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Accidental Actions: Fire
Influence of the Active Fire Protection Measures
(Annex D of ENV1991-2-2)

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Summary

The rule (3) of D.1 of Annex D of ENV1991-2-2 [1] defines a Fire Load reduction factor γ_n accounting for active fire protection measures. This factor γ_n is equal to 0,6 for approved fire extinguishing systems. This short definition of γ_n leading to this very rough procedure is the only reference on the Active Measures influence in the ENV1991-2-2 [1]. This points out one of the main improvements to be undertaken for ENV1991-2-2 [1].

This paper describes some existing methods considering the Active Measures (DIN18230, New-Zealand Method, Austrian Standards TRVB A126 and TRVB A100, SIA81, FRAME) and provides a summary table which should enable to improve the details given in ENV 1991-2-2 concerning the fire load reduction factor γ_n.

1. Introduction

Many methods of Fire Safety Engineering have pointed out the influence of the Active fire fighting measures:

- DIN 18230 "Baulicher Brandschutz im Industriebau" for Germany [2, 3, 4, 5]
- The Austrian Standards TRVB A126 et TRVB A100 "Brandschutztechnische Kennzahlen verschiedener Nutzungen, Lagerungen, Lagergüter" and "Brandschutzeinrichtungen rechnerischer Nachweis" [6]
- Fire Engineering Design for Structural Stability in New-Zealand [7]
- SIA 81 "Evaluation du risque d'incendie" for Switzerland [8]
- FRAME for Belgium [9]

Moreover it is obvious that people sleep safer in a hotel with smoke detectors and sprinklers with a structural fire resistance of R30 than in a R90 building without any active protection measures. Nevertheless only one sentence can be found in Annex D of ENV 1991-2-2 about this major factor.

2. Annex D of ENV 1991-2-2 [1]

EC 1 part 2-2 [1] considers the influence of active fire protection measures by the differentiation factor γ_n in Annex D. It is used in the scope of equation (D.1) determining the design fire load q_d.

$$q_d = \gamma_q \cdot \gamma_n \cdot q_k \qquad \text{(D.1)}$$

The characteristic value of the fire load q_k has to be multiplied by the global safety factor γ_q for the accepted failure risk in connection with the expected fire occurrence probability. The multiplication with γ_n finally leads to the design fire load.
Annex D of EC 1 does not contain much information about numerical values of γ_n. Beside the advice to fix γ_n to 0,6 for approved fire extinguishing systems the Eurocode only refers to national regulations.

3. DIN 18230 "Baulicher Brandschutz im Industriebau" [2, 4, 5]

3.1 General description of DIN 18230

In connection with the German Industriebaurichtlinie, DIN 18230 offers a calculation method to determine the requested fire resistance time of a compartment. The application of this standard which generally takes active and passive fire safety measures into account is restricted to industrial buildings with a limited floor area of 30000 m^2 [3]. Buildings which are not involved in industrial production or storage, e.g. skyscrapers, silos and power plants are excluded.

The first step in DIN 18230 is to calculate the fire load q_R by the following equation (1). It mainly depends on the combustibility of the component parts and the stored material in the compartment. Beiblatt 1 to DIN 18230 contains a summary of the combustion factor m and the calorific value H_u for commonly used materials. q_R is generally referred to the floor area A_f of the compartment.

$$q_R = \frac{\sum(M_i . H_{ui} . m_i . \psi_i)}{A_f} \qquad (1)$$

The equivalent time t_a is calculated by the following equation:

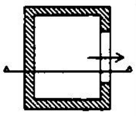
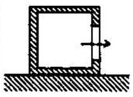
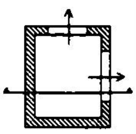
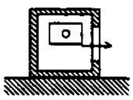
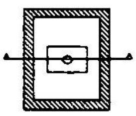
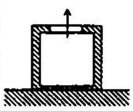
$$t_a = q_R \,.\, c \,.\, w$$

The transformation factor c considers the heat transfer through the fire compartment enclosure. It is equal to the conversion factor k_b in table E.1 of EC 1 part 2-2 Annex E [1]. The numerical values differ between 0,04 $\frac{\text{min.m}^2}{\text{MJ}}$ and 0,07 $\frac{\text{min.m}^2}{\text{MJ}}$ resp. between 0.15 to 0.25 $\frac{\text{min.m}^2}{\text{kWh}}$ in the German code, in relation to the thermal properties of the enclosure walls, ceilings and floor.

The ventilation factor w in equation (2) considers the ventilation conditions in the compartment. For its determination DIN V 18230 (sept. 1987) [2] defines the estimated opening area A_{v+h} which has to be calculated by adding the vertical opening area A_v to the horizontal opening area A_h multiplied by a dimensionless factor k_1 ($\Rightarrow$ DIN V 18230 (sept. 1987) [2] diagram 1).

$$A_{v+h} = A_v + k_f \, . \, A_h$$

The ratio of the estimated opening area A_{v+h} to the floor area A_f of the compartment is required for table 3 of the standard leading to the ventilation factor w. This table differentiates between the position of the openings.

Openings Position	Ground Plan	Section	A_{v+h} / A_f					
			to 0.05	>0.05 to 0.10	>0.10 to 0.15	>0.15 to 0.20	>0.20 to 0.25	>0.25
Compartment with openings on only one side			3.2	2.0	1.5	1.2	1.0	0.9
Compartment with openings on at least two sides			2.2	1.5	1.0	0.9	0.7	0.6
Compartment with horizon-tal opening			1.8	1.2	0.9	0.7	0.6	0.5

Tab. 1: Table 3 of DIN 18230 (sept. 1987) [6] for the ventilation factor w

Finally the required fire resistance time erf t_F can be calculated:

$\text{erf } t_F = t_a \, . \, \gamma \, . \, \gamma_{nb}$

γ is a global safety factor which depends on the compartment size and the relevant fire safety class SK_b 1 - 3. The fire safety class corresponds to the required safety level of each component part, e.g. dividing walls and load bearing elements are generally classified into class SK_b 3 (high requirements). For instance, for a column in a multi-storey building of 2500 m^2, γ is equal to 1.25.

γ_{nb} considers the influence of active fire safety measures like sprinkler systems or work fire brigades, e.g. if an automatic sprinkler system is provided, γ_{nb} gets to 0.6.
Other values for γ_{nb} can be taken from the following table which is the translation of the table 6 of DIN V 18230 (sept. 1987) [2].

work fire brigade number of firemen	sprinkler system	no sprinkler system
0	0.6	1.0
1 team	0.55	0.9
2 teams	0.5	0.8
3 teams	0.4	0.7
4 teams	0.35	0.6

Tab. 1 : Additional factor γ_{nb} according to DIN V 18230 (sept. 1987)

After its calculation the required fire resistance time has to be related to the corresponding fire resistance class R.

$0 < \text{erf}\ t_F \leq 15$ min $\rightarrow$ no fire protection
$15 < \text{erf}\ t_F \leq 30$ min $\rightarrow$ R 30
$30 < \text{erf}\ t_F \leq 60$ min $\rightarrow$ R 60
$60 < \text{erf}\ t_F \leq 90$ min $\rightarrow$ R 90
$90 < \text{erf}\ t_F \leq 120$ min $\rightarrow$ R 120

DIN 18230 only determines the required fire resistance time for a compartment. The verification and the design of each component part has to be done according to DIN 4102 part 4 [10].

3.2 Draft on DIN 18230 (july 1994 and september 1995) [4, 5]

In comparison to the prestandard of 1987 the draft editions of DIN 18230 from 1994 [4] and 1995 [5] do not contain substantial differences concerning the general calculation method of the equivalent fire resistance time. The determination of the ventilation factor w has been revised. The estimated opening area A_{v+h} has been replaced by the partial factors a_w and w_0. The factor a_w takes the height of the compartment into account, while w_0 depends on the ratios of the vertical and horizontal openings to the floor area. Both factors are determined by diagrams. Finally the ventilation factor can be calculated by a simple multiplication:

$$w = w_0 \cdot a_w$$

The values of the global safety factors have been modified slightly.
The following table contains the values of the additional factor for the influence of active fire safety measures. The symbol for this factor has been changed from γ_{nb} to a_L. The application has been enlarged to non-professional work fire brigades, detectors and manual sprinkler systems.

(1)			(2)	(3)	
work fire brigade					
number of firemen	professional	non-professional	detectors	manual fire extinguishing systems	automatic sprinkler systems
0	1.0	1.0			
1 team	0.9	0.95			
2 teams	0.8	0.85	0.9	0.85	0.6
3 teams	0.7	0.8			
4 teams	0.6	0.75			

Tab. 3: Additional factor a_L - DIN 18230 (draft july 1994) [5]

The final value of a_L is made up of a multiplication of column (1), (2) and (3).

4. Austrian standards TRVB A126 and TRVB A100 [6]

The basic concept of the Austrian standard TRVB is similar to the Swiss one used in SIA [8]. The specific fire risk B is determined according to the main equation in accordance with the individual factors as fire load Q, fire danger C, smoke danger R etc., which are given as table values.

$$B = Q.\ C.\ R.\ K.\ P.\ E.\ H$$

The characteristic risk number SF is depending upon the fire risk B and the measures of smoke exhausting.

$$SF = (G + K_1) \cdot B/K_2$$

The presence or absence of a sprinkler system is not taken into account in the formula above. The necessary active fire protection measures according to the fire resistance duration of the structural components are determined in accordance with the characteristic risk number SF.

Hereby, the possibility of changing fire protection measures exists.

For example, for the calculated characteristic risk number SF 3.0, both following solutions are allowed, the fire resistance class R60 with a fire alarm system or unprotected steel structures with a sprinkler system (in both cases a work fire brigade has to exist).

5. New-Zealand Method [7]

The chapter "Fire Engineering Design for Structural Stability" of [7] provides the following formula:

S_c = $c_1 \cdot c_2 \cdot c_3 \cdot c_4 \cdot \omega \cdot q_f$

where:

S_c = calculated security rating (minutes)
c_1 = enclosure (firecell) surface thermal coefficient
= 0.067 for typical applications
c_2 = structural element ductility or compression gravity loading factor
c_3 = 1.0 for unsprinklered firecells
= 0.6 for sprinklered firecells
c_4 = ventilation configuration coefficient
= 1.0 for satisfactory ventilation configuration when $A_v > 0.03\ A_{df}$
= 1.25 for unsatisfactory ventilation configuration when $A_v > 0.03\ A_{df}$
= 1.0 for any ventilation configuration when $A_v \leq 0.03\ A_{df}$
ω = ventilation factor
q_f = design fire load energy density/m² floor area (FLED)

The ventilation factor, ω, is given by:

$$\omega = \frac{A_{df}}{A_{dt}(A_v\sqrt{h_v}\,/\,A_{dt})^{0.5}}$$

where:

A_{df} = design fire area = lesser of A_f or 150 m²
A_f = firecell floor area
A_v = ventilation area considered accessed by the fire
h_v = weighted mean height of openings A_v
A_{dt} = total surface area occupied by the area of design fire

As in ENV 1991-2-2 [1], the sprinklers are considered by multiplying the fire load by a factor 0,6. The reduction is based on a paper of Malhotra [11].

6. Fire risk evaluation according to SIA documentation 81 [8]

6.1 Description of the method

In 1960 Dipl. Ing. ETH Max Gretener, head of the Brand-Verhütungs-Dienst BVD (Swiss Fire Protection Association) in Zurich, started to study possibilities to calculate the fire risk in industrial premises and other large buildings. He developed an easy to use risk assessment method which was first published in 1965 and focused on the needs of the fire insurance companies. In 1968 it was proposed to use the method also to set the fire protection measures by the fire police.

In 1984 the Fire Risk Evaluation Method SIA Documentation 81 was published. It was derived from the work of Max Gretener. The method was completely revised by a project team consisting of members from the VKF (association of monopolistic state insurance companies) the BVD (representing also the private fire insurance companies) and the Swiss Association of Engineers and Architects SIA. This project team adapted the method to new national and international knowledge and experience. Emphasis was given to make the method easy to use by fire police, insurance people, engineers and architects.

The method is well accepted in Switzerland and even recommended in the fire regulation as a tool to evaluate and compare the fire risk of alternative concepts (trade-off between sprinkler and detection and passive fire protection).

Below a short description of the method is given:
It is a method based on a large statistical survey on fire loads and on building losses. It consists in the verification of a global fire safety factor γ_{Fire}:

$$\gamma_{Fire} = \mathbf{R}_{accepted} / \mathbf{R}_{calculated} \geq \mathbf{1}$$

It is a check to verify that the calculated risk of given compartment is smaller than the accepted risk.

$\mathbf{R}_{accepted}$ is a function of the number and the mobility of the persons involved and of the location of the relevant fire compartment within the building.

$\mathbf{R}_{calculated} = \mathbf{A} \times \mathbf{B}$ **A** representing the probability of occurrence of a fire
B representing the probable amount of losses $\mathbf{B} = \mathbf{P}_{danger} / \mathbf{M}_{applied}$

$\mathbf{P}_{danger}$ is a function of the following parameters:

* fire load density and distribution
* combustibility of the fire loads
* smoke production
* production of corrosive agents

* combustibility of the building components
* area of the compartment or building
* storey of the compartment to be checked/height of the building

$M_{applied}$ is a function of:

* basic normal measures which includes the:
  - quality and number of internal fire fighting devices such as portable fire extinguisher and internal hydrants
  - reliability and quality of water supply
  - distance to nearest hydrants
  - quality of staff instruction in case of fire
* active measures which includes the:
  - type of fire detection devices and measures
  - reliability and rapidity of alarm transmission
  - reliability, rapidity and quality of fire brigades
  - type of fire suppression devices
  - presence of smoke and heat extraction devices
* passive, structural measures which includes the:
  - level of structural fire resistance
  - the type of the facade used as a barrier against the spread of fire
  - the fire resistance level of compartmentation
  - the ventilation characteristics of the fire compartment

With regard to questions of validity, the Swiss Fire Risk Assessment method has the advantage of not just claiming to have a purely scientifical background, but to be an empiricalistic procedure tested by a wide practical application. However it is based on a large background statistical data, and a scientific validation for this method could certainly be developed if needed.

6.2 Influence of active measures

The SIA-method grades the influence of active measures on the global fire risk. With regard to sprinklers the following parameters are taken into account:

- detection (sprinklers activate an alarm bell if water is flowing through the main valve)
- alarm transmission (the sprinkler alarm is often - in Switzerland mandatory - connected directly to the fire brigade)
- suppression function (water discharge on fire)

The method proposes the following risk reduction factors:

- detection (parameter S_{13}) : $S_{13} = 1.20$
- alarm transmission by specially protected telephone lines (parameter S_{24}) : $S_{24} = 1.20$
- suppression function : $S_{51} = 1.7$

or for annually checked sprinkler system designed according to regulations (*) : $S_{51} = 2.0$ (*)

The global risk reduction factor $\gamma_n = 1/(\Sigma s_i)$ is found to be:

- Sprinkler without automatic alarm to fire brigade:

$$\gamma_{n1} = \frac{1}{S_{13} \cdot S_{51}} = 0.49 \text{ (or 0,42 see*)}$$

- Sprinkler with automatic alarm to fire brigade:

$$\gamma_{n2} = \frac{1}{S_{13} \cdot S_{24} \cdot S_{51}} = 0.41 \text{ (or 0,35 see*)}$$

These values are lower than the value for the reduction of the design fire load in Annex D of ENV1991-2-2 [1]. $\gamma_n = [0.6]$.

While Annex D mainly considers the suppression function (reduction of fire load), the SIA method also considers alarm and alarm transmission (e.g. earlier evacuation and fire brigade action). This may explain the better rating of sprinkler systems within the SIA method. This better rating is supported by the insurance companies who apply premium reductions up to 60 % and more for sprinkler systems. This could lead to the assumption that their risk assessment systems also come to the conclusion of a risk reduction of roughly 60 % e.g. $\gamma_n = (1\text{-}0.6) = 0.4$.

7. Method FRAME [9]

The method FRAME for Fire Risk Assessment Method for Engineering is based on the Swiss SIA 81 made by Mr. E. De Smet and published by ANPI (Association Nationale pour la Protection Incendie) in Belgium. This method enables one to calculate two risks in case of fire, the risk for the contents and the risk for the people.

In the case of the risk of the contents, the sprinklers have an influence on the detection and on the fire extinction.
The risk reduction factor is 1,22 for the detection which can be considered only if there is a connection to the fire brigade. Concerning the fire suppression function, the risk is again reduced by a factor equal to 1,71 for sprinklers without independent water source, to 1,98 for sprinklers with one independent water source and to 2,65 for sprinklers with two independent water sources. This last case leads to a value of γ_n equal to $1/(2{,}65 \cdot 1.22) = 0{,}31$.

In the case of the risk for the people, the fire risk reduction factor is the same for the detection. But the sprinklers also play a part in the protection of the evacuation. The reduction factor is 1,27 if there are sprinklers only in high risk areas and is equal to 1,63 if there are sprinklers in the whole building.

8. Fire Safety Engineering taking into account the active fire fighting measures - Practical Example

A practical example came with the realization of the ARBED OFFICE BUILDING in Esch-sur-Alzette, Luxembourg. This new construction was erected between 1991 and 1993, is composed of two wings with nine levels and a total volume of 61 m^3 [12,13,14,15].

The Fire Engineering Design has used the new structural fire design standards of CEN by performing a global structural analysis on the entire steel structure, considering the combination rules for actions during fire and applying the estimated natural fire evolution according to the specific features of this building.

When it came to the natural fire evolution a first evaluation of the natural temperature-time curve was based on real fire loads existing in offices (900 MJ/m^2) and common areas (650 MJ/m^2) (i.e. 53 kg and 38 kg of wood respectively per m^2 of floor area), on ventilation conditions and on the size of the fire compartment. This produced a natural fire curve with a maximum temperature of 800°c at 20 minutes.

Due to the large size of the compartment because of the atrium connecting levels, the decision was taken to install a sprinkler system. Which meant, refering to Annex D of ENV 1991-2-2 [1], it was reasonable and on the safe side compared to the other standards to adopt a fire load density reduced for design by 40% . This lead to a natural fire with a maximum air temperature of only 400°C (figure 1).

Due to a possible problem in the water supply and delay in the intervention of the fire brigade, it was supposed that this natural fire would spread onto two consecutive levels over a total floor area of 300 m^2 (figure 2).

This fire scenario was applied to the entire structure and the numerical calculation by CEFICOSS proved that widely unprotected steel structure will not fail (Figure 3 shows the global deformations after 30 minutes).

The reason for this remarkable conclusion is the global frame behaviour, which could be activated by strong beam connections able to transmit bending moments and the natural fire which, if it occurs, is assumed to be softened by a complete set of active fire safety and fire fighting measures (figure 4)

The influence of this complete set of active fire measures should be defined more in details in ENV 1991-2-2 and can surely not by summarized by the single value 0,6 for the γ_n as it is now the case. An ECSC research [16] is now working on this topic and should offer the possibility to improve the ENV 1991-2-2 in the future.

9. Conclusion

The following table enables one to compare the Annex D of ENV 1991-2-2 [1] to the other methods.

Method	Sprinkler effect (Detection and extinction): γ_n
ENV 1991-2-2 [1]	0,6
DIN 18230 [2, 3, 4, 5]	0,54 (= 0,6 x 0,9)
New Zealand [7]	0,6
SIA 81 [8]	0,35 to 0,49
FRAME [9]	0,31 to 0,48
Insurance Companies	Premium reduction: Initial premium multiplied by up to 0,4

The value 0,6 of γ_n in Annex D of ENV 1991-2-2 appears very high and should be divided into sub-coefficients taking into account the sprinkler types, the water supply, the detection and the communication of the alarm to the fire brigade.

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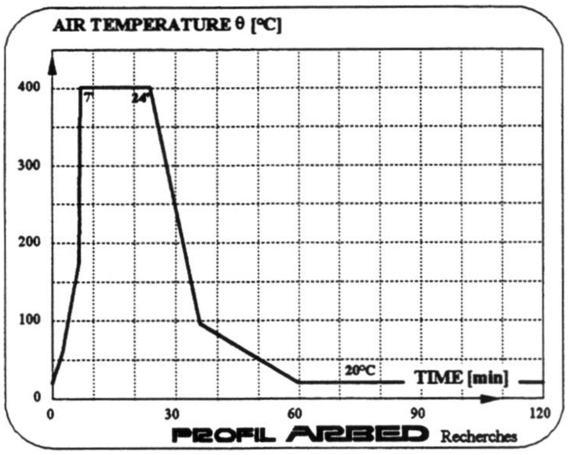

Figure 1

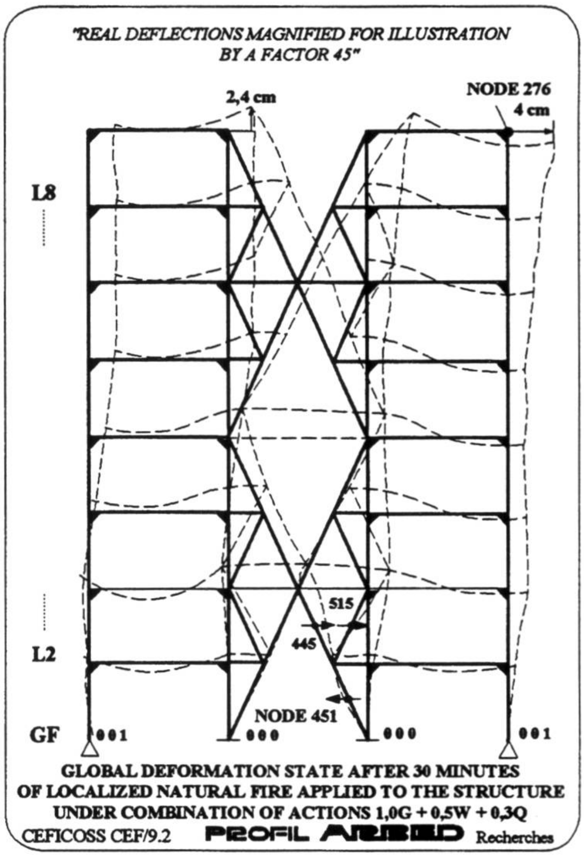

Figure 3

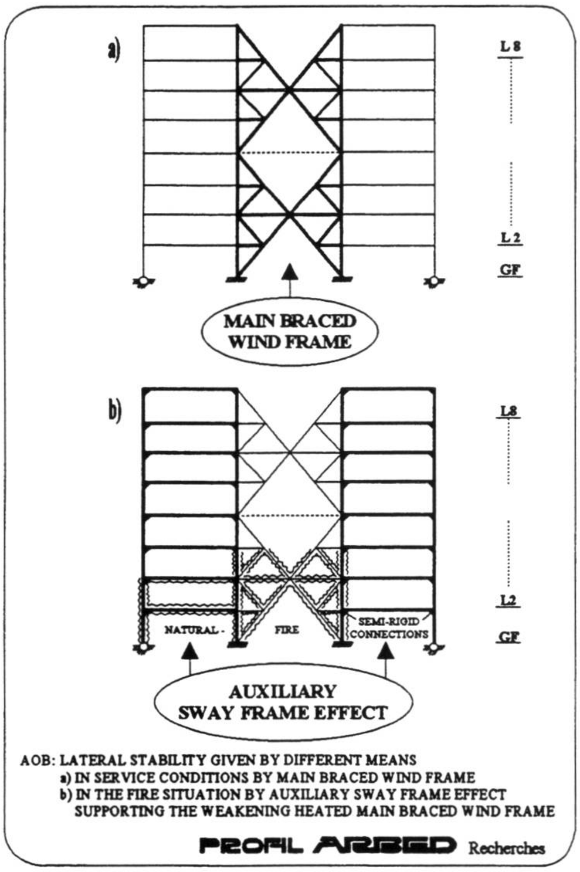

Figure 2

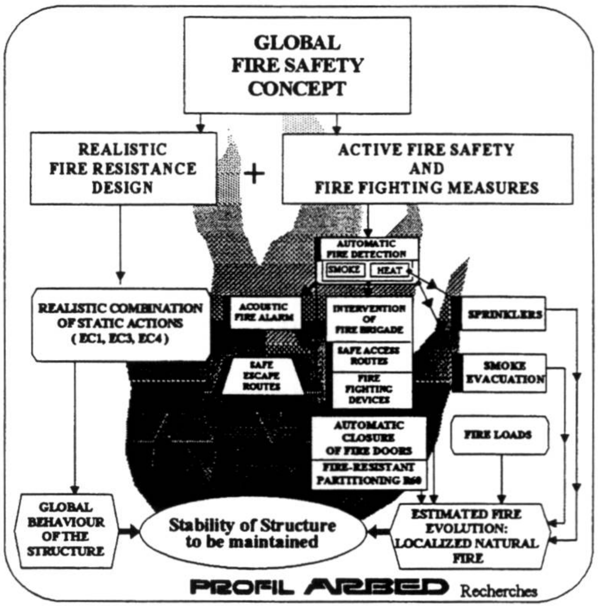

Figure 4

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