Technische Universität Braunschweig

iBMB MPA TU BRAUNSCHWEIG

National Annex EC 1-1-2 Germany

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  Technische Universität Braunschweig

Annex A

Weakenings/deficiencies of EN 1991-1-2 annex A

- For fuel-controlled fires, the time of maximum temeparture „is fixed“ => very strong simplification

(7) The maximum temperature Θ_{max} in the heating phase happens for $t^* = t^*_{max}$

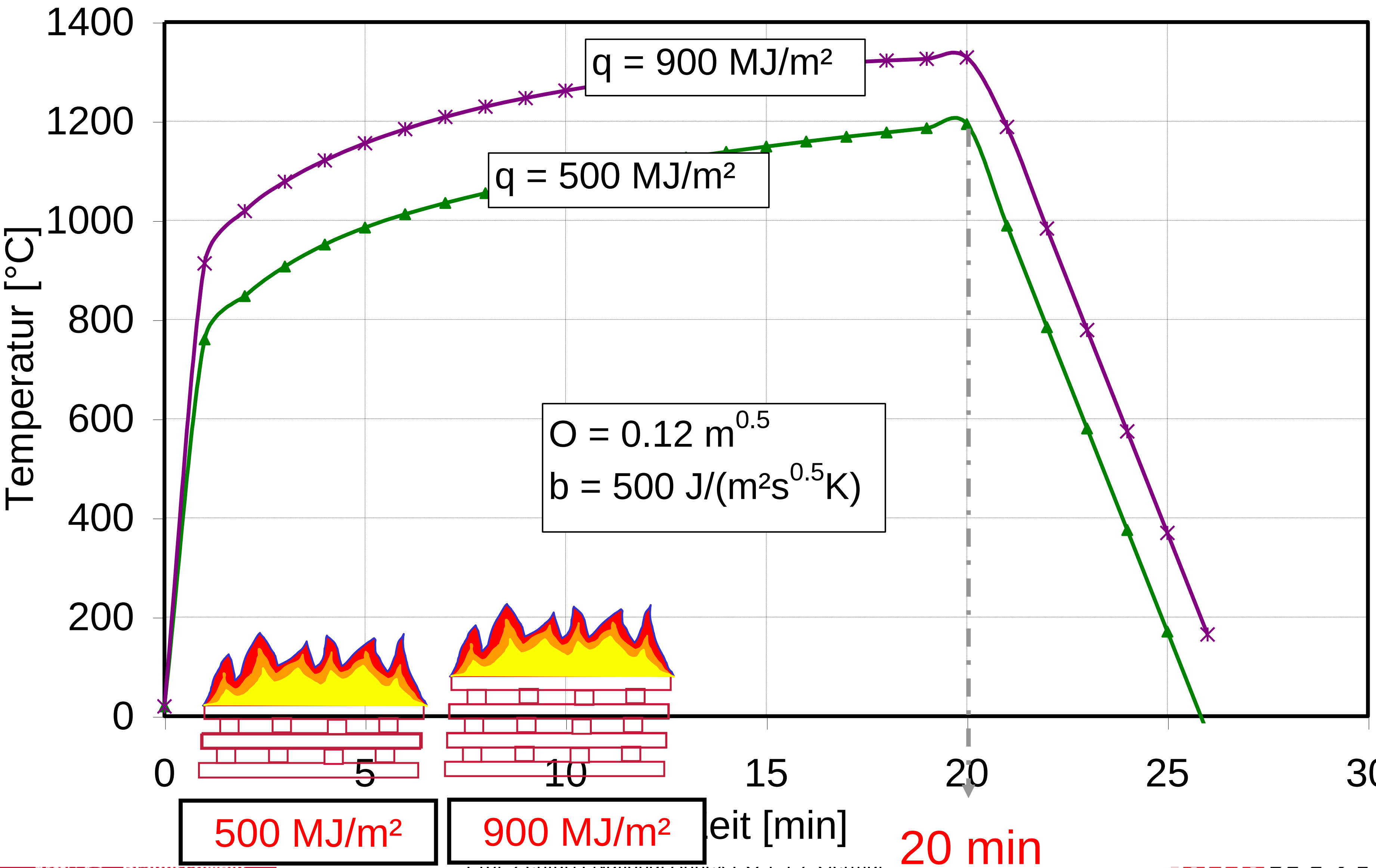
$$t^*_{max} = t_{max} \cdot \Gamma \quad [h]$$

with $t_{max} = \max [(0{,}2 \cdot 10^{-3} \cdot q_{t,d} / O) ; t_{lim}]$ [h]

(10) In case of slow fire growth rate, t_{lim} = 25 minutes; in case of medium fire growth rate, t_{lim} = 20 minutes and in case of fast fire growth rate, t_{lim} = 15 minutes.

- Decrease phase
  - For fire compartments with large openings and small thermal properties of enclosure => parametric curves provide a very fast decrease
  - For fire compartments with small openings and high thermal properties of enclosure => parametric curves provide a very slow decrease
- No temporal connection with RHR
- No flashover consideration

Fire load density



Comparing calculations with real fire tests

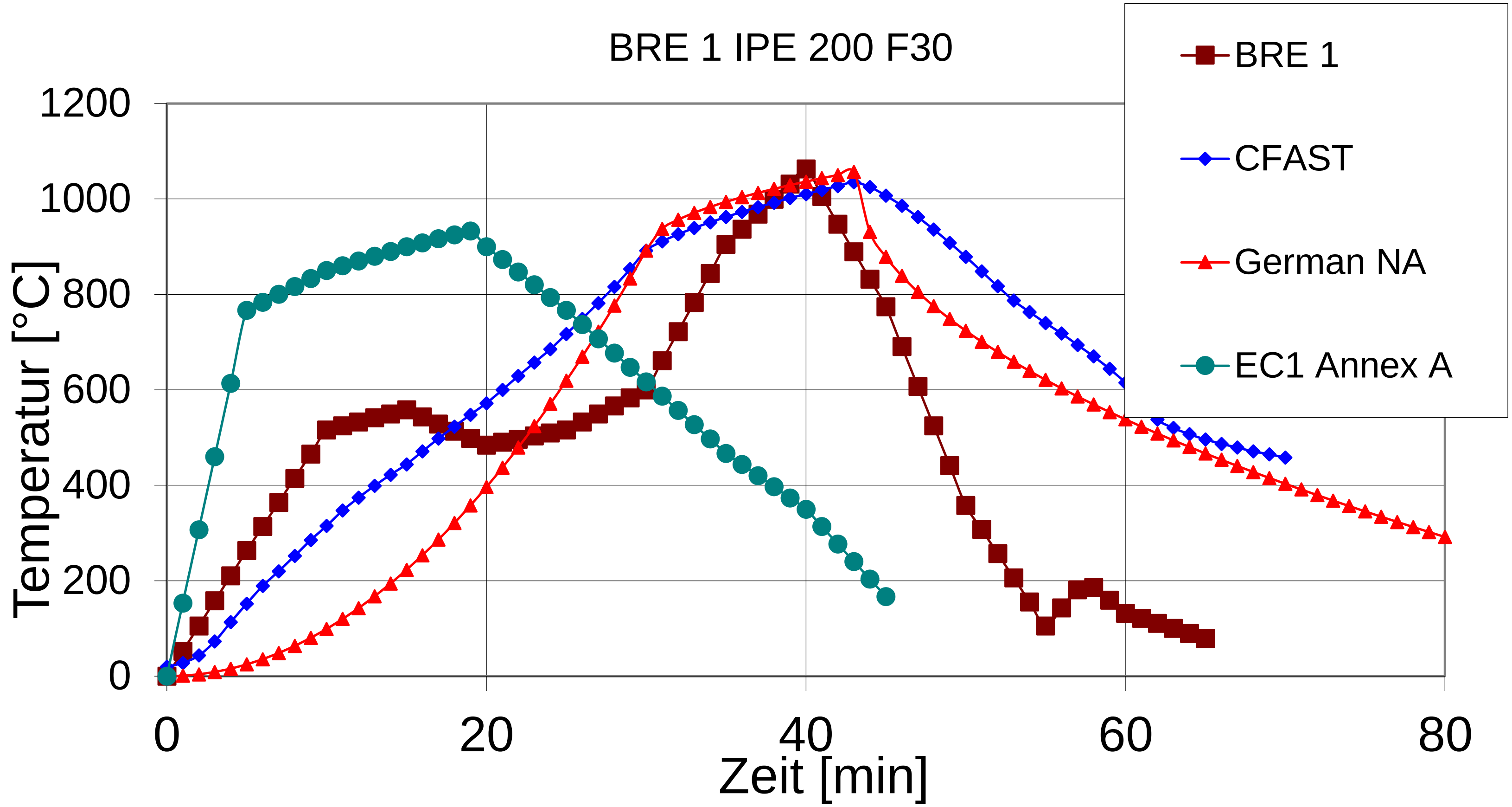
Tabelle 4 Randbedingungen der dokumentierte Brandversuche

	Versuch	BRE1	BRE2	BRE3	BRE4	CAR 6	HOT_1	HOT_2	HOT_3	LAT1	LAT2	LAT3	LAT4	LAT
Raum	Breite [m]	12	12	12	12.00	18.00	14.40	20.40	7.40	8.66	8.66	8.66	8.66	8.6
	Länge [m]	12	12	12	12.00	7.50	7.20	7.20	7.20	5.87	5.87	5.87	5.87	5.8
	Grundfläche [m²]	144	144	144	144	135	103.7	146.9	53.28	50.83	50.83	50.83	50.83	50.8
	Höhe [m]	4.00	4.00	4.00	4.00	4.00	3.50	3.60	3.60	3.90	3.90	3.90	3.90	3.9
Öffnung	Breite [m]	7.20	7.20	7.20	14.40	18.00	2.13	2.60	3.00	7.31	3.65	3.65	3.65	1.8
	Höhe [m]	3.40	3.40	3.40	1.70	2.00	2.97	3.00	1.24	2.31	2.31	2.31	2.31	2.3
	Brüstungshöhe [m]	0	0	0	1.7	0.8	0	0	1.76	0.75	0.75	0.75	0.75	0.7
Umfassungsbauteile	Dicke [m]	0.15 *)	0.12*)	0.12*)	0.12*)	0.1533 *)	0.3	0.3	0.3	0.19*)	0.19*)	0.19*)	0.19*)	0.19
	Wärmeleit-fähigkeit [W/(mK)]	0.97 *)	0.56 *)	0.56 *)	0.56 *)	0.59 *)	0.12	0.12	0.12	0.64 *)	0.64 *)	0.64 *)	0.64 *)	0.64
	Dichte [kg/m³]	1842 *)	1314 *)	1314 *)	1314 *)	1433 *)	500	500	500	1540 *)	1540 *)	1540 *)	1540 *)	1540
	Wärmekapazität [J/(kgK)]	1018 *)	957 *)	957 *)	957 *)	927 *)	1050	1050	1050	1100 *)	1100 *)	1100 *)	1100 *)	1100
	Emissionsgrad [-]	0.9	0.9	0.9	0.9	0.9	0.85	0.85	0.85	0.9	0.9	0.9	0.9	0.9
Brandlast	Brandlast	Holz	Holz	Holz+P	Holz	Möbel	Holz	Holz	Holz	Holz	Holz	Holz	Holz	Hol
	Brandlastdichte [kg/m²]	40.0	40.0	40.0	40	46.26	19.18	12.36	18.77	15.0	10.0	15.0	20.0	15.
Literatur		SCL00	SCL00	SCL00	SCL00	CAR01	HOT98	HOT98	HOT98	LAT87	LAT87	LAT87	LAT87	LAT

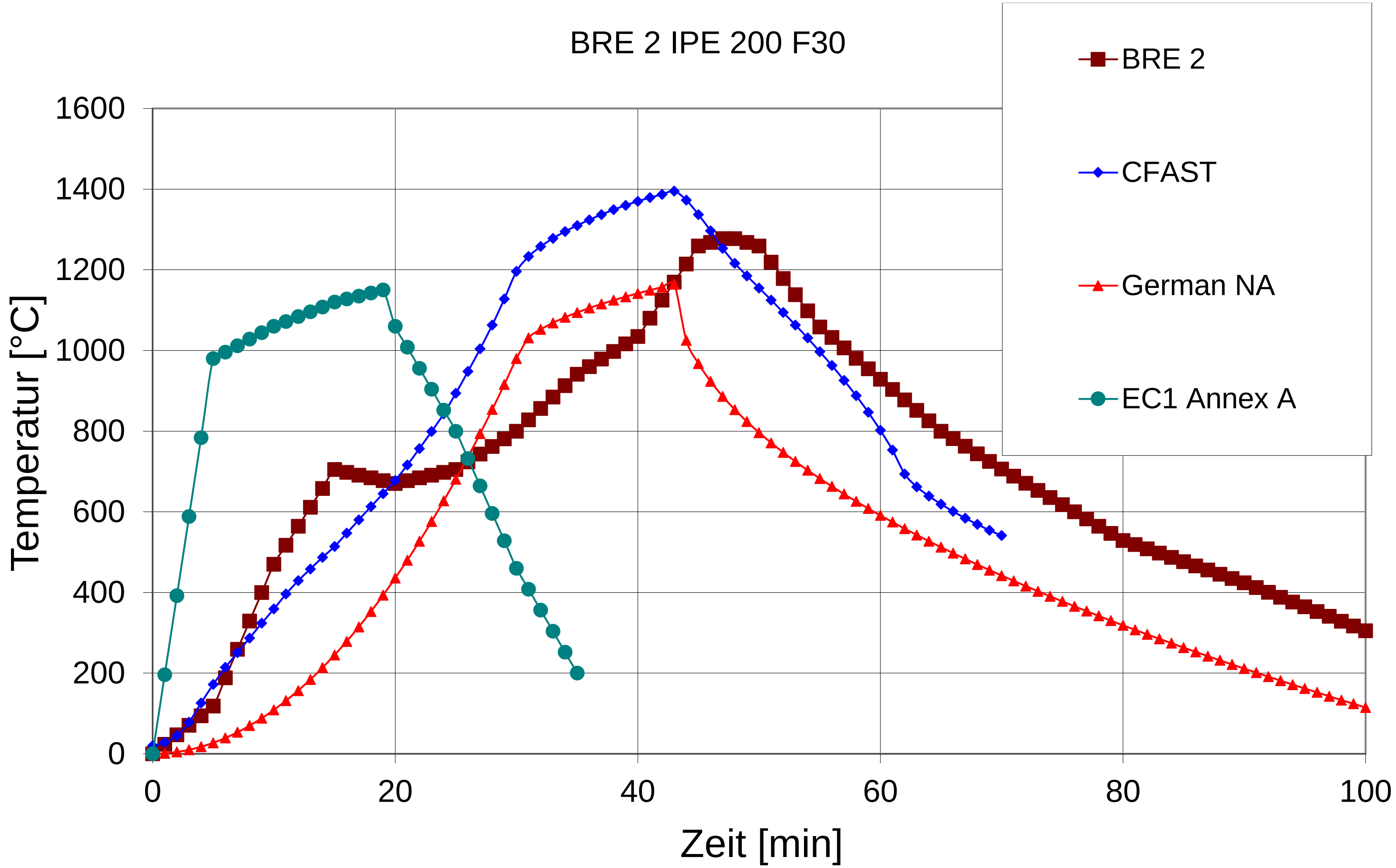
	Versuch	LEHRTE 8	LEHRTE_B	LEHRTE_W	METZ1	METZ2	METZ3	METZ4	SFB	VTT1	VTT2	ZEH
Raum	Breite [m]	3.59	3.59	3.59	3.38	3.38	3.38	3.38	7.2	4	4	3,60
	Länge [m]	5.05	5.05	5.05	3.68	3.68	3.68	3.68	7.4	2.2	2.2	3,60
	Grundfläche [m²]	18.1295	18.1295	18.1295	12.44	12.44	12.44	12.44	53.28	8.8	8.8	12,96
	Höhe [m]	2.50	2.50	2.50	3.13	3.13	3.13	3.13	3.60	2.6	2.6	2,60
Öffnung	Breite [m]	2.61	1.18	1.18	1.18	1.18	1.95	1.18	1.20	3.0	3	0,70
	Höhe [m]	1.66	1.66	1.66	2.18	2.18	2.18	2.18	3.00	1.2	1.2	1,80
	Brüstungshöhe [m]	0.80	0	0	0	0	0	0.95	0	0.8	0.8	0
Umfassungsbauteile	Dicke [m]	0.16 *)	0.16 *)	0.16 *)	0.25	0.25	0.25	0.1625 *1)	0.26	0.2	0.2	0,25*)
	Wärmeleit-fähigkeit [W/(mK)]	1.29 *)	1.29 *)	1.29 *)	1.0	1.0	1.0	0.69 *1)	0.25	0.35	0.35	1,25*)
	Dichte [kg/m³]	1813 *)	1813 *)	1813 *)	1950	1950	1950	1750 *1)	625	500	500	1850*)
	Wärmekapazität [J/(kgK)]	917 *)	917 *)	917 *)	1000	1000	1000	880 *1)	1000	1000	1000	920*)
	Emissionsgrad [-]	0.89 *)	0.89 *)	0.89 *)	0.65	0.65	0.65	0.65	0.85	0.9	0.9	0,8
Brandlast	Brandlast	Holz	Möbel	Möbel	Holz	Holz	Holz	Holz	Holz	Holz	Holz	Möbel, Papier, Kunststoff
	Brandlastdichte [kg/m²]	90.00	39.0	32.0	30.0	60.0	30.0	29.91	18.8	33.41	71	468
Literatur		BM78	BM78	BM78	SFB148	SFB148	SFB148	SCL01.2	SFB86.6	RAN00	RAN00	ZEH02.4

*) gemittelte Werte

EC 1-1-2 curves have problems with temporal course

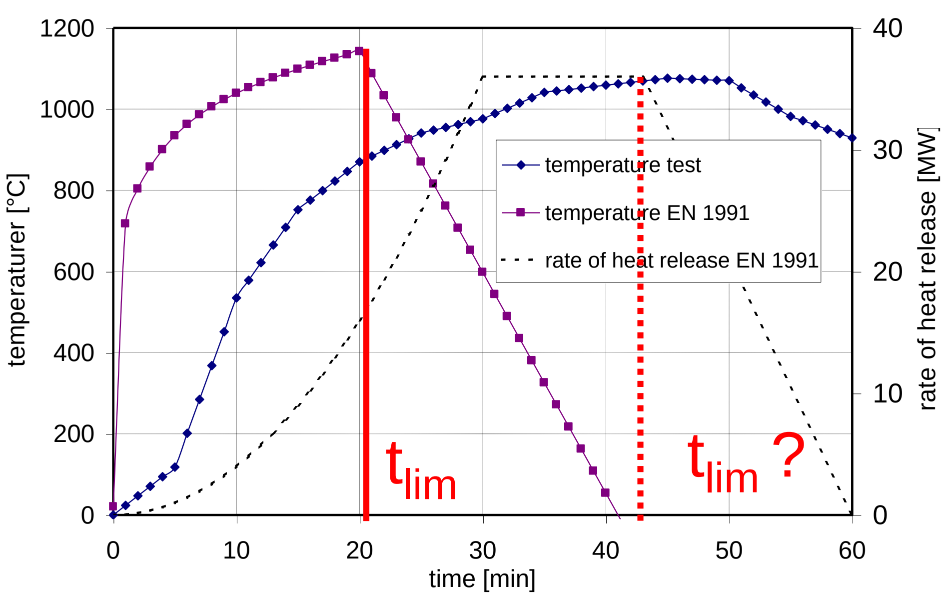


EC 1-1-2 curves have problems with temporal course



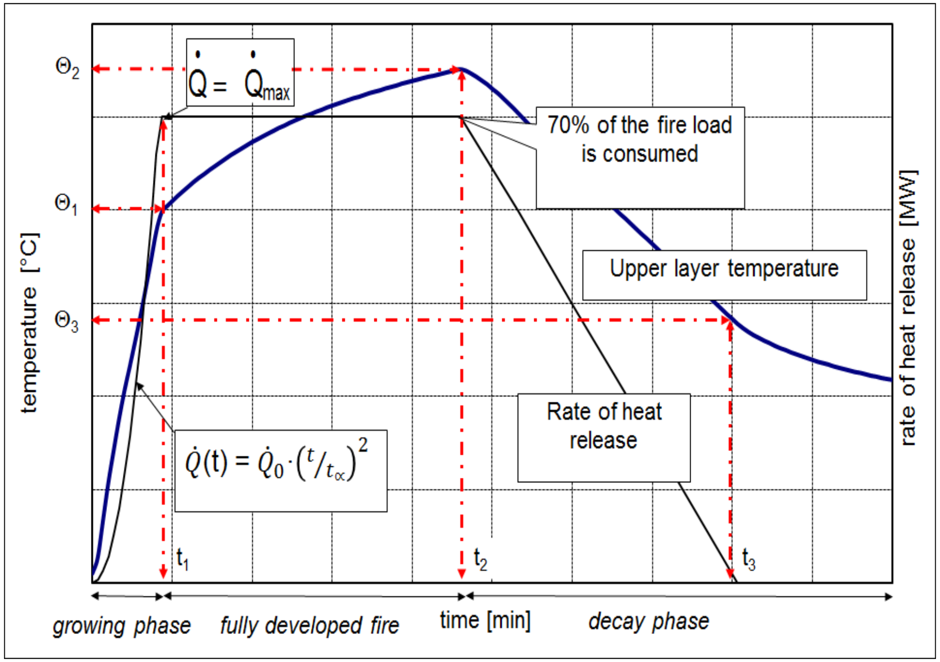
Parametric temperature-time curves

- EC 1-1-2 annex A



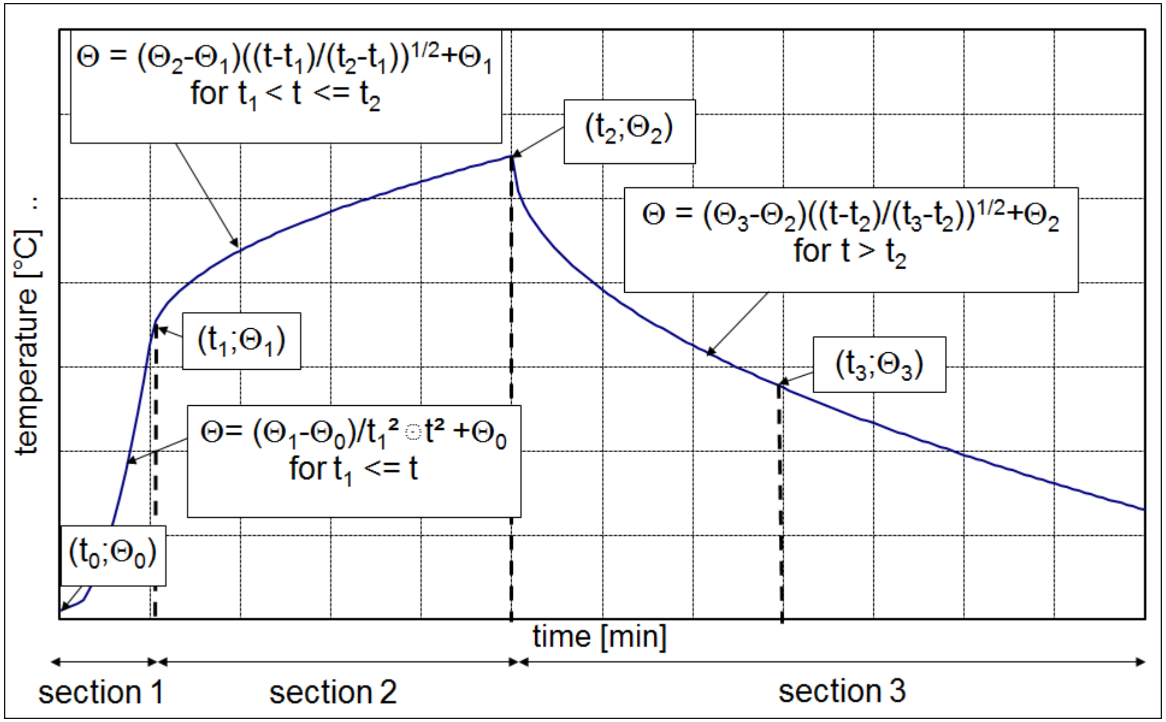
no temporal correlation between RHR and parametric curves

- German national annex AA



rate of heat release and temperature-time curve fit together

Definition of parametric temp.-time curves (German annex AA)



$$k = \left(\frac{\dot{Q}_{max,f}^{2}}{A_w \sqrt{h_w} \cdot A_T \cdot b} \right)^{1/3}$$

ventilation-controlled:

Θ_1 = -8.75 · 1/O – 0.1 b + 1175 [°C]

Θ_2 = (0.004 b -17) · 1/O – 0.4 b + 2175 [°C]

Θ_3 = -5.0 · 1/O – 0.16 b + 1060 [°C]

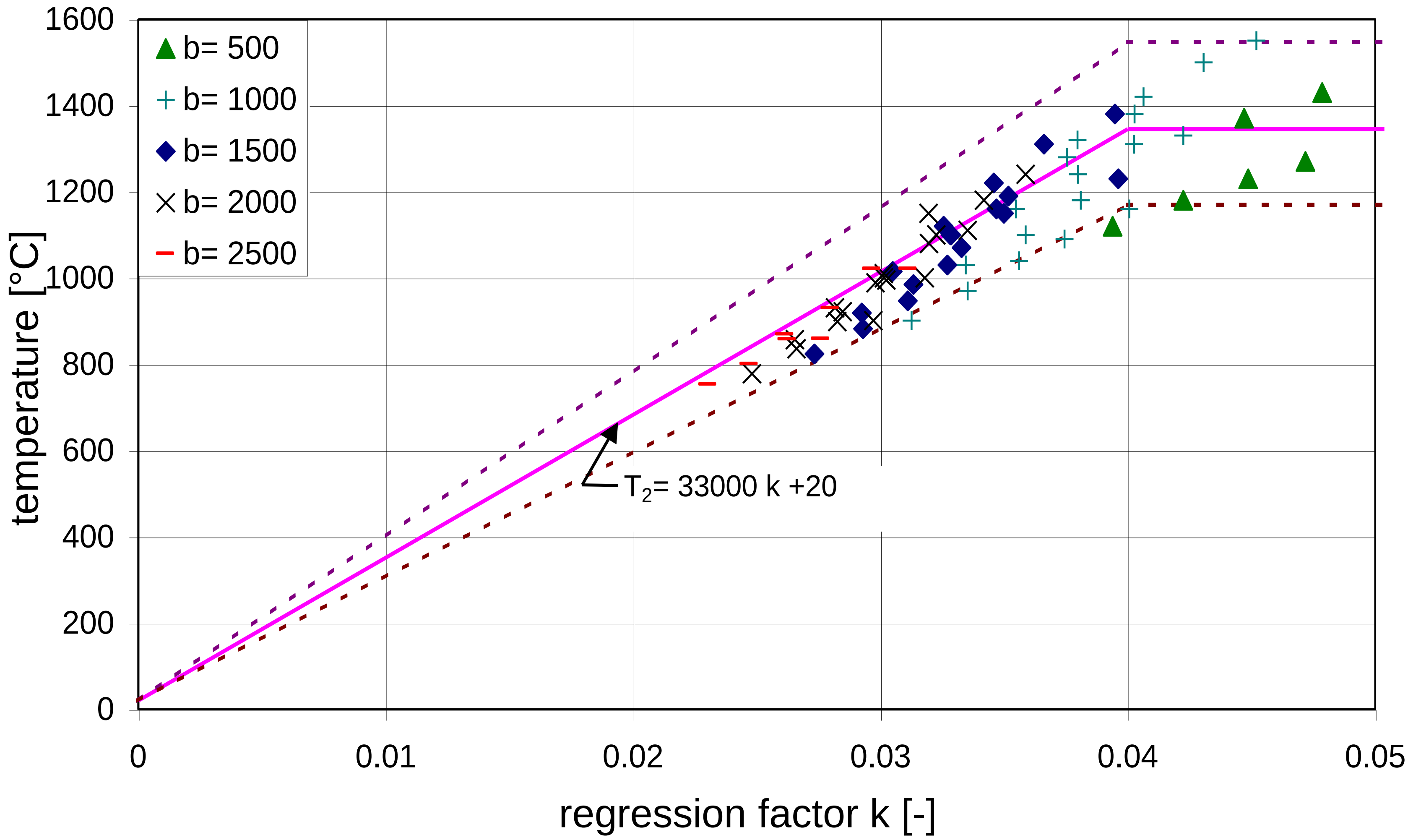
fuel-controlled:

Θ_1 = 24000 k + 20 [°C]

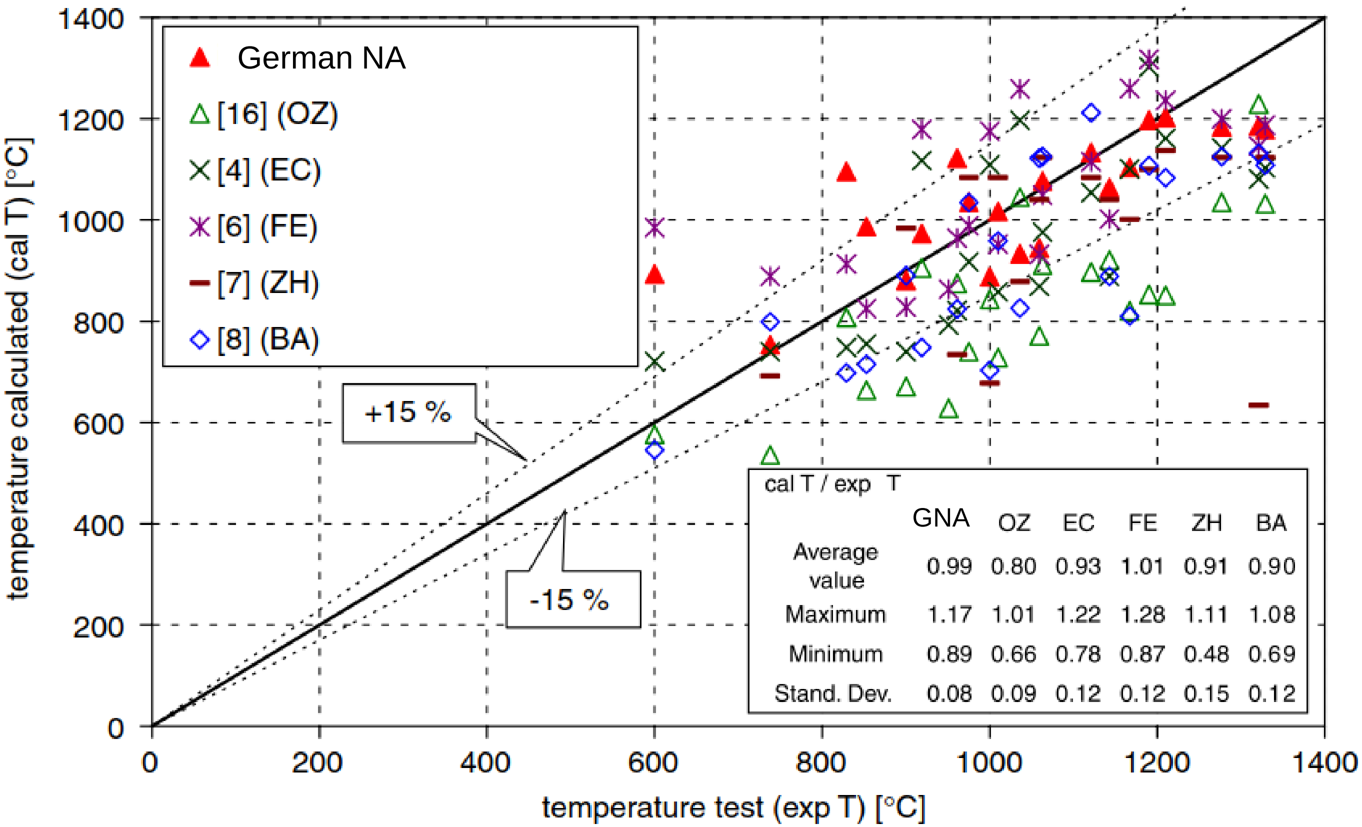
Θ_2 = 33000 k + 20 [°C]

Θ_3 = 16000 k + 20 [°C]

Comparison with zone model CFAST



Comparison of different methods



cal T / exp T

	GNA	OZ	EC	FE	ZH	BA
Average value	0.99	0.80	0.93	1.01	0.91	0.90
Maximum	1.17	1.01	1.22	1.28	1.11	1.08
Minimum	0.89	0.66	0.78	0.87	0.48	0.69
Stand. Dev.	0.08	0.09	0.12	0.12	0.15	0.12

Parametric fire curves in German NA

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A parametric natural fire model for the structural fire design of multi-storey buildings

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Received 17 September 2004; received in revised form 10 July 2006; accepted 8 August 2006

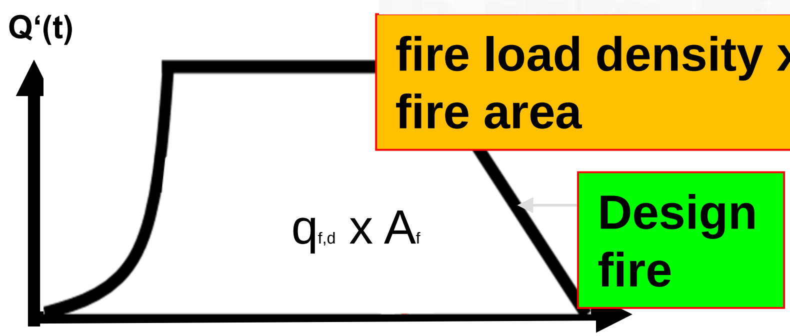
Annex E

Safety concept annex E - background

- Eurocodes
  - semi-probabilistic safety concept
  - probability of a failure of the building (or structural member) is at least as low as 10E-6
- Design rules of the Eurocodes
  - partial safety and combination factors for loads and partial safety factors for material properties
- FSE
  - similar safety concept should be applied to ensure sufficient safety in case of a fire

- Annex E of Eurocode 1 (EN 1991-1-2) incorporates a safety concept that affects the fire load density q
- Design value of q according to equation E.1:

$$q_{f,d} = q_{f,k} \cdot m \cdot \gamma_{q1} \cdot \gamma_{q2} \cdot \gamma_n \qquad [MJ/m^2]$$



- Fire load density is not the only important input parameter especially for steel structures the maximum heat release rate has more significant effect

Problem with EC 1-1-2 Annex E

Table E.2 : Partial factors γ_{ni}

γ_{ni} Function of Active Fire Fighting Measures										
Automatic Fire Suppression		Automatic Fire Detection			Manual Fire Suppression					
Automatic Water Extinguishing System	Independent Water Supplies 0 | 1 | 2	Automatic fire Detection & Alarm by Heat	Automatic fire Detection & Alarm by Smoke	Automatic Alarm Transmission to Fire Brigade	Work Fire Brigade	Off Site Fire Brigade	Safe Access Routes	Fire Fighting Devices	Smoke Exhaust System
γ_{n1}	γ_{n2}	γ_{n3}	γ_{n4}	γ_{n5}	γ_{n6}	γ_{n7}	γ_{n8}	γ_{n9}	γ_{n10}
0,61	1,0 | 0,87 | 0,7	0,87 or 0,73		0,87	0,61 or 0,78		0,9 or 1 / 1,5	1,0 / 1,5	1,0 / 1,5

- The multiplicative factors γ_n indicate 10 safety factors that consider active safety measures (fire alarm, sprinklers, fire brigade,…)

$$\gamma_n = \prod_{i=1}^{10} \gamma_{ni}$$

- when effects of two different fire protection measures are not independent of each other, e. g. fire detection system and fire brigade, safety benefit cannot be equal to the sum of the benefit of the single measures => mathematical not correct

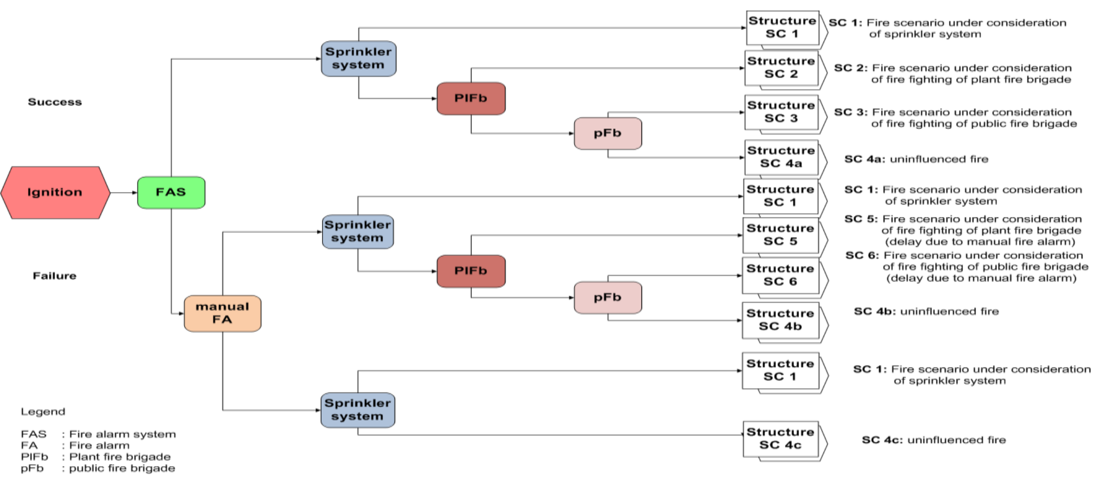
EC 1-1-2 Annex E

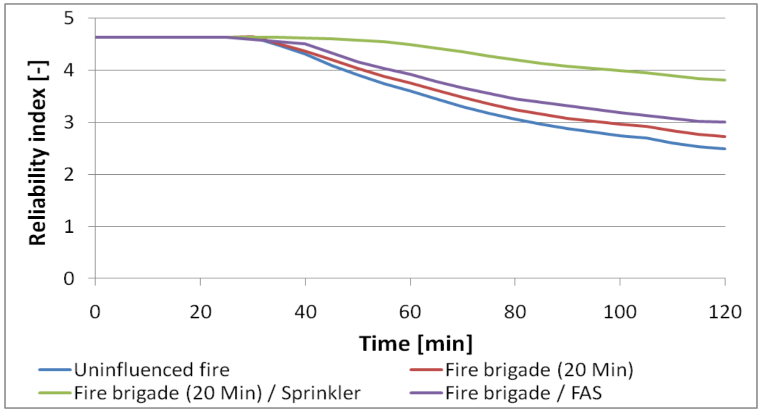
- System reliability analysis required

- Most influencing parameters of fire protection measures: sprinklers and fire brigade
- Probabilistic fire safety analysis
- Only measures considered that are stochastically independent

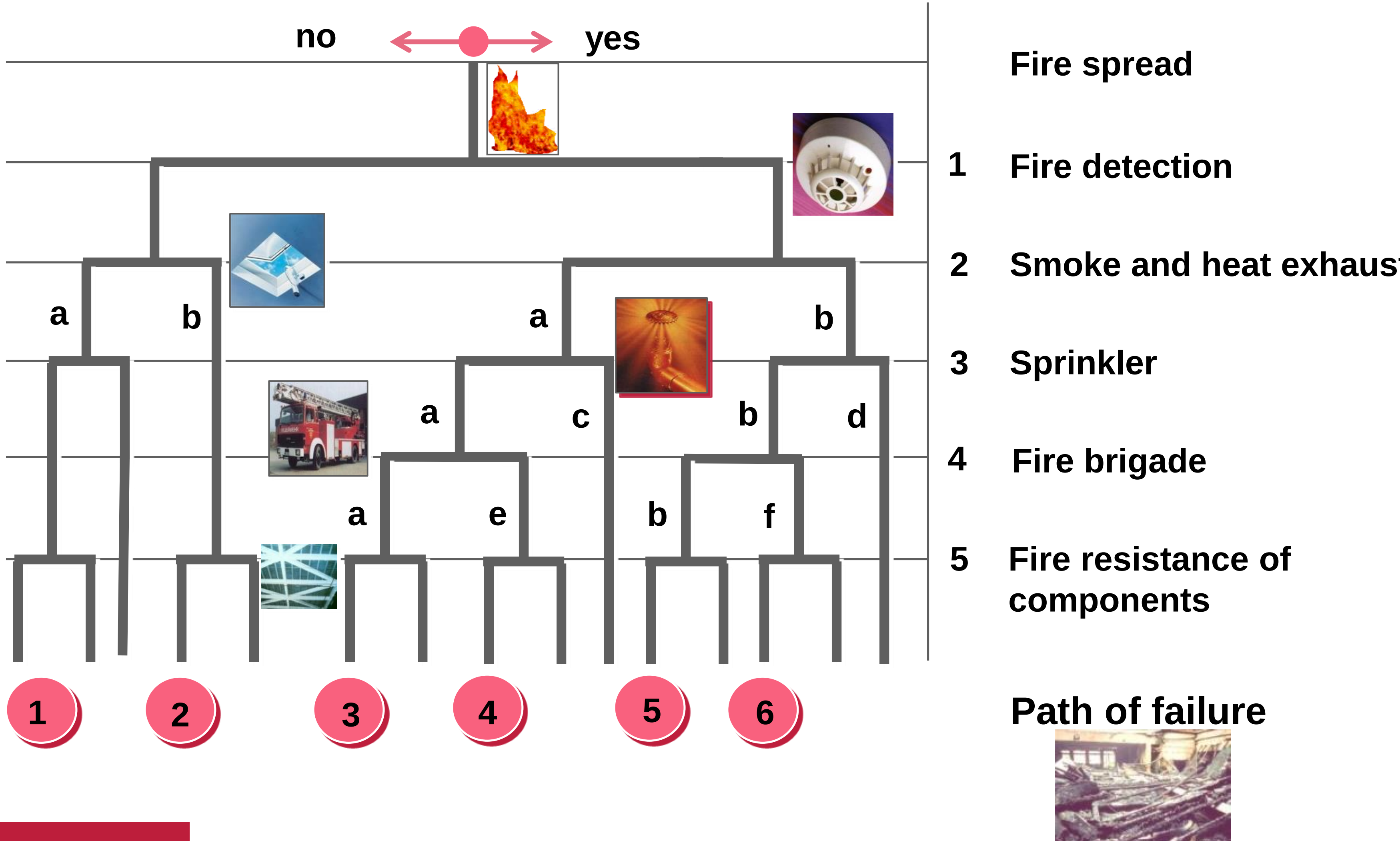
Improved safety concept

- The safety concept of EC1 was not accepted in Germany, an improved safety concept was developed, could be included in further editions of Eurocode
- The improved safety concept is based on full probabilistic analyses

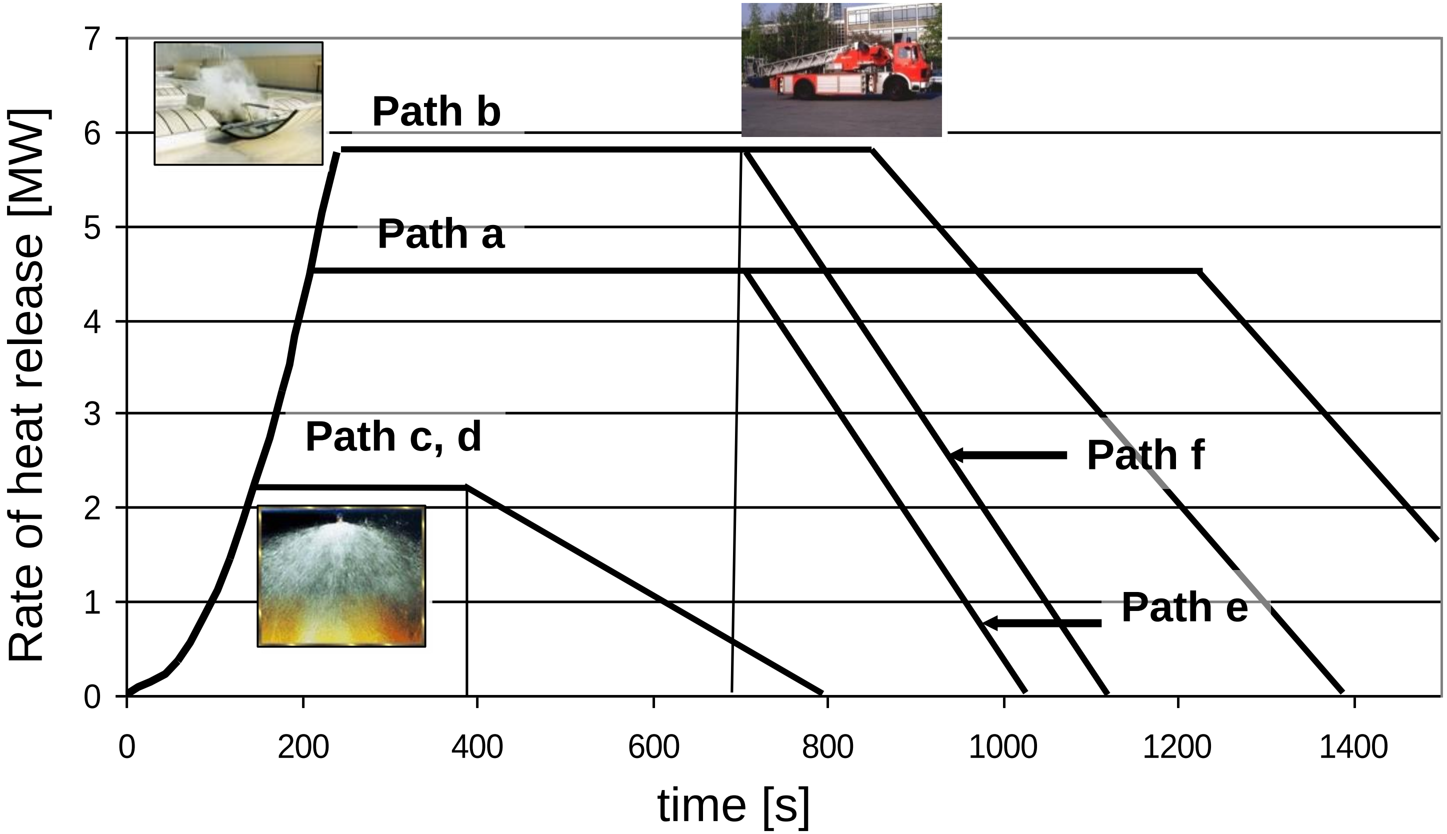




Event tree in fire situation



Potential course of fire



Required reliability in fire situation

Fire as an accidential situation:

- Probability of occurence per year of an initial fire in a unit

$$p_1 = a \cdot A^b$$

a: probability of occurence per m²
b: coeffizient (0,9 for offices and dwellings)
A: Area

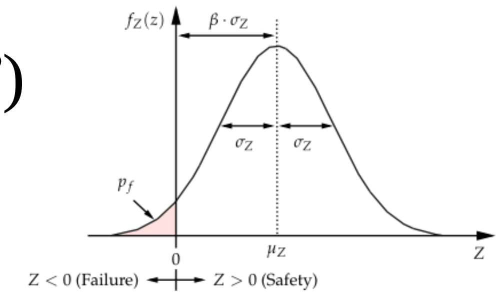
- Probability of occurence of a fire (fully developed) with
  p_2 = failure of fire fighting
  p_3 = failure of extinguishing system

$$p_{fi} = p_1 \cdot p_2 \cdot p_3$$

Valid only when p_1, p_2 , p_3 indipendent

- Probability of failure of a component due to collapse

$$p_f = \Phi(-\beta)$$



- Conditional probability of a component in fire situation

$$p_{f,fi} = \frac{p_f}{p_{fi}}$$

- Reliability index in fire situation

$$\beta_{fi} = -\Phi^{-1}(p_{f,fi})$$

Quelle: Bub et al., 1983

Required reliability

classification	characteristic	Example civil engineering
CC3	High consequences for human life **or** very large economical, social or polluting consequences	Assembly halls, shopping centre
CC2	Medium consequences for human life, substantial economical, social or polluting consequences	Dwelling and office buildings
CC1	Low consequences for human life **and** low or insignificant economical, social or polluting consequences	Farm buildings

Reliability class	Reliability index β und probability of failure p_f			
	Reference period 1 year		Reference period 50 years	
RC 3	5.2	1.0E-07	4.3	8.5E-06
RC 2	4.7	1.3E-06	3.8	7.2E-05
RC 1	4.2	1.3E-05	3.3	4.8E-04

reference: EN 1990

Required reliability

occupancy	Consequences					
	high		medium		low	
	β	p_f	β	p_f	β	p_f
Dwellings, office buildings and comparable occupancy	4,7	1,3E-6	4,2	1,3E-5	3,7	1,1E-4
hospital, care home, hotel, School, retail, Assembly hall, high rise building	5,2	1,0E-7	4,7	1,3E-6	4,2	1,3E-5
Industrial building	4,7	1,3E-6	4,2	1,3E-5	3,7	1,1E-4
Farm building	--	--	4,2	1,3E-5	3,7	1,1E-4

reference: DIN EN 1991-1-2/NA

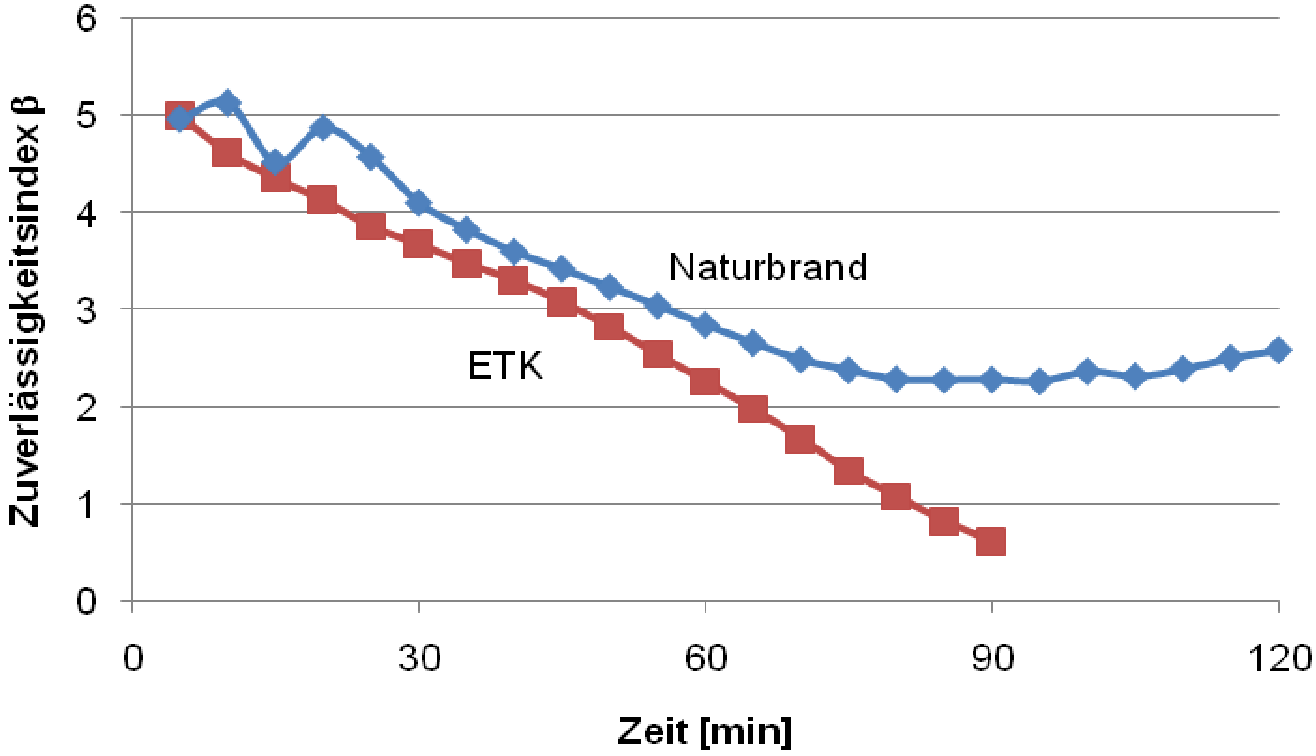
Derivation of safety concept in German NA

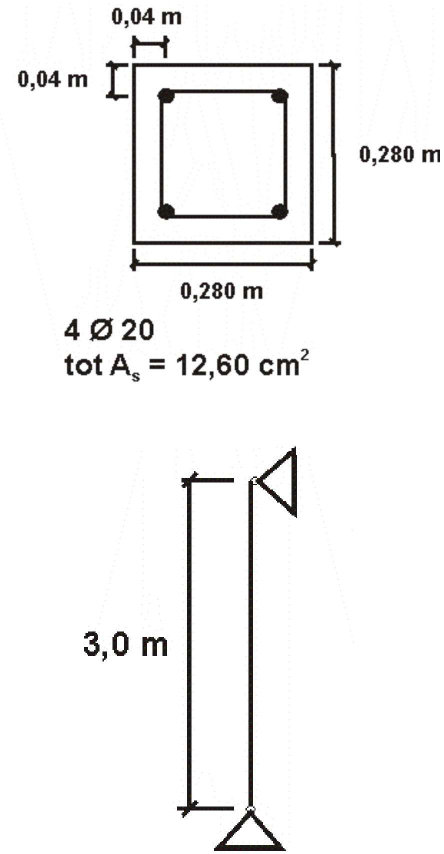
- Safety concept has to ensure that in case of natural fire design the required reliability is met

- Approach for the derivation of the safety concept
  - Identification of the decisive influence parameters for natural fire safety design by reliability analysis with steel, RC and timber components
  - Derivation of safety elements (characteristic values, partial safety factors) for these values in such a way that in case of design with deterministic method the required reliability is met

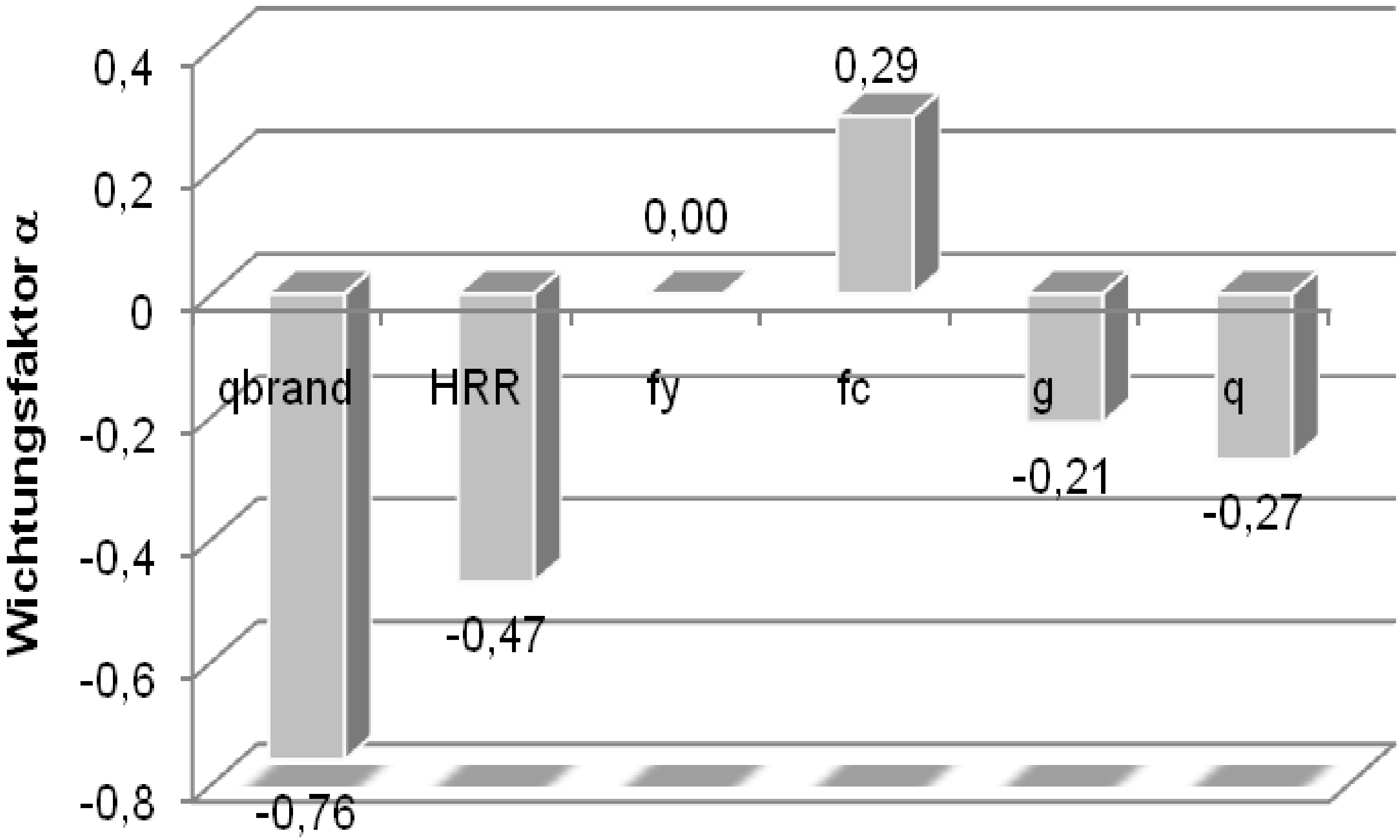
RC components – development of reliability

Stütze R90



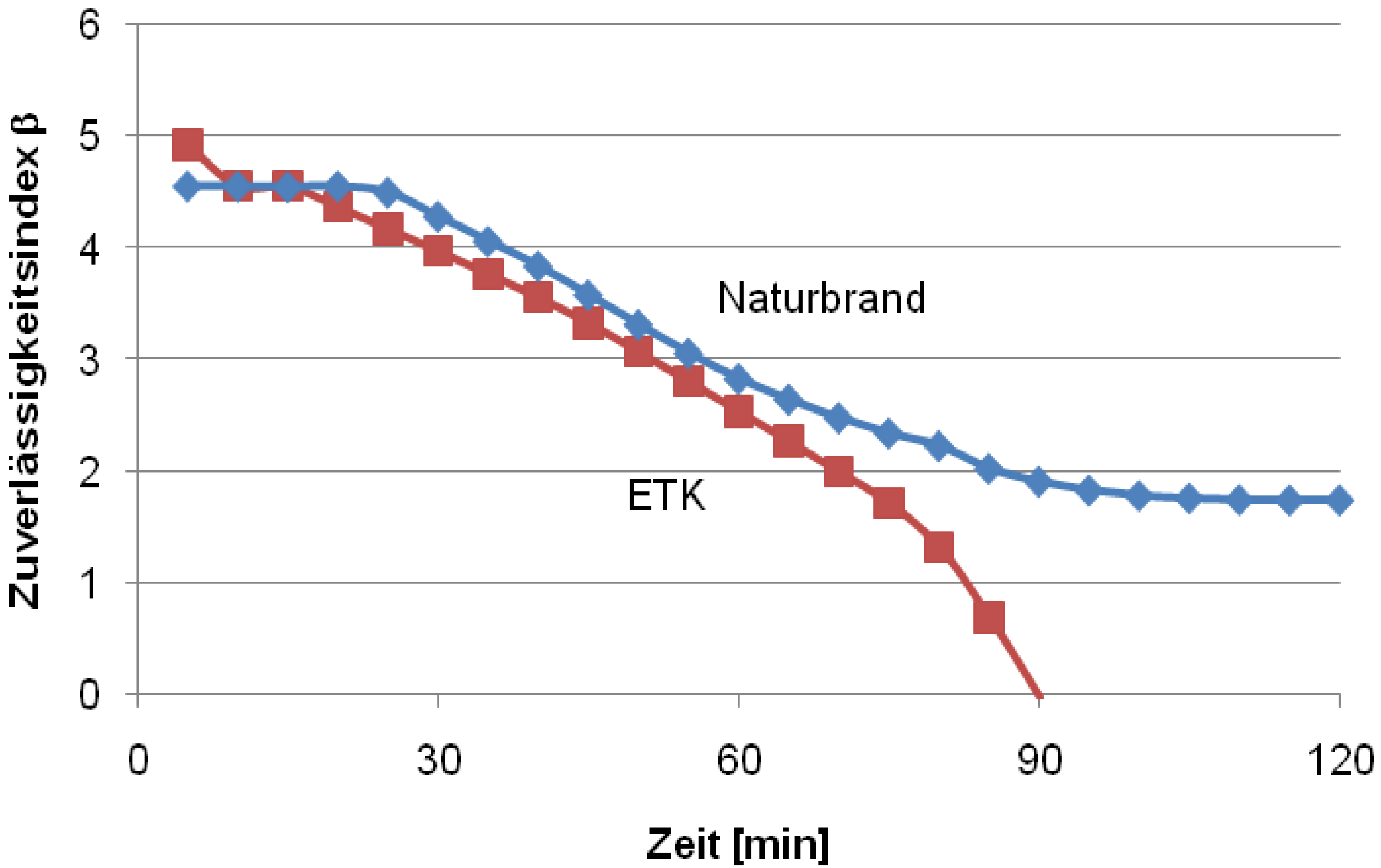


RC components – sensitivity factors at min β

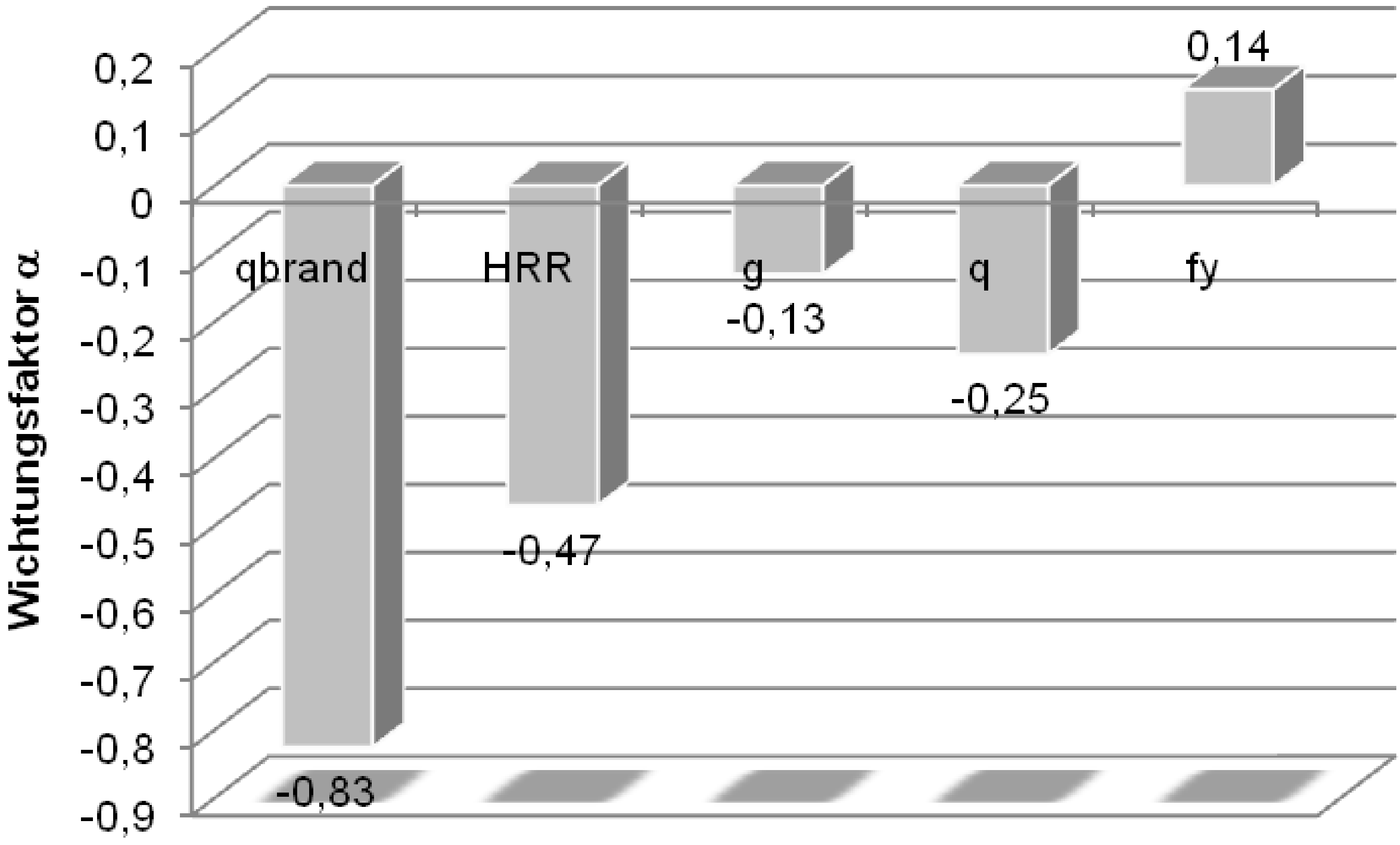


Steel compontens – development of reliability

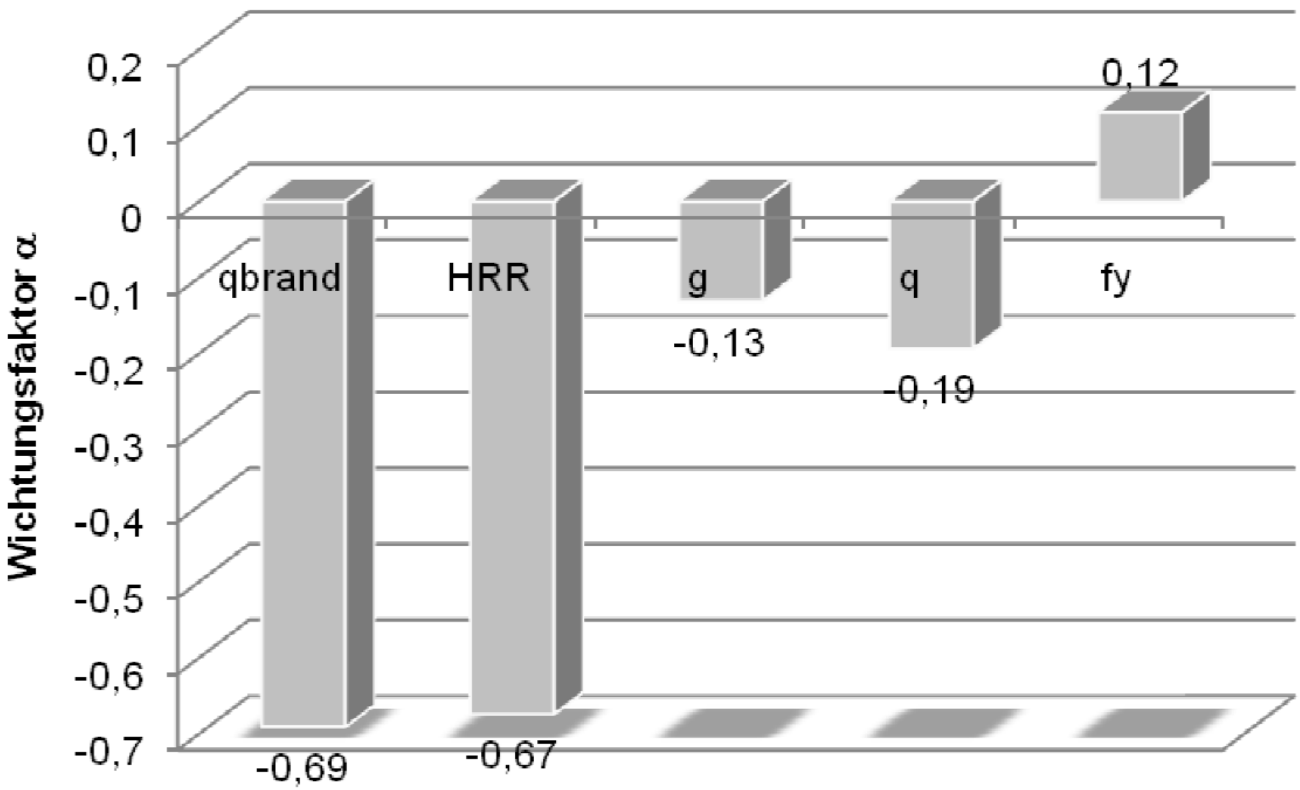
Stütze R90



R 90 steel components – sensitivity factors at min β



R30 steel component – sensitivity factors at min β



Results of reliability analysis: decisive influence parameters

- Dead and live loads (g, q)
- ➔ are considered with γ_M = 1,0 and their characteristic values
- Material parameters (f_y, f_c)
  ➔ are considered with γ_M = 1,0 and their characteristic values
- Fire specific values
  - Fire load q – mean value α = 0,8
  - Rate of heat release HRR – mean value α = 0,6
  - Definition of the characteristic value as 90% quantile

  ➔ Determination of partial safety factors

Partial safety factors for HRR and q in German NA

- Assumption of a Gumbel distribution for HRR and q
- $\alpha_{HRR} = 0{,}6$; $\alpha_q = 0{,}6$
- β_{fi} in dependence of the fire safety infrastructure and the probability of occurence of a fire

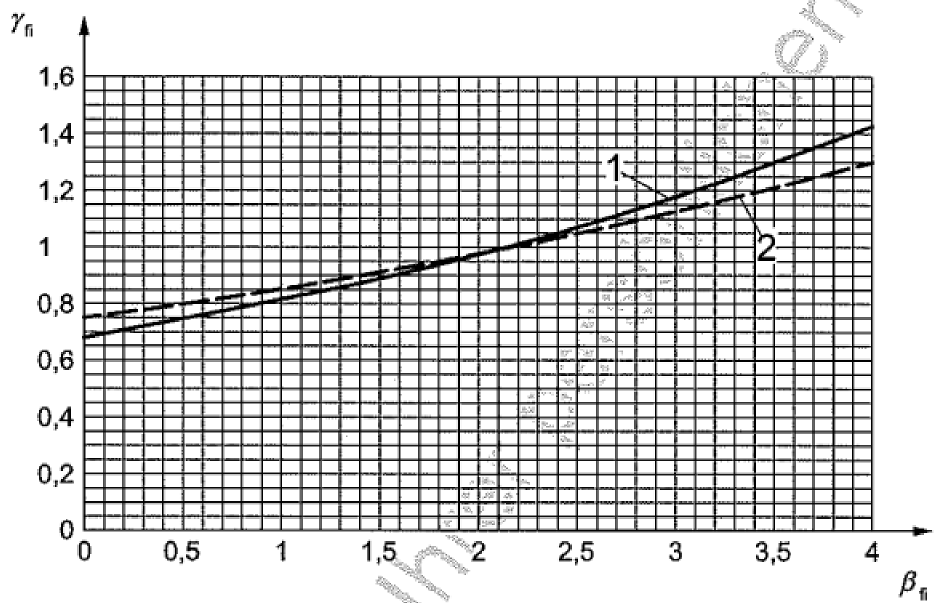
When the fire load density is determined according to the classification of occupancies according to BB.3.2, the partial factor $\gamma_{fi,q}$ is obtained from Equation (BB.15) as a function of the required reliability index β_{fi}:

$$\gamma_{fi} = \frac{1 - V \cdot 0{,}78 \cdot \left[0{,}577\,2 + \ln\left(-\ln\left(\Phi\left(\alpha \cdot \beta_{fi}\right)\right)\right)\right]}{1 - V \cdot 0{,}78 \cdot \left[0{,}577\,2 + \ln\left(-\ln(0{,}9)\right)\right]} \qquad \text{(BB.15)}$$

where $\Phi(\;)$ is the function of the standard normal distribution. For V, the coefficient of variation of the fire load density shall be taken to be $V_q = 0{,}3$; the sensitivity factor α (as a measure of the variance) is taken to be $\alpha = 0{,}6$.

The partial factor for the rate of heat release $\dot{Q}$ according to BB.4 is obtained from Equation (BB.15) with the coefficient of variation $V_{\dot{Q}} = 0{,}2$ and the sensitivity factor $\alpha = 0{,}6$. Thus it corresponds to the partial factor $\gamma_{fi,q}$ used for the individual determination of the fire load density according to BB.3.3.

Determination of partial factors acc. to German NA



Key

1 Fire load density according to BB.3.2

2 Rate of heat release according to BB.4 and fire load density according to BB.3.3

Figure BB.2 — Partial factors for the parameters of a natural fire related to the defined characteristic values (90 % quantile)

$p_{f,fi}$	B_{fi}
5,0E-01	0,00
4,0E-01	0,25
3,1E-01	0,50
2,3E-01	0,75
1,6E-01	1,00
1,1E-01	1,25
6,7E-02	1,50
4,0E-02	1,75
2,3E-02	2,00
1,2E-02	2,25
6,2E-03	2,50
3,0E-03	2,75
1,3E-03	3,00
5,8E-04	3,25
2,3E-04	3,50
8,8E-05	3,75
3,2E-05	4,00

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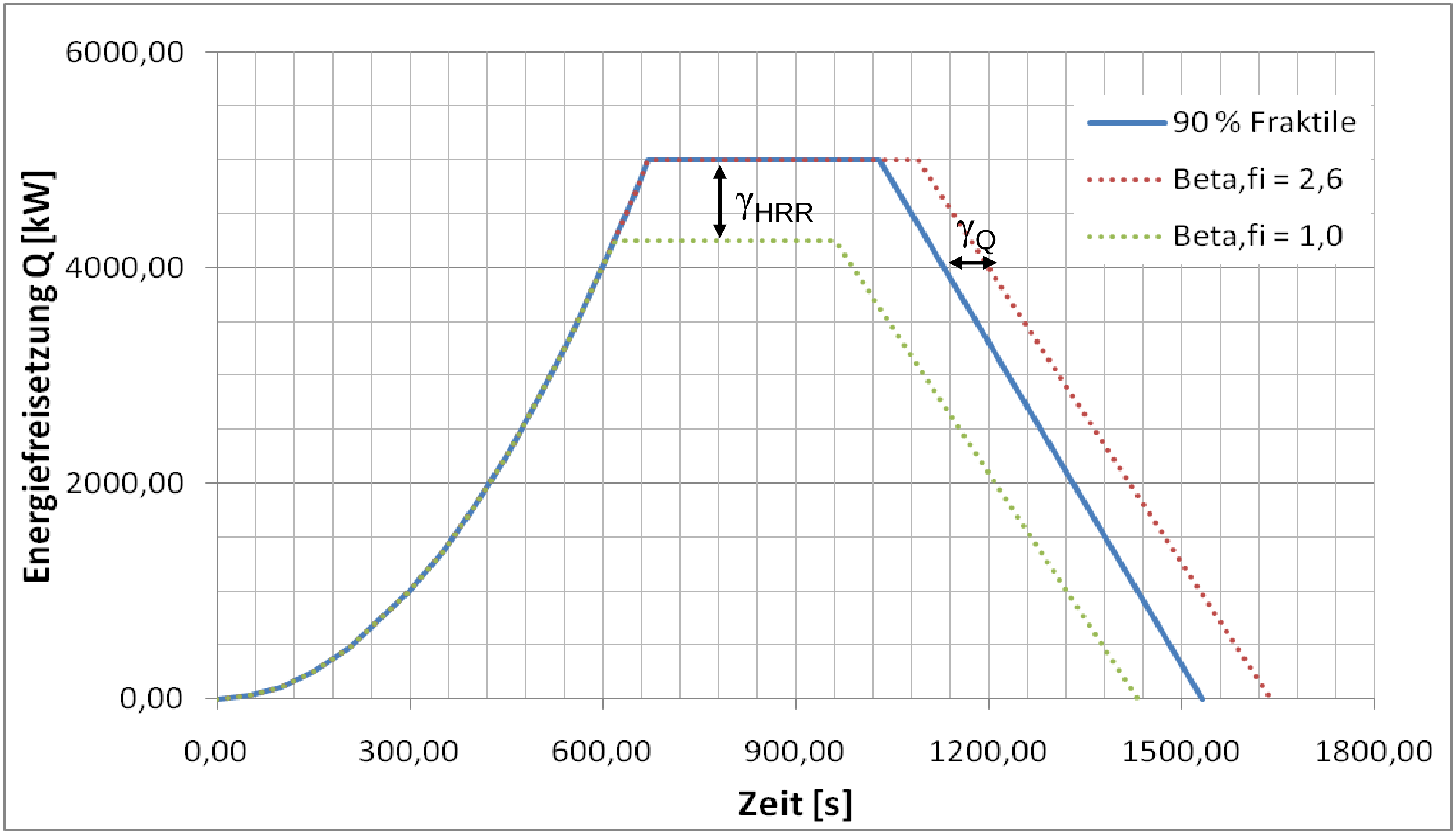
Design rate of heat release



Investigation of single components

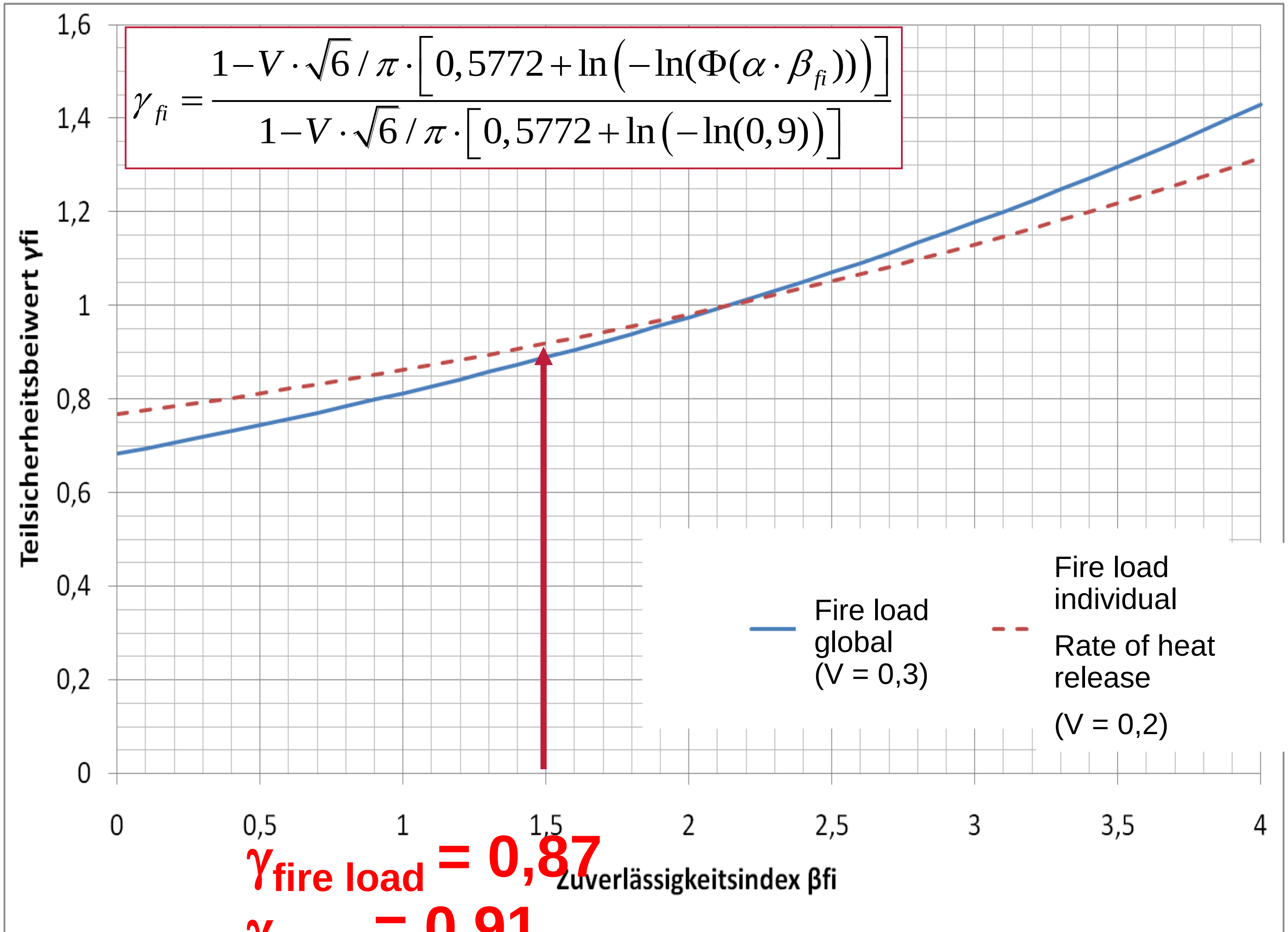
- Boundary conditions
  - Unit 200 m²
  - Probability of occurence: p_{fi} = 1,95E-5
  - Accepted probability of failure: p_f = 1,3e-6 (β_{fi} = 4,7)

$$p_{f,fi} = \frac{p_f}{p_{fi}} = \frac{1,3e-6}{1,95e-5} = 0,067$$

$$\beta_{fi} = -\Phi^{-1}(p_{f,fi}) = 1,50$$

Partial safety factors γ_{fi}

$$\gamma_{fi} = \frac{1 - V \cdot \sqrt{6}/\pi \cdot \left[0{,}5772 + \ln\left(-\ln(\Phi(\alpha \cdot \beta_{fi}))\right)\right]}{1 - V \cdot \sqrt{6}/\pi \cdot \left[0{,}5772 + \ln\left(-\ln(0{,}9)\right)\right]}$$



$\gamma_{fire\ load} = 0{,}87$

$\gamma_{RHR} = 0{,}91$

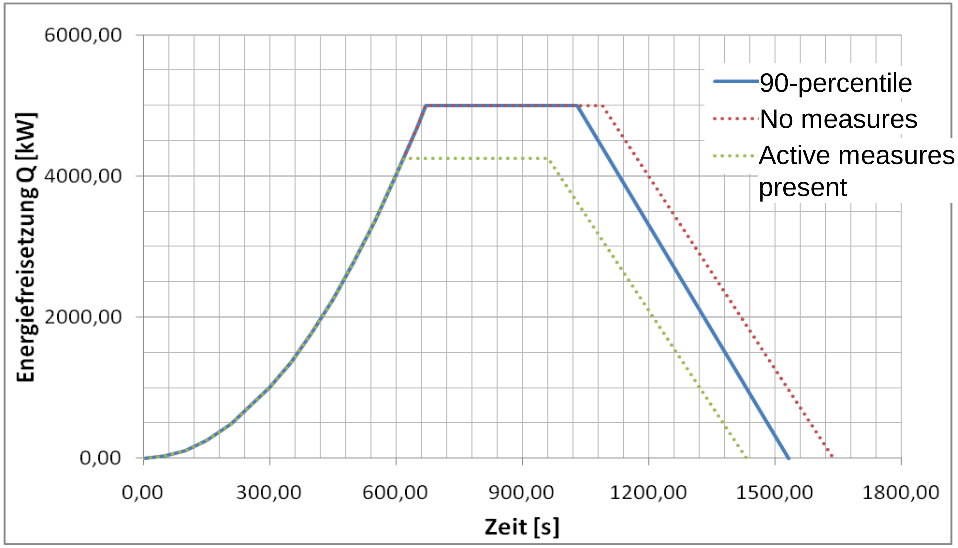
$p_{f,fi}$	β_{fi}
0,5	0
0,401	0,25
0,309	0,50
0,227	0,75
0,159	1,00
0,106	1,25
0,067	1,50
0,040	1,75
0,0228	2,00
0,0122	2,25
0,00621	2,50
0,00298	2,75
0,00135	3,00
0,000578	3,25
0,000233	3,50

$$p_{f,fi} = p_f / p_{fi}$$

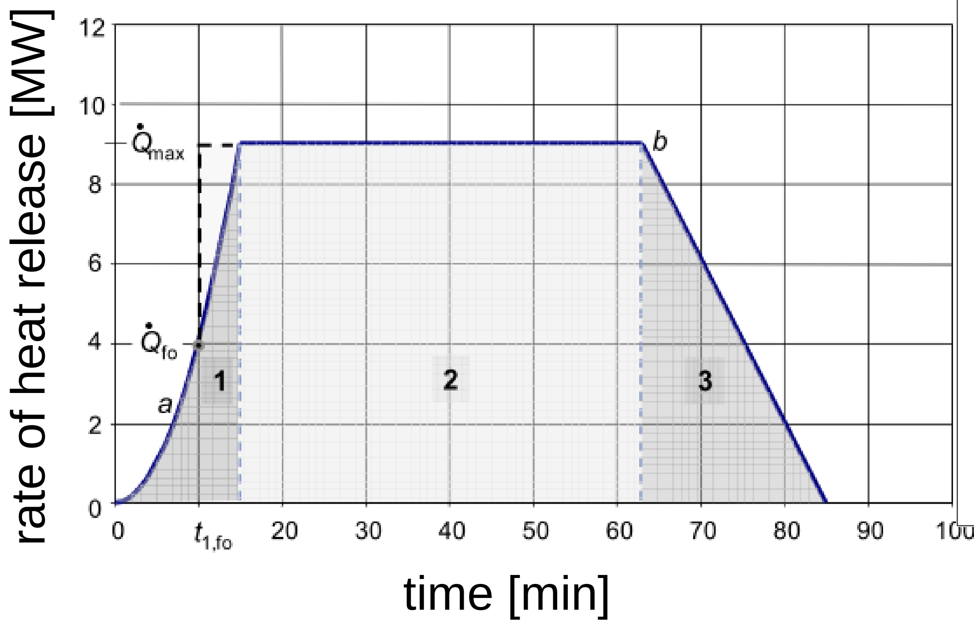
Improved safety concept

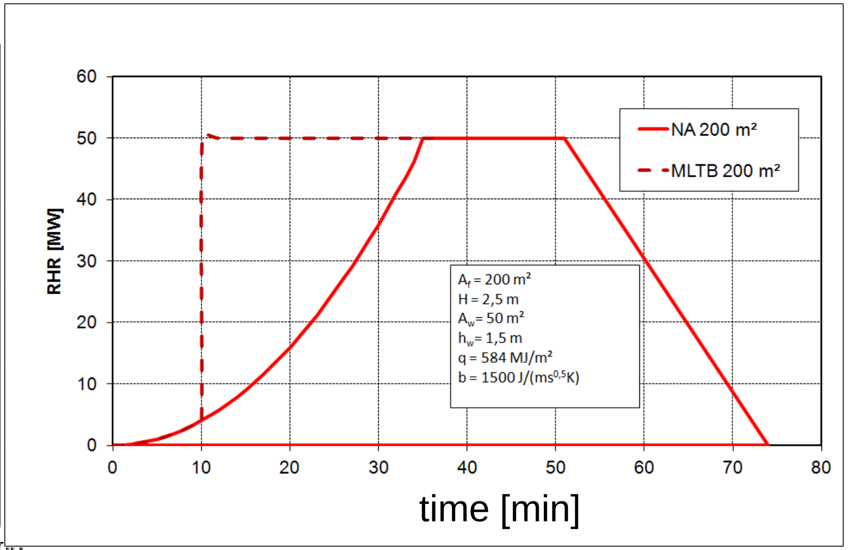
- Published in the German National Annex of EC 1-1-2
- Published in Interflam Proceedings 2010

- The design fire is based on the HRR of an undisturbed fire
- 90-percentile of fire load density and heat release rate
- Partial safety factors for fire load density and heat release rate RHR that were calibrated according to the safety benefit of the different active fire protection measures



Considering flash over by RHR in German NA





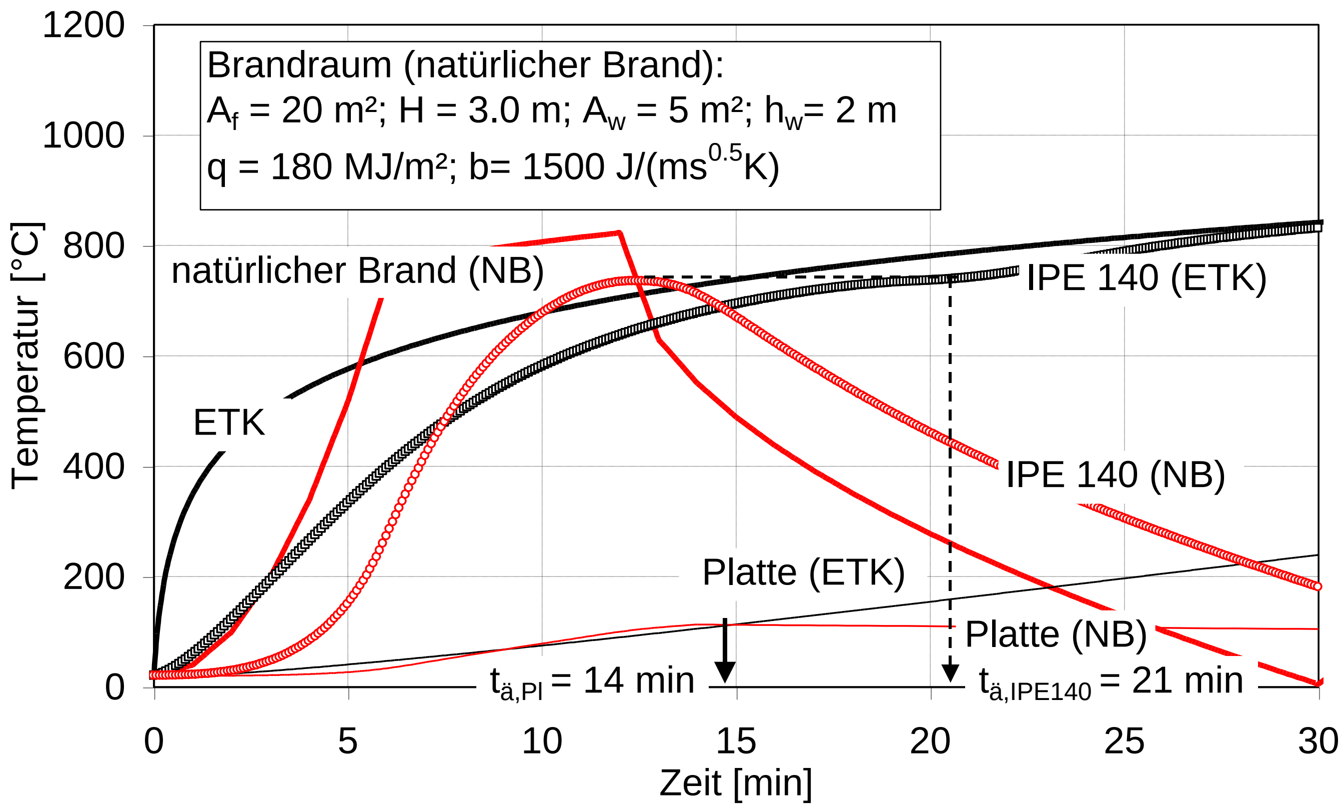
$$t_{1,fo} = \sqrt{t_\alpha^2 \cdot \dot{Q}_{fo}}$$

- Approach of Walton and Thomas

$$\dot{Q}_{fo} = 0{,}007\,8 \cdot A_t + 0{,}378 \cdot A_w \cdot \sqrt{h_w} \qquad \text{in MW}$$

Annex F

Equivalent time of fire exposure



- Method can applied for industrial buildings (DIN 18230)
- In small and medium-sized rooms => uniform temperature distribution => Problem for unprotected steel (Tsteel >> 500°C)

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