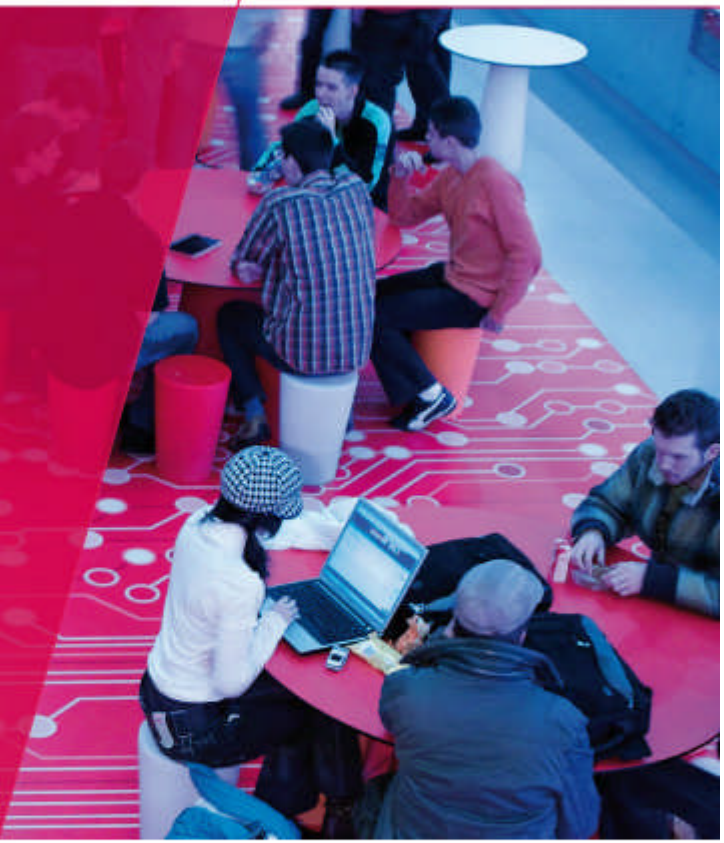
# Reliability of fire safety objectives



## Requirements vs objectives

- Prevention
- Suppression

**Ruud van Herpen  MSc. FIFireE**

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

# Ruud van Herpen


**Eindhoven University of technology:**
Fellow Fire Safety Engineering (Building & Architecture – unit BPS)

**Saxion University of applied sciences:**
Professor Fire safety in buildings

**Nieman consulting engineers:**
Technical director

Nieman

# Fire safety

## Safety chain

- Prevention
  - (passive: building)
  - (active: installation)
  - (active: organization)
- Suppression
  - (automatic: installation)
  - (manual: organization)

(*model IBB, CCV*)

# Fire safety

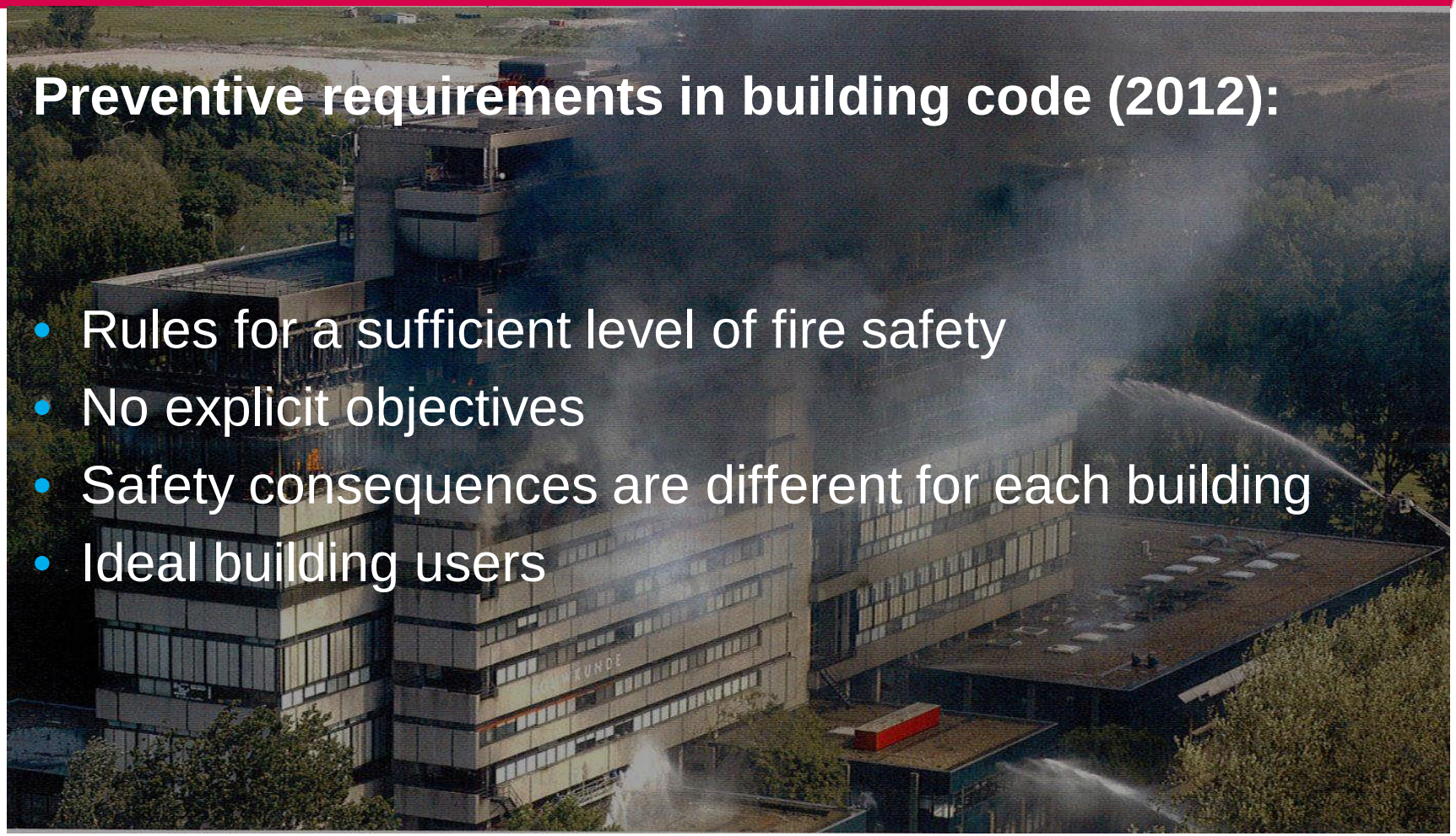
Fire in nursing home

*Rivierduinen (2011)*


iteit

ology

# Fire safety



**Preventive requirements in building code (2012):**

- Rules for a sufficient level of fire safety
- No explicit objectives
- Safety consequences are different for each building
- Ideal building users

# Safe environment

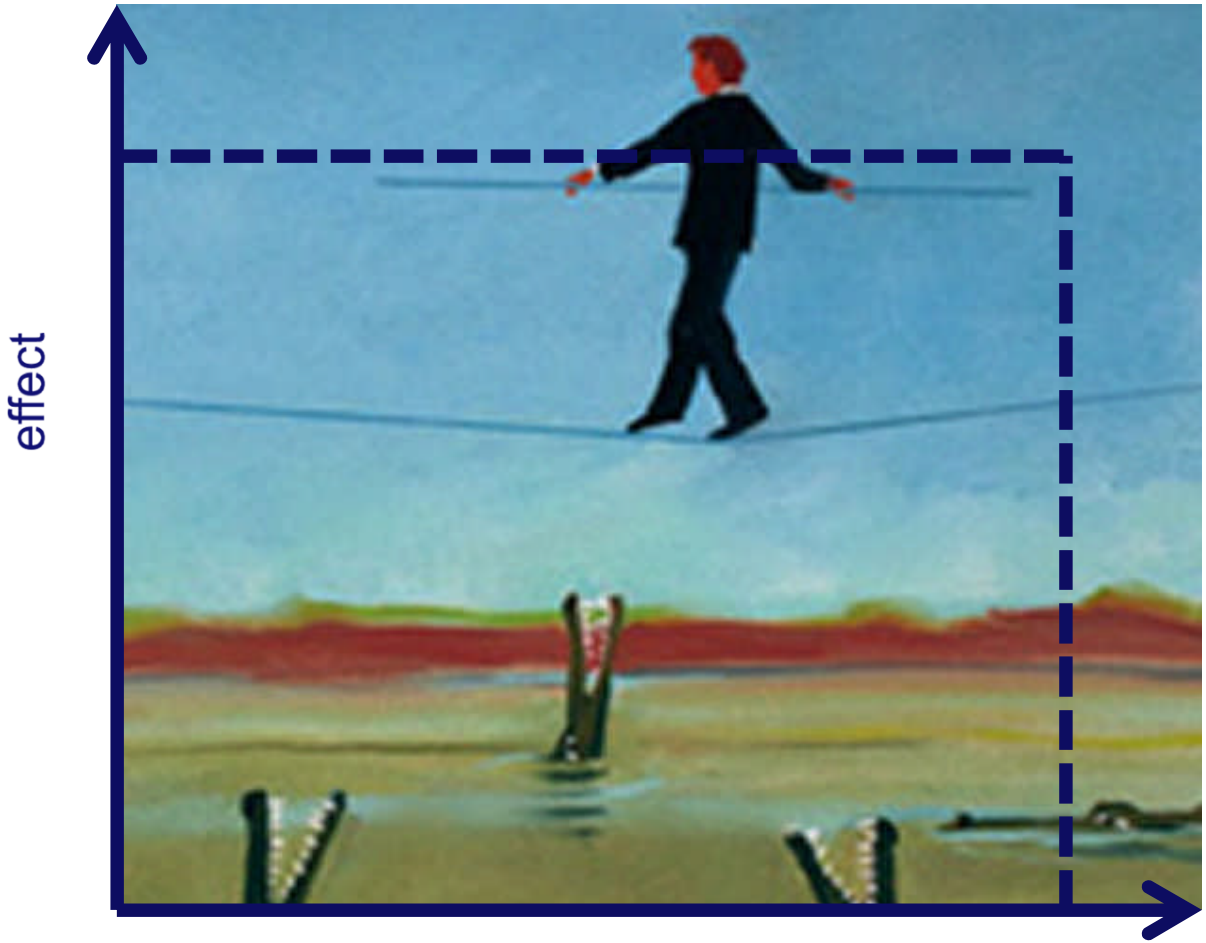
## Rules or objectives?

- Sometimes rules are not sufficient
- Sometimes rules may lead to unnecessary measures
- Rules obstruct innovation and are not suitable for tailor-made fire safety (fire safety concepts)

## Objectives are more important than rules

- Objectives contain failure risks
- Risk = $(\text{safety})^{-1}$

# Safe environment



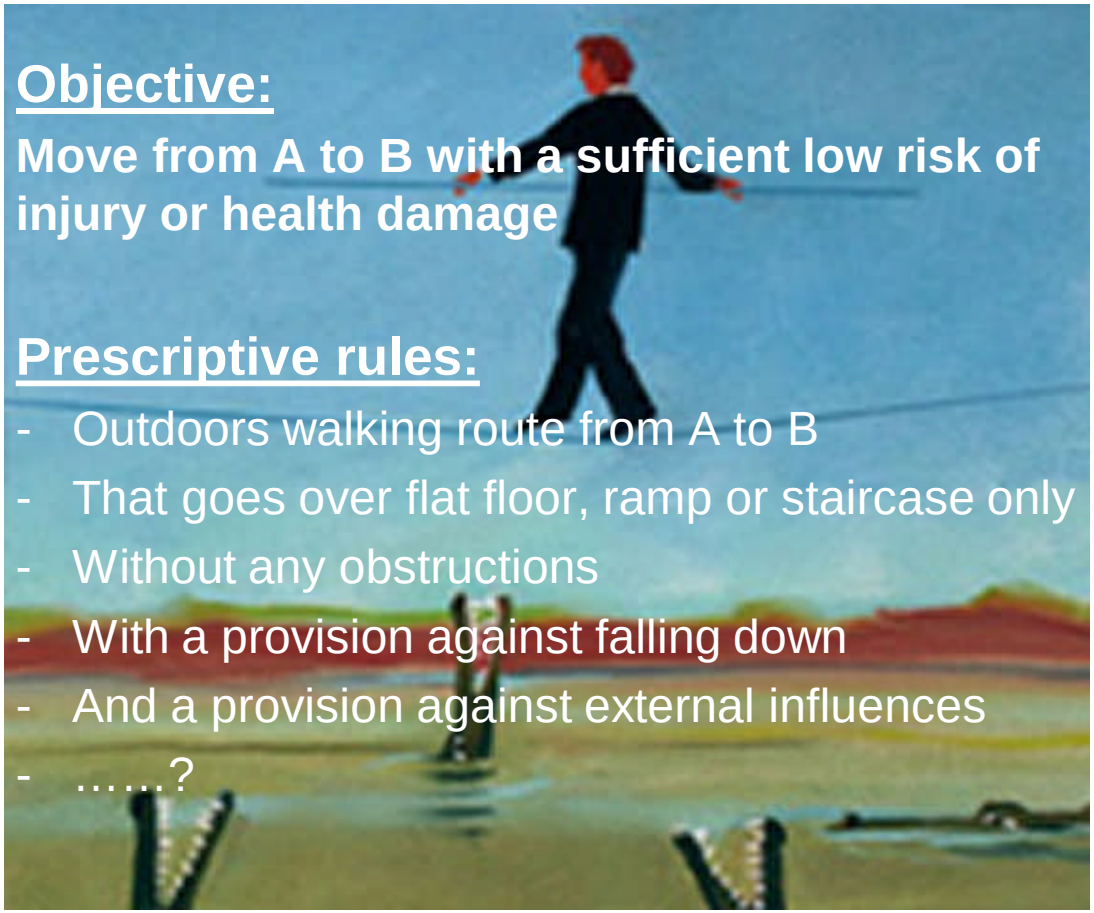
# Safe environment

B


A

# Prescriptive rules or performance based objectives?

B




A

# Prescriptive rules or performance based objectives?

**Public objectives for fire safety (building act):**

- Preventing victims by fire
  - Building users, assistance, …
- Preventing fire damage to third parties
  - Neighbouring plots

# Safety objectives

**The objectives of the public safety rules (building code):**

- Safe environment
- Safe building (structure)
- Safe compartments (spread of fire and smoke)
- Safe escape route
- Safe attack route

Critical incident:

compartimentfire

# Source, response and risk

source

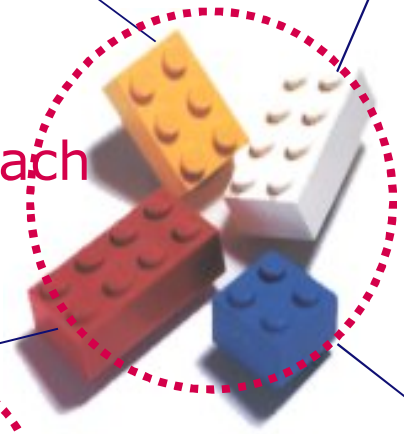
**Source: fire and smoke**
CFD, zonemodels, plume-models, combustionmodels,...

Risk-based approach

**Response (B):**
Thermodynamic and mechanical consequences for load-bearing and separating building constructions,..

[PASSIVE]

response



**Response (I):**
Fire detection and alarm, fire suppression systems, heat and smoke control,..

[ACTIVE]

**Response (O):**
Evacuation of building-occupants, assistance, human behavior...

# Source, response and risk

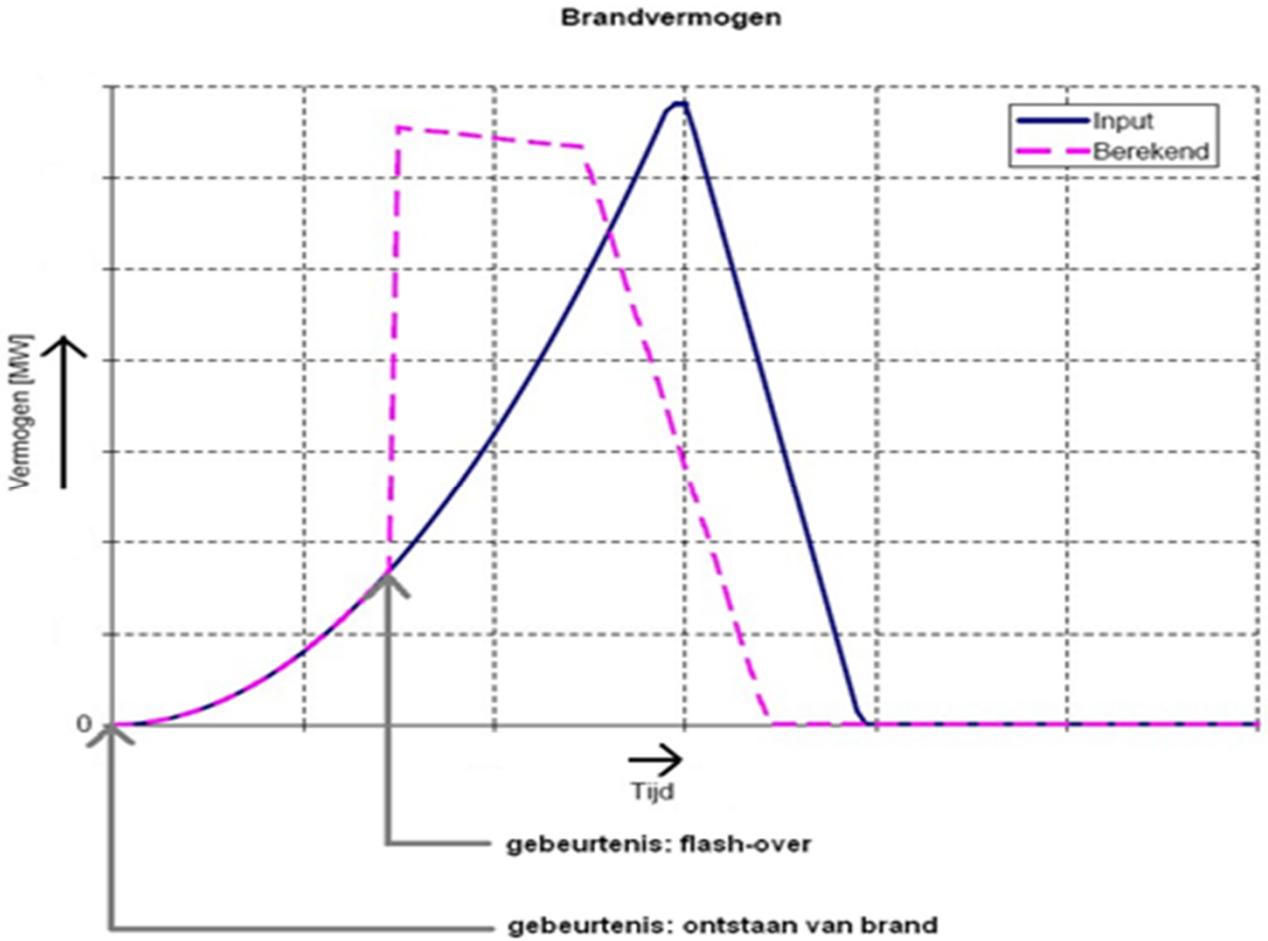
## Natural fireconcept as source

Taking into account project-specific characteristics:

- Fuel
- Building

# Source, response and risk

## Natural fireconcept as source



# Source, response and risk

**Project-specific approach (FSE):**

**Especially useful for existing buildings with specific building characteristics**

In case of unsufficient fire safety according to rules:

- Adjust building chatacteristics
  *or*
- Control source (organization/installation)
  *or*
- Adjust response (organization/installation)

BIO-measures !

# Example: Dwellings in a monastery

Existing building characteristics:

- Portico staircase with dead-end corridors
- Escape route doesn't meet the requirements

# Example: Dwellings in a monastery

## Objective:

- Safe escape

## Solutions:

- Redundancy
  (2nd escape route)
  ***or***
- Increase reliability of the existing escape route

Pressurized staircase

# Natural fireconcept and risks

**Safety in terms of acceptable failure risks:**

- Environment (neighbouring plots)
- Building (structure)
- Compartments (max. spread of fire and smoke)
- Escape routes (free of fire and smoke)
- Acces routes (free of fire and smoke)

**In case of a compartmentfire (post flashover)**

**Intended (remaining) lifetime of the building is relevant to the acceptable failure risk**

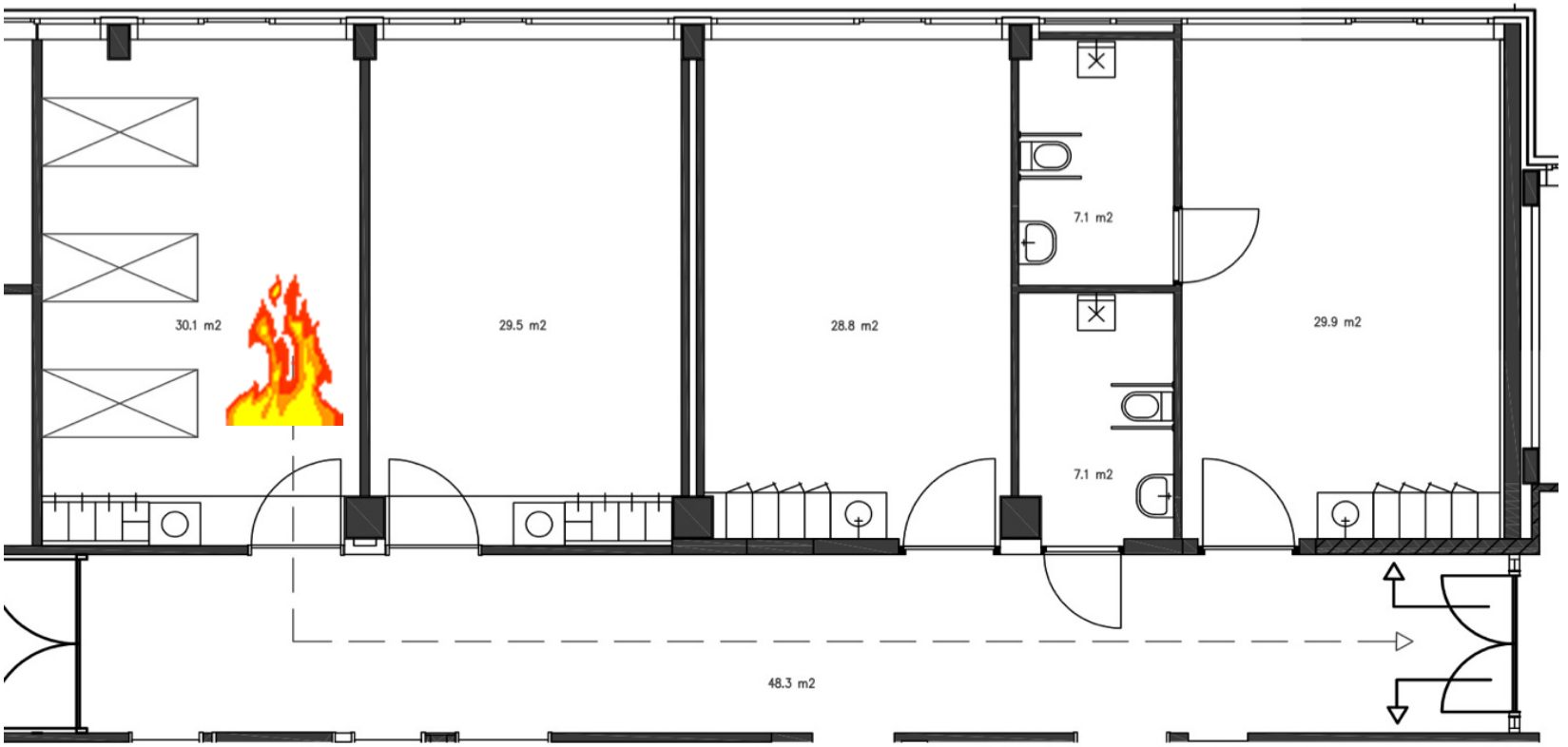
# Consequences for building components

## Load bearing constructions

## Separation constructions

- Separation between fire compartments: thermal failure? (spread of fire)
  - Internal separations
  - External separations
- Separation between compartment and escape route: airtightness failure? (spread of smoke):
  - Internal separations only

# Consequences for building components

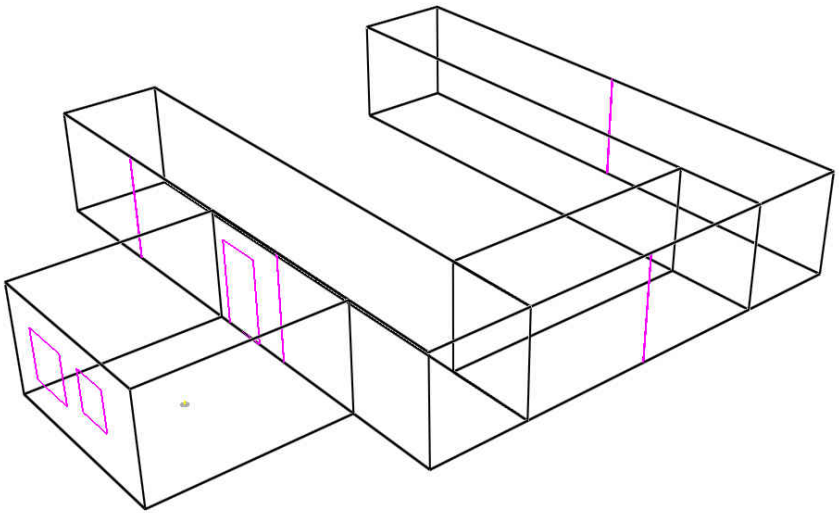


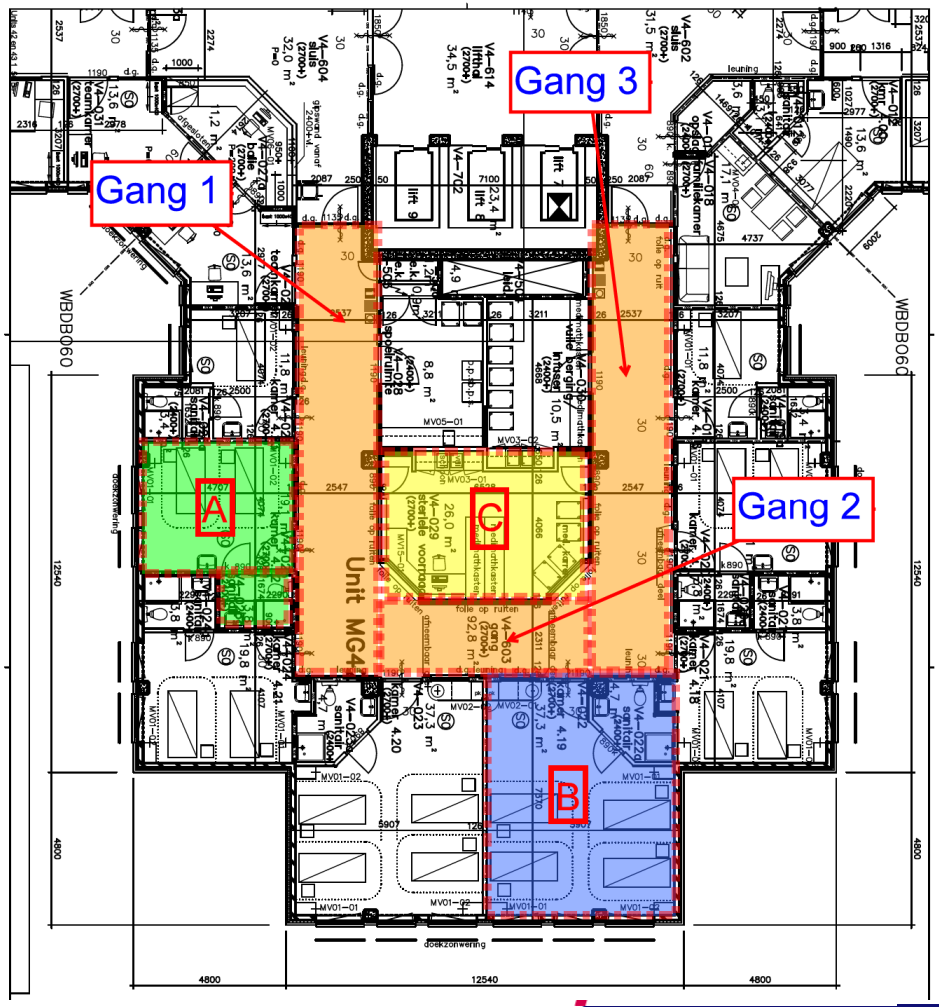
# Example: Amphia hospital Breda

## Corridor in nursing department

# Example: Amphia hospital Breda

## Corridor in nursing department





# Firesafety in prescriptive rules

**Prescriptive rules:**

- Standard measures: project-specific characteristics are not taken into account
- Limited robustness: changing boundary conditions in the future are not taken into account
- Consequence:
  High level of safety measures with limited fire safety

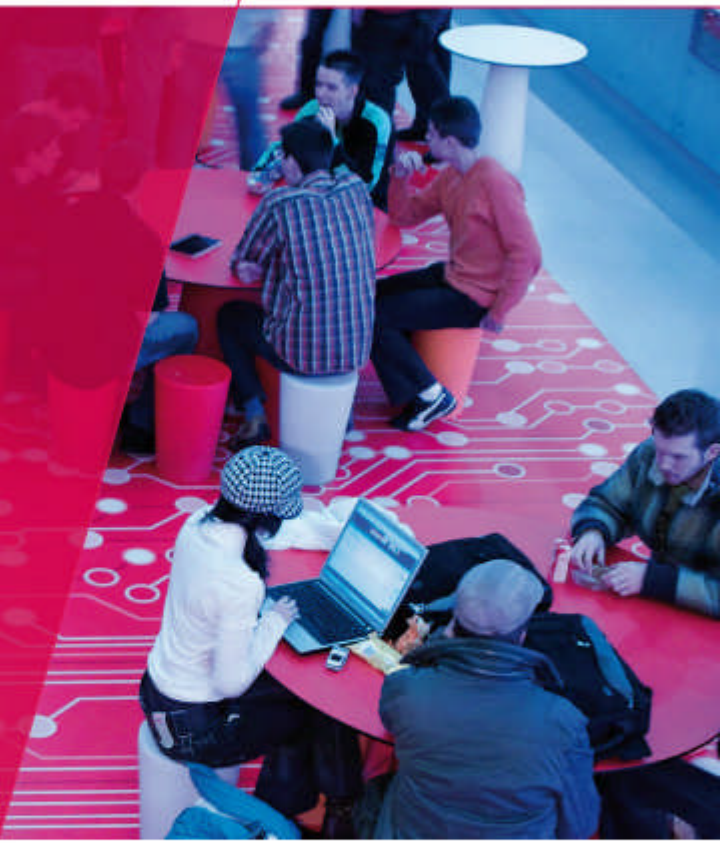
# Firesafety in performance based objectives

## Performance based objectives:

- Projectspecific measures: based on objectives, taking into account projectspecific characteristics in a natural fireconcept
- Robust safety concept: taking into account uncertainty in boundary conditions and changing boundary conditions in the future (risk analysis)
- Consequence:
  Tailor-made measures with optimal fire safety

# Market hall
# ASET / RSET assessment

## A probabilistic approach



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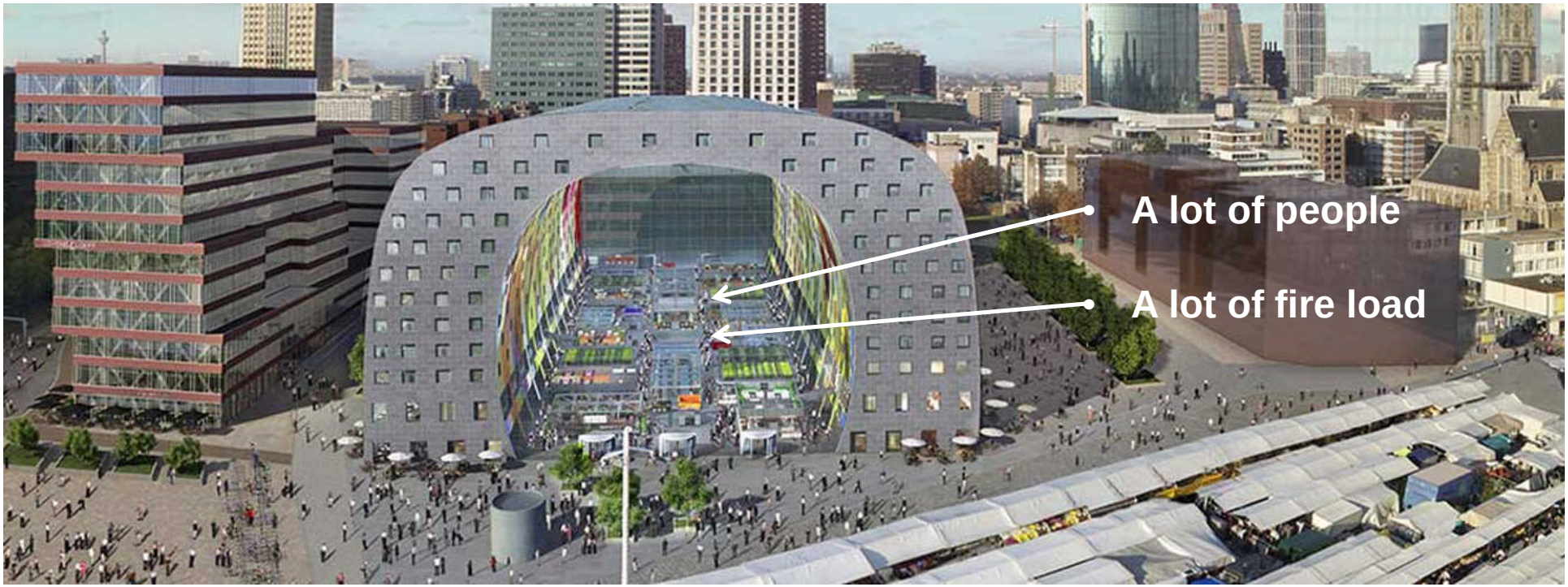
**Eindhoven**
University of Technology

**Where innovation starts**

# Example: Market hall




Rotterdam, NL

# Example: Market hall

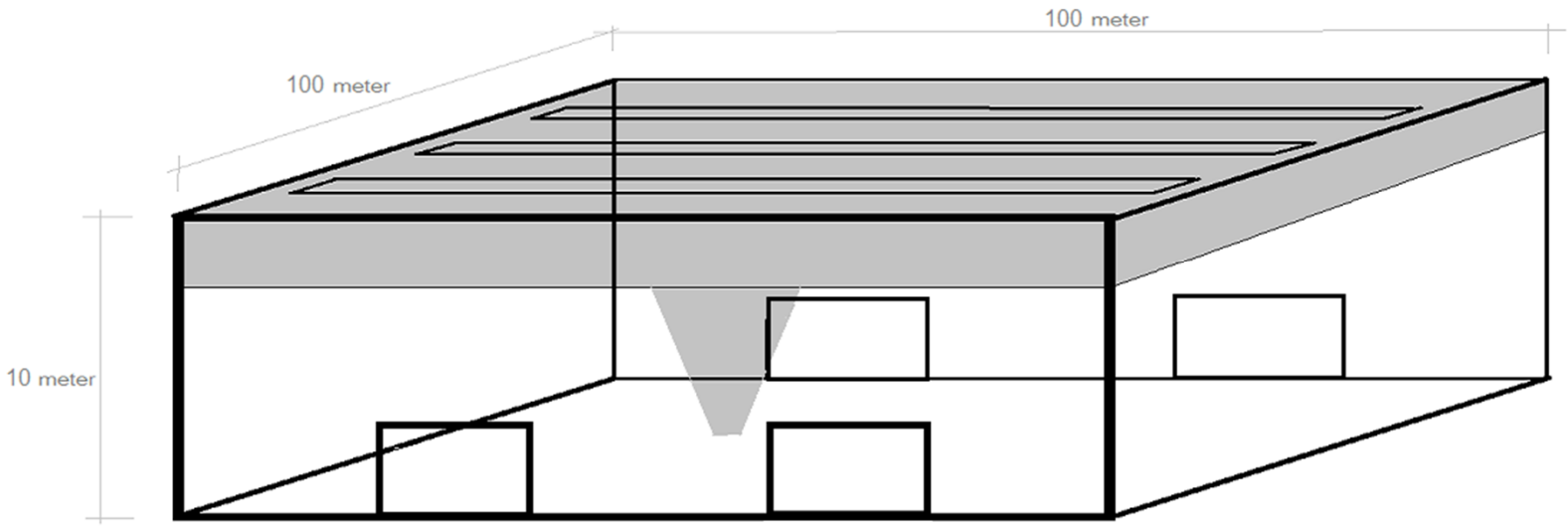

Bolton, UK

# Example: Market hall

**Combination of fire load and people in a large compartment:**

- Post flashover situation is important for safety of adjacent compartments, buildings and plots
- Pre flashover situation is important for safety of building users:
  - ASET > RSET for a safe situation
    - ASET: available safe egress time (depending on smokelayer conditions)
    - RSET: required safe egress time (depending on evacuation time)

# Market hall




Market hall, simplified model
10,000 $m^2$ floor area
10 m height

# Market hall, boundary conditions

**Mean conditions for ASET (smokelayer calculations):**

- Uniform distribution of fire load (fuel):
  - RHR = 250 kW/m$^2$ (medium)
  - Time constant tc = 150 s (fast)
  - Plume = Heskestad
  - Stoichiometric constant r = 1,27 (cellulose fuel)
- External separation constructions: adiabatic
- Smoke outlet system A(net) = 20 x 3 = 60 m$^2$ automatic
- Air inlet A(net) = 4 x (3 x 3) = 36 m$^2$ automatic
- Detection time = 5 min.

# Market hall, boundary conditions

**Mean conditions for RSET (evacuation calculations):**

- Uniform distribution of people
  - Number of people N = 4000 (mean)
- 3 exits available (mean)
- Max. walking distance = 135 m (90 m straight line)
- Walking speed = 1 m/s
- Detection time = 5 min.

# Market hall, assessment ASET / RSET

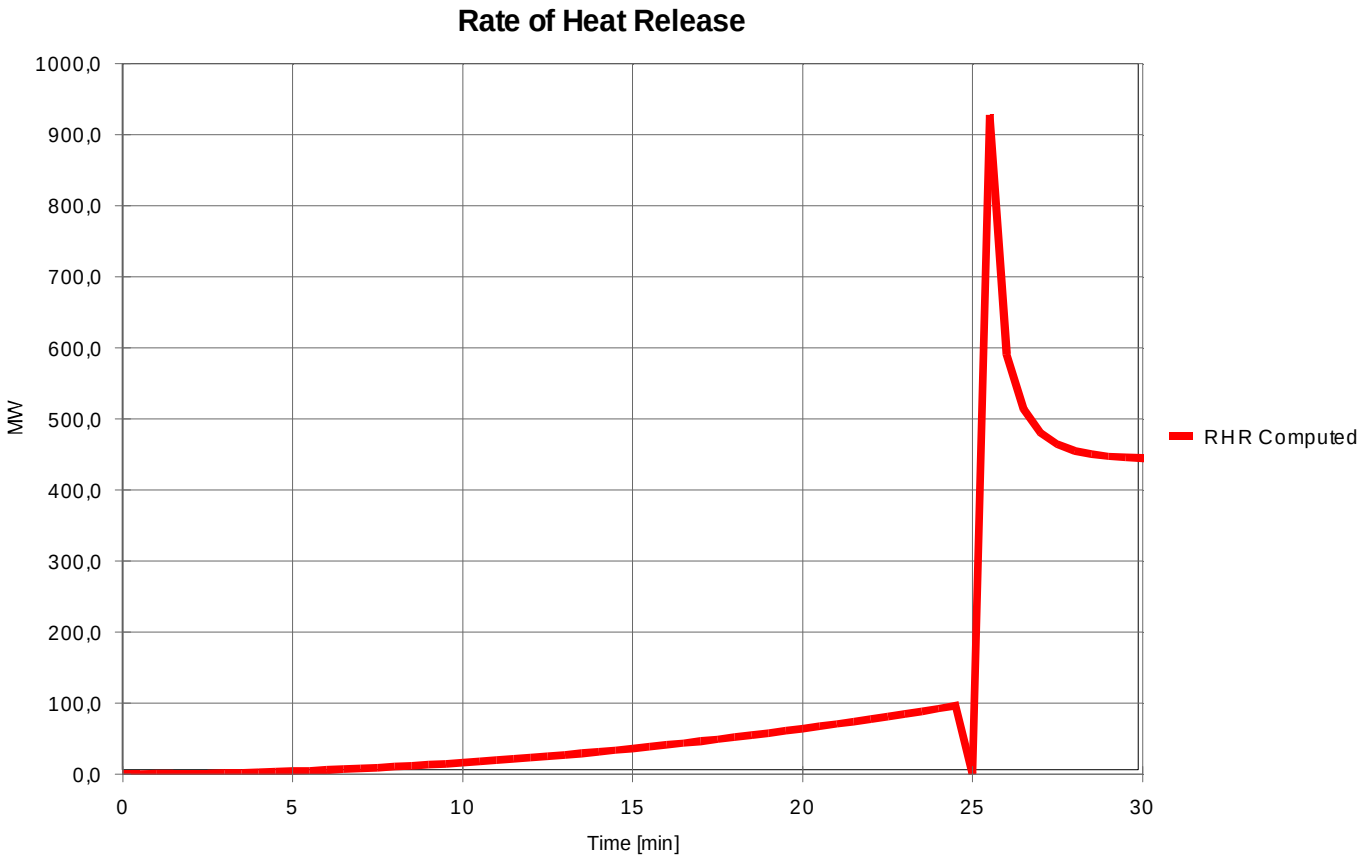
**ASET:**

- Assessment criteria:
  - Smokefree height > 2,5 meter
  - Smokelayer temperature < 200 $^{o}$C

**RSET:**

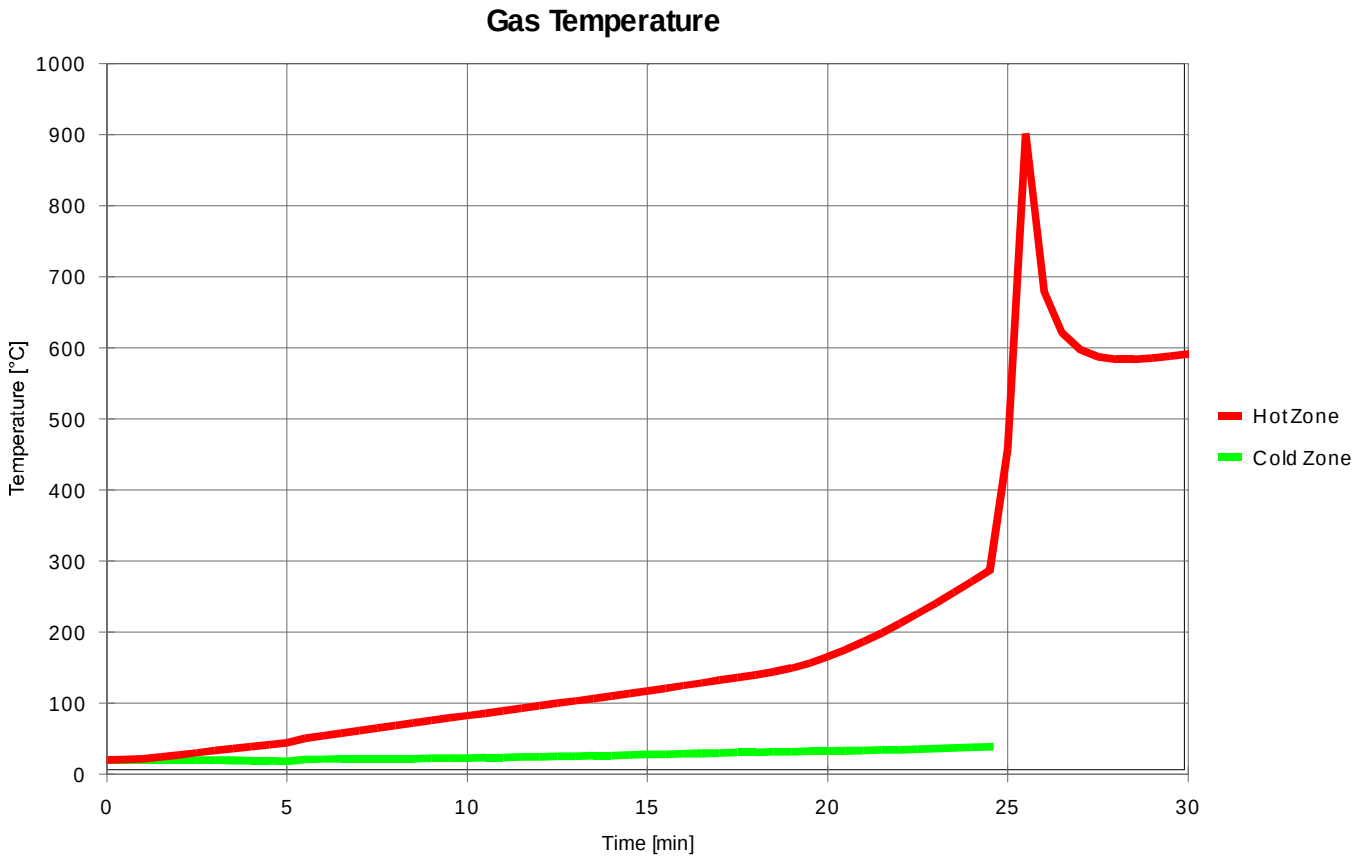
- Assessment criteria:
  - 100 % of building occupants outside compartment

# Market hall, ASET



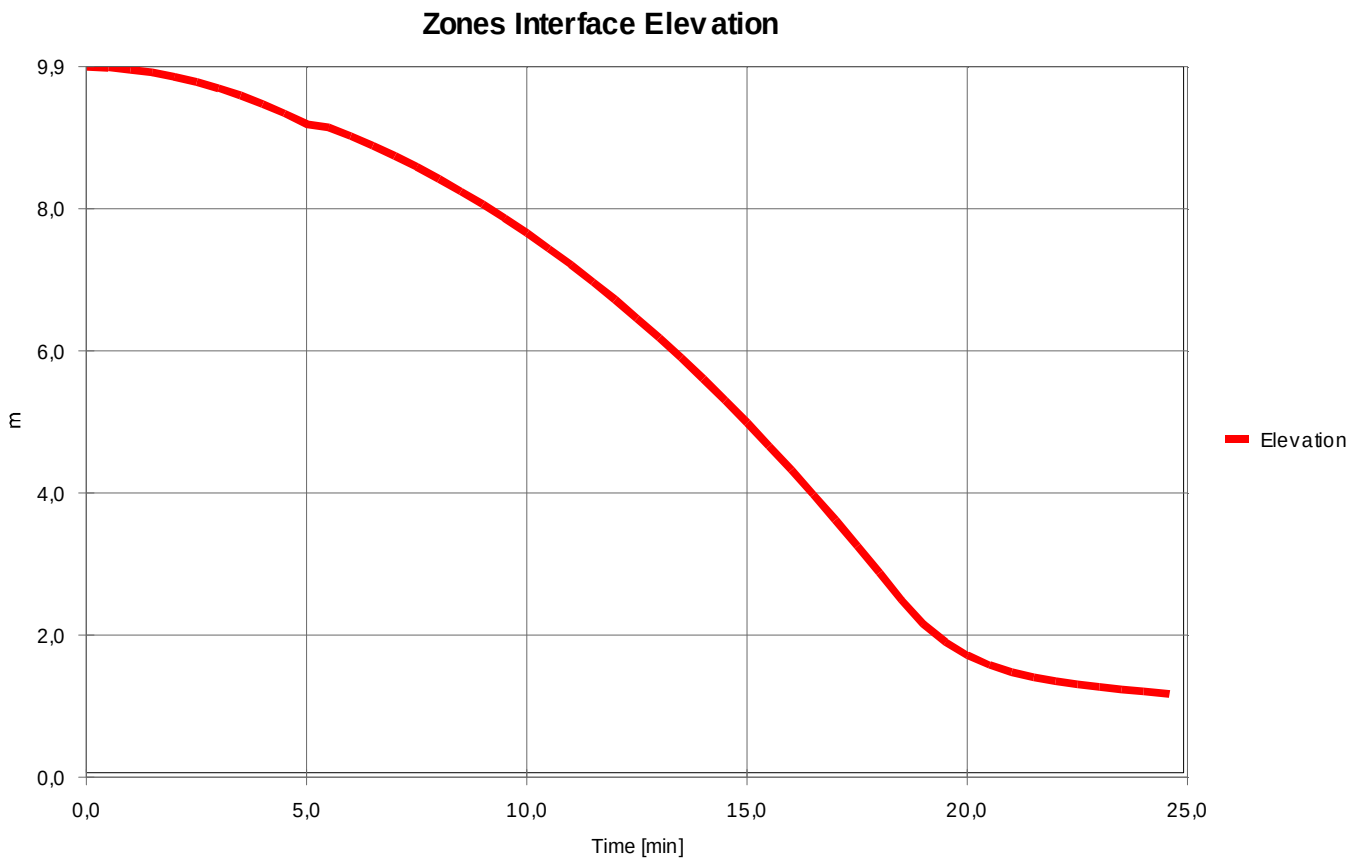

Analysis Name: IFV-case Markethall basis

# Market hall, ASET




Analysis Name: IFV-case Markethall basis

# Market hall, ASET




Analysis Name: IFV-case Markethall basis

# Market hall, ASET

| ASET | T < 200 °C | H > 2,5 m |
|---|---|---|
| Mean fire conditions | < 21,5 min. | < 18,5 min. |

Taking into account uncertainties in boundary conditions:
What parameters are stochastic?

- Building characteristics
- Fuel characteristics

# Market hall, ASET

| ASET | T < 200 °C | H > 2,5 m |
|---|---|---|
| Mean fire conditions | < 21,5 min. | < 18,5 min. |
| Fire load q (+0,3) | | |
| Rate of heat release RHR (+0,5) | | |
| Time constant for fire spread (-0,3) | | |
| Start plume - reference height (-0,5) | | |
| Detection time (+0,3) | | |
| Net opening (air supply) (-0,05) | | |
| Net opening (air exhaust) (-0,05) | | |

# Market hall, ASET

| ASET | T < 200 °C | H > 2,5 m |
|---|---|---|
| Mean fire conditions | < 21,5 min. | **< 18,5 min.** |
| Fire load q (+0,3) | < 21,5 min. | **< 18,5 min.** |
| Rate of heat release RHR (+0,5) | **< 20,0 min.** | < 25,0 min. |
| Time constant for fire spread (-0,3) | < 16,7 min. | **< 14,1 min.** |
| Start plume - reference height (-0,5) | < 24,5 min. | **< 18,0 min.** |
| Detection time (+0,3) | < 21,5 min. | **< 18,4 min.** |
| Net opening (air supply) (-0,05) | N.A. | N.A. |
| Net opening (air exhaust) (-0,05) | N.A. | N.A. |

# Market hall, RSET

| RSET | | 100% out |
|---|---|---|
| Mean building users conditions | 5 + 4,9 = | 9,9 min. |

Taking into account uncertainties in boundary conditions:
What parameters are stochastic?

- Building occupants characteristics

# Market hall, RSET

| RSET | | 100% out |
|---|---|---|
| Mean building users conditions | 5 + 4,9 = | 9,9 min. |
| Number of people (+0,3) | 5 + 6,4 = | 11,4 min. |
| Number of exits (-0,33) | 5 + 7,4 = | 12,4 min. |
| Walking speed (-0,5) | | N.A. |
| Other group characteristics | | N.A. |
| Detection time (+0,3) | 6,5 + 4,9 = | 11,4 min. |

# When is safe safe enough?

**Take into account uncertainty of boundary conditions (stochastic parameters)**

**Calculate failure probability:**

- P (ASET – RSET) < 0

**Define acceptable failure probability:**

- Example Eurocode 1 (for structural safety):
  - CC 1: P(f) < 4,83E-04 (beta > 3,3)
  - CC 2: P(f) < 7,23E-05 (beta > 3,8)
  - CC 3: P(f) < 8,54E-06 (beta > 4,3)

# When is safe safe enough?

PROBABILISTISCHE BEREKENING PRE-FLASHOVER BRAND
BESCHIKBARE TIJD EN BENODIGDE TIJD VOOR VLUCHTEN

Rookvrije hoogte H
Casus: Markethall

| variantenstudie randcondities | | | deterministisch gemiddeld x | deterministisch ASET; RSET t [min] |
|---|---|---|---|---|
| **RHR** | ref. brandvermogensdichtheid | kW/m$^2$ | 250 | |
| **tc** | tijdconstante | s | 150 | ASET = |
| **q** | vuurbelasting (variabel) | MJ/m$^2$ | 600 | 18.5 |
| **hp** | starthoogte pluim | m | 1 | |
| **Tdetect** | Detection time | min | 5 | |
| **N** | aantal aanwezigen | pers. | 4000 | RSET = |
| **Exits** | aantal uitgangen | - | 3 | 9.9 |
| | | | ASET-RSET | 8.6 |

| gevoeligheidsanalyse variatie V | st. deviatie s | variant x + dx | ASET-RSET t [min] |
|---|---|---|---|
| 0.50 | 125 | 375 | 15.1 |
| -0.30 | -45 | 105 | 4.1 |
| 0.30 | 180 | 780 | 8.6 |
| -0.50 | -0.5 | 0.5 | 8.1 |
| 0.30 | 1.5 | 6.5 | 7.0 |
| 0.30 | 1200 | 5200 | 7.1 |
| -0.33 | -1 | 2 | 8.6 |

| standaardafwijking dt/dx | s·dt/dx | (s·dt/dx)$^2$ |
|---|---|---|
| 0.05 | 6.50 | 42.25 |
| 0.10 | -4.42 | 19.51 |
| 0.00 | 0.00 | 0.00 |
| 1.00 | -0.50 | 0.25 |
| -1.06 | -1.58 | 2.51 |
| 0.00 | -1.48 | 2.19 |
| 0.00 | 0.00 | 0.00 |
| | variantie(t) = | 66.709 |
| | s(t) = | 8.168 |

maatgevend incident: lokale brand

oppervlakte [m$^2$] : 10000
instandhoudingsduur [jr] : 50
ontstaanskans [m$^{-2}$] : 2.00E-06

kans op brand p(fi) : 2.00E-02

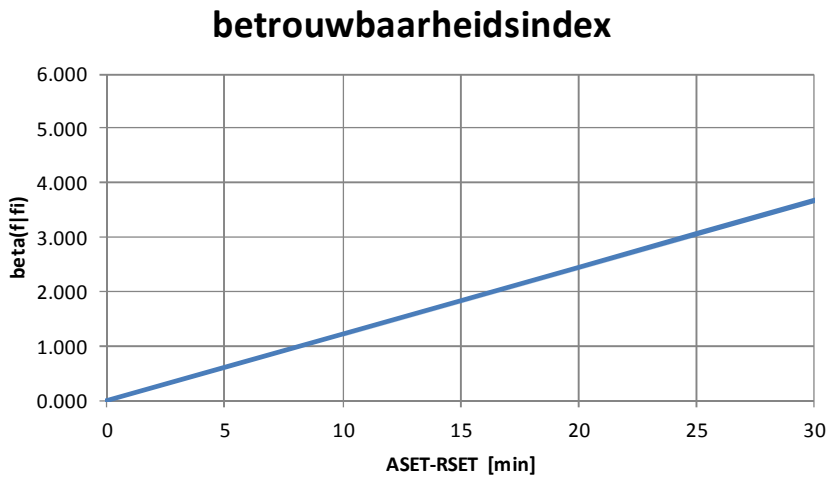
| | p(f) | p(f\|fi) | beta(f\|fi) |
|---|---|---|---|
| CC1: beta(f) > 3,3 | 4.83E-04 | 2.42E-02 | 1.97 |
| CC2: beta(f) > 3,8 | 7.23E-05 | 3.62E-03 | 2.69 |
| CC3: beta(f) > 4,3 | 8.54E-06 | 4.27E-04 | 3.33 |

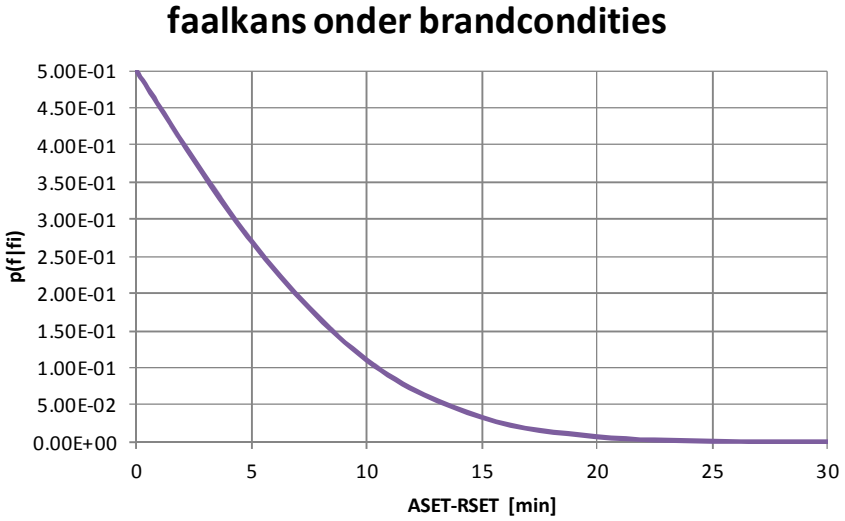
| betrouwbaarheid en faalkans (overschrijding) t [min] | s(t) | beta(f\|fi) | p(f\|fi) |
|---|---|---|---|
| 0 | 8.16754 | 0.000 | 5.00E-01 |
| 5 | 8.16754 | 0.612 | 2.70E-01 |
| 10 | 8.16754 | 1.224 | 1.10E-01 |
| 15 | 8.16754 | 1.837 | 3.31E-02 |
| 20 | 8.16754 | 2.449 | 7.17E-03 |
| 25 | 8.16754 | 3.061 | 1.10E-03 |
| 30 | 8.16754 | 3.673 | 1.20E-04 |
| 35 | 8.16754 | 4.285 | 9.13E-06 |
| 40 | 8.16754 | 4.897 | 4.85E-07 |
| 45 | 8.16754 | 5.510 | 1.80E-08 |
| 50 | 8.16754 | 6.122 | 4.63E-10 |

# When is safe safe enough?

## Smokefree height vs. evacuation time

**Betrouwbaarheidsindex en faalkans onder brandcondities als functie van het tijdsinterval ASET-RSET**



# When is safe safe enough?

PROBABILISTISCHE BEREKENING PRE-FLASHOVER BRAND
BESCHIKBARE TIJD EN BENODIGDE TIJD VOOR VLUCHTEN

Rooklaagtemperatuur Tu
Casus: Markethall

| variantenstudie randcondities | | | deterministisch gemiddeld x | deterministisch ASET; RSET t [min] |
|---|---|---|---|---|
| **RHR** | ref. brandvermogensdichtheid | kW/m$^2$ | 250 | |
| **tc** | tijdconstante | s | 150 | ASET = |
| **q** | vuurbelasting (variabel) | MJ/m$^2$ | 600 | 21.5 |
| **hp** | starthoogte pluim | m | 1 | |
| **Tdetect** | Detection time | min | 5 | |
| **N** | aantal aanwezigen | pers. | 4000 | RSET = |
| **Exits** | aantal uitgangen | - | 3 | 9.9 |
| | | | ASET-RSET | 11.6 |

| gevoeligheidsanalyse variatie V | st. deviatie s | variant x + dx | ASET-RSET t [min] |
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| 0.50 | 125 | 375 | 10.1 |
| -0.30 | -45 | 105 | 6.7 |
| 0.30 | 180 | 780 | 11.6 |
| -0.50 | -0.5 | 0.5 | 14.6 |
| 0.30 | 1.5 | 6.5 | 10.1 |
| 0.30 | 1200 | 5200 | 10.1 |
| -0.33 | -1 | 2 | 11.6 |

| standaardafwijking dt/dx | s·dt/dx | (s·dt/dx)$^2$ |
|---|---|---|
| -0.01 | -1.50 | 2.25 |
| 0.11 | -4.83 | 23.36 |
| 0.00 | 0.00 | 0.00 |
| -6.00 | 3.00 | 9.00 |
| -1.00 | -1.50 | 2.25 |
| 0.00 | -1.48 | 2.19 |
| 0.00 | 0.00 | 0.00 |
| | variantie(t) = | 39.056 |
| | s(t) = | 6.249 |

maatgevend incident: lokale brand

oppervlakte [m$^2$] : 10000
instandhoudingsduur [jr] : 50
ontstaanskans [m$^{-2}$] : 2.00E-06

kans op brand p(fi) : 2.00E-02

| | p(f) | p(f\|fi) | beta(f\|fi) |
|---|---|---|---|
| CC1: beta(f) > 3,3 | 4.83E-04 | 2.42E-02 | 1.97 |
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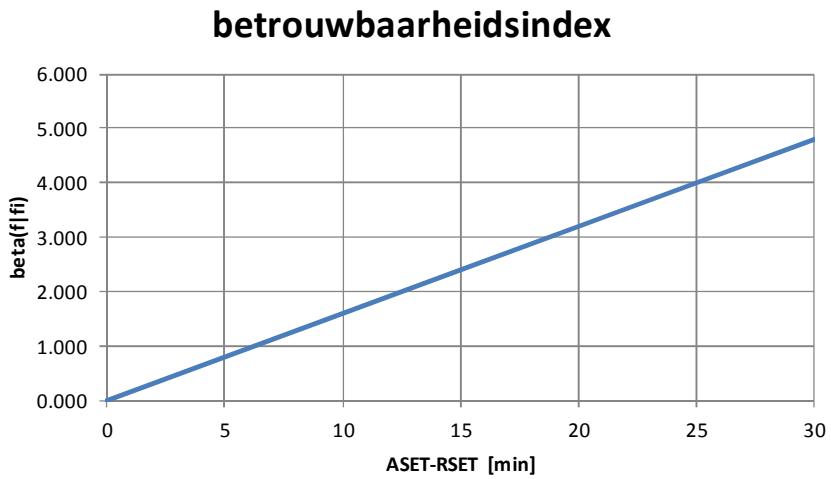
| CC3: beta(f) > 4,3 | 8.54E-06 | 4.27E-04 | 3.33 |

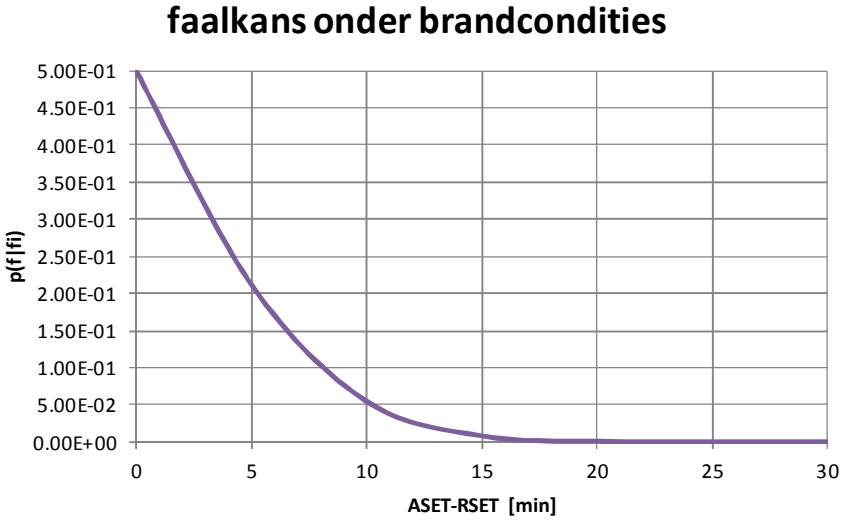
| betrouwbaarheid en faalkans (overschrijding) t [min] | s(t) | beta(f\|fi) | p(f\|fi) |
|---|---|---|---|
| 0 | 6.24947 | 0.000 | 5.00E-01 |
| 5 | 6.24947 | 0.800 | 2.12E-01 |
| 10 | 6.24947 | 1.600 | 5.48E-02 |
| 15 | 6.24947 | 2.400 | 8.19E-03 |
| 20 | 6.24947 | 3.200 | 6.86E-04 |
| 25 | 6.24947 | 4.000 | 3.16E-05 |
| 30 | 6.24947 | 4.800 | 7.92E-07 |
| 35 | 6.24947 | 5.600 | 1.07E-08 |
| 40 | 6.24947 | 6.401 | 7.74E-11 |
| 45 | 6.24947 | 7.201 | 3.00E-13 |
| 50 | 6.24947 | 8.001 | 6.19E-16 |

# When is safe safe enough?

## Smokelayer temperature vs. evacuation time

**Betrouwbaarheidsindex en faalkans onder brandcondities als functie van het tijdsinterval ASET-RSET**



# When is safe safe enough?

## Reliability of ASET-RSET results

| ASET – RSET (min) | T < 200 °C | H > 2,5 m |
|---|---|---|
| 0 | 50 % | 50 % |
| 5 | 78.8 % | 73 % |
| 10 | 94.5 % | 89 % |
| 15 | 99.2 % | 96.7 % |
| 20 | 99.9 % | 99.3 % |
| 25 | 100 % | 99.9 % |