Global Fire Safety Concept for Buildings

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Summary

In order to establish the basis for realistic and credible assumptions to be used in the fire situation for thermal actions, active measures and structural response, a new European Research financed by ECSC entitled "Competitive Steel Buildings through Natural Fire Safety Concept", started in 1994 [1]. It is being performed by 10 partners out of 11 European countries and is co-ordinated by PROFILARBED-Research. This paper describes the state of the art of the research

Introduction

Fire Engineering design is a recent discipline which is progressing constantly and dynamically. The fire was seriously taken into account in the construction only at the end of the sixties after dramatic fires which are still in all minds.

At the beginning, the only possibility to determine the fire resistance of a building element was to perform a test in a laboratory. The element was subjected in a furnace to an increase of gas temperature according to the normalised ISO curve with 821°C after 30 minutes, 925°C after 60 minutes and 1029°C after 120 minutes. Unfortunately this standard temperature-time curve involves an ever increasing air temperature inside the considered compartment, even when later on all consumable materials have been destroyed. In fact, after a given time, depending on the fire load and the ventilation conditions, the air temperature will necessarily decrease. The application of this unrealistic ISO Standard leads necessary to very different requirements from one country to another. For example, open car parks may be built with unprotected steel on one side of the Rhine and need 90 minutes of ISO fire resistance on the other side ! Big discrepancies exist in the fire resistance requirements of the European countries for all types of buildings ranging from industrial halls to high rise buildings.

In order to establish the basis for realistic and credible assumptions to be used in the fire situation for thermal actions, active measures and structural response, a new European Research [1] entitled "Competitive Steel Buildings through Natural Fire Safety Concept", started in 1994. The aim is to develop a **Global Fire Safety Concept** which deals with the Safety for Occupants, Fire-fighters and Structures. That's why we have to perform a structural analysis of the whole structure in the fire situation, consider a realistic i.e. accidental combination of loads, adopt for the fire simulation a natural fire curve depending on the fire load and the ventilation conditions. In a second step, the active fire fighting measures such as detection systems, alarms, sprinklers, ... are taken into account and their influence on the probabilistic reduction of the fire event and consequently on the improvement of the building Safety, is quantified.

The aim of this paper is to describe the state of the Art of this European research which implies 4 Working Groups (see figure 1).

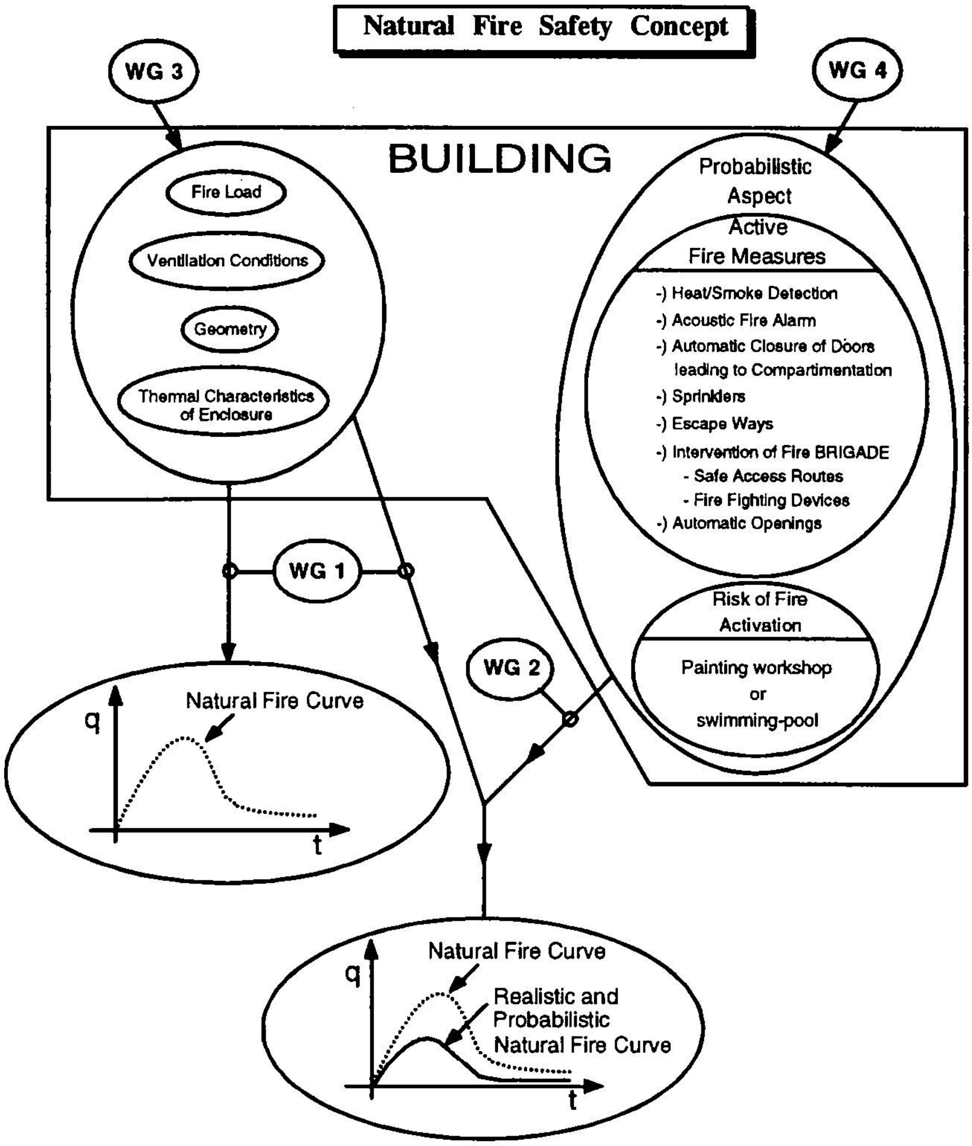

Figure 1: General guidelines of the research "Natural Fire Safety Concept"

1. Working Group 1: Natural Fire Models

The goal is to provide some ways to replace the ISO curve which has 3 main defects:

- The ISO curve has to be considered for the whole compartment even if this compartment is huge
- The ISO curve never goes down and implies an air temperature increasing to the moon!
- There is only **one** ISO curve for all the types of building, whatever the fire load or the ventilation conditions.

In order to answer to the first critics, a procedure has been defined to check whether the fire remains a localised fire or spreads and becomes a fully engulfed compartment fire. In case of localised fire a method has been developed to calculate the 4-dimensional temperature field $\theta(x,y,z,t)$. The two other defects are already dealt with in the annex B of ENV 1991-2-2 [2] which provides a first alternative to the ISO-curve and considers the fire load, the openings and the thermal characteristics of the walls (see figure 2).

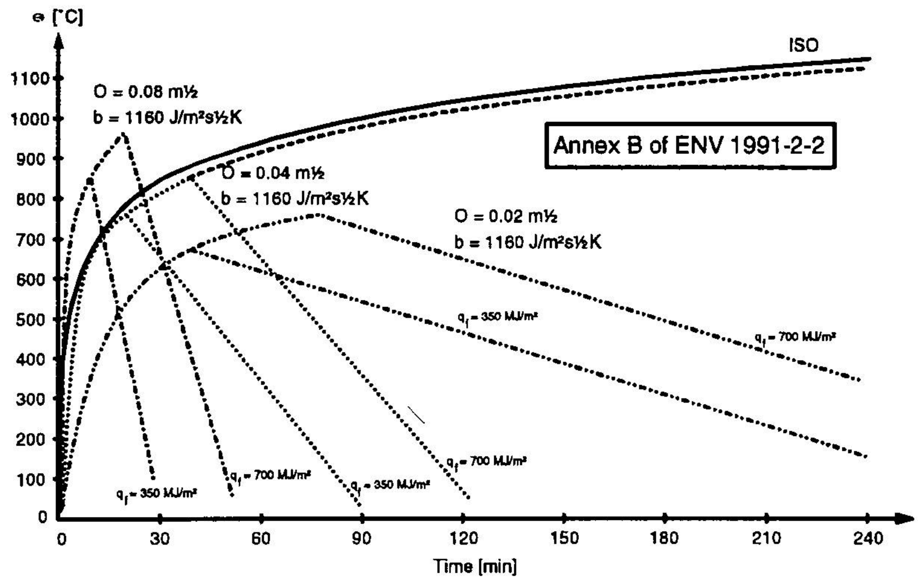

Figure 2: Annex b of ENV 1991-1

The Working Group 1 has improved this annex B in order to consider the fuel bed controlled regime; they are developing a programme One Zone model called OZONE which contains, in addition to the available One Zone programs, a combustion model to define itself the burning regime (fuel bed or ventilation controlled) and a sophisticated wall model which is really included in the air temperature calculation. Moreover they are collecting natural fire tests in order to create a database which enables us to check the models. Concerning the localised fire they have analysed the different air entrainment models which have a large influence on the temperature and the height of the smoke zone.

2. Working Group 3: Fire characteristics

To be able to use these calculation tools, it is necessary to know the fire characteristics such as the fire load, the Rate of Heat Release, the ventilation conditions, the thermal inertia of the compartment walls, the parameters defining the fire spread, the conditions leading to a flash-over, the amount of smoke entrained by the fire and the model of combustion that defines the oxygen needed for combustion, that reduces the peak of the Rate of Heat Release and increases the fire duration in case of lack of oxygen. It is the task of Working Group 3 to provide all these data.

3. Working Group 2: Probabilistic aspects

The probability that a fire breaks out in a swimming-pool is obviously much lower than in a painting workshop. Moreover the probability that this starting fire spreads and leads to a fully engulfed compartment depends of course of the active fire fighting measures such as the sprinklers which may extinguish automatically the fire, the firemen or the automatic fire detection (by smoke or heat) and the automatic transmission of the alarm to the firemen which allows a rapid fire brigade intervention.

Concerning the influence of the sprinklers, some surveys, some tests and numerical simulations attest that there is no risk for the stability of the structure if the sprinkler system has been well designed and works when a fire breaks out. The influence of the sprinklers on the structure behaviour is thus only a question of reliability. Will the sprinklers work when necessary ?

In order to quantify the influence of the active measures, the approach described in ENV 1991-1 has been used. The Eurocode 1 Part 1-1 concerning the actions and the resistance values is based on a probabilistic concept that has lead to safety coefficients γ ,so that this concept can be applied in practice. The safety factors γ for the actions and the material properties has been deduced by a semi-probabilistic approach (Annex A of ENV 1991-1) which assumes implicitly a target failure probability of 7E-5 per working life of the building, which is equivalent to a safety factor β of 3,8 :
p_f (failure probability) $\leq p_t$ (target probability) (1).
In case of fire, the main action is the fire which can be quantified by the fire load expressed in kg of wood or in MJ. However, this fire load becomes a real action for the structure only when there is a fire. The fire load influences really the structure only with a certain probability p_{acc}, p_{acc} being the product of p_1 (probability that a fire starts) and p_2 (probability that this starting fire turns to a flash-over or a fully engulfed compartment).

In case of fire which is considered as an accidental action the equation (1) becomes p_f (failure probability in case of fire) * p_{acc} (probability of fire) $\leq p_t$ (target probability). In that way the β is no more equal to the constant value 3,8 but depends of the probability that there is a fully engulfed fire compartment during the building life. Indeed the safety index β has to be determined by using $p_{t,fi}$ which is equal to (p_t /p_{acc}) (see figure 3) and enables us to determine the corresponding safety factor γ_i for the static loads, the material properties and the fire load.

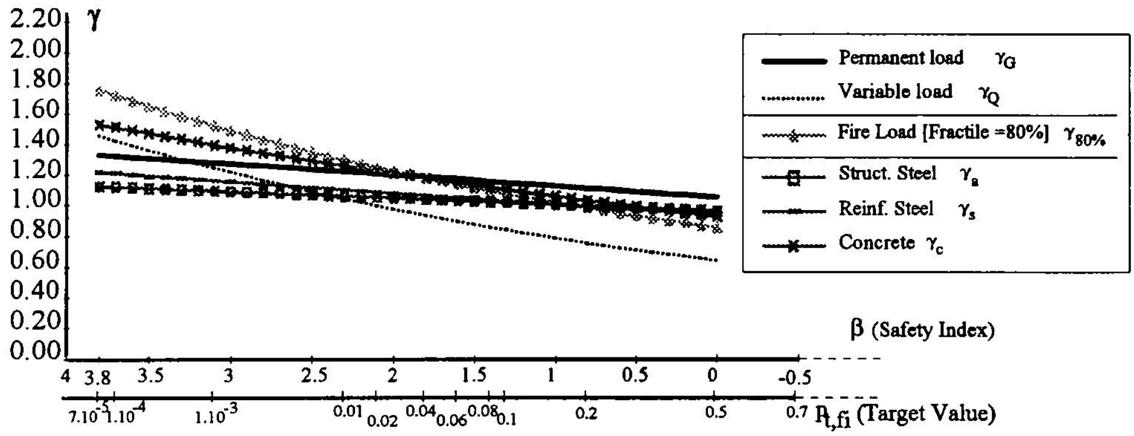

Figure 3: Global safety factor γ on the static loads, on the materials properties and on the fire loads

However this global procedure implies the calculation of the fire probability for each case. That's why we have developped a simplified approach which consists of splitting the safety factor $\gamma_{fire\ load}$ into 3 coefficients γ_{q1} to consider the compartment size, γ_{q2} to consider the risk of fire activation and γ_{ni} to take into account the influence of the active measures.

According to the background of the DIN 18230 [3], the probability to have a fully engulfed compartment per m² per year in the schools, hotels, or offices is equal to $5 \cdot 10^{-7}$.
By multiplying by 50, we obtain the probability for the complete life of the building estimated to 50 years: Probability of a compartment fully engulfed by the fire : $p_1\, p_2 = 5 \cdot 10^{-7} \cdot 50 = 25 \cdot 10^{-6}$. Let us assume in a first step a compartment area $A_f = 25m^2$.
With these values, the probability p_{acc} of a fully engulfed compartment is : $p_{acc} = p_1\, p_2\, A_f = 6{,}25 \cdot 10^{-4}$

The target value of the failure in case of fire $p_{t,fi}$ becomes then : $p_{t,fi} = \dfrac{p_t}{p_{acc}} = \dfrac{7.10^{-5}}{6{,}25.10^{-4}} = 0{,}112$ and the corresponding safety index β_{fi} is equal to 1,2. This factor β of 1,2 implies a safety factor γ of 1,0 in case of 80 % fractile for the characteristic fire load (see figure 3).

In the same way, we can obtain other safety coefficients γ for other compartment areas A_f as follows :

A_f [m²]	p_{acc}	P_t / p_{acc}	β	γ_{q1}
25	$6{,}25.10^{-4}$	0,11200	1,22	1,0
250	$6{,}25.10^{-3}$	0,01120	2,28	1,25
2500	$6{,}25.10^{-2}$	0,00112	3,03	1,5
5000	$12{,}5.10^{-2}$	0,00056	3,26	1,6
10000	$25{,}10^{-2}$	0,00028	3,45	1,65

The previous calculation is based on a probability of fire $p_1 p_2$ of 5.10^{-7} per year and m^2 corresponding to schools, offices or hotels. It is obvious that the risk is much higher for a fireworks industry and lower for a museum with Grecian statues.
For a building of 2500 m², the safety coefficient γ is equal to 1,5. What happens if the probability of having a fire is reduced by 10 ? From the figure 3 it can be deduced that the safety coefficient γ is reduced by a factor 0,85. Moreover, this factor 0,85 is rather constant if we make a variation on β. In this way, the buildings can be classified according to the danger of fire activation. For each class, it is possible to deduce an additional safety coefficient γ_{q2} according to the following table :

Type of building destination	Danger of fire activation	$\frac{(p_1p_2)}{(p_1p_2)\text{normal}}$	$\gamma_{q2} = \frac{\gamma}{\gamma_{\text{normal}}}$
Museum, Art gallery	low	10^{-1}	0,85
Hotel, School, Office	normal	1	1
Engine Fabrication	average	10	1,2
Painting Workshop, Chemistry Laboratory	high	100	1,4
Painting Fabrication, Fireworks Industry	higher	1000	1,6

In the same way, it is possible to quantify the influence of active fire fighting measures. Each active measure reduces the probability that a starting fire turns to a flash-over or a fully engulfment of the compartment.

Official Document		γ_{ni} Function of Active Fire Safety Measures										$\gamma_n^{min} = \gamma_{n1} \cdots \gamma_{n10}$ / $\gamma_n^{max} = \gamma_{n1} \cdot \gamma_{n3}$
		Automatic Fire Suppression		Automatic Fire Detection			Manual Fire Suppression					
Title	Date of publication	Automatic Water Extinguishing System γ_{n1}	Independent Water Supplies 0 | 1 | 2 γ_{n2}	Automatic fire Detection & Alarm by Heat γ_{n3}	Automatic fire Detection & Alarm by Smoke γ_{n4}	Automatic Alarm Transmission to Fire Brigade γ_{n5}	Work Fire Brigade γ_{n6}	Off Site Fire Brigade γ_{n7}	Safe Access Routes γ_{n8}	Normal Fire Fighting Devices γ_{n9}	Smoke Exhaust System γ_{n10}	
SIA 81 [5]	1984	0,50 / 0,59	/	0,83 or 0,69		0,83	0,67 or 0,63; $\gamma_{n6} \cdot \gamma_{n7} = 0{,}53$		/	1,0 / 1,39 *	0,85	0,13 / 0,49
ANPI [4]	1988	0,58 ⊙	1,0 | 0,86 | 0,65	0,82	0,68	included in ⊙	0,50	0,68	/	1,0 / 1,36 *	/	0,07 / 0,48
DIN V 18230-1 [3]	1987/95	0,60	/	0,90		/	0,60	/	/	/	/	0,32 / 0,54
ENV 1991-2-2 [2]	1995	0,60	/	/	/	/	/	/	/	/	/	0,60
NFSC PROPOSAL [1]	1997	0,70	1,0 | 0,95 | 0,9	0,90	0,80	0,90	0,70	0,85	0,9 or 1 / 1,5 *	1,0 / 1,4 *	1,0 / 1,5 *	0,22 / 0,63

Figure 4: Differentiation factor γ_{ni} accounting for various active fire safety measures.

Therefore, for each active measure it is possible to deduce a coefficient γ_n smaller than 1 to take into account the sprinklers, the firemen, the detection measures and higher than 1 to consider that some elementary measures, as for example the extinguishers on each storey, are not fulfilled. It is interesting to compare the coefficients γ_{ni} deduced from probabilistic considerations with other coefficients resulting from other methods which are based on empirical backgrounds (see figure 4).

4. Working Group 3: Statistics

The Working Group 4 is collecting statistics about real fires and about failure of active measures (A.M.). Its objectives is to deduce from these real statistics the probabilities needed for the probabilistic approach developed by the Working Group 2.

Type of Occupancies	Fire Probability	$P_1 P_2$
Museum, Artgallery	small	$25\ 10^{-7}$
Residence, Hotel, Office	normal	$25\ 10^{-6}$
Manufactory of machinery	mean	$25\ 10^{-5}$
Painting Workshop	high	$25\ 10^{-4}$
Manufactory of paints, Manufactory of fireworks	very high	$25\ 10^{-3}$

	Active Measures	Failure Probability of the active measure	$\dfrac{p_{acc}^{\text{without A.M.}}}{p_{acc}^{\text{with A.M.}}}$
Automatic Suppression	Sprinkler (S)	0,01	100
	S + 1 independent Water Supply	0,01*0,5	100*2
	S + 2 independent Water Supply	0,01*0,25	100*4
Manual Fire Suppression	Work Fire Brigade (WFB)	0,01	100
	Standard Fire Brigade (SFB)	0,1	10
	SFB + Automatic fire detection by heat	0,1*0,25	10*4
	SFB + Automatic fire detection by smoke (ADS)	0,1*0,0625	10*16
	SFB + ADS + Automatic Alarm Transmission to Fire Brigade	0,1*0,0625*0,25	10*16*4

Figure 5: Probabilities deduced from statistics.

5. Conclusion

The coefficients γ_{ni} et γ_{qi} enable us to quantify the risk of fire and the influence of the active fire fighting measures, to deduce a design fire load which will be used to calculate a fire curve and a resistance time $t_{fi,d}^{nat}$. This resistance time will have to be compared with the required time $t_{fi,req}$ which depends on the evacuation time and the consequences of the failure of the structure. This approach is quite easy to be used and at the same time is based on a safe scientific background issued from the ECSC research [1].

This Global Fire Safety Concept has been applied in practice to the new ARBED Office Building in Esch/Alzette. This allowed to use a steel frame without insulating material or any intumescent paint and to have it fully visible inside the atrium areas.

6. References

[1] SCHLEICH J.B.; Competitive steel buildings through natural fire safety concept. ECSC Research 7210-SA/522 etc., B-D-E-F-I-L-NL-UK & ECCS, 1994-98.
[2] CEN; ENV 1991-2-2, Eurocode 1 - Basis of design and actions on structures, Part 2.2 - Actions on structures exposed to fire. CEN Central Secretariat, Brussels, DAV 09.02.1995.
[3] DIN; Baulicher Brandschutz im Industriebau - Teil 1: Rechnerisch erforderliche Feuerwiderstandsdauer. DIN V18230-1, Beuth Verlag GmbH, Berlin, 1995.
[4] ANPI; Evaluation des risques. Association Nationale pour la Protection contre l'Incendie, Ottignies, 1988.
[5] SIA; Brandrisikobewertung, Berechnungsverfahren. Dokumentation SIA 81, Zürich, 1984.