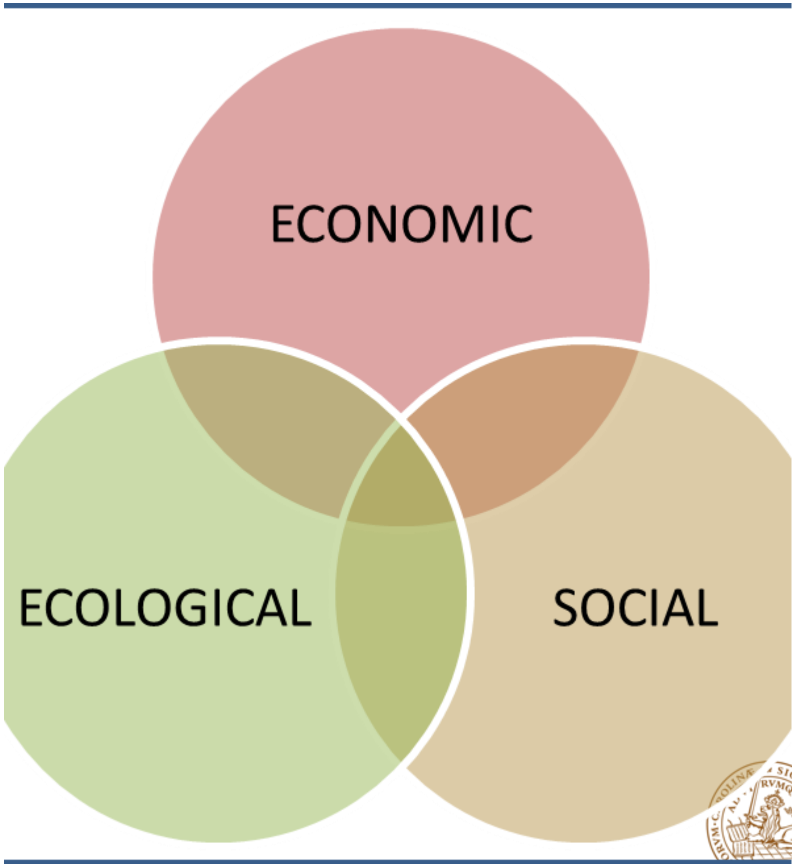
What do we mean by a sustainability?

- A sustainable society meets the our present needs without compromising the ability of future generations to meet their needs
- Sustainability requires an holistic approach at the system level
- Multifacetted:
    - ✓ Economic
    - ✓ Environmental
    - ✓ Social



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Life Cycle Thinking

- Environmental **LCA**
- Economic **LCC**
- Social **SLCA**

LIFE CYCLE SUSTAINABILITY ASSESSMENT (LCSA)
= LCA + LCC + SLCA

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Population growth, urbanization and globalization

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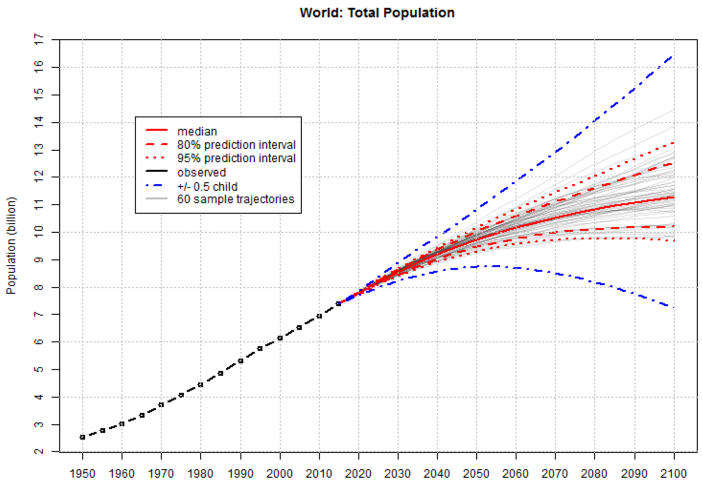
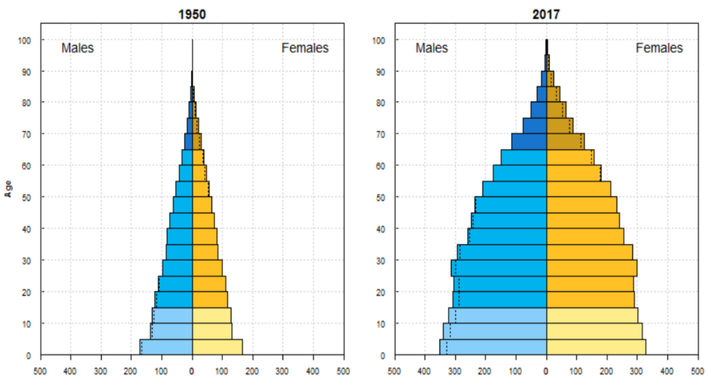
Demographics



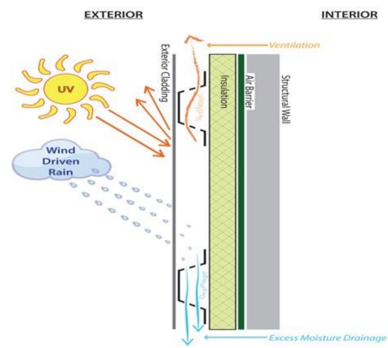


Source: UN Dept of Economic and Social Affairs. Population Division, 2017

- Population expected to continue to grow until (at least) 2050-2100
- Large movement of people and good internationally
- Aging society
- Demographic potential in developing countries and demographic debt in first world countries
- Increased international dependencies
- Globalization exasbates critical situation created by population growth and urbanisation

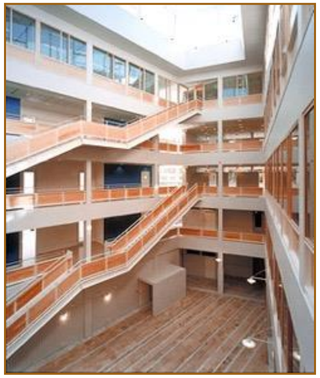
Tall Buildings, new materials

- More complex egress, due to increased number of tall building, denser urban areas, increased population with reduced mobility
- More complex suppression activities, limited access, sensitive environments, hard surfaces in cities
- New materials, need for better understanding of their fire safety
- Holistic aspect is necessary
- Performance and risk based engineering is important



Challenges in Fire safety

The impact on building design



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Fire Safety (Buildings) – Today

Innovative Buildings

⇓

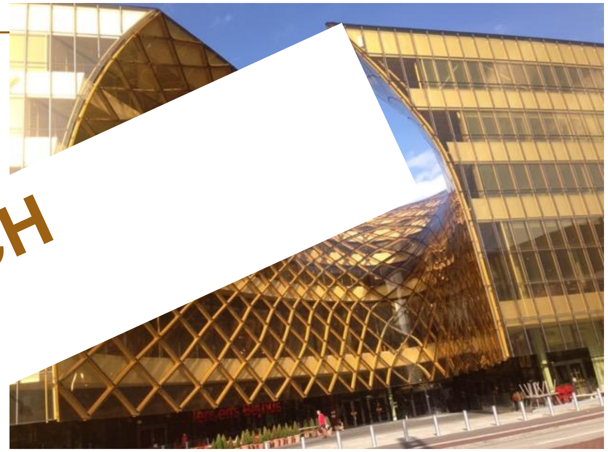
Multifunctional buildings

Green buil

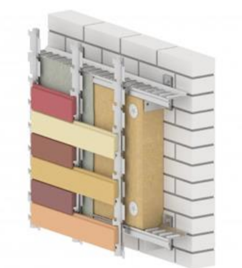
ystems

MULTIDISCIPLINARY APPROACH IMPERATIVE

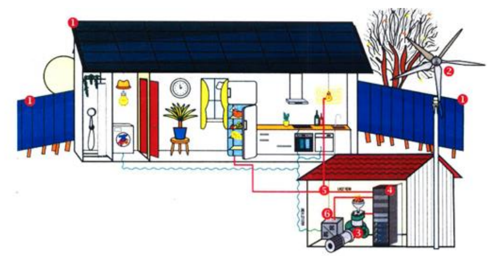
The Gherkin,



Emporia, Malmö



Facade systems



Digitalisation, ZEB

Informal Settlements

- …slums, shacks, ghettos, and shanty towns
- Growing problem due to poverty, war and in recent years climate refugees
- Inherently low standard, unregulated, poor access to water

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IAFSS Fire Science and Engineering Actions

Societal Grand Challenges	Fire Science and Engineering Fields of Research and Action
Climate change, resilience and sustainability	Forest Fires and Wildland-Urban Interface
	Societal Resilience
	Fire Safety and Sustainability
Population Growth, Urbanization and Globalization	Globally-Consistent Regulations, Standards, and Guidelines
	Tall Buildings and Urban Development
Cross-cutting	New Technology, Artificial Intelligence (AI) and Big Data
	Higher Education

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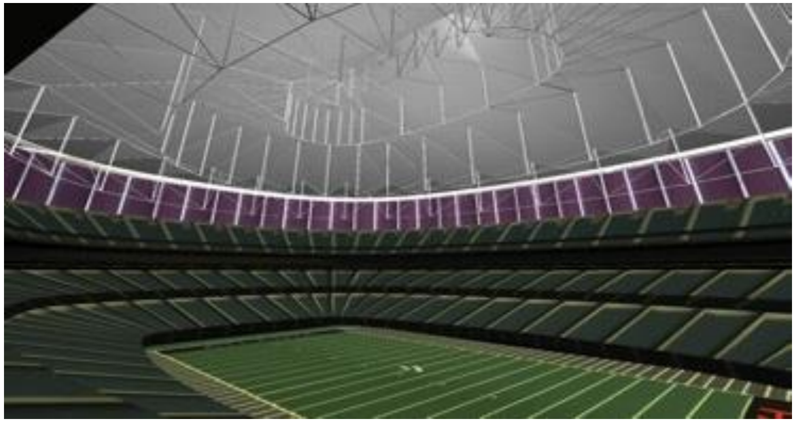
Key aspect: Performance Based Design

- Performance-based regulations design an objective, but do not say how it should be accomplished
- Objectives can be e.g. safe evacuation within a specified time, structure stability within a specified time
- This option allows more flexible solutions (large public areas), more cost-efficient designs and solutions for complex facilities which are impossible to tackle by prescriptive solutions
- However, challenges exist!



- Picture: Tensinet

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Challenges - Tools Modelling

- Appropriate tests for input in sub-models for fire and smoke spread (pyrolysis models etc.) in CFD for PBD
- Standardised ways to inform user of fire models on verification and validation in order to determine uncertainties e.g. for evacuation in special cases
- More knowledge on ALL uncertainties in the process.
- Establish procedures for safety margins, minimum safety levels

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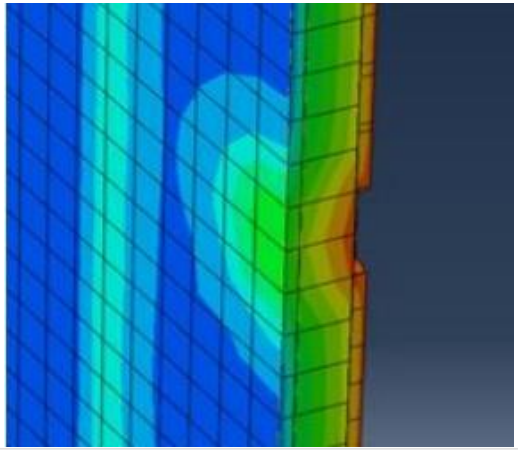
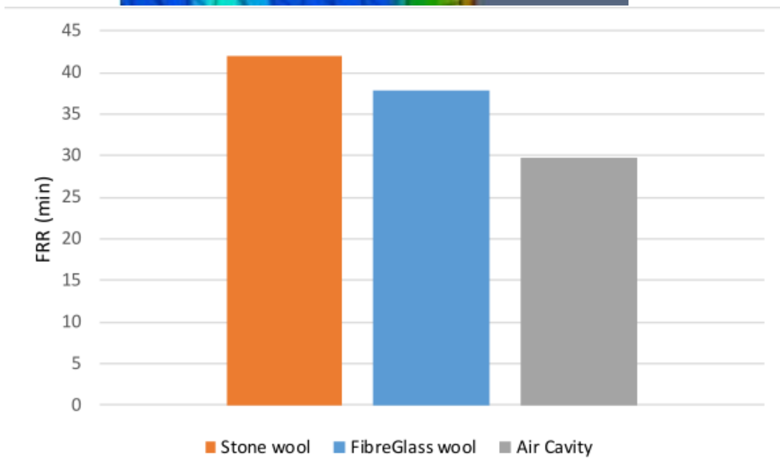
Challenges – Procedure

- More Quality control during the design process but also afterwards during running operations !!

- Good statistics to define probabilities for probabilistic designs and how to use them

- More feedback from real accidents – case studies





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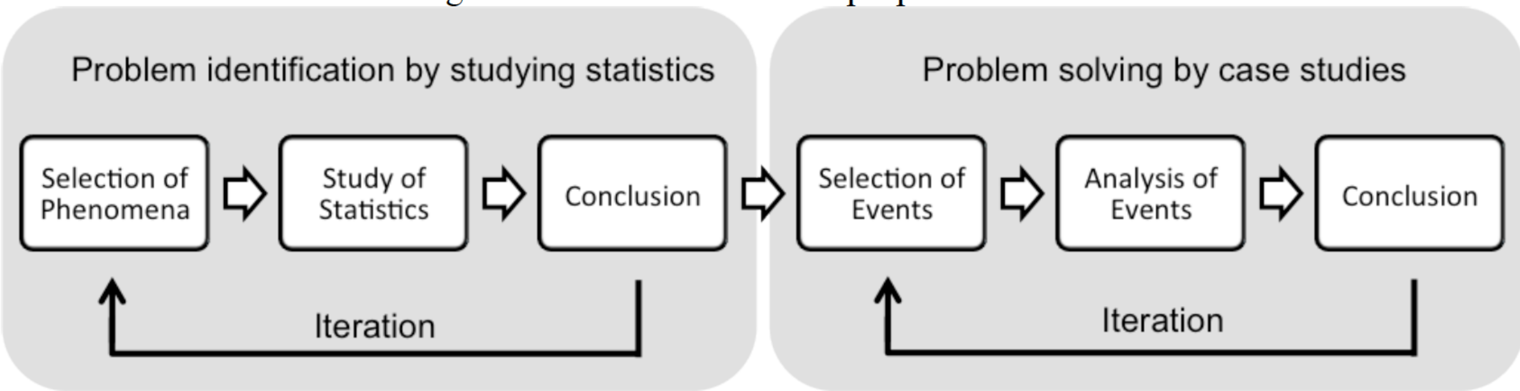
Use of statistics and case studies

Figure 2: Schematic chart of proposed method.



From Johansson et al, (2012) , Combining Statistics and Case Studies to Identify and Understand Deficiencies in Fire Protection, Fire Technology 48(4), pp. 945-96

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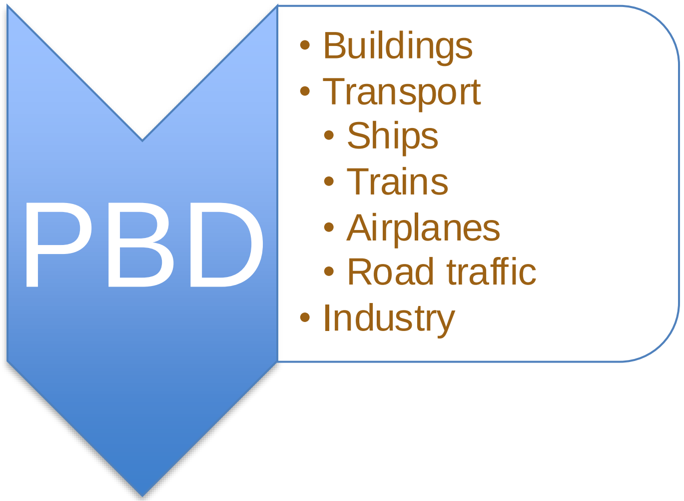
Challenges - Procedure

- Introduce harmonisation between different areas (transport, buildings) for PBD

- Develop more clear guidance for PBD else it will become too prescriptive PBD ☺.



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Procedures for new threats need other fire scenarios

- Antagonistic attacks with high combined external impact e.g. explosion and fire
- Arson type of fires e.g. school fires in Sweden
- Natural disaster e.g. earthquake in Japan causing fires afterwards or wildlife fires e.g. in Australia
- War…

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New type complex infrastructures: buildings/transport/health facilities

- Multifunctional building and transport infrastructures
  - More than one societal function e.g. transport, offices, housing, health care,…
  - More than one transport system: train, airport, railway tunnel, bus station,…
  - Larger amount of people in new type of buildings

Picture: Helsingborg City

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Introduction of new control technology continuity of operation

- Functional performance during fire becomes more and more important
- Advanced control systems for detection and activation of systems e.g. ventilation
- Advanced systems for crowd behaviour

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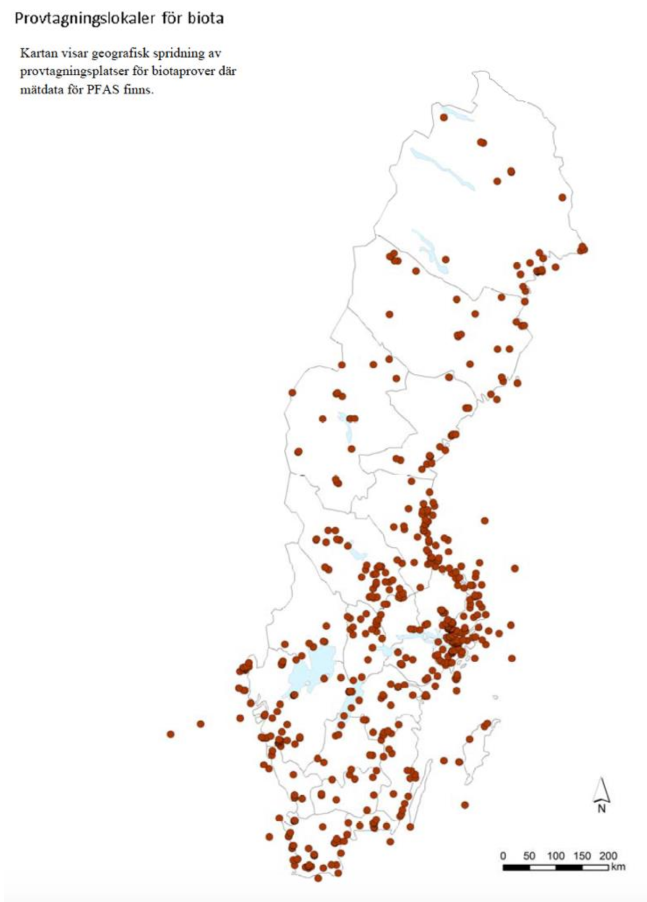
New challenges – protection of the environment

- Environmental aspects can not be neglected
  - Use of unsuitable extinguishing systems (PFAS etc)
  - Release of gases from electrical fires e.g. batteries
  - Use of environmentally FR
  - Effect of wildland fires on environment
  - …



Measured values PFAS in ground water in Sweden

Picture Naturvårdsverket

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New type of buildings/insulation

- Higher energy demands requires more insulation and other ventilation
  - More mechanical ventilation can cause underventilated fires
  - More insulated buildings can cause higher thermal impact

Picture:IRSN

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System thinking in fire testing?

- Based on standardised tests at international level and regional level.
- Quite often scenario defined whether it is a reaction to fire test or a fire resistance test.
- An example are façade systems used for retrofitting
  - Different Fires
  - Different Risks
  - Different type of systems
  - Very different type of tests
- Same type of thinking can be used for e.g. sandwich panels, cables, roofs etc. !!

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Haeundae Highrise - Busan Marine City Korea – 2010

Picture: Koreabridge.net

Dubai

Roubaix France

Atlantic city, USA

Azerbaijan

Grenfell

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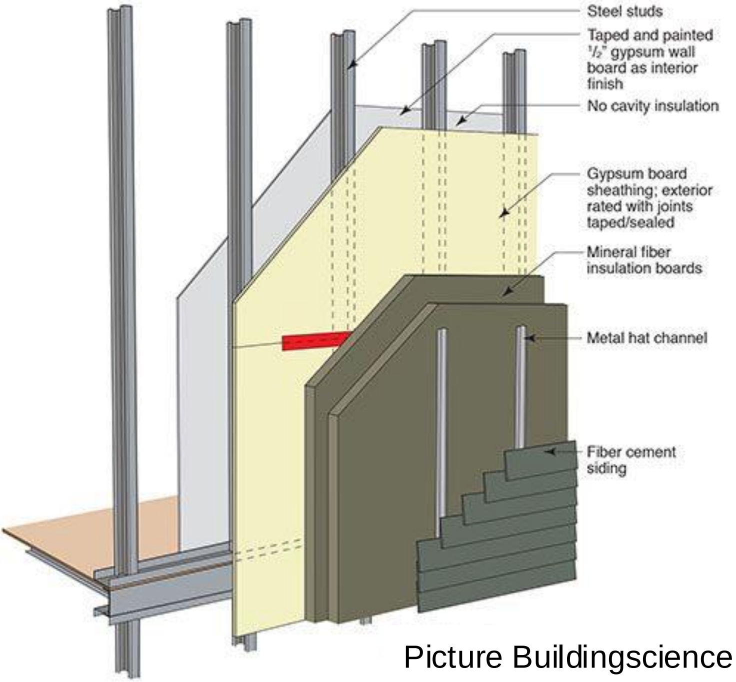
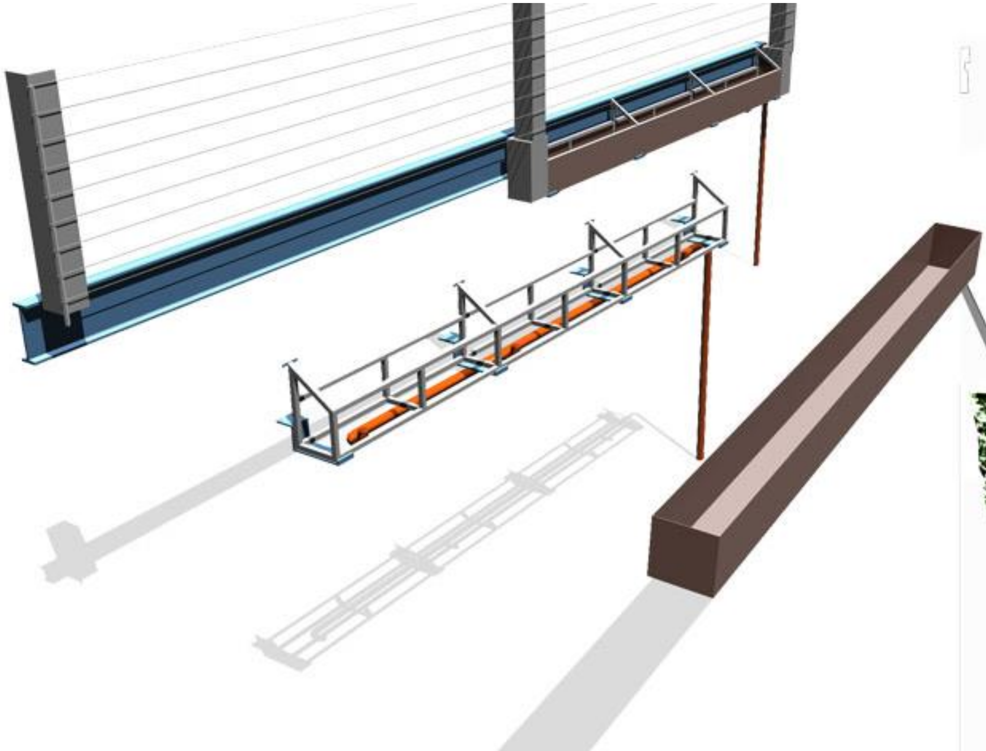
Different complex systems

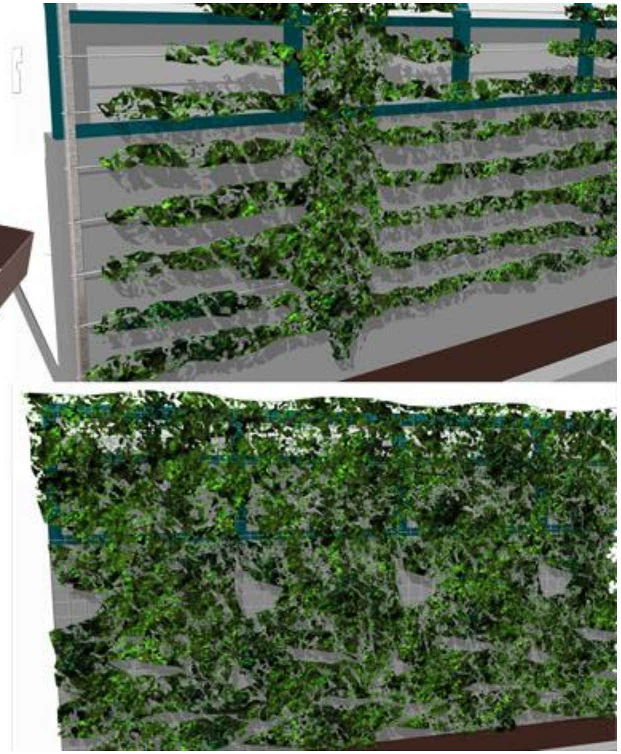


Picture Buildingscience.com

These system need also to fulfil other requirements such humidity, rain screen, ventilation in the air gap, stability for wind, architectonic, etc.

Different systems





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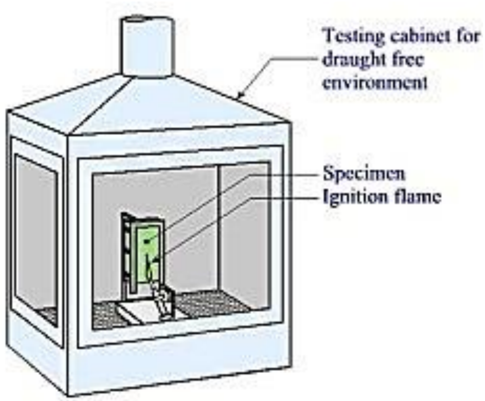
Which test methods ??



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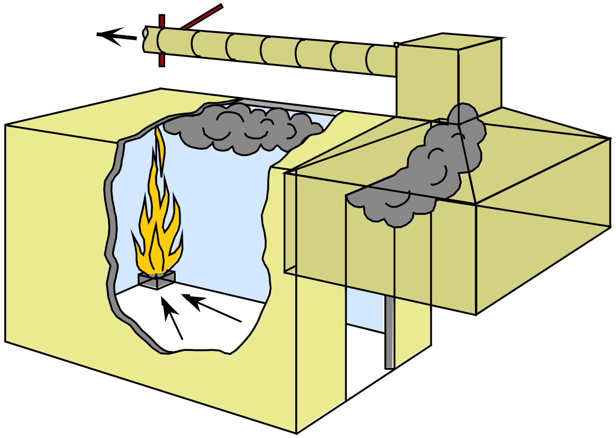

Picture SP

Picture SP

Picture SwRI

Picture FM global

Challenges for façade systems

- Different risks for façade systems exist.
- Façades constructions are very complex and are complete systems and not single materials or products.
- Before introducing test standards into regulations, regulators should identify which risk they want to reduce and choose the appropriate performance criteria or safety levels.
- As such, a suitable test method or a suitable performance based solution based on fire safety engineering can be chosen. The test and or procedure should cover the addressed risk !
- Substituting elements should be done with care !!

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Overall challenges - Ethics

- The use of functional performance criteria and trade-offs in FSE require **high ethical codes** of the engineer as it requires taking an independent position and a high level of self-criticism
- **Ethics plays also a role in performing research of overall systems** with different products, components and/or subsystems. Research should be on a broad basis and not on the basis of sponsoring by one player. An urgent need for overall independent research funding is needed.

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Challenges in education

- Fire safety engineers need to control different aspects of knowledge in order to address fire safety
- These are e.g. fire dynamics, chemistry, combustion, structural behaviour, risk analysis, performance based design, advanced modelling, active and passive systems, human behaviour in fires, societal behaviour, communication techniques, etc. etc.
- However we educate mainly courses in the building environment and need also to look into transport i.e. trains, ships (SOLAS art. 19), airplanes, etc.

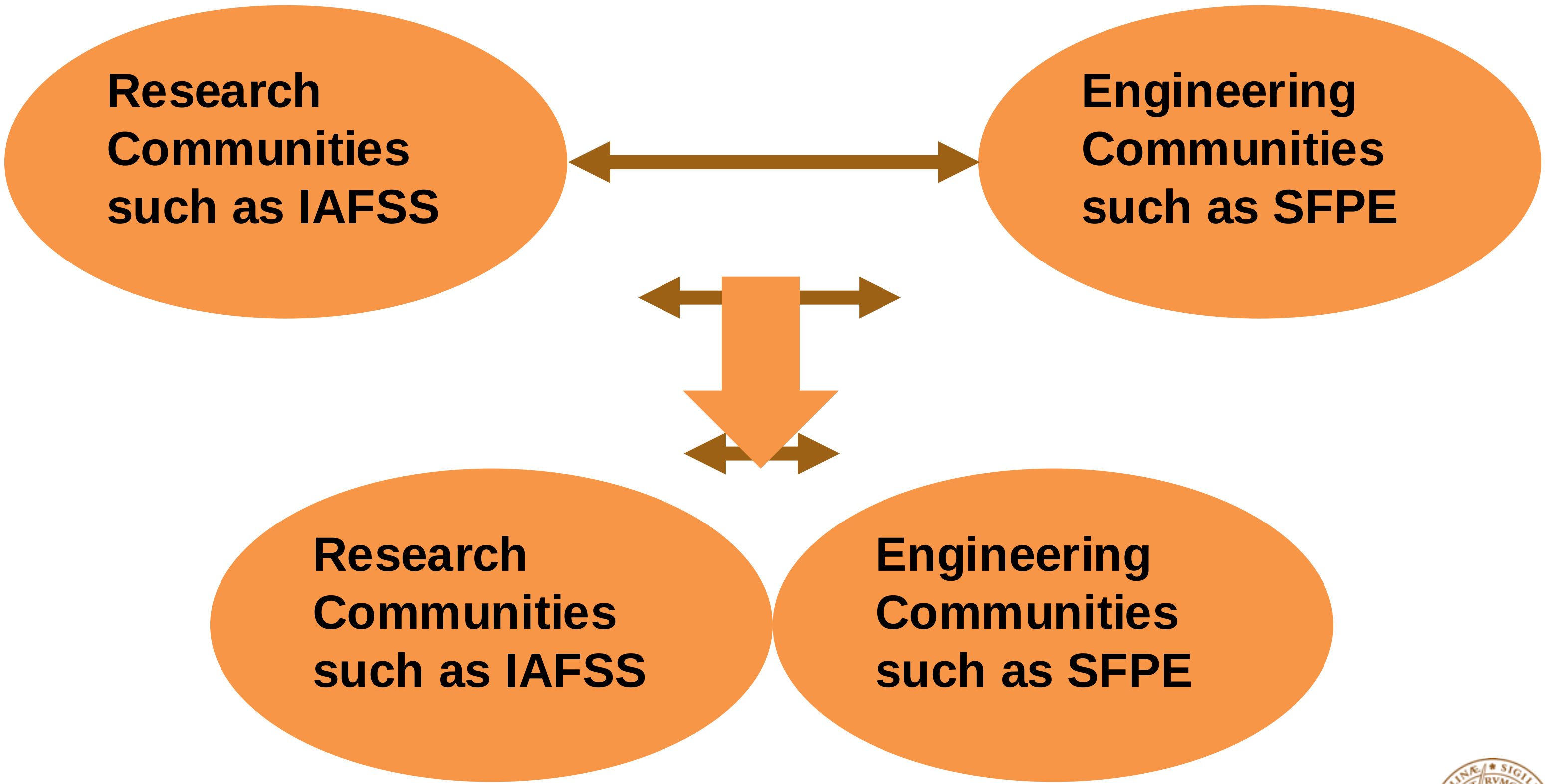
Challenges in education

- This put requirements on the educational teams so joined efforts are needed in order to lead to high quality engineers and PhD

- Example of joined activities: International master of FSE between Gent, Edinburgh and Lund with cooperation of ETH, Queensland and Maryland. Your research school in France.

- But we <u>need even specialist in certain areas </u>such as transport systems, ships, etc. This needs even PhDs in engineering to act as specialist and Research Schools

Research: Fire Science and Fire Engineering



Conclusions

- Fire behaviour of buildings products, content, barriers etc. should be addressed as **overall system behaviour** taking into account all aspects not only fire.

- **Performance based design** is certainly needed to replace detailed regulations to cover all fire safety goals such as safety of life, property protection, continuity of operation, environmental protection and to cover growing complexity and need for quality.

Conclusions

- Fire is a complex phenomenon with a combination of heat transfer, combustion, fluid dynamics, structural behaviour **and it is combined with** societal aspects and human behaviour. We need to realise this and prepare future engineers and PhDs in this overall **holistic approach**
- The **educational challenges** should be tackled on international level e.g. in international programs such as the International Master of Fire Safety Engineering or PhD schools for detailed specialization.
- **Forums** for international collaboration are needed e.g. for research IAFSS, for standardisation ISO, for engineering SFPE, etc. but they should be conducting more joint efforts.

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Thank you!
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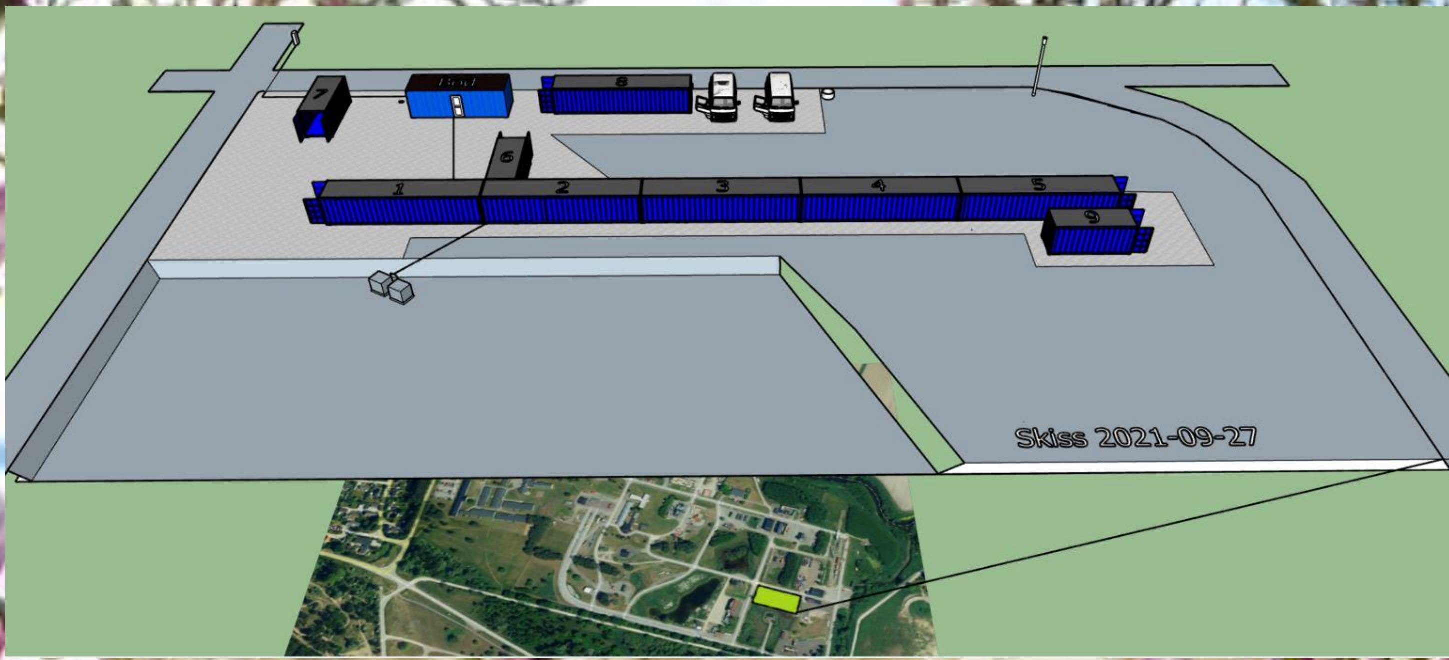

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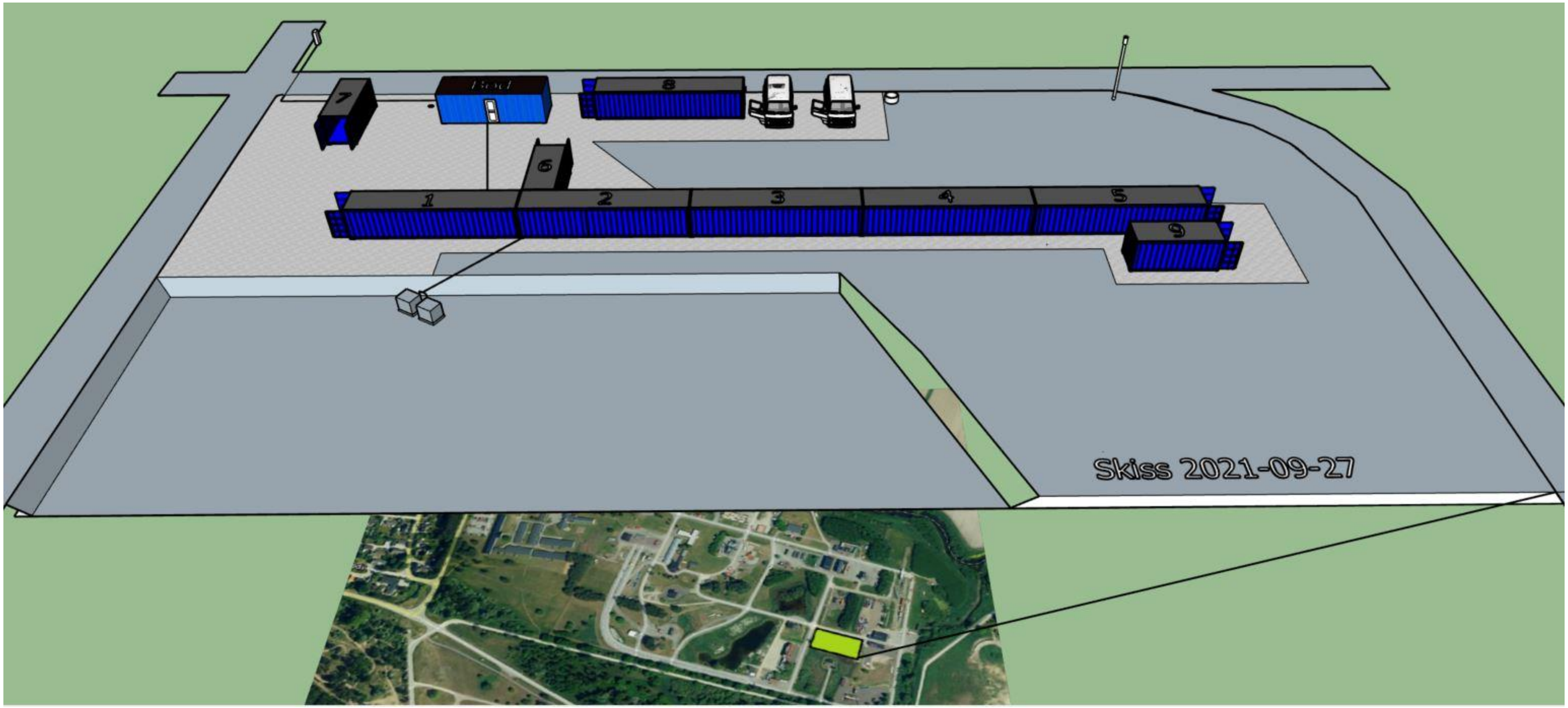
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