FRAME 2008.
Theoretical basis and technical reference guide.
THE POTENTIAL RISKS.

WHAT CAN BE DONE WITH THE FRAME CALCULATIONS?

Fire Risk assessment methods.
Use and advantages of ranking methods.
Point systems.
Quantitative Methods.
Event tree analysis.

Event networks in FRAME.

NETWORK FOR PROPERTY RISK.
SUBSYSTEM A: DISCOVER / NOTIFICATION.
SUBSYSTEM B: FIRE FIGHTING BY OCCUPANTS / STAFF.
SUBSYSTEM C: AUTOMATIC EXTINGUISHING SYSTEMS.
SUBSYSTEM D: FIRE BRIGADE AT FIRE SCENE.
SUBSYSTEM E: RESCUE PRIORITY / EVACUATION TIME.
SUBSYSTEM F: WATER SUPPLIES.

NETWORK FOR OCCUPANTS' RISK.
SUBSYSTEM A1: DISCOVERY AND NOTIFICATION.
SUBSYSTEM B1: FIRE FIGHTING BY OCCUPANTS and STAFF.
SUBSYSTEM C1: AUTOMATIC EXTINGUISHING SYSTEMS.
SUBSYSTEM D1: FIRE BRIGADE ON FIRE SCENE.
SUBSYSTEM E1: EVACUATION PERIOD.
SUBSYSTEM F1: REDUCED EXPOSURE.

NETWORK FOR ACTIVITIES' RISK.

Guidelines for Fire Risk Assessments.
The CFPA Guideline no 4.
NFPA 551 Guideline.

The “FRAME” approach of fire risk assessment.
The equilibrium between threat, protection and exposure.
Severity, exposure and probability.
Probability = Reverse of Protection.
Separate calculation for property, occupants, activities.
One calculation per compartment.
Risk value expression.
Insurance premium rates.
Risk aversion.

WHAT CAN BE DONE WITH THE FRAME CALCULATIONS?
DEFINITIONS AND BASIC FORMULAS.
Building and content.
Occupants.
Activities.

THE POTENTIAL RISKS.
Severity and worst case scenarios.
The fire load factor q.
The spread factor i.

Input data.
The link with the fire duration.
The value range for fire load factor q.
The value range of fire spread factor i.
Introduction.

Fire can be seen as an unwanted combination of three useful and necessary elements: oxygen, combustibles and energy. As they are needed for human life, the risk of fire cannot be eliminated by taking them away. Therefore, we will have to manage the risk, i.e. balance the benefits and disadvantages of the token risk, and see how we can handle it.

There are plenty of standards that define how to design fire protection systems. However, only a few methods exist to define how much fire protection a building would need to be reasonably protected. Building codes have such requirements, but these are mostly meant to assure a safe escape or rescue for the occupants, but not to salvage the building, nor to protect its content or the activities in it.

Most engineers and designers rely on their experience and the advice of colleagues to select a sufficient and cost-effective quantity of fire protection for new or existing buildings. It is also not easy to find out whether designs with comparable costs have also comparable efficiencies.

"FRAME" was developed as a tool to help a fire protection engineer to define a sufficient and cost-effective fire safety concept for new or existing buildings. Unlike building codes that are mostly meant to assure a safe escape or rescue for the occupants, "FRAME" also aims at protecting the building, its content and the activities in it. This method can easily be used to evaluate fire risks in existing situations, and to find out whether alternative designs have also comparable efficiencies.

"FRAME" appeals to risk professionals as it "feels good", i.e. the results of the calculations fit the intuitive evaluation, based on knowledge and experience. But as for all empirical methods, the question is often raised where does it stand scientifically? It is fairly clear that organising a research program to check the validity of all the parameters by fire tests is an impossible task, which goes beyond the need for accuracy. However, there is a general request for some proof or validation of the method, based on scientific knowledge.

The distrust for empirical methods is understandable, yet such calculation rules have been established and used with confidence in many fields and for many years before there was any scientific support for them. Men did have some empirical rules to build ships before Archimedes discovered the physical law for buoyancy. To permit confidence building and validation of "FRAME", the proposed approach in this Technical reference guide is to check if the method fits with available knowledge on risk assessment and fire.
How “FRAME” was developed.

The development of “FRAME” is the result of a 30-years search for a practical tool for designing adequate fire protection for buildings. Back in 1975, I learned about the method developed by the Swiss engineer Max GRETENER and I started to use it for design purposes. It worked quite well, but it had some drawbacks, which could be improved.

The major handicap was the use of tables for the various parameters. At the beginning, I did not have the complete tables, and later on it became clear after some tests, that some tables were not enough “fine tuned” to be used as an engineering guideline. The steps were sometimes too large, giving different results from guesswork by different persons on the same job. However, the general balance of factors was good and fitted well with the professional expertise of many of my fellow fire protection engineers.

Therefore, I gradually developed a new method to suit my needs as fire protection designer. Most tables were replaced by formulas for which measurable or identifiable values are used. Some influence factors were rearranged; others were split up to allow a different or a finer approach. The use of formulas became a rather easy task with the help of a programmable calculator.

The GRETENER-method was originally made for the property fire risk. Some fires with only minor property damage but with fatalities indicated the need for a similar approach for the human fire safety in a building. In the late seventies, MM. SARAT and CLUZEL developed in France such a variant of the GRETENER-method, aimed at life safety. Their method was called E.R.I.C. (Evaluation du Risque d’Incendie par le Calcul). Their work was of great help for me to develop the second part of the method, which is described in this book.

In 1980, a second version of the GRETENER-method was published by the Swiss organisation KF-SIA-BVD. It took into account the double fire risk profile (property and life) and added some refinements to reflect the last findings in the fire protection field. In my opinion, some shortcomings of the original method remained and some were even enhanced, but it contained some information, which allowed me to upgrade the method I was using.

In 1983, I started working in the insurance industry and there I realised that fire has another aspect, that of the consequential loss or business interruption. Therefore, I developed the third part of the method, following the same reasoning as for the property and life safety.

The method was named “FRAME” which is an acronym for “Fire Risk Assessment Method for Engineering”.

Since 1981, the N.V.B.B.-A.N.P.I., the Belgian Fire Protection Association has included “FRAME” in their training course for fire protection specialists. The first version of the method has been in Dutch and French in TD73 of the N.V.B.B.-A.N.P.I. in October 1988. At that time, a BASIC program was developed to facilitate the application of the method.

During the first ten years of using “FRAME” version 1, it became clear that it was a practical and reliable tool for most situations. The use of a numerical value for the fire risk for the property and the content, for the occupants and for the activities, is much clearer than a long description of positive and negative aspects. The method was proven by real case studies: For a series of buildings, which are considered by experts to be well protected, the calculated values indicate also well-protected buildings. On the other hand, calculating the risk values for documented real fires showed that the weak points were evidently visible in the “FRAME” calculations.

The first major revision of “FRAME” came in 1999-2000 to make it more compatible with new technologies and developments in the field of fire safety engineering. In the area of evacuation time requirements, there was a lack of compatibility with code requirements.
FRAME version 1985 did not take into account the requirements for multiple egress capacity, and counted only indirectly with the time passed in staircases. The evacuation time was also underestimated for very congested areas, as the compression effect of a crowd was not properly evaluated.

Moreover, in that period code requirements for exit paths in various countries converge toward a 300 seconds maximum evacuation time to reach a safe area after the fortuitous discovery of a fire. Furthermore, it was recognised that if people were unaware of an incipient fire, they might evacuate too late for their safety. This problem could arise in homes for elderly, hotels and similar occupancies. All these remarks were used to build a new formula for factor \( t \) in the FRAME 2000 version.

As multiple production centres tend to disappear, the formula for the salvage factor was simplified accordingly. The value factor formula was slightly modified to fit the year 2000 monetary values. Newer fire protection technologies were included in the calculation of the protection level.

A Windows-based software was made to assist the “FRAME” calculations. This software was made available in several language versions: English Metric - American Non Metric- Dutch – French – Spanish – German and Portuguese. The non-metric version had no success.

Since the development of “performance based” fire protection designs, it appears that FRAME can be applied as a proving tool. As the balance between the influence factors is a faithful reproduction of most code requirements and general engineering experience, the method can easily be used to compare the overall equilibrium of an engineered solution to a Code imposed protection level.

The latest (2008) development of “FRAME” are thus caused by this move toward performance based fire protection designs, and by the continuous changes in software platforms. A spreadsheet type has been developed with the help of Vinçotte Belgium (a regular user) and the input data have been updated with references to more recently developed EN-standards.
Assessing hazards and risks.

Hazards are usually defined as an incident scenario: “when this and that fails, the result will be some damage”. To transform a “hazard” into a risk, it must have some dimensions: a risk is a measured hazard.

Risk assessment has become an increasingly growing practice in all safety related disciplines. There are various methods in use to satisfy the needs of many decision making processes, where it is important not only to know what to do, but more important to have a reasonable insight in the cost/benefit balance of a proposed set of provisions.

All methods for risk assessment give some way of quantification of hazards, and in most of them there are also guidelines to compare the risk with a reference which is considered to be an “acceptable level” of risk.

There is much literature available about “acceptable risks”. One of the first publications on the subject was William W. Lowrance book “Of Acceptable risk”, Science and the determination of safety,” published in 1976. The author looks at the problems of determination of safety and the underlying concept of safety itself:

"When commencing the book, one intent was to develop a definition of acceptable risk that is universally applicable in all risk situations and more specific than the prevailing general definitions. Unfortunately, the original intent proved to be elusive. …

Acceptable risk is a function of many factors and varies considerably across industries (e.g. mining vs. medical devices vs. farming). Local cultures also play an important role in risk acceptability, as has been experienced by our colleagues working in global companies. Risk acceptability is also time-dependent in that what is acceptable today may not be acceptable tomorrow, next year or the next decade. …

Developing a single, distinct and commonly accepted definition of an acceptable risk level that is universally applicable is not possible. In general terms, all that can be said is that the residual risk, after determining the severity of outcome of an event and the event probability, and the taking of preventive action, must be acceptable in the particular setting being considered…”

Acceptable Risk levels.

Lowrance pointed out that people accept risks, even with deadly consequences, if the combination of probability, exposure and severity is low enough. He also indicates a number of factors that influence the way risk are accepted or tolerated.

Sometimes people are bound to accept a risk because they do not have the means to protect themselves or because they consider these risks as inherent to life. In this way, people accept in some countries floods or earthquakes as part of their living conditions.

Risks are less acceptable when the consequences are more severe, when more people are exposed to the risk at the same time, and when the duration of exposure is lengthy. A risk is considered less acceptable when the consequences are readily visible.

A risk is more easily accepted when the consequences are reversible, of short duration or repairable, when there is a visible benefit in taking the risk, and when one thinks to have control of the causes of the undesirable event.

When all these elements are taken into account one can perfectly explain why a lot of people prefer travelling in their own car above flying, even when the air travel is cheaper: A serious
A car accident will eventually give 5 deaths, a aeroplane crash will cause a hundred of victims; during a car trip, the danger is only perceived for short moments, but one will fear for the crash during the whole flight. In our car, we think that we have control of the situation as we choose the course of our trip. In such a situation, an air voyage must be much safer than a car trip to give us the same perception of safety.

An unknown or hidden risk will be less acceptable. In this way, we have more fear of a fire during the night than during daytime, although the probability is much higher when we do all kind of things, then when we are at rest.

There are plenty of statistics available to indicate us what level of frequency and severity of accidents are existing and what are the socially accepted levels of safety. The probabilistic approach of risk is widely used in the chemical and nuclear industry and for work accidents, but is almost unknown in approach of safety of buildings.

**Continuous exposure.**

When the exposure to a hazard is continuous, the risk can be expressed as a combination of a probability of occurrence or frequency and a magnitude of the consequent loss or severity. A simple method is a risk profile, a graphical method where different levels of probability and severity are given on a x/y graph. This method is usually based on U.S. MIL-STD-1629A, "Procedures for performing a Failure Mode, Effects and Criticality Analysis" which indicates severity levels from Minor to Catastrophic, and probability levels from Frequent to Extremely Unlikely.

Each identified risk will be shown by a point on the risk profile. On that graph profile, three distinct zones can be defined:

- **Green zone:** shows the acceptable risks with a low value for the product severity * probability, the red zone the unacceptable risks, and the yellow zone those risks that give concern for corrective action.
One of the oldest and widespread methods for risk assessment was developed back in 1976 by Kinney et al. and is widely used for the analysis of workplace hazards. Risk assessment is also included in the standards for the safety of machinery, which consider three elements: severity, probability of occurrence and exposure, like the Kinney Method.

Both use a tree step approach, which can also be applied to fire risks:

Step 1: A possible accident (fire) is described by its triggering elements and its development. The resulting damage such as death, injury, destruction, interruption of work, etc. is evaluated according to a descriptive ranking system (e.g. minor damage, repairable, permanent damage, catastrophe) or eventually by its monetary equivalent.

Step 2: The possible victims of the damage are considered as well as the frequency and duration of their exposure to a situation where the accident could occur. The combined time elements are also evaluated on a second ranking scale (e.g. exceptional, occasional, frequent, permanent) or by total exposure time.

Step 3: The probability of occurrence of the possible accident of step 1 is considered. It is accepted that the accident will not occur with the indicated effect, as long as the available protection system does not fail. The probability of occurrence is evaluated according to a third ranking scale (e.g. likely, improbable, almost impossible) or by a frequency value (10^-n occurrences/year).

A partial failure with minor damage could occur, but shall be considered as a different accident scenario.

**The Kinney method**

In the Kinney method, the mathematical expression of the risk is the formula:

\[ \text{Sev} \times \text{Poc} \times \text{Exp} \leq \text{C} \]

whereby:
- \( \text{Sev} \) = measure for severity
- \( \text{Poc} \) = measure of probability of occurrence
- \( \text{Exp} \) = measure of exposure
- \( \text{C} \) (constant) = measure of acceptable risk level

The values used by Kinney for the severity, probability and exposure are:

<table>
<thead>
<tr>
<th>Value of Poc</th>
<th>Probability of Occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>can be expected, almost certain</td>
</tr>
<tr>
<td>6</td>
<td>very possible</td>
</tr>
<tr>
<td>3</td>
<td>combination of unusual circumstances</td>
</tr>
<tr>
<td>1</td>
<td>possible in the long run</td>
</tr>
<tr>
<td>0.5</td>
<td>conceivable but unlikely</td>
</tr>
<tr>
<td>0.2</td>
<td>highly unlikely</td>
</tr>
<tr>
<td>0.1</td>
<td>practically impossible</td>
</tr>
</tbody>
</table>
The proposed values for each factor are situated on a non-linear (semi-logarithmic) scale, and the calculated risk factor is compared with the following "decision table". The non-linear scale represents the risk aversion phenomenon, i.e. the human attitude to reject high severity / low probability risks more than low severity / high probability risks.

The decision table categorizes the identified risks and allows to establish an priority program for risk reduction.

<table>
<thead>
<tr>
<th>Risk factor value</th>
<th>Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>No attention required</td>
</tr>
<tr>
<td>20 to 70</td>
<td>Attention required</td>
</tr>
<tr>
<td>70 to 160</td>
<td>Corrective action required</td>
</tr>
<tr>
<td>160 to 320</td>
<td>Immediate corrective action required</td>
</tr>
<tr>
<td>&gt; 320</td>
<td>Stop activities</td>
</tr>
</tbody>
</table>

For fire, which is also a non-continuous hazard, such methods offer a better approach, and "FRAME" uses a formula which is similar to the Kinney -method: 
This formula can also be written as: \( P / D \times A \)

The potential risk \( P \) is decisive for the severity, \( 1/D \) indicates the probability of occurrence: A high protection level results in a low failure rate i.e. a low probability.

The acceptable risk \( A \) is a measure for the exposure: The more exposure (to property, people, activities), the lower the acceptable risk is.

The similarity between the "FRAME" basic formulas and the expression used in the KINEY method clearly shows that "FRAME" is not a "point-system" but a probability – severity – exposure based method.

**The safety of machinery approach.**

For the safety of machinery, the way to combine severity, probability of occurrence and exposure into an acceptable risk has been clearly defined and explained in EN1050 and EN954-1.

Although the EN 1050 standard has been replaced recently by the EN-ISO 14121-1:2007 and the EN 954-1 by the ISO 13849-1, the principles remain valid and can be also used to evaluate fire risks with some modifications.

In order to conclude that a certain level of risk is sufficiently low to be accepted, one has to verify the reliability of the protection. This reasoning has been widely developed and pushed by the European Directive 89-392 or "Machinery Directive" and by European standards EN1050 and EN954-1, indicating how the safety of machine can be materialised. This approach is also feasible for the evaluation of the fire risk in a building and is worth to be reviewed in more detail.

The EN 954-1 norm defines five levels of protection (B, 1, 2, 3, 4), related to 5 risk classes, related to 3 characteristics of the unprotected risk:

- **S**: The degree of possible injury:
  - S1: reversible injury (can be cured)
  - S2: irreversible injury or death
- **F**: frequency of danger and exposure
  - F1: low frequency and/or short duration of exposure
  - F2: high frequency, or continuous or long exposure
- **P**: possibility to escape from the risk
  - P1: the victim can identify the risk and escape in time
  - P2: there is no possibility to escape.

These criteria give five risk classes:
- Class I: S1
- Class II: S2 + F1 + P1
- Class III: S2 + F1 + P2
- Class IV: S2 + F2 + P1
- Class V: S2 + F2 + P2

To this classification of risks fits a similar classification of protection:
- The B(asic) category of protection means that the installation is built according to the codes of good practice with materials of good quality. There is no risk until there is a
failure of one or more elements. This is the absolute minimum safety level, acceptable for
risk class I only.
• Protection category 1 means that the installation is built according to the codes of good
practice with materials of good quality, and that the reliability of safety elements is
guaranteed by tests, over sizing or redundancy. This degree of protection is acceptable for
risk classes I and II.
• Protection category 2 means that the installation complies with the requirements of
category 1 and that the correct functioning of the safety elements is regularly checked.
This degree of protection is acceptable for risk classes II and III.
• Protection category 3 means that the installation complies with the requirements of
category 2, and that a single failure in the safety function does not mean that this function
is impaired, and that the failure is rapidly detected. This degree of protection is acceptable
for risk classes III and IV.
• Protection category 4 means that the installation complies with the requirements of
category 3, that a single failure of the safety function is immediately detected and that a
multiple failure does not impair the safety function. This degree of protection is required
for risk class V.

These requirements are based on a number of axioms and principles:
• The probability of occurrence of the danger is more or less constant: The majority of the
machines is conceived for a certain lifetime and has thus a built-in failure probability.
• The reliability of system elements will be improved by tests, overseeing, and "fail-safe"
design.
• One can differentiate the situation when the victim can escape or not from the risk. A fast
warning is essential.
• If the protection is reliable, the real occurrence of the accident will be reduced.
• Protections (safety systems) can be made reliable by checks, self-surveillance and
redundancies.

An important remark is that protection is only the second defence, prevention is always first.

The duty of preventing risks is a priority. Risks must be reduced at the source and dangerous
situations replaced where possible by more safe situations. The application of the general
prevention principle means in practice that the residual risk will be found in the lower classes, which require less elaborate protection measures.

When comparing this classification of risks with the safety levels that are generally acceptable to society, the following relationship can be established: Class I corresponds with the level of repairable damage, class III with the single death accident. The tolerance levels are in fact identical to the probability of failure of the protection systems. For example, a category 2 protection could have a failure rate of $1.10^{-6}$.

<table>
<thead>
<tr>
<th>tolerance limit</th>
<th>class/category</th>
<th>BASIC PROTECTION</th>
<th>category1</th>
<th>category2</th>
<th>category3</th>
<th>category4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;1.10^{-4}$</td>
<td>Class I</td>
<td>minimal</td>
<td>recommended</td>
<td>more than</td>
<td>more than</td>
<td>more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>required</td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>$&lt;1.10^{-5}$</td>
<td>Class II</td>
<td>insufficient</td>
<td>necessary</td>
<td>Recommend ed</td>
<td>more than</td>
<td>more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>required</td>
<td>required</td>
</tr>
<tr>
<td>$&lt;1.10^{-6}$</td>
<td>Class III</td>
<td>insufficient</td>
<td>insufficient</td>
<td>necessary</td>
<td>recommend ed</td>
<td>more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>required</td>
</tr>
<tr>
<td>$&lt;1.10^{-7}$</td>
<td>Class IV</td>
<td>insufficient</td>
<td>insufficient</td>
<td>insufficient</td>
<td>necessary</td>
<td>more than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>required</td>
</tr>
<tr>
<td>$&lt;1.10^{-8}$</td>
<td>Class V</td>
<td>insufficient</td>
<td>insufficient</td>
<td>insufficient</td>
<td>insufficient</td>
<td>necessary</td>
</tr>
</tbody>
</table>

The same principles explained in the standards for machinery can also be applied for fire safety, but such a systematic approach of fire risks has not received much attention, and the techniques to make the fire protection system reliable has been often defined at random.

Making structural elements of a building fire resistant is in fact a technique of over sizing, Exit requirements often boil down to redundancy. To limit fire propagation, material requirements are based on tests, where fire detection systems are made reliable by self-surveillance. Sprinkler systems are subject to inspections for reliability, but for water supplies, redundancy is preferred. Fire brigade systems are secured by a combination of testing (through exercises), over sizing (dispersed fire posts) or redundancy.

Classifying risks and protections in 5 classes and 5 categories is a mere decision tool. In practice, there is a wide variation of possible damage and a large spectrum of available protection systems. The variety of influence factors is so large that a more gradual approach of risks and protections is advisable. It is this detailed evaluation of a large number of factors that makes the FRAME attractive for fire risk assessment.

Although FRAME has been developed in a period when nobody in the fire safety field was talking about failure probabilities and protection categories, it stands very well compared with this new approach.

_The existing acceptable level of Fire Risk._

As there are very few people that are worried about the existing fire risk in our society and as there is no public discussion on unacceptable situations in this field, one can suppose that the present level of fire safety complies with the expectations of our citizens: We consider that the available level of fire safety in our (West-European) society is acceptable.

So, what level of safety do we have reached?
Usually the basic acceptable level of risk is defined in a situation of permanent exposure, i.e. that the danger and the risk are always together. Such a risk will be accepted when the probability of an accident with one death is less than 1 per million of persons per year, or $1.10^{-6}$/person*year.

A number of studies and evaluation methods indicate that the acceptance of risk is reduced by the square of the number of possible victims: for 3 deaths, the acceptability is 10 x less, for 10 victims, it is 100 x less, and for a 100 deaths, it is 10.000 x less. This explains easily the much higher safety requirements imposed on nuclear industry and aviation, and makes it understandable why our safety rules are less stringent for low buildings compared to high rise buildings, that are less easily evacuated.

If the exposure is not permanent, the risk will be more easily accepted. Such is the case for the fire risk: In most European countries, the number of deaths by fire is between 4 and 15 per million habitants per year. This level of $5 \times 10^{-6}$ deaths per person*year is 5 times higher than the basic level of permanent exposure but lower than the road traffic risk.

For the risk of damage to our homes, we can make the following calculation: Of the average of 13.000 fires per year in Belgium, about 10.000 are residential fires. With an average surface area of homes is 160 m², and 400 million m² total habitable area of Belgian homes, the probability of a residential fire in Belgium is $40. \, 10^{-6}$/year.m². This numbers is also valid in various other European countries. With an average of 4 persons per house, the probability of a person threatened by a home fire is $= \, 1 /1000$ per person per year. With 5 victims per million inhabitants, this means that the probability that one cannot escape from a residential fire is about 0.5 % of the incidents.

In Bern, Switzerland, the property insurance is mandatory with the Canton insurance, which collaborates tightly with the fire brigades. Because of this particular situation, detailed statistics are available. These indicate that in 40 % of the cases the fire is already extinguished before the arrival of the fire brigade, for 90 % the fire is limited to the room of origin and only in 8 % there is a developed fire (flash-over), which is still controlled by the fire brigade in 2/3 of the cases. We can estimates that the situation is not significantly different In Belgium, and therefore conclude that the accepted level of property damage (total destruction of a house of 160 m²) is about $40 \, 10^{-6}$/year. This level is equivalent to 40 % of what is usually accepted for a risk with heavy but repairable consequences (= 100. $10^{-6}$). This higher level of requirements can be explained by the direct nuisance caused by a residential fire.

According to the NFPA, 412 000 residential fires occurred in the US in 2006 with 2580 civilian deaths. The US Census bureau gives approx. 300,000,000 inhabitants in 2006 and 126,300,000 housing units. Comparing this figures results in a probability of death of $8.6 \, 10^{-6}$/person. year and 0.003 fires per year per housing unit. The probability that one cannot escape from a residential fire is about 0.6 % of the incidents.

According to the National fire statistics in the UK, 88 700 building fires occurred in Britain in 2006 of which 55 800 were dwelling fires. There were 363 deaths in dwellings, which means an average of 6 deaths per million population. In 2006, there were 6.5 deaths per 1,000 dwelling fires, compared with 1.1 per 1,000 fires in other buildings.

In summary, we can conclude that we are using the following levels of safety for our houses:

- the probability of death shall be less than $5.10^{-6}$/person. year
- the probability of total destruction shall be less than $40. \, 10^{-6}$/year

The levels of acceptable risk are not identical for the people and for the property, which is easily explained as the impact is different.
Fire Risk assessment methods.

Fire risk assessment has been practiced for many years. The development of performance based fire codes and fire safety engineering has increased the interest for tools that can be applied in fire safety issues. The existing methods can be broadly classified as risk ranking methods and probability based methods. FRAME (and Gretener) stays somewhere in between these, as it combines a probability approach with a risk index value.

Use and advantages of ranking methods

Ranking methods or point systems are described as follows in the FiRE- Tech WG6 report:

"Ranking methods or semi-quantitative methods are used in a wide range of applications. These methods have often been developed with the purpose of simplifying the risk assessment process for a specific type of building, process etc.

Ranking methods remove most of the responsibility from the user to the producer of the method. But the user of a ranking method remains responsible of the data gathering but the producer of the method has narrowed his freedom of quantification.

In general, a group of experts first had to identify every single factor that affects the level of safety or risk, which represents positive features (increase the level of safety) and negative features (decrease the level of safety). The importance of each factor has to be decided by assigning a value. This value is based on the knowledge and the experience of experts over a long time coming from insurance, fire brigade, fire consultants, scientists etc. Assigned values are then operated by some combination of arithmetic functions to achieve a single value. The value can be called as "risk index" and is a measure of the level of safety/risk in the object and it is possible to compare this to other similar objects and to a stipulated minimum value.

Not all ranking methods include a basic level for a satisfactory protection, but give only a relative position as situation A is better/ worse/ equivalent to situation B. This can be an advantage for the user which can define his own level of protection, but in practice, most inexperienced users want that an expert system gives them a clue on "what is good enough".

An advantage of fire ranking methods is their simplicity, they are considered as very cost effective tools. Another advantage of this method is the structured way in which the decision making is treated. This facilitates understanding of the system for persons not involved in the development process and makes it easier to implement new knowledge and technology into the system."

Point systems.

The most elementary ranking methods are point systems. The WG6 report mentions a number of them: The Risk Value Matrix of NFPA 909, Code for the Protection of Cultural Resources, the fire safety evaluation system (FSES) of NFPA 101A, Guide on Alternative Approaches to Life Safety, the US commercial property insurance rating schedule, XPS FIRE of Munich Re, the hierarchical approach to fire ranking undertaken at the University of Edinburgh, Fire Risk Index Method of the Nordic countries.

Characteristic for points systems is the weighed value approach of a combination of parameters in a matrix with normalised values for easy mathematical manipulation.

The final result of the matrix manipulation is a vector, describing the overall fire safety level in terms of all the parameters. The fire risk index may be calculated according to:
where \( S = \text{risk index expressing the fire safety level} \)
\( n = \text{number of Parameters} \)
\( w_i = \text{weight of Parameter i} \)
\( x_i = \text{grade for Parameter i} \).

FRAME and Gretener are also classified in the WG6 report as point systems, but this does not justice to the probabilistic basis of these methods. It is true that FRAME includes a basic level for satisfactory protection which is expected by inexperienced users as well as a weighed value approach for a number of factors.

The essential difference between FRAME and point systems is that point systems combine the weighed parameters in a SUM, where FRAME (and Gretener) combine weighed in a PRODUCT, which corresponds with the probabilistic basis of event networks.

**Quantitative Methods.**

At the other end of the spectrum of fire risk assessment tools, quantitative methods linked to fire simulation models are found. Because of the complexity of fire simulation models, a lot of computer capacity is often required to enable multiple scenarios to be evaluated in a relatively short time frame.

Developing such methods cost a lot and, unless funded by public finance, these methods are only accessible for a fee. The developers are reluctant to unveil the part of the decision making process which is included in the software. It makes the use of these methods less transparent and less acceptable for decision makers.

The results of fire simulation models depend much on the good knowledge of the user of fire phenomena and the precision required for the input data. As they use multiple and/or complex fire scenarios they are usually limited to a specific type of occupancies where those scenarios are relevant.

One such method which is freely available, is FiRECAM (Fire Risk Evaluation and Cost Assessment Model) developed in Canada by the National Research Council, who is also working on FIERAsystem, a similar method for light industrial occupancies.

FiRECAM calculates the Expected Risk to Life (ERL) of the occupants and the Fire Cost Expectation (FCE) in a high-rise apartment or office building as a result of a set of probable fire scenarios that may occur in the building. To undertake the evaluation of life risks and fire costs, FiRECAM simulates the ignition of a fire in various locations in a building, the development of the fire, smoke and fire spread, occupant response and evacuation, and fire department response. These calculations are performed by nine sub-models interacting with each other in a loop.

FiRECAM has some interesting features which were not included in FRAME v.2, such as the possibility to define a mixed occupancy load, the presence of smoke alarms, building cost estimates. Some of these features were added in FRAME 2008.

The FiRECAM program includes a visual representation of the building and graphical reports, but gives no clear answer to the basic question: “is it good enough?” The major drawback is
that its application is limited to the Canadian market, as it based on Canadian data, including response time for fire services and building costs.

**Event tree analysis.**

The outcome of a hazardous event often depends on more than one condition. This can be visualised and explained with event networks or event trees, which show the cause, effect and interaction between various events.

An event tree is a graphical logic model that identifies and quantifies possible outcomes following an initiating event. The tree structure is organized on a time scale. Probabilities can be calculated from the tree, and consequences are typically assigned to the end states but may cumulate along the tree.

![Example of a simple event tree](image)

An other graphical model is the fault tree: A fault tree is similar to an event tree in that it starts with an event, but instead following the consequences, it traces the causes.

A decision tree is a method for representing the possible outcomes following a succession of events, where the ensuing path is subject to choice. The analysis operates similarly to an event or fault tree.

An influence tree is a representation of the relationship of the decisions and uncertainties in a decision problem. The diagram is more flexible and less unidirectional than any type of tree diagram. It is designed to focus more on the elements of decision making and less on relevant underlying physical phenomena.

The event tree technique can be used for a quantified fire risk assessment, combining calculations of fire development with escape modelling for each scenario. The risk analysis itself is carried out by quantitatively evaluating a number of fire scenarios. The evaluation calculates the fire development and the evacuation process for all scenarios in the event tree.

The risk for each scenario is calculated by multiplying the probability of the specific scenario by its consequence. The total risk associated with a building is the sum of the risks for all scenarios in the event tree. The purpose with an event tree is to consider both successful and unsuccessful operation of the fire safety measures in the building.

To produce a definitive measure of the risk it would be necessary to consider every combination of fire source, fire scenario and target location within the building. However, the
computational effort required increases with the number of sources, scenarios and targets considered.

General there is a great uncertainty created when a limited number of scenarios are used in ETA. The numbers of scenarios are based on the selection of events to be included in the analysis. Events are chosen depending on the focus of the analysis. In a life safety analysis, events that are related to the fire development and to the possibility of successful escape are of more interest than events related to the fully developed fire and the integrity of fire compartments.

However, the uncertainty on scenario selection is not specific to the use of ETA. It does only become more “visible” in this transparent technique. All risk analyses methods model the risk and a model is always an attempt to describe and make prediction about real outcomes.

One of the most important things using ETA is which reliability data are available when modelling fire risks. There are numerous sources of information but how could an analyst be sure that the reference data available is suitable for the current analysis?

Solving fire risk problems with ETA techniques do require professional skills in fire modelling and risk analysis. If this skill is not available in the organisation, external assistance is appropriate.

Ranking methods do have the benefit that the analyst is not forced to provide as much data as when working with ETA. On the other hand, in an ETA, the analyst has full control of input and output, which means that any ETA needs an external check by an equally expert person or organisation as the analyst.

The outcome of a fire risk ETA will be a number of “fire risks”, identified by a probability and a severity value, or a position on a frequency / severity diagram or risk profile. The fire risks located in the lower left corner (green area) are below the average frequency / severity and are considered acceptable, where those in the upper right corner (red area) are certainly unacceptably high.

The ETA itself will not yield any decisions, the stakeholders will have to decide what is the extent of the green and red zones on the distribution diagram.
Event networks in FRAME.

"FRAME" is also based on event networks, as it uses a combination of "cause and effect" relationships and probabilities of success or failure. But instead of a selected number of event trees, it is based on 3 "worst case" scenarios. All other scenarios are statistically included as partial "worst case" scenarios in the same way as fire loss claims are handled by insurers.

The next flow-charts show the networks used to evaluate the fire risk for property, people and activities. As these are three independent but related evaluations, three distinct networks are used.

The weighing factors in "FRAME" assess the elements that have an impact on the probability as well as on the severity of a fire. An increase of probability means a shift upward on the y-axis of the risk profile, whereas an increase of severity results on a shift to the right on the x-axis. In both cases, it means a change towards less acceptable risks.

Usually probabilities are written as a number of occurrences per period, like \(10^{-5}/50\) years of exposure. In "FRAME", a logarithmic scale is used. This corresponds with the integration of the probability / severity curve, i.e. it includes all incidents with various combinations of probability and severity. And it has the additional benefit of producing "user-friendly" results: A risk reduction from R=2 to R=1 is easier to understand for a decision maker than a "probability x severity" reduction from \(10^{-2}\) to \(10^{-3}/50\) years.

The yellow and grey fields indicate input data, to be identified for the compartment that is assessed. The "yellow" data have an impact on the severity of the fire damage and/or the number of casualties of a fire in the concerned compartment. The "grey" data in the fields have an effect on the probability of occurrence of such a fire. Some input data have an effect on both severity and probability: these are shown with yellow/ grey backgrounds.

The green fields indicate related values, which are directly calculated from the yellow and grey input data.

The blue fields indicate subsystems where several (sub) factors are combined. These inputs are further detailed in the subsystems.

The orange fields indicate the possible outcome on a time scale.

The networks begin with the basic probability that a fire starts by "accident" : a lightning strikes, a human error, the cat jumps and turns over a burning candle... This basic probability gives the value of Ao = 1.6.

**Node 1.** In a number of situations, there are additional ignition sources present, linked to main and secondary activities, the heating systems, electrical equipment, the use of inflammable products, etc. These items define the value of factor a and increase the probability of fire occurrence and hence increase the value of the risk.

**Node 2.** An ignition source is not sufficient for a fire, there must be something to burn: This is defined as the fire load, split up in a fixed "immobile" fire load from all the building products, and a "mobile" fire load from the contents. The "immobile" fire load influences also the
F.R.A.M.E.

evacuation environment (factor r) and the "mobile" fire load plays a role in the build-up of the hot gases layer (factor v). Factor q represents the fire load in the risk calculation.

Node 3. Once a fire has started, it will grow at a certain speed: a fast growing fire will increase the risk and factor i copes with that. The fire growth is defined by 3 sub factors: flammability of the content (sub factor T), reaction to fire characteristics (sub factor M), and available surface for fire growth (sub factor m). The reaction to fire characteristics also play a part in factor r.

Node 4. As a fire grows, a hot gas layer is built up at the ceiling. The feed for this layer comes mainly from the content or mobile fire load, and the layer development can be controlled by smoke venting. The ceiling height defines the space available for the hot and cold layers. This is reflected by factor v.

Subsystem B. The success of the first intervention depends also on the available means as well as on the training of the staff: this is evaluated in subsystem B, fire fighting by occupants and staff.

Subsystem C. When automatic protection such as sprinklers is installed, the fire will be controlled very fast in most cases: The success rate of the automatic protection is evaluated by subsystem C.

Subsystem D. If the fire is not controlled yet by the staff and/or sprinklers, the growing fire will be tackled by the fire brigade. It will take some time for the fire brigade to reach the fire scene: This and the strength of the fire brigade is considered in subsystem D: fire brigade at the fire scene.

Subsystem E. At the fire scene, the fire brigade may have to give priority to rescue operations, reducing the effectiveness of the fire fighting: this priority is measured by subsystem E that includes the elements to calculate factor t (evacuation time).

Nodes 5, 6 and 7. The success of the fire fighting operations before flashover occurs depends much on the local conditions: size and shape of the compartment, level and accessibility of the fire compartment: factors g, e and z are used to evaluate this.

Subsystem F. Fire fighting success depends also on the availability and the reliability of the water supplies: this is considered in subsystem F, combining the water supplies factor W and sub factors of S.

Node 8. If flashover occurs, the total content of the compartment will certainly be lost. It will depend on the structural fire protection whether a building will collapse after flashover. Factor F considers the structural fire protection and the probability of building collapse.

Node 9. Whatever the size of the loss is, the actual cost will depend on the value of the content, which is evaluated by sub factor c.
FIRE GROWS
See previous page

Fire expands inside the compartment, still controllable by fire brigade before flashover

MEDIUM DAMAGE

Flashover inside compartment

CONTENT DESTROYED

LARGE DAMAGE

BUILDING COLLAPSE

5. SIZE and SHAPE of COMPARTMENT : factor g

LENTH

WIDTH

6. LEVEL(S) : factor e

HEIGHT

7. ACCESSIBILITY of COMPARTMENT : factor z

ACCESS TO BUILDING

F. WATER SUPPLIES QUANTITY / RELIABILITY

STRUCTURE

EXTERNAL WALLS

ROOF / CEILING

INTERNAL WALLS

8. STRUCTURAL INTEGRITY : factor F

CATASTROPHE

9. PROPERTY VALUE AT RISK : sub factor c

MONETARY VALUE

REPLACEABLE ?
**F.R.A.M.E.**

- **SUBSYSTEM A: DISCOVER / NOTIFICATION**

  - **FIRE DETECTED BY PEOPLE: HUMAN PRESENCE** or WATCH SERVICE
  - **MANUAL FIRE ALARM DEVICES**
  - **SPRINKLERS**
  - **HEAT DETECTORS**
  - **SMOKE / FLAME DETECTORS**
  - **ZONE / POINT IDENTIFICATION**
  - **SYSTEM SUPERVISED**
  - **10. FIRE ALARM SYSTEM EFFICIENCY** subfactors in N & S
  - **CALL TO FIRE BRIGADE**
  - **WARNING TO OCCUPANTS**
  - **D. FIRE BRIGADE ON FIRE SCENE**
  - **B. FIRE FIGHTING by OCCUPANTS / STAFF**
  - **EVACUATION**

Subsystem A, discovery/ notification. This subsystem evaluates the probability of a successful early evacuation and intervention. It takes into consideration the presence or absence of manual and automatic fire detection and notification systems as well as the reliability and capabilities of such systems. In node 10, the result is split up between sub factors of N, normal protection and S, special protection.

- **SUBSYSTEM B: FIRE FIGHTING BY OCCUPANTS / STAFF**

  - **EXTINGUISHERS**
  - **HOSE STATIONS**
  - **FF EDUCATION**
  - **WARNING**
  - **11. STAFF FIRE FIGHTING SUCCESS RATE** in factor N
  - **FIRE DAMAGE EXTENT**

Subsystem B, fire fighting by occupants and staff, takes into account the presence of portable extinguishers, hose reels, and staff training. In node 11, it gives a combination of sub factors of N, normal protection.
**F.R.A.M.E.**

- **SUBSYSTEM C: AUTOMATIC EXTINGUISHING SYSTEMS.**

  - **SPRINKLER PROTECTION**
  - **ON PUBLIC WATER SUPPLY**
  - **SINGLE WATER SUPPLY**
  - **DOUBLE WATER SUPPLY**
  - **SINGLE SHOT AUTOMATIC AREA/ ROOM PROTECTION**
  - **LOCAL AUTOMATIC SYSTEMS**

  Subsystem C, automatic extinguishing systems: takes into account the presence of automatic extinguishment systems like sprinklers covering a complete compartment. In **node 12**, it groups those sub factors of S that consider the existence and reliability of such systems.

- **SUBSYSTEM D: FIRE BRIGADE AT FIRE SCENE**

  - **CALL TO FIRE BRIGADE**
  - **TIME TO FIRE SCENE**
  - **FIRE BRIGADE STRENGTH**

  Subsystem D, fire brigade at the fire scene: takes into account the arrival time of the fire brigade, the type and strength of the brigade and in **node 13**, it is split up between sub factors of N and S.
Subsystem E, evacuation time.

In node 14 the travel time inside the compartment, through exits and on stairs for independent and mobile persons is calculated. Node 15 considers sub factor p, which gives a correction for mobility, organisation and risk awareness.

The combination of both in node 16 defines the RSET, the required safe egress time to leave the building. The higher this evacuation time is, the longer the exposure is for life safety, hence an increase in risk. Equally, the fire brigade will spend more time on rescue operations, thus reducing the effectiveness of fire fighting.
Subsystem F, water supplies:

Node 17 considers the type of water supplies available for fighting, the quantity compared with the fire load, the distribution system, as defined by factor W. Large quantities, reliability, redundancy and energy supplies are combined through sub factors of S in node 18.
F.R.A.M.E.

- NETWORK FOR OCCUPANTS' RISK.

1. ACTIVITY RELATED IGNITION
   - Fire load immobile Qi
   - Fire load mobile Qm

2. Total fire load
   - growing phase
   - decline phase
   = factor q

3. Fire growth speed = factor i

4. Hot layer build-up.
   = factor v

5. Reaction to fire of surfaces:
   Sub-factor M

6. Available surface for fire spread?
   Sub-factor m

7. Ceiling height:
   Hot / cold gas

8. Heat venting through openings in walls and ceiling

9. IGNITION SOURCES
   Sub-factor a in A

10. NATURAL CAUSES,
    HUMAN ERRORS
    $A_0 = 1.6$

11. MAIN and SECONDARY ACTIVITIES
    - HEATING SYSTEMS
    - ELECTRICAL EQUIPMENT
    - EXPLOSION HAZARDS
    USE of FLAMMABLES

12. THREAT INCREASES:
    see next page

13. A1. DISCOVER / NOTIFY:
    See at:
    PROTECTION (N & U)

14. B1. FIRE FIGHTING BY OCCUPANTS / STAFF

15. C1. AUTOMATIC EXTINGUISHING SYSTEMS
    See ESCAPE FACTOR U

16. MANUAL MEANS,
    TRAINING: see at:
    NORMAL PROTECTION

17. LOSS POTENTIAL:
    What can burn?

18. Fire growth:
    build-up of hot gases layer inside compartment

19. AVAILABLE SAFE EGRESS TIME (ASET): sub-factor r

THREAT INCREASES: see next page

IGNITION SOURCES
Sub-factor a in A

Fire growth:
build-up of hot gases layer inside compartment

LOW THREAT

A1. DISCOVER / NOTIFY: See at: PROTECTION (N & U)
For the life safety, risk network a somehow different combination is made.

Nodes 1, 2, 3, and 4 come back in the network, but the impact of the subsystems A1, B1 and C1 is not same for life safety as for property protection, hence a slightly different calculation.

In node 19, the "immobile" fire load and the reaction to fire characteristics (sub factor M) are combined to evaluate the ASET, the available safe egress time. Factor r, the environment factor considers the speed of fire and smoke growth and the effect of it on the life safety risk.

Node 5 is not present in the life safety network: size and shape of the compartment are considered in the evacuation time calculation.

If flashover occurs, all people still present will be killed. Therefore, the compartment shall be evacuated before flashover occurs. It means that the structural fire protection does not play a significant role for the safety of the occupants and shall not be considered as beneficial for life safety. Factor F is not taken into account.
**Subsystem A1**: discovery/notification. This subsystem evaluates the probability of a successful early evacuation and intervention. It takes into consideration the presence or absence of manual and automatic fire detection and notification systems as well as the reliability and capabilities of such systems. It is split up in *node 20* in sub factors of N, normal protection and U, the escape factor.

### Subsystem B1: Fire Fighting by Occupants and Staff

- **Extinguishers**
- **Hose Stations**
- **FF Education**
- **Warning**

11. **Staff Fire Fighting Success Rate in factor N**

- **FIRE STOPPED:**
  - **NO EVACUATION**
- **LOW THREAT**
Sometimes evacuation may be not necessary, as the fire is controlled by the first intervention by the staff: this is evaluated in subsystem B1, which has the same components as subsystem B.

### SUBSYSTEM C1: AUTOMATIC EXTINGUISHING SYSTEMS.

- **FULL SPRINKLER PROTECTION**
- **SPRINKLER PROTECTION in CRITICAL AREAS**
- **SINGLE SHOT AUTOMATIC AREA/ ROOM PROTECTION**
- **RELIABILITY LEVEL**
- **SMOKE VENTING ACTUATED BY DETECTION**
- **21. SYSTEMS SUCCESS RATE in factor U**
- **FIRE / SMOKE DEVELOPMENT SLOW DOWN**
- **LOW THREAT**

When automatic protection such as sprinklers is installed, the fire will be controlled very fast in most cases, reducing the need for a total evacuation. The success rate of the automatic protection is evaluated by subsystem C1, automatic extinguishment systems.

Subsystem C1 takes into account the presence of automatic extinguishment systems, be it for a complete compartment or locally in a high-risk zone. In node 21, it contains those sub factors of U that consider the existence of such systems. Reliability of water supplies is not an issue for life safety and is not considered.

### SUBSYSTEM D1: FIRE BRIGADE ON FIRE SCENE.

- **CALL TO FIRE BRIGADE**
- **TIME TO FIRE SCENE**
- **FIRE STATION STRENGTH**
- **22. FIRE BRIGADE SUCCESS RATE in factors N & U**
- **D1. FIRE BRIGADE AT FIRE SCENE**
- **OCCUPANTS ASSISTANCE & RESCUE**

If the fire is not controlled yet by the staff and/or sprinklers, the growing fire will be tackled by the fire brigade. It will take some time for the fire brigade to reach the fire scene: This and the strength of the fire brigade is considered in subsystem D1, fire brigade at the fire scene. In node 22, it is split up between sub factors of N and U.
People are at risk as long as they are in the building on fire. This is measured by subsystem **E1**, which is identical to subsystem E.

### SUBSYSTEM E1: EVACUATION PERIOD

- LENGTH : \( l \)
- WIDTH : \( b \)
- EXIT PATH OPTIONS : \( k \)
- NUMBER OF PERSONS: \( X \)
- NUMBER OF EXITS UNITS: \( x \)
- VERTICAL TRAVEL DISTANCE: \( H^+ / H^- \)

**TRAVEL TIME**
- in compartment
- through exits
- on stairs

**E1. EVACUATION PERIOD** : factor \( t \)

**16. REQUIRED SAFE EGRESS TIME (RSET)**

**MOBILITY**
- AWARENESS
- EVACUATION PLAN
- PANIC ?

**14. BASIC TRAVEL TIME**

**15. REACTION + TRAVEL TIME CORRECTION** : \( p \)

### SUBSYSTEM F1: REDUCED EXPOSURE

- **SUBCOMPARTMENTS**
- **RATING of SEPARATIONS**

**SMOKE / FIRE SLOW DOWN**

**STAIRWAYS**
- PROTECTED
- SMOKEPROOF
- EXTERIOR
- (TOBOGGANS)

**HORIZONTAL EXITS**
- CAPACITY

**AREAS OF REFUGE**

**F1. REDUCED EXPOSURE**

**23. SHORTER EVACUATION TIME** sub-factors in \( U \)

**COMPLETE SIGNAGE**

However, the occupants can be in safety in a shorter time, when measures are taken that shorten the exit travel time, by redundant evacuation means, and by additional barriers for smoke and heat propagation. This is measured in **subsystem F1**. In **node 23**, this is considered by sub factors of \( U \).
Subsystems A, B, C and D play a similar role as for the property risk and come back in this network.
Node 5 "compartment size and shape", 6 "levels", and 7 "accessibility" define the growth of fire damage from small to medium damage in a similar way as for the property risk.

Node 10 "property value at risk" defines the size of the cost of any fire loss, while subsystem F "water supplies" is taken into account to evaluate the water supply resources for the fire brigade and sprinkler systems.

Node 24 evaluates the dependency of the activities on that particular location by considering the added value generated at that place.
Node 25 considers the existence and success rate of local systems that are installed to protect areas or equipment with a high impact on business continuity.

Finally, node 26 brings up all organisational measures that can be taken to speed up a restart after a fire, thus reducing the impact on the activities.

Guidelines for Fire Risk Assessments.

In the past years, both the NFPA and CFPA Europe have issued guidelines for the use of fire risk assessments (FRA).

The NFPA has issued NFPA 551, Guide for the Evaluation of Fire Risk Assessments and the CFPA has issued its Guideline n° 4: Introduction to Qualitative Fire Risk assessment.

Both documents provide the potential user of a FRA with useful information to make up his mind. Can FRAME, which is older than both documents stand up against their criteria?

- The CFPA Guideline no 4.

The CFPA Guideline is meant to be an introduction to a qualitative method of assessing fire risks. The emphasis of the document is on safety in a workplace both for staff and visitors.

Risk is defined as “product of occurrence probability of an incident with damages and the expected loss dimension”.

Risk assessment is defined as: “the process of estimating the magnitude of risk and deciding whether or not the risk is tolerable”

And tolerable risk is: “risk that has been reduced to a level that can be endured by the organisation having regard to its legal obligations and its own health and safety policy”.

The approach in the document defines RISK as a function of HAZARD x EXPOSURE, where HAZARD can have a range from 0 to 1 and EXPOSURE can have a range from 1 to 3.

"In other terms HAZARD can be present (1) or not (0) and EXPOSURE levels may be considered as follows:
Level 1: properties and goods can be damaged; people are not exposed directly to the hazard;
Level 2: people can be harmed, but they can leave the workplace if necessary; properties and goods can be seriously damaged;
Level 3: possible deaths, people injured, goods and premises destroyed, as an incident develops."

This is very much a simple way of using a risk profile, with exposure levels that are inspired by the safety of machinery approach. Not very much of a surprise, as one of the reference documents in the bibliography is a book that refers to the Italian DECRETO MINISTERIALE 10 marzo 1998 that defines the criteria for fire safety at the workplace.

The fire risk assessment procedure describes the following steps:

- Identify hazards I
- Identify people and goods exposed to a hazard
- Remove and reduce the fire hazards
- Determine level of risk
- Assign risk categories
- Decide if the safety measures are adequate
- Decide if the residual risk is tolerable
- Review adequacy of action plan
The qualitative method given in this guideline describes basically all the stages a FRAME user will have to go through to reach the final decision, but lacks the quantification tool that is most wanted by less experienced persons.

- NFPA 551 Guideline.

This American guideline has a different scope:

"1.1 Scope: This guide is intended to provide assistance, primarily to authorities having jurisdiction (AHJs), in evaluating the appropriateness and execution of a fire risk assessment (FRA) for a given fire safety problem. While this guide primarily addresses regulatory officials, it also is intended for others who review FRAs, such as insurance company representatives and building owners.

1.2 Purpose: This guide is intended to assist with the evaluation of FRA methods used primarily in a performance-based regulatory environment. While the primary audience is anticipated to be authorities having jurisdiction, it is expected that the guide will be a useful resource for anyone conducting an FRA. This guide does not mandate the methods for use in demonstrating acceptable risk; rather, it describes the technical review process and documentation that are needed in evaluating an FRA.

1.3 Application: This guide is intended to be applied to the assessment of performance-based solutions, studies, code equivalencies, or regulatory compliance evaluations developed using FRA methods.

1.4 Qualifications for Practitioners.
Persons undertaking FRAs, as anticipated by this guide, should document their qualifications and make them available to the authority having jurisdiction. Depending on the FRA being undertaken, the documentation could include educational background, past experience with FRAs, and professional registration. The form of the documentation should meet the needs of the authority having jurisdiction within the context of applicable laws and regulations.

1.5.1 The perception of risk, and therefore the acceptance of risk, is influenced by the values of the stakeholders. Thus, the values of the stakeholders should be established in the risk metrics, which may include life safety, property, business interruption, and intangibles. The metrics associated with these values may be people affected, dollars of loss, acreage, and so forth. The expression of the metric is usually rate based (e.g., frequency, or probability of occurrence over a specified time period). The stakeholders may attach different weights to a given risk, based on their perspective. Each AHJ may have its own weighting, depending on its role."

Chapter 2 gives references, Chapter 3 gives definitions. Chapter 4 addresses evaluating a fire risk assessment (FRA) by discussing the stakeholders, an overview of the review process by the authority having jurisdiction (AHJ), scope of FRAs, bounding the FRA, and uncertainty.

Chapter 5 presents the different types of FRA methods, including guidance on the appropriate selection and application of the various types of risk methods and models.

Depending on the stakeholder, one or more of the following items may receive focus in the acceptance criteria:
(1) Human losses
(2) Environmental damage
(3) Property damage
(4) Business interruption
(5) Risk control program implementation costs
(6) Loss of image
(7) Loss of community confidence
(8) Loss of structures and objects with heritage significance
FRAME specifically deals with 3 of these acceptance criteria. It means that when the stakeholder has other criteria, FRAME will not give an answer to all his objectives.

Table 5.1.2.1 defines five categories of FRA methods: (1) Qualitative method; (2) Semi quantitative likelihood method; (3) Semi quantitative consequence method; (4) Quantitative method; and (5) cost-benefit risk methods.

NFPA 551 par. 5.5 section provides a framework for understanding and evaluating Quantitative Fire Risk Assessments. Par 5.5.1 explains how fire risks are calculated in these methods:

5.5.1.1 For a single scenario sequence,...

5.5.1.2 If the output includes the assessment of many risks, such as business as well as individual, then the multiple outcomes, \( R_{tj} \), can be represented by:

\[
R_{tj} = \sum_{i} \sum_{j} C_{ij} * F_{i}
\]

\( R_{tj} \) = multiple outcomes  
\( C_{ij} \) = multiple losses  
\( F_{i} \) = sequence frequency

NFPA 551 par 5.5 refers thus to the event tree analysis approach, but does not include the exposure aspect which considerably influences the acceptability of a risk.

FRAME could be seen as a simplified cost-benefit risk method, as the output is a determination of “optimum” level of fire protection based on minimizing “overall risk” or some other risk criterion.

Chapter 6 provides a general guide for the AHJ as to the availability of the information (data from the literature, electronic data, technical drawings and documentation, and automated computational methods) in the FRA. This information may be needed and used by the AHJ for the evaluation of the FRA. The chapter is broken into two parts: issues of general quality associated with all methods and issues pertinent to particular current methods.

Chapter 7 describes the information that should be provided in the FRA report. It is permissible to prepare multiple documents to fulfil the intent of the FRA report.

Chapter 8 defines two possible approaches that an AHJ could use to verify the soundness of an FRA: direct review and third-party review.

FRAME has certainly a number of features that comply with the criteria of NFPA 551. A stakeholder can thus decide with the information and recommendations of Chapter 5 whether FRAME suits his needs.
The “FRAME” approach of fire risk assessment.

“FRAME” was originally developed as a tool for the fire protection designer, to manage the fire risks in a building, i.e. to find a suitable and affordable combination of protection features that reduces the fire risk to an acceptable level.

The method looks at the fire risk from three viewpoints: the risk for the building and its content, the risk for the occupants, and the risk for the activities in that location. For each viewpoint, a typical fire scenario can be identified.

There are five basic ideas for the method:

1. Adequate protection means equilibrium between threat, protection and exposure.
2. Severity, frequency and exposure expressed as result of influence factors.
3. A severe fire only occurs when the combination of protection techniques fails.
4. Separate calculation for property, occupants, and activities.
5. One set of calculations per compartment.

The equilibrium between threat, protection and exposure.

The first basic idea of the “FRAME”-method is that there is equilibrium between threat, protection and exposure in an adequately protected building.

Where can such equilibrium be situated? One might say that the equilibrium is somewhere near the point where the possible cost of the losses is comparable to the certain cost of the protection.

The possible cost of a fire includes the material damage, business interruption and unemployment, the "cultural" cost of loosing something unique, the lost lives, the cost of handling the aftermath of a fire, environmental damage, possible litigation, the loss of market, and loss of image. Typical of all these costs is that they represent a large amount of money and labour, which is only needed once the fire has happened: these expenses are made AFTER the fire.

The certain cost of protection is not only that of insurance premiums or fire fighting equipment, but it includes also the cost of training, maintenance, inspections and tests, emergency planning, choice of safe materials, as well as taxes to finance the public fire brigade, hospitals, police, waterworks. Typical of these costs is that they represent a smaller amount of money and labour, but needed year after year, even BEFORE any fire has occurred.

The equilibrium between the fire risk and the fire protection that can be expected by using “FRAME” is situated at a level where the damage of a serious fire will be less than 10 % of the value of the concerned compartment. It is also the level of protection for which a fire insurance premium rate of approx. 1 ‰ of the insured value can be negotiated.

This equilibrium assumes a long-term vision on property preservation. After all, people do not want to rebuild their houses every ten years because they had burnt. It also considers the human safety and the impact on the community.

In industry, it is possible that this concern for long-term preservation is not required. The technological development may be such that machinery is obsolete in less than ten years. In such case, another level of equilibrium can be perfectly acceptable for the management. However, as it is not a common practice to burn a factory to replace obsolete machinery, “FRAME” uses the same level of equilibrium to define what an adequate level of protection is.
For the human safety, the adequate level of protection is assumed the situation that there are no deaths, except the person that provoked the fire. In most European countries, the socially accepted level of fire safety is 5 victims per year per million inhabitants.

For business interruption, “FRAME” will give an evaluation of the overall sensitivity. The idea is that an adequate level of protection is such that the activities are only temporarily interrupted, and that life can be “back to normal” after a short period, necessary for clean up and (temporary) repairs.

Some parts of an activity may be very vulnerable by fire, and the most appropriate method for detecting the weak points is to bring up scenarios of fire incidents and find out how they affect the vital activities. This type of risk analysis is outside the scope of a general method. It should be made on a regular basis for every building of any organisation.

**Severity, exposure and probability.**

The second basic idea is that severity, probability and exposure can be expressed in a formula with a number of influence factors.

A first set of influence factors will define numerical values for the worst cases, and these values will be named the potential risks P, reflecting the severity.

A second set of values will define numerical values that measure the level of exposure: A risk becomes less acceptable when the exposure is greater. The elements that define the level of exposure are the presence of ignition sources, the value of building and content, the evacuation circumstances, and the economic importance of the activity. These elements will be used to calculate the acceptable risk levels, A.

The third set of influence factors will define the protection level. The probability of a fire is the reverse value of the protection level.

**Probability = Reverse of Protection**

A fire can only develop into a disaster if all the available protection has failed. Thus, the higher the level of protection is, the lower will be the probability of a disaster.

The level of fire protection can be expressed as a combination of values for the different protection technologies. These values will represent the following elements:

- The universal extinguishing agent: water
- The design of escape routes
- The fireproofing of the construction
- The methods of detection and notification
- The manual fire fighting means
- The automatic fire extinguishing systems
- The public and private fire brigades
- The physical separation of risks
- The organisation for rescue and salvaging

These elements define the quality and quantity of the fire protection available for a particular situation. The numerical value for the protection is the Protection Level.
Separate calculation for property, occupants, activities.

Three calculations will be made for each situation: The first for the building and its content (property, the second for the occupants, and the third for the business or activities that take place in the building.

These three calculations are necessary because the “worst case” is probably different for the buildings, persons or activities, as well as there can be differences in the effectiveness of the protection.

For the building and its content, total destruction is assumed the worst case. All factors, which can influence the size of the fire, are therefore included in the Potential Risk calculation, and in the same way, all means to fight a fire are included in the calculation of the Protection Level. The Acceptable Level is related to the fire sources, the value of the building and its content, and for the delay in fire fighting caused by the necessary evacuation of people.

For the occupants, any beginning fire is already a threat and is therefore the "worst case". Those factors, which have influence on a developing fire, are included in the Potential Risk. The Acceptable Level is related to the fire sources, the evacuation time, and for those elements that make a fire run faster than the people to be rescued do. The Protection Level is calculated with those elements that speed up the evacuation or slow down the growth of the fire.

For the activities, a fire that damages everything, even without complete destruction is considered the most harmful. Therefore, the Potential Risk includes the same factors as for the building, except for the fire load. The Acceptable Level is related to the fire sources, the value of the goods, and the dependency of the activities on that particular location. The Protection Level is calculated from the means of protection and from the organisational measures that help a business to restart after a fire.

A separate calculation of the risk and the protection shall be made for each compartment.

One calculation per compartment.

Within one building, several different situations can exist: For this reason, "FRAME" uses a one level fire compartment as the basic unit for the calculations. For multi-storey buildings, each level has to be considered separately. For buildings with more than one fire compartment, each compartment shall be reviewed on its own.

Risk value expression.

The expression of the fire risk on a numerical scale is very much a convention, in the same way as using metric or American units for the characteristics of a building. In the KINNEY method, risk values vary between 0.05 and theoretically 10.000 (a continuous threat of catastrophe). Why does FRAME (and its predecessor Gretener) use a scale that locates the value of the risk in a range around 1?

- Insurance premium rates.

The most elementary reason is that Gretener originally wanted to develop a technical system for insurance premium rates, and these happen to be around 1 % of the insured value. To obtain a similar scale, it was most convenient to work with logarithmic based expressions. A lot of work has been done by trial and error to find suitable coefficients to transform measurable and identifiable data such as building dimensions, system characteristics, and reliability data into working formulas.
F.R.A.M.E.

- Risk aversion.

People do not like high severity risks even with low probabilities. This risk aversion is the basis for the whole insurance industry. By buying an insurance policy, the owner a building transforms a high severity / low probability loss (my house being destroyed by a fire) into a high probability / low severity loss: I have to spend every year a bit of my money on insurance premiums.

This aspect of risk aversion must be reflected in the results of any risk assessment method. Kinney solved this by defining the values of the contributing factors on a non-linear scale. In FRAME, risk aversion is incorporated in the formulas used for P, A and D.

A pure logarithmic transformation of the Kinney-formula would be a sum of log values: "log Sev + log Poc ≤ Log C - log Exp " and not a division as in the FRAME formula R = P/D.A.

However, by choosing for FRAME probability parameters values in the range around 1 and a risk value scale of the type (1+log), FRAME produces values whereby minor risks are slightly underestimated and higher risks overestimated, which corresponds with the risk aversion phenomenon.

This difference between a pure log based risk scale and the (1 + log) scale is given in the following table, which illustrates the value changes by both formulas:

<table>
<thead>
<tr>
<th>basic value for &quot;log S&quot;</th>
<th>0.8</th>
<th>1</th>
<th>1.2</th>
<th>1.4</th>
<th>1.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>risk *2 =+ log (2)</td>
<td>1.1</td>
<td>1.3</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
</tr>
<tr>
<td>risk * 2 = x {1 +log (2)}</td>
<td>1.04</td>
<td>1.3</td>
<td>1.56</td>
<td>1.82</td>
<td>2.08</td>
</tr>
<tr>
<td>risk * 5 = + log (5)</td>
<td>1.5</td>
<td>1.7</td>
<td>1.9</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>risk * 5 = x {1 +log (5)}</td>
<td>1.36</td>
<td>1.7</td>
<td>2.04</td>
<td>2.38</td>
<td>2.72</td>
</tr>
<tr>
<td>risk * 10 = + log (10)</td>
<td>1.8</td>
<td>2</td>
<td>2.2</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>risk * 10 = x {1 +log (10)}</td>
<td>1.6</td>
<td>2</td>
<td>2.4</td>
<td>2.8</td>
<td>3.2</td>
</tr>
<tr>
<td>risk / 5 = - log (5)</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>risk / 5 =/ {1 + log (5)}</td>
<td>0.47</td>
<td>0.59</td>
<td>0.71</td>
<td>0.82</td>
<td>0.94</td>
</tr>
<tr>
<td>risk / 10 = - log (10)</td>
<td>-0.2</td>
<td>0?</td>
<td>0.2?</td>
<td>0.4?</td>
<td>0.6</td>
</tr>
<tr>
<td>risk / 10 =/ {1 +log (10)}</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
</tr>
</tbody>
</table>

This modified formula avoids negative values for R, which would hurt the users’ need to express the risk on a positive growing scale. Furthermore, preventive actions, such as avoiding ignition sources, have a greater risk reducing effect than adding a high level of protection.

As preventive measures are in most cases more economical than protection systems, this feature of "FRAME" pushes the user to the more profitable design alternatives.
WHAT CAN BE DONE WITH THE FRAME CALCULATIONS?

The aim of a “FRAME” calculation is to find out if the equilibrium between threat, protection and exposure is achieved. For an adequately protected compartment, the values of the Risks are equal to or below 1.

Several situations are now possible:

- The method is used to check an existing situation without any attempt to design improvements: the calculation will balance the weak and strong points and indicate how far the real situation is away from a good one.

- Fire protection systems that are made to comply only with the legal requirements for life safety will often result in inadequate protection for the building or the activities: this is somehow logical: once the people are safe, the building can be "allowed" to burn.

- The protection system is satisfactory, as all the values are good.

- After a first calculation, it seems that some improvements are still necessary: The fire protection engineer with some experience will "feel" the weak points as they show up during the calculation. Looking through the details will reveal the areas of possible improvement, and a new calculation can be made to get as final result: a well-designed fire protection system.

Loss estimates.

One interesting aspect of the FRAME calculation is the relationship between the value of the Risk R and the amount of damage that can be expected after a serious fire situation. Luckily, not every beginning fire develops into such way, but the possibility to define a "normal" loss expectancy with the method exists. The following scale can be used.

<table>
<thead>
<tr>
<th>Value of R</th>
<th>% of compartment destroyed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1.0</td>
<td>10 % or less</td>
</tr>
<tr>
<td>1.0 to 1.3</td>
<td>10 to 20 %</td>
</tr>
<tr>
<td>1.3 to 1.5</td>
<td>20 to 30 %</td>
</tr>
<tr>
<td>1.5 to 1.7</td>
<td>30 to 50 %</td>
</tr>
<tr>
<td>1.7 to 1.9</td>
<td>50 to 80 %</td>
</tr>
<tr>
<td>More than 1.9</td>
<td>80 to 100 %</td>
</tr>
</tbody>
</table>

This relationship has one particular application: it may trigger the quest for arson. In fact, in compartments where the value of the risk is below 1.5 after a careful calculation, but where the actual damage is more than 30 % of the compartment, the difference between what can be expected under "normal" conditions and the real damage is so strong that some "help from the outside" is the most likely explanation.

Comparing the method with the fire codes.

It may seem that there is a contradiction between FRAME and the content of building codes and regulations. In fact, in many cases where the safety of the public is the major concern, building codes require non-combustible and even fire resistant construction, but in FRAME the fire resistance factor F is not used for calculating the risk for the occupants, R₁.

However, this contradiction is not real, because of the following:
- The environment factor $r$ takes into account the combustibility of the surfaces. The penalty introduced by this factor for flammable materials is such that it is impossible to obtain a good value for $R_1$, if it is a compartment with a concentration of people.

- The method is conceived in such a way that the user looks first for an adequate protection for the property before looking at the protection of the people. In this way, he will check if additional protection is required for the occupants of an already well-protected building.

The preference of code making authorities for passive fire protection can be explained by their concern for safety of the fire fighters and the protection of the neighbourhood. Not all proprietors wish to have adequately protected buildings and sometimes prefer to pay insurance premiums. Therefore it is understandable that codes and regulations limit the theoretical possible choices to those construction methods that have built-in safety. Fireproofing for low hazard buildings can therefore be preferred to sprinklers, and is in most cases less expensive.

Trade-offs and equivalent designs.

The method can be used to check alternative designs or trade-offs in cases where older buildings are to be adapted to new requirements, but where the explicit rules ask for costly modifications.

In such situations, it can be useful to make first a calculation for the building in accordance with the rules to find out what the level of protection is that is to be obtained, and than make a second calculation with the proposed trade-off to find out if the same or a lower risk level is obtained.

Providing that the authorities and the designers agree on the inputs in the calculation, they will find that this way of working can avoid lengthy discussions on what to do to reach a reasonable agreement.

Self-control.

Finally, the best application for FRAME is that of self-control for the engineer who has to make up his mind on a fire protection system: as the method requires a systematic review of most of the influence factors of a fire risk, it obliges the engineer to think in a professional way and it helps him to reduce the influence of subjective appreciation.
DEFINITIONS AND BASIC FORMULAS.

**Building and content:**
The Fire Risk \( R \) is defined as the quotient of the Potential Risk \( P \) by the Acceptable Risk Level \( A \) and the Protection Level \( D \)

\[
R = \frac{P}{A \times D}
\]

The Potential Risk \( P \) is defined as the product of the fire load factor \( q \), the spread factor \( i \), the area factor \( g \), the level factor \( e \), the venting factor \( v \), and the access factor \( z \).

\[
P = q \times i \times g \times e \times v \times z
\]

The Acceptable Risk Level \( A \) is defined as the maximum value 1.6 minus the activation factor \( a \), the evacuation time factor \( t \), and the value factor \( c \).

\[
A = 1.6 - a - t - c
\]

The Protection Level \( D \) is defined as the product of the water supply factor \( W \), the normal protection factor \( N \), the special protection factor \( S \) and the fire resistance factor \( F \).

\[
D = W \times N \times S \times F
\]

**Occupants:**
The Fire Risk \( R_1 \) is defined as the quotient of the Potential Risk \( P_1 \) by the Acceptable Risk Level \( A_1 \) and the Protection Level \( D_1 \)

\[
R_1 = \frac{P_1}{A_1 \times D_1}
\]

The Potential Risk \( P_1 \) is defined as the product of the fire load factor \( q \), the spread factor \( i \), the level factor \( e \), the venting factor \( v \), and the access factor \( z \).

\[
P_1 = q \times i \times e \times v \times z
\]

The Acceptable Risk Level \( A_1 \) is defined as the maximum value 1.6 minus the activation factor \( a \), the evacuation time factor \( t \), and the environment factor \( r \).

\[
A_1 = 1.6 - a - t - r
\]

The Protection Level \( D_1 \) is defined as the product of the normal protection factor \( N \) and the escape factor \( U \).

\[
D_1 = N \times U
\]

**Activities:**
The Fire Risk \( R_2 \) is defined as the quotient of the Potential Risk \( P_2 \) by the Acceptable Risk Level \( A_2 \) and the Protection Level \( D_2 \)

\[
R_2 = \frac{P_2}{A_2 \times D_2}
\]

The Potential Risk \( P_2 \) is defined as the product of the spread factor \( i \), the area factor \( g \), the level factor \( e \), the venting factor \( v \), and the access factor \( z \).

\[
P_2 = i \times g \times e \times v \times z
\]

The Acceptable Risk Level \( A_2 \) is defined as the maximum value 1.6 minus the activation factor \( a \), the value factor \( c \), the dependency factor \( d \).

\[
A_2 = 1.6 - a - c - d
\]

The Protection Level \( D_2 \) is defined as the product of the water supply factor \( W \), the normal protection factor \( N \), the special protection factor \( S \) and the salvage factor \( Y \).

\[
D_2 = W \times N \times S \times Y
\]
**THE POTENTIAL RISKS.**

### Severity and worst case scenarios.

The Potential Risk is the expression of the severity component of a fire risk evaluation. The potential risk will thus be calculated with those elements that can contribute to a worst case scenario.

The worst case scenario for defining the risk for the building and its content is that of total destruction. The magnitude of such a total destruction will be defined by a fire scenario and by an appreciation of the controllability of the fire by the fire brigade.

The Potential Risk \( P \) for property, is defined as the product of the fire load factor \( q \), the spread factor \( i \), the area factor \( g \), the level factor \( e \), the venting factor \( v \), and the access factor \( z \).

\[
P = q \times i \times v \times g \times e \times z
\]

The first 3 factors in the formula reflect the fire scenario: duration (factor \( q \)), development (factor \( i \)) and flashover conditions (factor \( v \)). The other 3 factors reflect the impact of the building configuration on controllability of the fire by the fire brigade: compartment characteristics (factor \( g \)), level (factor \( e \)) and access possibilities (factor \( z \)). The combination of fire scenario and the controllability define the severity of the fire risk.

The scenario for assessing the risk \( R_1 \) for the occupants has been defined as any beginning fire. The formula for the Potential Risk for the occupants, \( P_1 \), reads thus as follows:

\[
P_1 = q \times i \times e \times v \times z
\]

\( P_1 \) is calculated by using five of the previously defined factors, which reflect best a developing fire, which is the likely scenario during the evacuation period of the occupants. Therefore, the area factor \( g \) is deleted from the formula, but the others are maintained: The presence of fuel is considered in the fire-load factor \( q \); the speed of the developing fires in the spread factor \( i \); the threat of smoke is evaluated by the venting factor \( v \).

The complexity of evacuation in a high-rise building, compared to a ground level situation, the human reactions in such conditions, and difficulties encountered to bring adequate help are reflected in the formula by the level factor \( e \), and the access factor \( z \).

The worst-case scenario for the activities is a fire that touched everything even without destroying it. Thus, the total fire load is not very relevant for the Potential Risk for the activities and the fire load density factor \( q \) is deleted from the formula.

All the other factors remain valid for the Potential Risk \( P_2 \), as factor \( q \) expresses the difference between partial and complete destruction.

The formula for the Potential Risk for the activities, \( P_2 \), thus reads as follows:

\[
P_2 = g \times i \times e \times v \times z
\]

\( P_2 \) is calculated by using five of the previously defined factors.
As the same factors are used for the three formulas, it is possible to calculate the three Potential Risks in one operation.

**The fire load factor q.**

- Input data.

The fire load factor q is calculated with the fire load density of building elements and content. It indicates how much can burn per area unit. The formula is:

\[
q = \frac{2}{3} \times \log (Q_i + Q_m) - 0.55
\]

In theory, one must make a list of all available combustible materials with their specific heat value, make a calculation of the total possible heat release and divide this by the area of the compartment. This may be a cumbersome job. However, it is possible to make reasonable good estimates of the fire load densities from building and occupancy types.

In practice, the next tables give reasonable estimates of the values of \(Q_i\) and \(Q_m\) (in MJ/m²) so that an exact calculation is not always necessary. Any intermediate value is also accepted.

The distinction between the fire load for the building and that of the content helps to estimate the fire load. The first table with values of \(Q_i\) comes from the original Gretener method. Gretener established these values based on a survey of buildings in Switzerland. These types of buildings can also be found in other areas and the table can be used in every other country.

<table>
<thead>
<tr>
<th>Typical values for Qi</th>
<th>MJ/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Totally non combustible construction ( e.g. concrete / steel only)</td>
<td>0</td>
</tr>
<tr>
<td>B. Non-combustible construction, with max. 10% allowance for combustible construction elements as windows, roof covering, etc.</td>
<td>100</td>
</tr>
<tr>
<td>C1. Wooden structure with non combustible covering</td>
<td>300</td>
</tr>
<tr>
<td>C2. Fire resistive construction with wooden floors</td>
<td>300</td>
</tr>
<tr>
<td>D. Only the structural elements are non-combustible</td>
<td>1000</td>
</tr>
<tr>
<td>E. Combustible construction</td>
<td>1500</td>
</tr>
</tbody>
</table>

The second table with values of \(Q_m\) gives an estimate of the mobile fire load density, based on several surveys found in the technical literature, as well as in the manuals for fire simulation zone models. Sometimes, it is not clear whether these surveys give the total fire load density or the mobile part only.

MM. CLUZEL and SARAT, who developed the ERIC variant of the Gretener method, checked the fire load for offices and apartments and concluded that 80 % of the residential buildings have a fire load of less than 300 MJ/m². For low hazard non-industrial occupancies, the next table gives average values:

<table>
<thead>
<tr>
<th>Mobile (moveable) fire load density Qm</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Low fire hazard (LH or light hazard) occupancies</td>
<td>200</td>
</tr>
<tr>
<td>a1. Offices</td>
<td>400 - 550</td>
</tr>
<tr>
<td>a2. Dwellings</td>
<td>500 - 780</td>
</tr>
<tr>
<td>a3. Schools</td>
<td>200 - 340</td>
</tr>
<tr>
<td>a4. Hospitals</td>
<td>250 - 330</td>
</tr>
<tr>
<td>a5. Hotels</td>
<td>250 - 330</td>
</tr>
</tbody>
</table>

The column “range” gives an overview of the data found in a number of surveys and other documents.
Using the heat absorption capacity of water, the fire load density can be linked to the water flow requirements for sprinklers: spray density, duration of operation and an efficiency factor.

Light Hazard systems require a density of 5 l/min.m² for 30 minutes. The amount of heat required to evaporate water at room temperature is about 2.5 MJ / litre. Therefore, the theoretical quantity of heat that can be absorbed by a light hazard sprinkler system is 5 l/min.m² * 2.5 MJ/l * 30 min = 375 MJ/m².

The estimates for industrial and storage occupancies can be calculated in a similar way, with higher water density requirements and with 60 and 90 minutes operating times as defined in European sprinkler rules. These operating areas are somewhere in the middle of the NFPA 13 design curves.

The original SIA 81 method has a long list of occupancies and typical fire load densities, and this list is also used in the Austrian standard TRBV 100.

For storage, the fire load density is calculated from the density required for an operating area of 3000 sq.ft or 260 m² and a duration of 120 minutes. The equivalent value used is 300 MJ/m² for a density of 1 l/min/m².

The estimated fire load density reflects the heat output of a fire that burns for two hours. The real fire loads are probably higher, but the logarithmic formula allows a certain level of error without affecting the conclusion.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>b. Ordinary fire hazard with low fire load (OH1 / NFPA: OH Gp1)</td>
<td>600</td>
</tr>
<tr>
<td>c. Ordinary fire hazard with medium fire load (OH2 / NFPA OH Gp2)</td>
<td>1500</td>
</tr>
<tr>
<td>d. Ordinary fire hazard with high fire load (OH3 / NFPA OH Gp2+)</td>
<td>2000</td>
</tr>
<tr>
<td>e. Ordinary fire hazard with very high fire load (OH4)</td>
<td>2500</td>
</tr>
<tr>
<td>f. High hazard class HH1</td>
<td>2500</td>
</tr>
<tr>
<td>g. High hazard class HH2 (NFPA EH Gp1)</td>
<td>3000</td>
</tr>
<tr>
<td>h. High hazard class HH3 (NFPA EH Gp2)</td>
<td>3750</td>
</tr>
<tr>
<td>i. Rack storage</td>
<td></td>
</tr>
<tr>
<td>j. Large drop sprinklers protected storage</td>
<td>6750</td>
</tr>
<tr>
<td>k. ESFR protected storage 7m high</td>
<td>7500</td>
</tr>
<tr>
<td>l. ESFR protected storage 5.5 bar</td>
<td>12000</td>
</tr>
</tbody>
</table>

- The link with the fire duration.

Most mathematical fire models express the severity of the thermal action of a fire as a function of the duration of the fire. The standard fire curves, (see Eurocode EN1991-1-2) are logarithmic temperature-time curves. The curves have a fast growing head, representing the start of flashover conditions and a more horizontal body, representative of a severe fire with a more or less constant rate-of-heat-release.
The blue curve is the ISO 834 curve, the red curve is the “external fire curve” and the dotted line shows the “hydrocarbon curve”.

When factor q is drawn as a function of fire load Q, based on a heat release of 250 kW/m², the same curve is found as the Temperature /Time curve of ISO standard R 834.

Natural fire models add to this curve a slow growing beginning, usually a $t^2$ - curve, representing the initial development of fire before flash-over, and a declining tail (linear or $t^2$) to represent the extinguishing phase of the fire.

The nearly horizontal part of the temperature-time curve covers two current scenarios in real fire conditions: it can be either a post-flash-over ventilation controlled fire or a situation where the heat output of the fire is nearly in balance with the heat absorption potential of the water flow applied by the fire brigade and sprinklers. In both cases a nearly constant RHR (rate-of-heat-release) is assumed, and the duration of the fire is almost linear linked with the available fire load. The tail end of the fire extinguishing is not very interesting in risk assessment, as the key question is to define when and how often the thermal action will be sufficiently strong to cause the undesirable event.

Introducing a beginning phase in a fire model is more significant, as it gives an indication of the time delay before the severe thermal action starts, and influences greatly the effectiveness of defensive actions such as fire operations and sprinkler actuation.

Additional parameters define the shape of natural fire curves. Generally, local conditions (ventilation, compartment size, etc.) are taken into account to transform the standard curve into a less or more severe fire model. The "equivalent time"-concept simplifies the fire severity evaluation to a comparison between the peak of a natural fire curve with the standard ISO 834 fire curve.
In FRAME the duration part of the fire model is represented by the logarithmic expression used for the fire load factor $q$. The 0.55 correction can be seen as that part of the fires’ heat output that is lost in the growing phase, goes into the smoke and is left in the extinguishing phase. The logarithmic formula for $q$ reflects also the fact that the total fire risk is a integration of probability and severity linked values.
F.R.A.M.E.

- The value range for fire load factor q.

![Graph showing the value range for fire load factor q.](image)

The value of q is equal to 1 for a total fire load density of 210 MJ/m², which is the kind of fire load one can find in an office in a non-combustible construction. The value of q equals to 0 for a value of 7 MJ/m², which is something like the energy coming from a floor carpet in a concrete bunker.

The value of q for a fire load density of 15000 MJ/m² is 2.23. The value curve for factor q flattens with increasing fire load densities; This illustrates the remark that underestimating very high fire loads does not affect the conclusion of the risk assessment.

**The spread factor i.**

When one wishes to start a campfire, he will use materials that spread the fire rapidly, choose materials that burn easily such as wood and paper, take the small twigs first, and maybe use some accelerant. One can see that the fire spread is essentially a surface phenomenon.

Most fire models are very elementary when dealing with the heat release of fires. Yet, this aspect of fire development could be a key issue, especially for human safety, as the developing phase of the fire defines the time available for the escaping from the fire area. Scientific literature refers to a simple t²-curve with a growth parameter value for slow, medium, fast and ultra-fast fire development. There is almost no research into what parameters influence fire growth.

In FRAME, three influence factors have been identified as contributing to the fire growth and hence to the fire severity: the volume/area ratio of the combustibles, the combustibility of the surfaces and the ignition characteristics of the surface materials. These have been identified by three parameters and combined in the fire spread factor i.

The fire spread factor i indicates how easy a fire can spread through a building. It is calculated from the average dimension of the content m, the flame propagation class M, and the destruction temperature T. The formula for i is:

\[
i = 1 - \frac{T}{1000} - (0.1 \log m) + \frac{M}{10}
\]

In this formula T is expressed in centigrade (°C), m in meter and M has no dimension.
The combination and balancing of the three parameters is the result of reasoning and experienced guesswork, there is no scientific evidence available to support the combination as such, but there is NEITHER any scientific material that indicates that the combination is WRONG.

- **Sub factor T, destruction temperature**

We know that most materials will react to fire, even if they do not necessarily burn. For most materials, one can indicate a temperature level where destruction starts.

<table>
<thead>
<tr>
<th>RECOMMENDED VALUES FOR T, the destruction temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflammable liquids</td>
</tr>
<tr>
<td>Human beings, plastics, electronics</td>
</tr>
<tr>
<td>Textiles, wood, paper, food</td>
</tr>
<tr>
<td>Average content of residential buildings</td>
</tr>
<tr>
<td>Machinery, household appliances</td>
</tr>
<tr>
<td>Metals</td>
</tr>
<tr>
<td>Non combustible construction materials</td>
</tr>
</tbody>
</table>

Any intermediate value is also acceptable. E.g. in a warehouse were packed and unpacked metal spare parts are stored, T= 250°C = (100° C + 400°C ) : 2 can be used.

- **Sub factor m, the average dimension**

Factor m is the average dimension of the content and reflects the ratio between the total volume of the content and the total surface. We know that the smaller an object is, the easier it will burn. In fact, smaller objects have a higher surface to mass ratio. A solid block of wood has a much smaller total surface than the same mass of sawdust. So, in order to define how much surface a fire will find on a certain amount of combustibles, one have to reckon with the ratio between the total volume (m³) and the total surface (m²).

This can be done by using the average dimension m of the content (expressed in meter). For average dimensions above 1 m, the value of the factor is reduced, for smaller sizes it is increased.

To calculate m it is required to estimate the size (length, width, height or thickness) of typical objects in the content and to calculate an average dimension. Take n typical dimensions, expressed in meter, and the n-th root of the product is calculated as the average dimension of the content.

The most commonly used value for m is 0.3 as the average dimension of most objects in our daily environment. Other typical values are:
- Palletised storage of goods: m = 1
- Industries producing smaller objects: m = 0.1
- Industries producing film type goods: m = 0.01
- Grain, pellets and similar goods: m = 0.001
Sub factor M, flame propagation or “reaction to fire” class.

For the purpose of evaluation the speed of fire spread, 6 flame propagation classes, called M are used. It is important to notice that these classes apply for the surfaces. A closed metal container with gasoline can be classified as M = 0, and a TV-set in a polystyrene box will be classified M = 4 or even M = 5. For mixed contents, such as in warehouses, an average class e.g. M = 2.5 can also be used in the formula.

The original classification was based on the French method for classifying building materials according to their flame propagation characteristics as tested per NF P92-501/504/507 and the CEA classification of goods. These references are no longer available, and more suitable guidelines for the classification of surfaces can be found in the EN standards EN 13501-1 and EN 12845.

Based on these standards, the following scale is proposed:

<table>
<thead>
<tr>
<th>Classification</th>
<th>M -value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 per EN13501-1 or Incombustible</td>
<td>0</td>
</tr>
<tr>
<td>A2 per EN13501-1or Nearly incombustible</td>
<td>0.5</td>
</tr>
<tr>
<td>B per EN13501 or EN12845 Cat. I : Difficult to ignite (self extinguishing)</td>
<td>1</td>
</tr>
<tr>
<td>C per EN13501-1 : Slow burning materials</td>
<td>2</td>
</tr>
<tr>
<td>D per EN13501 or EN12845 Cat. II: Combustible surfaces</td>
<td>3</td>
</tr>
<tr>
<td>E per EN13501-1 or EN12845 Cat. III Flammable surfaces</td>
<td>4</td>
</tr>
<tr>
<td>F. EN12845 Cat. IV : Highly flammable surfaces</td>
<td>5</td>
</tr>
</tbody>
</table>

A weighted average is also acceptable. E.g. where unpacked and expanded plastic protected metal spare parts are stored, a combination of A1 and F can be used.

The value range of fire spread factor i.

The value of i will vary in the range of 0.5 to 1.65. The first value is representative for a storage of large blocks of concrete. The last one is typical for a heap of chips of expanded polystyrene. For most houses, the value of i will be about 1.2, assuming e.g. that m= 0.1, T = 200 and M = 3.

With the logarithm in the basic formula, the value of i, for a "residential" fire situation (i=1.2) is then comparable to an ISO 834 standard fire. The i-value of 0.5 means that a fire in a storage of concrete blocks should be comparable to 20 % of an ISO fire, the polystyrene fire (i=1.65) could be 3 times as severe. There is no scientific information available (such as tests or research reports) that confirms or denies the proposed relationship between content size, reaction to fire and reaction temperature. Any other guess or approach is welcome, but the range seems fairly reasonable, as indicated shown by the links that can be made with the usual fire growth curves.

The link with fire growth curves.

In zone models, the impact of fire growth is typically expressed by a fire growth curve, usually a $t^2$ – curve, whereby 4 growth curves are used for the development of the fire from 0 tot 1 MW.

These 4 growth rate curves are used for simplicity and convenience. In most zone model programs, the user can adapt the value of the heat release rate to simulate other design fires.

- slow: the fire grows from 0 tot 1 MW in 600 seconds
- medium: the fire grows from 0 tot 1 MW in 300 seconds, the burning or heat release rate (HRR) is 250 kW/m².
fast: the fire grows from 0 tot 1 MW in 150 seconds, the burning or heat release rate (HRR) is 500 kW/m²
and ultra fast: the fire grows from 0 tot 1 MW in 60 seconds

The link between fire spread factor i and the heat release rate is given by the following formulas:

\[ i = \log \left( \frac{HRR}{25 \text{ kW/m}^2} \right) \]

OR:

\[ HRR = 25 \times 10^{(i)} \text{ kW/m}^2 \]

This link can be explained as follows:

- The HRR of 250 kW/m² is typical for a medium growth fire, e.g. fire in an office environment. In such environment typical values to define factor i are: \( m = 0.3, M = 2, T = 250 \), resulting in factor \( i = 1 \).
- The slower growth fire can be found in ordinary hazard group 1 fire risks, like metal workshops. In such environment, typical values to define factor i are: \( m = 0.1, M = 0, T = 400 \), resulting in factor \( i = 0.7 \), which gives a HRR of 125 kW/m².
- Fast growth fires are found where combustible liquids or melting plastics are found, say OH3 type activities. In such environment, typical values to define factor i are: \( m = 0.1, M = 3, T = 100 \), resulting in factor \( i = 1.3 \), which gives a HRR of 499 kW/m².
- Ultra fast growth fires are typical for flammable liquids and foamed plastics. In such environment, typical values to define factor i are: \( m = 0.05, M = 5, T = 0 \), resulting in factor \( i = 1.63 \), which gives a HRR of 1066 kW/m².
- Ultra slow growth fires: The lowest value to be found for i is 0.4, for something which is almost impossible to ignite, like a storage of metal or concrete and corresponds to a HRR of 60 kW/m².

The benefit of fire spread factor i.

The advantage of using factor i, instead of the conventional 4 growth curves, is that a finer tuned approach is possible. For example, it can demonstrate that adding combustible padding in a room for noise insulation will result in a much faster fire growth. This was one of the major contributing factors to the catastrophic The Station night-club fire on February 20, 2003.

The FRAME factor i for a non-combustible night-club environment would be \( i = 0.85 \) (\( m = 0.3, M = 1, T = 250 \)), resulting in a HRR of 177 kW/m². Bringing in combustible foam padding would change \( M=1 \) to \( M=4 \) and \( i = 1.15 \), resulting in a HRR = 353 kW/m², but it would also
change the environment factor $r$ from 0.3 to 0.6, reducing considerably the acceptable risk $A_1$. These two changes of the values of the influence factors reflect faithfully how the risk increases by using combustible padding in a otherwise low hazard environment.

**The venting factor $v$.**

The venting factor $v$ indicates the influence of smoke and heat inside the building. Any fire produces a large quantity of hot gases, which stay below the ceiling as a smoke layer. This smoke can damage the building and its content and is a major threat for the life of the occupants and the fire fighters. The average quantity of smoke produced by a fire is about 20 $\text{Nm}^3$ per kg of burned material. It is clear that any building will be rapidly filled with smoke, unless there is a way to get the smoke out of it.

The smoke can eventually escape to the outside by openings in the exterior walls and the roof. As smoke and heat stays inside the compartment, flashover conditions can occur, which will render the fire uncontrollable. The venting factor compares the venting capacity with the sources of smoke. It is calculated by the formula:

$$ v = 0.84 + 0.1 \cdot \log Q_{m} - \sqrt{k} \cdot \sqrt{h} $$

- Input data.

The first element for this factor is the potential heat release inside the building. The most relevant measure for it is the mobile fire load $Q_{m}$, as defined previously for factor $q$.

The second element to consider is the height $h$, between the floor and the ceiling of the storey. The higher the ceiling, the thicker the smoke layer can be before it becomes impossible to stay underneath.

The third element in the formula is the smoke venting ratio $k$. The fire itself will help smoke in some way to get out, as the pressure build-up by the hot gases will break windows, plastic sheeting will burn away, etc. Some buildings are equipped with static or dynamic smoke venting systems. All these result in the creation of a "smoke escape area".

This area is the aerodynamic surface of all openings by which the smoke can go to the outside. The ratio between this "smoke escape area" and the total floor area of the compartment, is the venting ratio $k$, the third element of the formula.
The ventilation factor of a single level compartment is calculated with the average height between floor and ceiling, as typical for the available space where smoke can accumulate. However, in an atrium or duplex type compartment, the ceiling height is the distance between the ceiling and the highest floor which has to be evacuated by an path inside the compartment.

Only when there is a direct exit for the mezzanines, the whole height of the atrium can be seen as the ceiling height. Remember that the software accepts only 15 m as maximum for the ceiling height. Higher values have to be topped off at 15 m to avoid unrealistic low values for factor $v$ in compartments with high ceilings.

- The link with flash-over conditions.

Generally speaking, localised fires are easier to handle: They do not impose a severe action on the building elements and can be approached for extinguishment. The transition from a localised fire to a fully developed fire is described in the scientific literature and expressed as a function of the fire heat release, the (square root) of the height between ceiling and floor, and the area of available ventilation openings. (E.g. Thomas's flashover correlation, ventilation limit theory by Kawagoe).

In FRAME this relationship is found back in the ventilation factor $v$, which is calculated in a similar way with the log of the mobile fire load, the venting ratio $k$, and the (square root) of the height.

The effect of this factor in the potential risk $P$ reflects an increased severity for high fire loads inside the compartment, and a decrease in severity when favourable ventilation conditions allow for localised fires.

- The value range of venting factor $v$.

The value of $v$ equals to 1 for a building with adequate venting capacity for a developing fire. A value above 1 means that the building can be filled up with smoke in a short time. Tests have shown that a venting area of 1 to 2% of the floor area is generally adequate to vent the smoke of a developing fire.

When “FRAME” was developed, a commonly used document for designing smoke venting systems was the “Fire Research Technical Paper n° 10: Design of Roof-venting systems for single storey buildings”, published in 1964.

The following examples compare the requirements of this technical paper, with the smoke venting requirements to obtain a $v$-factor of 1, for a compartment of 1200 m² (g-factor = 1).
F.R.A.M.E.

- In an office building, a typical fire load would be about 200 MJ/m², the ceiling height about 3 m (10ft). $k$ has to be 0.003 to obtain $v = 1$.
- A fire that covers the operating area of one sprinkler in a light hazard system (16 m²) would then give in the compartment a smoke layer of 1 m thick and a free height of 2 m.
- In a factory, a typical fire load would be about 1500 MJ/m², the ceiling height about 5 m (15ft). $k$ has to be 0.011 to obtain $v = 1$. A fire that covers the operating area of 4 sprinklers in ordinary hazard (12 m² * 4) would give a smoke layer of 1.5 m thick and a free height of 3.5 m. The value of $k = 0.011$ fits well with the practice of using 1 : 100 as venting ratio for factories with medium fire loads.
- In a warehouse, a typical fire load would be about 6000 MJ/m² for a 6 m high storage of consumer goods, the ceiling height about 7.5 m (25ft). $k$ has to be 0.017 to obtain $v = 1$.
- A fire that covers the operating area of 9 sprinklers in high hazard (9 m² * 9) would give a smoke layer of 3 m thick and a free height of 4.5 m. The value of $k$ fits well with the practice of using 1 : 50 as venting ratio for warehouses.

More recent standards and calculation methods for smoke and heat venting systems, such as TR 12101-4 and NFPA 204 give formulas and procedures to design static and forced ventilation systems. The results will give either a venting area or a smoke extraction capacity. These design figures can be used in the FRAME calculation.

Whether the FRAME expression is a correct transcription of the scientific theories used for smoke vents design is not yet proven, but in practice properly engineered smoke venting systems always give a $v$-value slightly below 1, meaning that the fire severity is reduced, which is exactly what smoke venting systems do.

**Building configuration.**

The building configuration can be a risk aggravating element as it defines in some way the success rate of a fire brigade intervention. The building configuration is evaluated in the area factor $g$, the level factor $e$, and the access factor $z$. The shape of the compartment, the presence of intermediate galleries and multiple levels and the location versus the access level are also included.

In the "natural fire concept" approach the increase in compartment size from 2500 m² to 10.000 m² causes a 15 % increase of fire severity value. For the same situation, the $g$-factor in FRAME doubles the value of $P$, which means a 100 % increase in fire severity value, reflecting not only the increased probability of ignition but also the decrease in controllability of the fire, resulting from the reduced capacity of occupants and fire brigade to gain early control in a large building or less accessible spot.

It should be noted that in FRAME the $g$-factor does not intervene in the risk assessment for the occupants. As any developing fire is considered as "worst case for people", the size of the compartment is not considered as relevant for severity and/or probability of the risk to persons. However, the size and shape of the compartment is considered in the calculation of $A_1$, but this is a measure for the "exposure" and is dealt with separately.

**The area factor $g$.**

The area factor $g$ indicates the horizontal influence of the fire. The factor $g$ is calculated with the values of $l$, the theoretical length of the compartment, and of $b$, the equivalent width, expressed in meter.
F.R.A.M.E.

The area factor \( g \) indicates the horizontal influence of the fire, which can spread through the whole building, if there is no effective barrier or fire fighting action.

Such a barrier will be a firewall that has sufficient strength to withstand the effect of a large fire. Firewall construction is described in standards and codes of good practice. In “FRAME” the whole area of one floor must be considered as one fire area, unless it is divided by firewalls that comply with the following criteria:

- The complete wall construction, including doors, shall have at least a two-hour fire rating according to ISO 834, for stability and integrity;
- The wall shall be built in such a way that the fire cannot spread over or around it;
- The wall shall be built in such a way that it will not break down if the building collapses in the fire area.

The factor \( g \) is calculated with the values of \( l \), the theoretical length of the compartment, and of \( b \), the equivalent width, expressed in meter. The formula for the area factor \( g \) is:

\[
g = \frac{b + 5 \times \frac{3}{2}(b^2 \times l)}{200}
\]

- Input data.

The theoretical length "\( l \)" of a compartment is the longest distance between the centres of two sides of the compartments' perimeter. The equivalent width "\( b \)" is the quotient of the total area of the compartment by the theoretical length. This approach transforms any compartment of irregular shape into a rectangle with the same surface area.

In a square building a fire can spread from the middle in almost the same way in any direction. In a long, narrow building, the fire development will be restricted when it reaches the walls. Therefore, the value of \( g \) is lower for a long narrow building than for a square one with the same floor area.

The formula for \( g \) considers the size and the shape of the compartment. When a building is only accessible from its narrow side (see below) the values of \( l \) and \( b \) are reversed to reflect the increased difficulty for the fire brigade to control a fire in such a building.
The value range of the area factor g.

The value of g is 1 for a rectangular building of 20 m x 80 m. It goes up to 9.0 for a building of 300 m by 300 m.

The area factor is the most influential factor for the choice of property fire protection. For compartments of 1600 m² to 4000 m², the weight of factor g in the formula can be balanced by installing automatic fire detection, while for larger compartments automatic sprinkler protection will be needed.

For compartment of more than 25000 m² it will be difficult to provide adequate fire protection and reducing the risk by compartmentalisation is the most recommended solution.

The level factor e.

The level factor e indicates the vertical influence of the fire, namely upward by smoke and heat, and downward by heat, water damage and collapse. It also evaluates the increased difficulty for the fire brigade to cope with a fire that is not located at street level.

There are two possible ways to interpret the vertical influence of the fire, e.g. imagine a building with three floors above the access level and two basements:

One way is to assume that the potential risk increases at ground level due to the presence of five other levels, the other is to consider that more and/or better performing equipment is needed to cope with a fire that is further away from the access level. For this reason, it is more logical to take as criterion the number of levels that the compartment is away from the access level.
F.R.A.M.E.

The level factor $e$ will be calculated from the level number $E$, by the formula:

$$
e = \left( \frac{|E| + 3}{|E| + 2} \right)^{0.7|E|}$$

- **Input data**

In this formula $E$ means the absolute value of $E$. To find $E$, number all levels of the building as follows: The main access level has number $E = 0$. Levels above the access are numbered 1, 2, 3, etc. Levels below the access level are numbered -1, -2, -3, etc.

For a building on a slope, it is possible to have more than one access from the street level. In this case, more than one level can have $E = 0$ as level number, but the basements will still have negative numbers, and the storeys will have positive numbers.

![Level numbers example](image)

The formula also accepts decimal values; e.g. when there are galleries between levels, and one can add the additional floor space as the decimal part of the level number. A first level of a theatre with a gallery of 40% additional floor space can be entered as level number 1.4.

For atrium type compartments, where several mezzanines look out at a larger floor level, a specific method is used to define the value of $E$ the level factor. The rule is: before the decimal point: the floor number, and after the decimal point: the percentage additional floor area of the mezzanines, if necessary more than 100%.

It is necessary to consider the largest floor as "access floor". When e.g. a compartment is composed of a small ground floor and a passage to a larger floor above, the "access level" for the risk evaluation will be the larger upper floor.

The area of the mezzanines is added as a decimal part of the floor area and added to the floor number $E$, which is increased.

- The value range of the level factor $e$. 

59
The formula evaluates the fact that the mutual influence of the levels diminishes when they are further away from each other. Factor e equals to 1.0 for the access level. It increases to 1.6 for the fifth level, goes up to 1.75 for the 10th level and reaches 2.00 for the 200th level.

The formula has been developed to give a curve that fits the original Gretener table for the levels. The values given by Gretener correspond with the wide spread practice in building codes to equalize the risk on higher levels by reducing the allowable area per compartment.

\[ \text{factor e} \]

\[ \begin{array}{c|c|c|c|c|c|c|c|c|c|c}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 8 & 10 & 15 & 20 \\
--- & --- & --- & --- & --- & --- & --- & --- & --- & --- & --- \\
1.00 & 1.20 & 1.40 & 1.60 & 1.80 & 2.00 & 0 & 1 & 2 & 3 & 4 \\
1 & 2 & 3 & 4 & 5 & 6 & 8 & 10 & 15 & 20 \\
24 & 40 & 80 & 120 & & & & & & \\
\end{array} \]

\[ \text{level number} \]

---

The access factor z.

The access factor z indicates how difficult it is for the fire brigade to get into the fire area. It is calculated by the formula:

\[
z = 1 + 0.05 \cdot \text{INT} \left[ \frac{b}{20 \cdot Z} + \frac{H^-}{25} \lor \frac{H^-}{3} \right]
\]

In this formula INT means "integral part" of what follows and \lor means OR (an alternative).

- Input data.

Factor z makes the difference in potential risk between a building, which is surrounded by others as in the older cities, and those that are built in the open, with a nice access road around it. Free access to a building requires a door, a gate or a light wall to enter the building and some road or solid soil to install the fire brigade vehicles under stable conditions.

The first part of the formula relates the equivalent width b to the number of access directions Z and to 20 meter, in many countries the length of a standard fire hose. If the fire brigade must work from one side, they will need as many hoses for one stream as the width of the building divided by 20 m.

To define Z, an imaginary map of the building is drawn with the north at the main entrance of the building. Looking for free access for the fire brigade and identify the number of cardinal
points (north, east, south, west) from which such access is possible. The value of Z is 1, 2, 3 or 4.

The second part of the formula compares the height difference $H+$ or $H-$ from the access road level with 25 m upward and 3 m downward. The 25m meter “step” upwards was selected on the following basis:

- 25 m is the reference height for aerial ladders.
- Up to 50 meter hose stations can be supplied with water from standard fire pumps.
- 75 meter is about the height where intermediate reservoirs are needed for pumping up water.

The downward step of 3 m, was selected as it represents the average height of a basement: When the fire brigade has to go downward, the access is even more difficult, as heat and smoke will come towards them.

In atriums, it is the highest mezzanine which the fire brigade has to access from inside the compartment that has to be used as "reference floor level" for the atrium. On the example given with factor $v$, for the building at the left the highest balcony is not considered, as access from outside the compartment is possible. On the right, the highest balcony is the floor level for the atrium. In this way, the factors $e$, $z$, and $v$ will take into account the higher risk in the situation at the right.

The value of $z$ equals 1 for a compartment where a fire can normally be fought from the outside.

- The value range of access factor $z$.

The value range of factor $v$ is between 1.00 for buildings with good access and 1.20 for buildings with limited access. Higher values are possible, but will only occur for compartments which are almost inaccessible for fire fighting operations from the access level such as basements located more than 3 levels below ground or the upper levels of high rise buildings.
The ACCEPTABLE RISK LEVELS.

The Acceptable Risk Levels reflect the fact that people can live with the threat of fire up to a certain level. People have already built up a system that allows them to cope with the problem in a certain way: They take preventive measures such as using non-combustible building materials, they have installed a protective system (the fire brigade) and they try to share the remaining risk with others through insurance.

The acceptable risk is the link with the exposure component of a fire risk evaluation: The acceptable level of risk is reduced when the exposure to the fire is increased: This will be the case when the fire can happen more often (more ignition sources), when the fire grows faster than average, when the exposure time for the occupants is long, and when there are high value goods or important activities exposed.

The exposure will be different for property, people and activities. Therefore it is necessary to express the differences in acceptance level in the formulas. The values used in the method are chosen in such a way that they have a range around 1.

The exposure component.

The EN954-1 approach of risk evaluation indicates that a higher level of protection reliability is required when the exposure of the subjects to the risk is frequent or prolonged. There is thus a requirement for some measurement of the exposure.

This consideration has resulted in three slightly different formulas in FRAME to calculate the exposure, one for the property, one for the people, and one for the activities.

- Exposure for property

To measure the exposure for property, FRAME uses basically the monetary value of the property, transformed in the c2-factor. A similar approach exists in the insurance industry where an additionally premium is asked for high value properties. This practice is unusual for property values below 7 to 8 million Euro / US Dollar, which is also the lower limit used by FRAME. A correction is added to reflect the uniqueness of the content by the c1-factor.

An additional consideration made in FRAME is the fact that fire brigades will give priority to saving the occupants before starting large fire extinguishing operations. This means that lengthy evacuation will in fact increase the exposure for the property. The result is the formula:

$$A = \{1.6 - a\} - (t + c1 + c2)$$

- Exposure for people

Usually people are considered to be safe, when they have left building on fire: the most evident measurement for the exposure is the evacuation time. But experience learns that the fire propagation in a building is not a uniform phenomenon and that rapid fire spread is the major reason for fire victims. This means that to evaluate correctly the exposure of people, evacuation time and fire propagation shall be jointly considered. In FRAME this results in the formula:

$$A1 = \{1.6 - a\} - (t + r)$$

The most significant factor for fire spread is the presence of ignitable surfaces, mostly building finishing and packaging materials. This is the reason why FRAME uses an r-factor, calculated with the immobile fire load Qi (building materials) and the combustibility factor M (for the surface conditions).
The evacuation time shall be calculated for the actual conditions of the compartment and its occupants. The t-factor in FRAME does this, considering the whole path from the most remote corner of the compartment to the outside of the building, the capacity of the occupants to move, and the compression effect when too much people use the same path.

One additional consideration that has been built in FRAME is the fact that multiple death accidents are considered to be far more unacceptable than single death situations.

Multiple deaths in a fire are likely to occur where long evacuation times come together with rapid fire spread. The combined values of high t- and r-factors will result in a value of $A < 1$, which means an increase in fire risk.

- Exposure for the activities.

An often-neglected aspect of fire risk is the business interruption potential. In fact, code requirements do not consider at all the impact of a fire on the economic life of a building. In the past, mostly insurance companies and corporate risk managers were concerned about it.

Fire was easily accepted as a fortuitous event (an act of god), business interruption insurance was optional, unemployment after a fire was not a social issue. Risk managers have spent a great deal of their efforts to bring business continuity after fire in the picture, and more recently authorities have become more concerned about the impact of fire on vital constructions such as major hospitals, power plants, ministries, road tunnels etc.

FRAME deals with this aspect of exposure in the following way. The duration of a fire is less important for its impact on the activities, as even a partial fire can stop an activity for several months, particularly if toxic combustion products like dioxins would be generated. Because of this "partial fire" consideration, the fire load factor $q$ was not retained in the potential risk $P_2$, as well as the correspondingly most effective protection (fire resistance) $F$ for the protection degree $D_2$.

The most evident elements for assessing the impact on a fire are also the monetary loss and the uniqueness of the content, so the $c$-factor is maintained. The evacuation time is not important for this issue.

In reality, it appears that large losses in storage buildings do not have a big impact on business interruption, but that fires in controlling areas and bottleneck installations are very critical. A measure for this was found in the "added value/turnover" ratio, used as $d$-factor. It gives a good indication of the dependency of an activity on a certain location. The result of these considerations is the formula:

$$A_2 = (1.6 - a) - (c_1 + c_2 + d)$$

The formulas for the Acceptable Risk Levels thus read as follows:

$$A = 1.6 - a - t - c$$

$$A_1 = 1.6 - a - t - r$$

$$A_2 = 1.6 - a - c - d$$
The Acceptable Risk Level A (for the building and its content) is calculated from the maximum level 1.6, the number of fire sources (activation factor a), the priority given for the human safety (evacuation factor t) and the severity of the loss (value factor c).

The Acceptable Risk Level A₁ (for the occupants) is calculated from the maximum level 1.6, the number of fire sources (activation factor a), the required safe egress time (evacuation factor t) and the available safe egress time (environment factor c).

The Acceptable Risk Level A₂ (for the activities) is calculated from the maximum level 1.6, the number of fire sources (activation factor a), the severity of the loss (value factor c), and the impact on business (dependency factor d).

The maximum level 1.6 is defined by comparing low potential risks with generally available levels of protection. It reflects the possibility of having a fire started by natural causes such as lightning, human errors, and deficiencies of a normally working system. The value 1.6 is relevant for most industrialised countries.

**Probability of ignition.**

A number of fire safety studies consider the probability of ignition to be more or less uniform within compartments with similar occupancies, supported by statistical values. A few surveys have established such values for offices, housing, industrial building: they are in a range around $10^{-6}$ events per m² per year. The probability of ignition is therefore linked to the compartment floor area: the larger the compartment, the more likely a fire will occur. In prescriptive codes, compartment size limitations are apparently not linked to probability, but inspired by a concern for controllability of the fire by limiting the total quantity of combustibles (area x fire load density).

This approach is probably too much of a simplification: In fact the size of a compartment does not only define the number of (evenly) distributed ignition sources, but has also an impact on the time necessary to discover the fire, the occurrence of secondary ignition sources and the time necessary for the fire brigade to reach the seat of the fire.

In FRAME the occurrence of ignition is used as part of the exposure evaluation by sub factor a: A building and its users are only exposed to the fire once ignition has occurred: The more ignition sources available in building or compartment, the higher the exposure is and hence, the less a fire risk becomes acceptable.

**Sub-factors a, activation or ignition sources.**

A traditional way of presenting a fire hazard is to refer to the fire triangle. It needs oxygen, a combustible and an ignition source to start a fire. Usually the combustible and the oxygen are readily available, so one has to check the presence of ignition sources, of which five groups can be identified.

The most important group of ignition sources lays in the activities itself, main and secondary. The main activity is what is going on in the compartment: industrial work, storage, trades, residential, teaching, etc. Secondary activity is something that is adding a different hazard. Storage can be a secondary activity, or welding or cooking, or the use of flammable liquids for painting.
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- The main activities.

Most codes and regulations include already some classification of the main activities related to the fire hazard, and are based on the combined presence of combustible and ignition sources. Such classification is e.g. used for designing sprinkler systems, where the following types of activities are listed:

a) A combination of a low fire load and a low number of ignition sources, such as for residential buildings.

b) A combination of a low fire load and a moderate number of ignition sources, such as in the industry of non-combustible products.

c) A combination of a moderate fire load and a moderate number of ignition sources, such as in many industries.

d) A combination of a high fire load and a moderate number of ignition sources, such as in the paper and woodwork industry.

e) A combination of a high fire load and a low number of ignition sources, such a in storage.

And more unlikely:

f) A combination of a high fire load and a high number of ignition sources.

In “FRAME”, such a “main activity list” is proposed to define \( a_1 \), the first part of the activation factor.

<table>
<thead>
<tr>
<th>Fire source : Main activities</th>
<th>( a_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. Low fire load and a low number of ignition sources (residential, offices, etc.)</td>
<td>0</td>
</tr>
<tr>
<td>A2. Low fire load and a moderate number of ignition sources (Industry of non-combustible products)</td>
<td>0</td>
</tr>
<tr>
<td>B. Moderate fire load and a moderate number of ignition sources (Most industries, large stores, retail shops)</td>
<td>0.2</td>
</tr>
<tr>
<td>C. High fire load and a moderate number of ignition sources : Industry of combustible products such as paper, wood, petrochemicals</td>
<td>0.4</td>
</tr>
<tr>
<td>D. High fire load and a low number of ignition sources (warehouses and similar storage)</td>
<td>0</td>
</tr>
</tbody>
</table>

The classification of the main activities can be broadly compared with the sprinkler classification: Light Hazard class will comply with A1; EN 12845 sprinkler class OH1 or NFPA OHGp1 with A2; EN sprinkler class OH2 or NFPA OHGp2 with B; EN sprinkler classes OH3 or High Hazard and NFPA Extra Hazard with C, and storage with D. High hazard activities will often also have additional activation factors present.

- The secondary activities.

Secondary activities are only taken into account when they create an additional number of fire sources, compared with the main activities. The secondary activities that are taken into account for the calculation, are those whereby sparks, hot surfaces, friction heat or easily ignitable products are involved.

Welding will not be a secondary activity in a garage, but in a carpenters' shop. Shrink-wrapping will be a secondary activity in a warehouse, but not in the packaging department. Unauthorised smoking can be considered as a secondary activity where smoking control is not very effective.

The classification of the secondary activity will define \( a_2 \), the second part of the activation factor \( a \).
The third group of well-known fire sources is the heating systems. Both building and process heating are to be considered. Hot water or steam systems do not present a particular hazard, except when the heating unit itself is located inside the compartment and not in a separated room. The type of fuel used is important: coal and oil are less hazardous combustibles than gas or waste materials.

Systems using combustible thermal fluids are somehow more hazardous than those with water are. Air conditioning systems are also more hazardous because they can accumulate dusts and grease and can transport smoke and burning particles from one place to another.

Electrical heating systems rely on thermostats to operate correctly, and a failure of these sensors makes the heating system a fire source. Electrical radiators and convectors are to be considered as heat generators in the compartment itself, as well as stoves and similar apparatus.

The most hazardous heating systems are those that work with open flames or hot radiating surfaces.

"FRAME" uses the following typical values for calculating $a_3$, the influence of the heating systems on the activation factor. The 3 components (heat transfer method, location of the generator and energy source) are added:

<table>
<thead>
<tr>
<th>Fire source : Process and room heating systems</th>
<th>$a_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No heating present</td>
<td>0</td>
</tr>
<tr>
<td>Heat transfer through water, steam, or solids</td>
<td>0</td>
</tr>
<tr>
<td>Heat transfer through pulsed air or through oil</td>
<td>0.05</td>
</tr>
<tr>
<td>Heat generator in a separate room</td>
<td>0</td>
</tr>
<tr>
<td>Heat generator in the compartment itself</td>
<td>0.1</td>
</tr>
<tr>
<td>Energy source: electricity, coal, fuel oil</td>
<td>0</td>
</tr>
<tr>
<td>Energy source: gas</td>
<td>0.1</td>
</tr>
<tr>
<td>Energy source: wood or waste materials</td>
<td>0.15</td>
</tr>
</tbody>
</table>

The fourth group of ignition sources comes from the electrical system. In many cases of unknown fire origin, electricity is blamed to be the cause of the fire. Although the rules for electrical systems have been continuously improved to get safer systems, it must be admitted that electricity is a powerful source of concentrated energy, which can start fires.
An electrical system that is built according to the rules, and is regularly checked by a competent authority is not considered as an additional source of fire. A system that is not checked can become hazardous because of wear, abnormal use and modifications. A system that is not in accordance with the codes represents a definite fire hazard.

The classification of the electrical system will define $a_4$, the fourth part of sub factor $a$.

<table>
<thead>
<tr>
<th>Fire Source: Electrical Installations</th>
<th>$a_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical installation in compliance with the rules and regularly checked</td>
<td>0</td>
</tr>
<tr>
<td>- in compliance with the rules without regular checks</td>
<td>0.1</td>
</tr>
<tr>
<td>- not according the rules</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- Flammable liquids, gases and dusts.

The last group of fire origins is the use of flammable liquids, gases and dusts. These products are fire sources because they can start a fire on a low energy ignition element such as a spark or a hot surface.

That the use of flammable liquids, gases and dusts is classified in the electrical codes may be surprising, but the electricians are aware of the fact that electrical equipment produces sparks and has hot surfaces. So they foresee special equipment in the presence of flammable liquids, gases and dusts. One can use the classification for "hazardous areas" and distinguish four types of areas:

- The use (or storage) of flammable products is such that an explosive mixture in the air is almost continuously present.
- The use (or storage) of flammable products is such that an explosive mixture in the air can be present under normal working conditions.
- The use (or storage) of flammable products is such that an explosive mixture in the air can be present under abnormal working conditions, such as a failure of ventilation.
- The use (or storage) of flammable products is only occasional and limited in quantity such that an explosive mixture in the air is most unlikely.

According to the type of "classified areas" which are present inside the fire compartment, this will increase the value of the activation factor with $a_5$.

The classification of hazardous areas can be done either according to the European ATEX 137 Directive or according to NFPA 70 National Electrical Code.

<table>
<thead>
<tr>
<th>Fire Source: Flammable gases, liquids and dusts</th>
<th>$a_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent explosion risk ATEX zone 0;</td>
<td>0.3</td>
</tr>
<tr>
<td>Explosion risk under normal operating conditions</td>
<td>0.2</td>
</tr>
<tr>
<td>ATEX zone 1 NEC : Class I Div.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Occasional explosion risk ATEX : zone 2; NEC : Class I Div.2</td>
<td></td>
</tr>
<tr>
<td>Dust explosion hazard ATEX zone 20/21/22 ; NEC : Class II</td>
<td>0.2</td>
</tr>
<tr>
<td>Production of combustible dusts without extraction</td>
<td>0.1</td>
</tr>
</tbody>
</table>

- What about arson?

There is a sixth group of fire origins that is not mentioned here: arson. If arson has to be included in the evaluation, it would mean that arson could be tackled with an increase in fire
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protection. Although the effect of arson can be limited by the fire protection, provided that the protection system is not impaired, it must be admitted that arson is not a fire safety problem, but a security problem. Therefore there is no factor for arson foreseen in this method.

The evacuation time factor $t$.

In general, life safety from fire is achieved if the required safe egress time (RSET) is shorter than the available safe egress time (ASET), where the ASET is defined as the time when fire-induced conditions within an occupied space or building become untenable.

The evacuation time factor $t$ in FRAME is representative for the required safe egress time, and the environment factor $r$ considers the ASET, the available safe egress time (see below).

RSET means Required Safe Egress Time. This time is usually calculated by simulating the evacuation movement of the people in the compartment, whereby some assumptions are made for the reaction of people in case of a fire, the composition of population and the way the flow of the persons is going. In “FRAME” a simplified method is used to estimate the required safe egress time and the result is transformed into factor $t$.

The evacuation time factor is taken into account for the risk evaluation for the occupants, but also for property. This is done to reflect the priority given by the fire brigade to saving lives. The impact of the evacuation on saving the activities is minimal, hence the evacuation time is not used in the assessment for the activities.

The formula for the evacuation time factor is:

$$t = \frac{p \times [(b + l) + (X/x) + 1.25 \times H^+ + 2 \times H^-] \times [x \times (b + l)]}{800 \times K \times [1.4 \times x \times (b + l) - 0.44 \times X]}$$

The formula is based on a simplified evacuation time calculation, and the formulas and values found in the SFPE FPE-handbook (chapter 3-13 Movement of People: The Evacuation Timing).

- Basic evacuation time calculation.

The first part of the formula concerns the calculation of the evacuation distance, and is composed of $(b+l) + X/x + 1.25 \times H^+ + 2 \times H^-$. 

![Evacuation Diagram](image-url)
FRAME assumes that the occupants will travel at a constant speed $S$ on an exit path that has the same width as the doors. On stairs, the speeds of movement are slightly lower and, at low densities, relatively fit people can average about 1.1 m/s descending along the stair slope, which is slower than on level parts. But as fire safety codes require stairs to be wider than the door openings, and as people will take staggered positions on stairs, which increases the flow capacity, it can be assumed that the descend speed is basically the same as in the corridor. For up going stairs, the FRAME formula assumes that the movement is 60 % slower.

$H^+$ or $H^-$ is the vertical distance of the exit path toward the ground level (see factor $z$).

$1.25 * H^+ :$ is the equivalent distance for going downstairs for a distance of $H^+$ , assuming that the length of the stairs is 1.25 times the height.

$+2 * H^- :$is, alternatively, the equivalent distance for going upstairs for a distance of $H^-$ , and assuming that the stair is 1.25 times the height of the stair and that a person walks about 60 % slower on a rising stair than on a level path.

The sum of the length and the width of the compartment is the longest travel distance (in meters) inside a compartment for a person when he is stays in one corner of the compartment and has to walk to an exit in the opposite corner.

$X/x :$ is the passage of $X$ persons through $x$ exit units. Assuming the it takes about one second per person to go through the door opening, this part of the formula translates the passage of one person into a walking distance of about one meter. The passage of one person per second has been observed in uncontrolled total evacuation drills in well-populated office buildings.

- The influence of the pedestrian density.

It is a fact that evacuation will slow down in congested areas. The SFPE Fire Engineering Handbook gives in Chapter 3-13 information on this phenomenon: “Expressed quantitatively, when the pedestrian density is less than about 0.5 persons /m², people are able to move along walkways at about 1.25 m/s, an average unrestricted walking speed. With greater density, speed decreases, and it decreases very markedly with very high densities, reaching a standstill when density reaches 4 or 5 persons /m², equivalent to a fairly crowded elevator situation.”

The SFPE handbook gives a general formula for the flow

$$ \text{Flow} = [1.26(\text{density})] - [0.33(\text{density})^2] $$

From this the evacuation speed can be derived as:

$$ \text{Flow} / \text{density} \text{ or } \text{Speed} \ S = 1.26 - 0.33 \ D $$

Whereby $D$ is the density expressed in persons per m².

The density of people on the evacuation path can be derived from $X$, the number of persons, $x$ the number of exit units and $(b + l)$, the length of the exit path. A simple way to estimate the density is to assume that the total number of persons is equally distributed over an evacuation path which is $(b + l)$ meter long and is $x * 1.2$ m wide. The 1.2 m width is based on the assumption that a 1 exit unit door is 80 cm wide and the corridor that leads to that door is on each side 20 cm wider than the door, which gives a corridor width of 1.2 m.

This gives for the density : $X / (b + l) * x * 1.2$ and the SFPE formula can be rewritten as :

$$ S = 1.26 - 0.33 * [X / (b + l) * x * 1.2] $$

Or : $S = \{1/ [ x * (b + l)] \} * [1.26 * x * (b+ l) - 0.396 * X]$
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Or: \( 1.11 \times S = \left\{ 1/ \left[ x \times (b+ l) \right] \right\} \times \left[ 1.4 \times x \times (b+ l) - 0.44 \times X \right] \), which can be found in the "FRAME” formula for sub factor \( t \)

The 1.11 part of the formula is integrated in the 800 value = 720 * 1.11

- The number of occupants \( X \)

\( X \) is the number of persons that can be present in the compartment. In factories, it is usually the number of persons per working shift. It is recommended to use the occupant load factors that are given in the local building codes. Otherwise, use the following table, which gives a number of persons per floor area, based on the NFPA 101 Life Safety Code. The indicated values are the number of persons per m². To find \( X \), the total number of occupants, multiply the total floor area of the compartment by this occupant load factor.

<table>
<thead>
<tr>
<th>Type of occupancy</th>
<th>Occupant load factor in persons /m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>01. Waiting spaces</td>
<td>3</td>
</tr>
<tr>
<td>02. Places of assembly, concentrated use (halls, churches, dancing's)</td>
<td>1.5</td>
</tr>
<tr>
<td>03. Places of assembly, normal use (conference rooms, restaurants, cafés)</td>
<td>0.6</td>
</tr>
<tr>
<td>04. Classrooms in schools, no fixed seating</td>
<td>0.5</td>
</tr>
<tr>
<td>05. Day nurseries</td>
<td>0.3</td>
</tr>
<tr>
<td>06. Schools: laboratories, shops and vocational rooms</td>
<td>0.2</td>
</tr>
<tr>
<td>07. Medical institutions</td>
<td>0.1</td>
</tr>
<tr>
<td>08. Jails, detention houses</td>
<td>0.1</td>
</tr>
<tr>
<td>09. Residential buildings (houses, hotels, pensions)</td>
<td>0.05</td>
</tr>
<tr>
<td>10. Sales area on street floor, below street floor</td>
<td>0.3</td>
</tr>
<tr>
<td>11. Sales area on floors above street floor</td>
<td>0.2</td>
</tr>
<tr>
<td>12. Offices</td>
<td>0.1</td>
</tr>
<tr>
<td>13. Factories</td>
<td>0.03</td>
</tr>
<tr>
<td>14. Storage and warehouses</td>
<td>0.003</td>
</tr>
</tbody>
</table>

The spreadsheet will accept any occupant load factor or total occupant load.

- The number of exit units \( x \)

\( x \) is the number of exit units. Most references (codes and egress calculation methods) reckon with “exit units” of 50 - 60 cm of useful width (with some 20 cm lost). Through one exit unit, approx. 60 persons/min can evacuate at normal walking speed, up to 120 persons/min at maximum density. If more people try to use this exit, they will be queuing to pass, which slows down the exit movement.

In “FRAME” the \( X/x \) part of the factor \( t \) formula corresponds with an exit speed of one person per second per exit unit of 60 cm useful width.

Code requirements can be very specific for the width of exits, but for a risk assessment, the minimal width for an exit can be defined at 0.6 m (2 ft) except for special conditions. E.g. in a hospital, it is clear that the minimal width is that of the beds which are used in the hospital.

The FRAME user can basically define the number of exit units according to his local standards to avoid discussions with the authorities. Alternatively, he can count with 60 cm width per unit but with a "lost" width of 20 cm at each passage: A 80 cm wide door has thus an effective width of 60 cm, and a 2 m wide corridor will have an effective width of 1.80 m or 3 exit units.

Large gates, which are normally closed, should be considered as only one exit unit, and not for the whole width of the gate.
In cases where the exit path contains stairs that are narrower than the access or exit doors, the number of exit units should be measured on the stairs, using a free width of 75 - 80 cm as minimum unit width.

In the next example, the single door defines the width for exit A. For exit B, it is the narrow part of the corridor at C that will define the width of the exit path.

To avoid the introduction of an inadequate number of exit units, a warning has been added on the calculation sheet when the value X/x exceeds 120.

- The mobility sub factor p

The mobility factor p corrects the calculated time estimation for such complications as people who need guidance or help, panic, unclear evacuation schemes, etc. Factor p considers the evacuation time under such conditions as a multiple of the calculated time for healthy mobile and independent persons.

The following table gives an overview of the most common situations:

<table>
<thead>
<tr>
<th>The mobility factor p</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Mobile and independent persons (adults, workers)</td>
<td>1</td>
</tr>
<tr>
<td>B. Mobile persons needing guidance (pupils, visitors)</td>
<td>2</td>
</tr>
<tr>
<td>C. Persons with limited mobility (patients, elderly, inmates)</td>
<td>8</td>
</tr>
<tr>
<td>D. There is no clear evacuation plan</td>
<td>+2</td>
</tr>
<tr>
<td>E. There is a danger for panic</td>
<td>+2</td>
</tr>
<tr>
<td>F. People with limited perception capacities, such as patients, elderly, disabled persons, sleeping guests in hotels, etc.</td>
<td>+2</td>
</tr>
</tbody>
</table>

The calculation sheet permits the calculation of a weighed mobility factor for a mixed group of occupants.

A more detailed evaluation that takes into account more aspects of human response and behaviour, such as:

- response to perception of fire and smoke
- time delays to start the movement
- crowd behaviour and management
- familiarity with the location
- building layout and way finding

has not been included in “FRAME” as these elements are difficult to evaluate and can lead to too much variation of factor p, depending on the users’ knowledge of the situation. The basic assumptions of a horizontal exit path = b + l added to a passage time = X/x give a conservative time estimate that copes with the uncertainties of the human behaviour.

- Available evacuation paths.
The sub factor k is the number of separate exit directions or exit paths available. The total evacuation time is reduced when people have more than one way to find an exit that leads to the open air outside the building.

In buildings with a moderate to high occupant load, such as offices and places of assembly, the fire safety codes require more than one exit path and a more or less even distribution of the exit units along the perimeter of the compartment.

The various national requirements how to calculate the required width of the exits differ considerably. The basis is always the occupant load of the compartment, multiplied by a width coefficient. In some countries the calculated width is required for each exit, while others calculate the total required width for all exits together and impose limiting conditions on the differences, such as considering one exit inaccessible to define the required number of different exits.

When all the exit units are needed to satisfy the evacuation need for the occupants at 120 persons/unit, all exits together shall be considered as a SINGLE useful exit path. Only where there is an excess of exit units present, FRAME will consider these as extra exit paths. This may be the case in buildings with low density occupant loads (factories, warehouses), where the number of doors is defined by operational requirements and/or by maximum allowable travel distances imposed by codes.

In FRAME v.2 the user was requested to define the number of distinct exit paths by checking their capacity and relative position. Two directions were considered as separate when they had adequate capacity and when a person must turn for 90° or more to go from one exit path to another. Thus a maximum of 4 separate exit paths was accepted. This was often not well understood, so an attempt was made for FRAME 2008 to define sub-factor k by a four step (automated) calculation.

a) define O, the number of exits that end in the open air, basically external doors and exterior stairways, but no ladders.

b) Define the maximum capacity of all the exits together. This is done by multiplying the number of exit units by 120.

c) The third step is to divide this capacity by the number of occupants that are present. This quotient is the theoretical number of "distinct" exit paths. When all the exit units are needed to satisfy the evacuation need for the occupants, they are considered as a SINGLE useful exit path. The real number of distinct exit paths shall be not more than 4 (implying a 90° angle between them).

d) The number of the AVAILABLE and DISTINCT exit paths "k" is then the smallest value found in steps a) and c) i.e. it is either defined by the number of "outlets" or by the number of distinct exit paths.

- The reference evacuation time

The value of 720 had been "backward engineered" from a neutral point for a low hazard situation such as: a non industrial activity in a modern non-combustible building, with a basic manual fire protection but no automatic fire detection, located in a small urban area with a semi-professional fire brigade.

For such a situation, the value of P1 will be = 1 and the value of D1 = 1.20. This means that the value of A1 can be = 0.83 for a well protected building with R1 = 1. The activation factor was assumed as a = 0.1 (e.g. electrical installation in compliance with the rules without regular checks, no other special hazards) and for the environment factor r = 0.1 log (Qi + 1) + M/10 = 0.25, i.e. Qi = 0 and M = 2.5 (medium to slowly burning surfaces).
With the $A_1 = 0.83$ value, $t$ should than be: $1.6 - 0.1 - 0.25 - 0.83 = 0.42$.

With 720 as correction factor, this corresponds with an evacuation time $0.42 \times 720 = 300$ seconds or approx. 5 minutes, after the evacuation signal is given. In practice, this means that the people in the building will have already evacuated at the time the fire brigade arrives at the fire scene, which is considered as a comfortable situation.

To verify the validity of the 720 correction, some more cases were considered:

In a building with a higher hazard which is either expressed by a higher activation factor $a$ and/or a higher environment factor $r$, the margin left for $t$ will be smaller, or otherwise the longer the evacuation time is, the higher the risk is estimated.

For a low hazard industrial building ($a = 0.3$), the comfortable evacuation time would then be reduced to $0.22 \times 720 = 158$ seconds or 2.5 minutes.

For a high hazard industrial building, the value of $A_1$ would always be equal or lower than 0.83, which means that there nothing like a “comfortable evacuation time” in such conditions.

When a building is equipped with automatic fire detection and alarm systems, the value of $D_1$ increases to 2.16, which means that for $R_1 = 1$, the value of $A_1$ can be $0.46$ or $t = 1.6 - 0.2 - 0.2 - 0.46 = 0.74$ or an acceptable evacuation time of $0.74 \times 720 = 532$ or approx. 9 minutes. This can also be accepted as the detection and reaction times will be shorter, leaving more time for the evacuation itself.

**The environment factor $r$.**

The environment factor $r$ considers the ASET, the available safe egress time. This time is usually calculated by simulating a "worst case" design fire in the design compartment by zone model computer program and checking the time necessary to reach untenable conditions, usually expressed as the time to reach a cold air layer of less than 2.5 m, a high CO content of the cold air, or an unacceptable level of vision.

Some catastrophic fires have taught us that a fast developing fire is a major threat for the occupants of a building. Contributing to such a fast fire spread, even in building with a low total fire load, are the combustible elements of the construction, and in particular surface elements such as wall decoration, floor carpeting, ea. made of easily combustible materials.

The ASET is largely defined by smoke layer conditions that are taken into account by the ventilation factor $v$, but for the speed of smoke and heat production the environment factor $r$ is used as reference measurement. Factor $r$ indicates how fast the fire can develop and is calculated with the values of $Q_i$, the "immobile" fire load, and of $M$, the flame propagation class.

$$r = 0.1 \log (Q_i + 1) + M/10$$

A potentially fast developing fire will result in a high value of factor $r$, which means a short ASET.

- Comparison of ASET and RSET.

In a scenario type fire safety analysis, it is common practice to compare a worst case RSET with a worst case ASET, but in reality the probability of such a simultaneous occurrence is low, and in many situations there may still be a comforting safety margin. For a risk assessment approach, measuring the gap between ASET and RSET is probably a better option, and this is applied in FRAME.
The formula for A1, the acceptable risk for the occupants, considers that margin between RSET and ASET as a contributing element for the risk assessment. The ASET is largely defined by smoke layer conditions which are taken into account by the ventilation factor v, but for the speed of smoke and heat production the environment factor r is used as reference measurement. A potentially fast developing fire will result in a high value of factor r, which means a short ASET.

When a comfortable margin can be expected between the RSET and ASET, the value of A1 will be above 0.8, which means a lower risk. On the other hand, when the calculated RSET is high, the value of A1 will be go below 0.8, indicating an increased risk. When a building has only basic fire protection, the value of A1 of 0.8 is compensated by a protection degree D which is around 1.25.

The Content factor c

The content factor c indicates how bad the loss of the building and its content would be. It defines the monetary and material aspects of the “exposure”. Two sub-factors are used to reflect the lost value.

\[ c = c_1 + c_2 \]

\[ c_1 \] will evaluate the possibility to replace the building and its content. Historical sites, museums, special on purpose built factories are often unique and impossible to replace. Equipment with long delivery times, special designed machinery, large complexes, are difficult to replace. The value of \( c_1 \) will be 0, 0.1 or 0.2 as the building and its content are considered as easily, difficulty, or impossibly to replace.

To appreciate this aspect of the risk assessment, the user of FRAME will have to look for information about delivery and construction times, replacement possibilities, etc.

\[ c_2 \] will reflect the monetary value of the goods. Very high values can be insured, but both society and the insurance industry are not interested in catastrophic fires and therefore the acceptance level is reduced according to the monetary value involved.

The value of \( c_2 \) has been defined based on the year 2000 value of compartment and content. The calculation sheet foresees the possibility to enter the actual value of the building and to calculate the year 2000 value with the local building cost index.

\[ c_2 = \frac{1}{4} \log(V/7.10^6) \quad \text{when} \quad V > 7.10^6 \text{ euro (2000)} \]

The dependency factor d

The dependency factor d evaluates the impact of a fire on the activities that happen in the building. It defines the economical aspect of the “exposure”.

A warehouse fire can result in a huge monetary loss, but as long as the production facilities of a factory remain untouched, the business will not be affected very much, as the most likely result of the fire will be some delay in deliveries. On the contrary, if there is a bottleneck operation present in a process, then even a small fire there will cause considerable disturbances of the production.

The factor that indicates the best how much a business can be touched by a fire is the difference between the value of the incoming materials and the outgoing products. This is the "added value" and is sum of the costs of personnel, financial costs, investments, and the
company results. The turnover is the total yearly monetary value of all the revenues coming from the economic activity of the unit, which is considered.

The dependency factor \( d \) is the ratio of added value by turnover. The higher this ratio, the more sensitive is the activity. For most companies, this ratio can be found in the economical information of the company. As a guideline, the values for \( d \) can be estimated as follows:

<table>
<thead>
<tr>
<th>Typical values for the dependency factor ( d )</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High technology industry and services</td>
<td>0.7 to 0.9</td>
</tr>
<tr>
<td>Industry of consumer products (automobile, household electronics)</td>
<td>0.45 to 0.7</td>
</tr>
<tr>
<td>General industry (machine construction, semi-finished products)</td>
<td>0.25 to 0.45</td>
</tr>
<tr>
<td>Commercial companies, warehouses</td>
<td>0.05 to 0.15</td>
</tr>
<tr>
<td>Administrations</td>
<td>0.8</td>
</tr>
<tr>
<td>Average for most businesses</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The recommended values are based on financial data reports that are easily found in the economical press. The trigger for a more accurate calculation of the added value factor \( d \) is usually a managements’ remark like “if we lose this place, we are in trouble” or “we do not have a business interruption insurance”. The proper information source is usually the accountant, and the research for a more accurate appreciation has to include also the quest for contingency planning and salvage plans necessary to define the proper value of the salvage factor \( Y \).
THE PROTECTION LEVEL D.

The protection level is the probability component of the fire risk evaluation. The worst-case scenario will only occur when the protection fails. So the higher the protection level is, the lower the probability of a worst-case fire will be.

Protecting the property.

The scenario for defining the risk for the building and its content is that of total destruction. The Protection level includes considers all elements that can reduce the probability of such total destruction: An adequate water supply to fight the fire (factor W), standard or "normal" fire protection measures (factor N), special provisions or special protection (factor S) and the fire resistance of the building elements (factor F).

The elements that increase the probability of fire damage will be calculated with "penalty" points. That is the case when the water supplies or standard protection features are deficient, which will result in values of factors W and N below 1, and in values for the Fire Risk which will increase: The numbers reflect the idea that those compartments which have not a basic protection are the worse risks.

On the other hand, special provisions for extra protection and for fireproofing are giving bonuses as they increase the level of protection for the building and its content. The factors S and F are normally higher than 1 and this reflects an improvement in the degree of protection.

Protecting the occupants.

The scenario for assessing the Risk R₁ for the occupants has been defined before as any beginning fire. As such, a fire can be extinguished with rather small amounts of water, the quality of the water supply is negligible for the safety of the people, and thus the Water supply factor W is not considered to calculate D₁.

The normal protection, fire alarm, manual fire fighting and fast fire intervention are certainly of importance for reducing the growth of the fire. Therefore, the value of N is used for calculating D₁.

The escape factor U replaces the special protection factor S and the fire resistance factor in the formula for the risk calculation for the occupants. The reason for this is that both special protection and fireproofing have influence on the safety of the people, but not in the same way as for the building and its occupants.

Protecting the activities.

The values of the water supply factor W, the normal protection factor N, and the special protection factor S are used for the protection level for the activities. As the scenario of the worst case is a fire that touches everything even without complete destruction, FRAME does not use the fire load density factor q for the potential risk calculation.

In the same way, the protection element that is most specifically aimed to cope with the fire load, i.e. fire resistance, is not considered when defining the protection level for the activities D₂.

Specific methods of reducing the consequential losses of a fire are considered to give bonuses for the salvage factor Y.
The formulas for the calculation of the Protection levels thus read as::

The Protection level $D$ for the building and its content is defined as the product of the water supply factor $W$, the normal protection factor $N$, the special protection factor $S$ and the fire resistance factor $F$.

$$D = W \times N \times S \times F$$

The Protection level $D_1$ for the occupants is defined as the product of the normal protection factor $N$ and the escape factor $U$.

$$D_1 = N \times U$$

The Protection level $D_2$ for the activities is defined as the product of the water supply factor $W$, the normal protection factor $N$, the special protection factor $S$ and the salvage factor $Y$.

$$D_2 = W \times N \times S \times Y$$

The three formulas have the same structure but differ as they follow different scenarios.

**The link with failure rates.**

The value obtained for $D$, $D_1$, $D_2$ give an indication of the failure rate of the protection concept, on a logarithmic scale. No system is fail-safe, but the more redundancy available, the better the chance that the system will perform as expected. The failure rate can be estimated to be $1/10^D$.

This can be illustrated as follows:

Take factor $N$, where the intervention time of the fire brigade is evaluated in sub factor $n_3$.

Suppose that all the sub factors $n$ of $N$ are $=0$, which means for the fire brigade that they will arrive on the scene of the fire within 10 minutes. The probability that the fire grows beyond control is then 10 % (which is supported by statistic evidence)

Sub factor $n_3 = 2$  brigade arrives within 10-15 min, the value of $N$ becomes 0.9 and $1/D$ increases with 1.11 (which means that the failure probability increase with $10^{1.11} \% = 13 \%$

Sub factor $n_3 = 5$  brigade arrives within 15-30 min, the value of $N$ becomes 0.77 and $1/D$ increases with 1.30 (which means that the failure probability increase with $10^{1.30} \% = 20 \%$

Sub factor $n_3 = 2$  brigade arrives after 30 min, the value of $N$ becomes 0.6 and $1/D$ increases with 1.67 (which means that the failure probability increase with $10^{1.67} \% = 47 \%$

In common words: When the fire brigade arrives within 10 minutes on the fire scene, there is a 10 % chance that the fire grows still beyond control. But, all other factors remaining equal, when the intervention time lays between 10-15 minutes, the probability of a total loss increases by a 13 %. And when the intervention time lies between 15-30 minutes, this probability increase by 20 %, and when the intervention time lays above 30 minutes, there is a 47 % increase of the total loss probability.

A protection level of $D=2.0$ means that there is about 1 chance for 100 that a fire will develop out of control. This value is obtained when the protection system is composed e.g. of a manual alarm system, an intervention within 10 minutes by a professional fire brigade, an adequate water supply and a fire rating of the building elements of 60 minutes.
When there is more protection, e.g. when automatic addressable fire detection is installed, the value of $S$ increases from 1.48 to 2.65, the improvement of $D$ is 1.79, or $1/D = 0.558$. By the same calculation, the failure probability decreases with $10^{-0.558} \% = 47 \%$.

The combination of single supply sprinkler system with a volunteer fire team would give an $S$-value $= 1.89$ which means a failure rate of 1.3 %.

A total lack of water for fire fighting will give a $W$-value of 0.32, which gives a failure rate 47.8 %, which means that if there is no water available, there is about 1 chance in 2 that the fire cannot be controlled.

**THE WATER SUPPLY FACTOR $W$.**

In order to fight a fire one will need a water supply that is continuously available for fire fighting, and has enough water in it to cope with the fire.

- Water for fire fighting.

Water is the general available and most commonly used extinguishing agent. The capability of water to extinguish a fire is unique:
- It is chemically "inert" as it is already oxidised.
- It has a high heat absorption capacity due to its specific heat, low boiling point, but high boiling heat.
- It is easy to store and to transport, as it is a liquid.
- It is a good conductor of heat and a good wetting agent, which increases its cooling effect.
- It is generally available and cheap.

In “FRAME”, the existing water supplies are evaluated for their use as fire fighting resource in the water supply factor $W$ and the special protection factor $S$.

The old Gretener method has no provisions for water supplies, probably because good water supplies are available in a country like Switzerland with its mountains and lakes. In a flat country like Belgium, having adequate supplies for fighting is not evident. Public water supplies are designed for drinking water distribution, with smaller piping and lower pressure from water towers and pumping systems. FRAME evaluates the capacity of these systems by the water supply factor $S$.

To define the value of $W$, the water quantity available is compared with the total fire load density and the distribution system is checked for its ability to convey the required quantity of water to the fire scene in a 2 hr period. In the special protection factor $S$, bonus points are awarded for superior water supplies.

- Guidelines for water supplies.

To check the validity of the FRAME approach, a review was made of the available information on the Internet.

Before all, it was found that there are no internationally accepted rules for defining the water supplies required for adequate fire fighting. The main differences are due to the local fire fighting tactics and the available equipment and to the legal obligations imposed on the local governments, the water supply companies and the owners of buildings.

The following documents have been consulted to check the validity of the FRAME approach:
Comparing the requirements formulated in these various documents, they converge toward a 60 m³/h flow to suppress a 25 MW fire. This corresponds with a 100 m² fire with a 250 kW/m² heat release typical for office occupancies.

For occupancies where more severe fires can be expected the flows are increased and an additional flow is required to protect adjacent fire cells or building from exposure and the storage volume is linked to an estimated duration between 30 minutes and 3 hours.

FRAME uses a basic relationship between the fire load density and the required quantity of water for fire fighting, i.e. the quantity in m³ is 1/4\textsuperscript{th} of the fire load density in MJ/m². This approach is based on a 260 m² maximum fire area and 40 % efficiency for the heat absorption by the extinguishing water. The maximum controllable size of a fire is assumed to be 260 m², which is approx. the design area for wet sprinkler systems in the EN12845 standard for OH and storage risks. Based on the heat absorption capacity of water, the flows required by the rules can be attributed to the extinguishment of smaller fires, more in the 100 to 150 m² bracket.

The rules add an additional flow for exposure protection, linked to the size of the compartment, which FRAME does not. It would be possible in FRAME too, by using the length and width of the compartment in addition to the fire load density. This can give only minor differences in the final property risk assessment, as the weight of the water storage capacity in the calculation varies between 1 and 0.81.

The rules define flows and automatically link them to requirements for the distribution network. In FRAME, the distribution network is evaluated for its capacity to convey the required quantity of water on the fire scene in less than 2 hours, which is comparable with the duration requirements in most of the mentioned rules. The weight of the distribution system is 1 (adequate), 0.9 (limited) and 0.74 (none). The last value is used when a large volume storage is considered, but without network to convey it, e.g. the Dutch tertiary water supplies.

The rules are less explicit in their pressure requirements. Partially this is because the fire brigade overcomes most pressure problems with their pumper, but also because the water companies prefer not to guarantee a minimum pressure on their network.
In FRAME, the available static pressure is compared with the height of the building to evaluate its effectiveness for fire fighting.

The rules also specify that the nearest hydrant must be at a short distance from the building, and give specifications for the type and number of hydrants to be installed. In FRAME, the availability of hydrants is judged in comparison with the perimeter of the compartment: the larger the compartment, the more hydrants are needed, as indicated in the rules.

Summary.

The water supply factor $W$ of FRAME considers basically the same aspects of the water provisions as most official rules and guidelines. The basic difference between FRAME and most of the mentioned methods is that the FRAME estimate is based on a larger fire area. This compensates in a way the lack of a flow requirement for exposure protection, linked to the compartment area. FRAME does not lower the water supply requirements when the fire safety features are improved as in the above mentioned methods, which is a conservative approach, and justified because these safety features are evaluated separately.

The water supply factor formula.

The water must be transported (through a piping system) to the place of the fire, it must be accessible to the fire brigade through hydrants, and it must be under pressure to reach the seat of the fire.

Water supplies do not always comply with these criteria, and in reality fire fighting operations were sometimes hampered by a lack of water, resulting in a larger loss. This is the reason why there is a water supply factor with the following formula:

$$ W = 0.95^w \quad \text{and:} \quad w = \sum w_i $$

For every weakness in the water supply system, FRAME will count a number of "penalty points": $w_i$, reflecting the difference in quality between the actual water supply and an adequate one.

- The type of water storage.

Water storage can be broadly divided into to two categories: "automatically" and "manually" filled storage.

Automatically filled storage is rivers, canals, lakes that are filled by rain throughout the year and large potable water distribution systems with automatic pumps and controls. Their use is not reserved for fire fighting only, but can be e.g. the city potable water supply.

Manually filled storages are e.g. rainwater ponds and water towers that require a human supervision and intervention to operate pumps, valves, etc. Their use could be fire fighting, but it could also be to supply water for a process or a boiler system.

The first element of the water supply factor is the type of water storage: An automatic filled water storage, but for mixed use, is considered as standard. Manually filled water storage and the lack of water storage will receive "penalty points".
Type of storage

A. Water storage for mixed use, automatically filled
B. Water storage for mixed use, manually filled
C. No water storage available

Note: when there is no water storage available the maximum value for \( w = 10 \). The “penalty” points for lack of capacity, pressure and the distribution network are not added to this score.

- The capacity of the water storage.

Large quantities of water are required to extinguish a fire. A sprinkler system for an ordinary hazard occupancy needs (per NFPA 13) a minimum flow of 700 gpm for 60 minutes or 42000 gallons (160 m³) of water. European standards ask for similar quantities. This is equal to the average daily water use of 200 families. Higher hazard classes will require water flows that are three to four times higher. Such water demands are not necessarily met by distribution systems that are designed for supplying potable water to the population and the water storage may have a limited capacity.

The required quantity of water is linked to the fire load that is present in the compartment. FRAME uses the following equation for the required quantity for extinguishing the fire: \( 0.25 \text{ m}^3 \text{ of water per MJ/m}^2 \text{ of fire load density} \).

On the whole, a water storage of a certain volume is needed for fire extinguishment and the required quantity is linked to the fire load of the building and its content. If less water is stored, then one must consider the water storage capacity as insufficient and this will be the second type of "penalty points" in the calculation of the water supply factor.

<table>
<thead>
<tr>
<th>Capacity of water storage</th>
<th>( w_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adequate capacity</td>
<td>0</td>
</tr>
<tr>
<td>Lacking up to 10 %</td>
<td>1</td>
</tr>
<tr>
<td>Lacking 10 to 20 %</td>
<td>2</td>
</tr>
<tr>
<td>Lacking 20 to 30 %</td>
<td>3</td>
</tr>
<tr>
<td>Lacking more than 30 %</td>
<td>4</td>
</tr>
</tbody>
</table>

In FRAME v.2, the user had to define himself the lacking capacity. In the FRAME v.3 calculation sheet, the estimated quantity of water available for fire fighting shall be entered and the penalty is calculated automatically by comparison with the fire load density.

- The water distribution system.

In countries like Switzerland with its lakes and mountains, it is not too difficult to build elevated water reservoirs to get a water supply with adequate capacity and pressure. In flat areas like Belgium, water towers and pumping systems are needed and the public water supply will be smaller and at a lower pressure.

The water distribution systems are usually designed for average water consumption, and peak consumption as for fire fighting will cause important pressure drops in the smaller piping systems. A large quantity of water is of no use if it has to come through a small piping system. Therefore, the size of the piping system is to be checked according to the required quantity of water.

An adequate distribution piping system is required, its size depending on the total water capacity required. The distribution system shall be capable to supply the required quantity of fire extinguishment water to the fire scene in 2 hours without considerable pressure losses.
The following table gives the flow capacity of piping systems, based on a maximum water velocity of 2 m/sec, which guarantees low friction losses over larger distances. Network (looped) systems are adequate for twice these flows.

<table>
<thead>
<tr>
<th>Distribution pipe size</th>
<th>Flow in m³/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>None or &lt; DN80</td>
<td>0</td>
</tr>
<tr>
<td>DN 80 (3&quot;)</td>
<td>34.3</td>
</tr>
<tr>
<td>DN100 (4&quot;)</td>
<td>59.2</td>
</tr>
<tr>
<td>DN150 (6&quot;)</td>
<td>134.3</td>
</tr>
<tr>
<td>DN200 (8&quot;)</td>
<td>232.3</td>
</tr>
<tr>
<td>DN250 (10&quot;)</td>
<td>366.8</td>
</tr>
<tr>
<td>DN300 (12&quot;)</td>
<td>526.1</td>
</tr>
<tr>
<td>DN350 (14&quot;)</td>
<td>676.9</td>
</tr>
</tbody>
</table>

FRAME compares the required water quantity for extinguishment with the available flow capacity and attributes "penalty points" for a piping system that is too small.

Rivers and lakes can be used as water reservoirs, but then the fire brigade still needs pumpers and hoses to bring the water from the river to the place of the fire. Such natural water storages must be considered as water supplies without a distribution system, unless they are used as water storage for a dedicated firewater loop with adequate pumping capacity installed.

<table>
<thead>
<tr>
<th>Distribution network</th>
<th>w_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Distribution network adequate</td>
<td>0</td>
</tr>
<tr>
<td>J. Piping too small for the required flow</td>
<td>2</td>
</tr>
<tr>
<td>K. No distribution network</td>
<td>6</td>
</tr>
</tbody>
</table>

- The hydrant connections.

It is not sufficient to have a water distribution network; there must also be an adequate number of hydrants to allow the fire brigade to use quickly the water supply. As the fire brigade usually attacks the fire from all possible sides, they will need connection points around the whole compartment.

A good distribution exists when there is about one 70 mm (2.5") hose connection per 50 m of perimeter: one 70 mm connection can supply two 45 mm (1.5") hose lines, so that the whole perimeter can directly be reached with hose lines. An 80 mm (3") connection can be considered as equal to two 70 mm connections, and a 110 mm (4") connection is equal to three 70 mm connections.

FRAME compares the perimeter (twice the theoretical length plus the equivalent width) with the number of hose connections to check the suitability of the hydrant system, and gives penalty points when less than one connection per 50 m are available.

<table>
<thead>
<tr>
<th>Hydrants</th>
<th>w_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>L. One 70 mm (2,5&quot;) hose connection per 50 m perimeter</td>
<td>0</td>
</tr>
<tr>
<td>M. One connection per 50 to 100 m perimeter</td>
<td>1</td>
</tr>
<tr>
<td>N. Less than one connection per 100 m perimeter</td>
<td>3</td>
</tr>
</tbody>
</table>

- The pressure of the system.

The last element of the water supply is the pressure of the water distribution system. Can the fire brigade reach the top of the building with the pressure on the system or do they need pumpers to increase the pressure? In metric units, this is easy to check: 1 bar of static
pressure equals to 10 m water column pressure and some residual pressure is required at the nozzle. The top of the building can be reached by hose streams, without additional pumps, when a static pressure of 35 m water column (or 3.5 bar) above the height of the building is available. When there is less pressure on the system, FRAME counts with "penalty points".

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Wₜ</th>
</tr>
</thead>
<tbody>
<tr>
<td>P. Static pressure is height + 35 m</td>
<td>0</td>
</tr>
<tr>
<td>Q. Less static pressure</td>
<td>3</td>
</tr>
</tbody>
</table>

**THE NORMAL PROTECTION FACTOR N.**

Under the "normal" or standard protection, FRAME will consider the following elements, which are generally available, or can be installed at a limited cost:
- A "notification chain" that conveys the message of the discovery of a fire to the fire brigade and the users of the compartment.
- An adequate number of extinguishers and small hose stations.
- A basic training for all occupants of the building how to use an extinguisher.
- A public fire brigade intervention within 10 minutes after notification.

In the same way as for the water supply factor, "penalty points" will be given for those compartments where a below standard normal protection exists, and the normal protection factor N is calculated by the formulas:

\[ N = 0.95^n \text{ and: } n = \sum n_i \]

- Discovery and warning.

A "chain of notification" will be needed that guarantees the rapid discovery of a fire and the warning of all concerned: This implies some human presence to detect a fire, a manually operated alert system, and messages to notify the fire brigade and to give an alarm to the occupants. Any flaw in this organisation will collect penalty points for the normal protection. A correct chain of "discovery and warning" consists of

a) A “guard service”, e.g. continuous human presence in the building and/or a watchman service.

b) A “notification system” to signal the existence of a fire to the fire service: this can be a telephone network with a “fire call” number, or a manual push button system linked to the guard post who will call the fire service, or linked to an automatic call system for the fire service, or any other organised way to contact the fire service.

c) Sometimes the notification remains local, e.g. when the guard has no instructions or means to call the fire service. This will be penalised.

d) An audible alarm signal to the occupants to evacuate the compartment. In noisy environments a visual signal may also be required.

There are many ways to organise a fire guard service. In many buildings, the human presence during working hours will be complemented by a guard, who will make regular rounds during idle hours. A building with an "around the clock" human presence can be considered as having an organised human presence.

Once a fire is detected, the guard service must have the means to call the fire brigade and to alert the occupants of the building. One way to do it is to have in the building a manual fire alarm system installed with push buttons connected to a central fire alarm in a guardhouse. It is then the duty of the guard to call the fire brigade and to alert the occupants and the persons
responsible for the evacuation. This can be done by telephone, or by a personal call system, or by bells or sirens.

It is also possible that the operator of the central station is replaced by an automatism to send the message to fire brigade and occupants, or that the alert can be given by telephone, provided that there are enough telephones in the building, and that there is a special number for the fire alert.

When the human presence is only guaranteed during daytime, it might be useful to make a separate calculation for day and night conditions, e.g. in factory that is shut down for the night or the weekend. The day time calculation can consider a compartment with a high activation factor a when the activities are going on, but also with guaranteed human presence, and for the night time calculation a compartment is taken which is more like a storage with a lower activation factor but no guarding.

<table>
<thead>
<tr>
<th>Discovery and warning</th>
<th>n₁</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. A guard service with organised human presence, manually operated alert system, notification to the fire brigade and alarm to the occupants.</td>
<td>0</td>
</tr>
<tr>
<td>B. without organised human presence</td>
<td>2</td>
</tr>
<tr>
<td>C. without manually operated alerting system</td>
<td>2</td>
</tr>
<tr>
<td>D. without guaranteed notification to the fire brigade</td>
<td>2</td>
</tr>
<tr>
<td>E. without alarm to the occupants</td>
<td>2</td>
</tr>
</tbody>
</table>

A building where there is no organised human presence, but which is equipped with automatic smoke detectors can have penalty points for the lack of human presence, but the automatic detectors shall be awarded bonus points in the calculation of the special protection.

- Extinguishers and hose stations.

The second part of the normal protection is the presence of an adequate number of portable extinguishers and small hose stations to permit a rapid intervention of the occupants on a starting fire. The type, number and distribution of these manual fire fighting means are governed by local codes and standards, which differ quite a bit from one country to another.

Local standards shall be used to define the number and type of hand extinguishers. Hose reels and hose stations should be located in such a way that any place in the building can be reached by at least one hose stream. Hose reels are adequate for buildings with a low fire load and untrained users. Hose stations are preferred where the fire load is high and where the people are trained.

Because of the limited capacity of portable extinguishers, the normal protection will require both extinguishers and hose stations. FRAME gives penalty points for inadequate numbers of extinguishers and hose stations.

<table>
<thead>
<tr>
<th>Manual fire fighting</th>
<th>n₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Extinguishers adequate</td>
<td>0</td>
</tr>
<tr>
<td>G. Inadequate number or lack of extinguishers</td>
<td>2</td>
</tr>
<tr>
<td>H. Hose stations adequate</td>
<td>0</td>
</tr>
<tr>
<td>I. Inadequate number of hose stations</td>
<td>2</td>
</tr>
<tr>
<td>K. No hose stations available</td>
<td>4</td>
</tr>
</tbody>
</table>

For smaller buildings, code and standards may accept that such a building is only equipped with either extinguishers or hose stations. In FRAME, the absence of one of these, shall always be penalised, but the impact of such absence is limited and the overall risk may well remain acceptable.
A minimum training of all occupants how to use the extinguishers and hose stations is indispensable if one wants to get use of these apparatus. As the use of extinguishers is not part of a standard education, the user of FRAME will often have to count some penalty points for the lack of such training.

- The intervention of the public fire brigade.

The main burden of the fire fighting will stay with the public fire brigade. In the beginning of a fire, it is not very important how many fire fighters can come to the place of the fire, if they are there very soon on the spot. Having the fire brigade on the fire scene in less than 10 minutes after notification is considered as the best achievable. Local circumstances can make that the fire brigade needs more time to get to the fire and in such cases add penalty points for the normal protection.

A safe estimate of the intervention time can be made with the distance to the nearest fire station and a travelling speed of 30 km/h (20 mph) for the fire brigade.

THE SPECIAL PROTECTION FACTOR S.

Under the "special" protection, FRAME will consider those elements which are not generally available, but which improve the capability and the reliability of the fire fighting system. These elements, which usually require an additional investment, are:

- Automatic fire detection, which reduces the time necessary to start fire fighting.
- Improved water supplies: either by having more water stored, by duplicating, by guaranteeing its availability.
- Automatic fire protection systems, in particular sprinkler systems.
- Well equipped fire brigades.

The special protection factor S is calculated by adding all the bonuses given for those elements that exist and using the number in an exponential formula. The exponential formula flattens out the effect of the bonuses as one can expect that a building will rarely need all the measures that are provided.

\[ S = 1.05^s \text{ and } s = \sum s_i \]
Automatic fire detection.

There are several types of automatic fire detection systems and the development of electronic data processing has improved their performances as well as their usefulness.

If automatic detection systems have been criticised in the past for some lack of reliability, it was mainly because they are active systems and in order to be effective they have to be sensitive to phenomenon's which are related to fire, but not only to fire.

Automatic fire detection systems have caused false alarms, by reacting to non-fire situations such as heavy smokers, by operating errors like keeping the system activated during welding operations, by component failures and a lack of maintenance. Newer systems have built-in supervision and are more user friendly and less prone to false alarms.

The weakest point of any automatic fire detection lies outside the system: will there be an answer? If there is no guaranteed connection to the fire brigade, then any detection system should be considered as useless: There must be a permanently staffed guard service or an automatic transmission to the fire brigade.

FRAME gives only bonus points for automatic fire detection systems linked to a fire brigade, either directly or indirectly through a central alarm station. The bonus will be higher when the system is faster and more reliable.

Sprinkler systems connected to a fire alarm by flow switches or similar devices will be considered as slow thermal detection systems. Smoke and flame detectors will be considered as fast detectors. Electronic supervision of the system and individual identification of a small fire zone (e.g. per detector) will give extra bonuses. In FRAME v.3 a small bonus is added for smoke alarm units which have become widespread and sometimes mandatory in housing.

<table>
<thead>
<tr>
<th>Automatic detection</th>
<th>$S_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>By sprinklers</td>
<td>4</td>
</tr>
<tr>
<td>By thermal (heat) detectors</td>
<td>5</td>
</tr>
<tr>
<td>By smoke or flame detectors</td>
<td>8</td>
</tr>
<tr>
<td>With electronic supervision of the system</td>
<td>2</td>
</tr>
<tr>
<td>With individual identification of small fire zones</td>
<td>2</td>
</tr>
<tr>
<td>Smoke alarm units</td>
<td>2</td>
</tr>
</tbody>
</table>

Improved water supplies.

It was already clear that the water supplies are of prime importance for fire fighting operations. Rivers, lakes and any other water storage that can guarantee 4 or more times the quantity of water needed (see before at the water supply factor), can be considered as inexhaustible and merit bonus points.

The water has to be conveyed to the fire scene by a flow/pressure source with a reliable energy source: a water tower, pump, elevated reservoir.

Water storages that are only used for fire protection and those that are under the control of the user of the building are more reliable when the user regularly checks them. The same can be said for water supplies that have double pump-and-driver sets, as it often practised for sprinkler systems. The top of water supply reliability is to have duplicated water storage and pumping sets.
F.R.A.M.E.

## Water supplies

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inexhaustible water supplies (4 times adequate)</td>
<td>3</td>
</tr>
<tr>
<td>For fire fighting only</td>
<td>2</td>
</tr>
<tr>
<td>Under control of building user (independent)</td>
<td>2</td>
</tr>
<tr>
<td>Highly reliable: One water storage with a double flow/pressure source</td>
<td>5</td>
</tr>
<tr>
<td>Duplicated highly reliable: two storages, each with a flow/pressure source</td>
<td>12</td>
</tr>
</tbody>
</table>

- Sprinkler systems and other automatic protection.

The most expensive but at the same time the most effective way of protecting a building is to have the automatic built-in fire brigade, called sprinklers.

A sprinkler system is designed for a preconceived type of fire risk. The weak point of sprinklers is the possible change of occupancy during the lifetime of the sprinkler system. Any sprinkler system that is not adapted for the occupancy below is condemned to be a slow thermal detection system, not a fire extinguishing system.

Otherwise, as long as the system meets the requirements of the occupancy, it will get bonus points and these will be even more when the reliability of the sprinklers is improved by connecting it to reliable or duplicated water supplies.

Sometimes whole compartments are protected by other automatic fire protection systems based on the use of foam or CO₂ for special hazards. These systems are quite expensive and generally designed for a single operation. As such, they can justify a bonus for special protection.

## Automatic protection

<table>
<thead>
<tr>
<th>Protection</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinklers with one (public) water supply</td>
<td>11</td>
</tr>
<tr>
<td>Sprinklers with one independent water supply</td>
<td>14</td>
</tr>
<tr>
<td>Sprinklers with two independent water supplies</td>
<td>20</td>
</tr>
<tr>
<td>Other automatic extinguishing systems (CO₂, foam)</td>
<td>11</td>
</tr>
</tbody>
</table>

- The responding fire station.

The oldest and still irreplaceable part of the fire fighting operations is the fire brigade. Large industrial plants have their own fire brigades inside the plant area with their own equipment. They can be organised on a permanent around the clock basis, or on a temporary basis, i.e. only fully staffed during working hours.

The same is possible with the public fire brigades. Some stations are permanently staffed, others call in part-time fire fighters. In rural areas, it is possible that the police will be the fireguard and that the fire brigade is only staffed by volunteers. In most countries, the fire services operate now from more than one fire station: the nearest fire station will respond first to an emergency call, and more stations will respond when needed.

Fire fighters receive the same training whether they are full-time, part-time or volunteers and most brigades are equipped with the same types of trucks and equipment.

This means that the Gretener and FRAME v.2 appreciation of the type of fire brigade is no longer valid. It has been replaced in FRAME 2008 by an appreciation of the type of the first responding fire station and an evaluation for industrial fire brigades.
Responding Fire station:

1. Full time station 24h/24  7d/7
2. Variable professional crewed station (day time crewed, night time retained)
3. Retained station (part time professionals)
4. Volunteer station

1. Part time industrial fire brigade (working hours)
2. Full time industrial fire brigade 24h/24

The Fire Resistance Factor F.

The fire resistance factor $F$ reflects the capability of a building to resist the negative effects of a fire. The early collapse of a building during a fire has been quite often the main reason for a catastrophe. Fire fighting inside a building without adequate fire resistance is almost impossible, and some fire fighters that tried it, have paid their action with their lives.

- The average fire resistance.

The value of the fire resistance factor is defined by the fire resistance of the main components of the building: the structure, the outside walls, the roof or ceiling, and the inner walls. FRAME checks the fire resistance of each component, balances their importance and calculates an "average" fire resistance rating. The ratings of the elements will be expressed in minutes as defined by tests based on ISO R 834, and used in the formula:

$$f = \frac{1}{2} f_s + \frac{1}{4} f_f + \frac{1}{8} f_d + \frac{1}{8} f_w$$

- $f_s$ is the average fire resistance (REI) of the structural and separating elements.
- $f_f$ is the average fire resistance of the outside walls (E = flame tightness)
- $f_d$ is the average fire resistance of the ceiling or the roof (RE)
- $f_w$ is the average fire resistance of interior walls (EI)

To avoid unrealistic high values for the fire resistance factor, no fire ratings higher than 120 minutes will be used in the formulas, although structural elements with higher fire ratings can be required to divide the building into compartments as was explained for the area factor $g$.

The main argument to limit the ratings in the formula to 120 minutes is that, when explaining the calculation of the fire load factor, the estimates of the fire load are based on a two hour operation of a (theoretical) sprinkler system.

A second argument is that fire resistance is a passive protection and its contribution to the fire protection system should not be overestimated.

The formula for calculating the fire resistance factor $F$ is:

$$F = \left[ 1 + \frac{f}{100} - \left( \frac{f^{2.5}}{10^6} \right) \right] \times \left[ 1 - \left( \frac{S - 1}{40} \right) \right]$$

Factor $F$ is calculated with the "average fire rating" $f$ but with a correction for the special protection factor $S$. This can be justified as follows:

Fire proofing is basically a passive protection and is particularly useful to allow the fire brigade to work without the danger of a collapsing building. As the intervention will be faster and as more means are available to fight a fire, it will be less necessary to reckon on fire proofing.
This correction also indicates that it is unwise to rely only on "active systems" for very large buildings or for compartments with a very high fire load: The experience from the past has taught us that in these cases a minimum of fire proofing is required. A compartment without any fire proofing, relying only on special protection would have a fire resistance factor below 1, which means in fact an inadequate fire resistance.

- **The structural fire resistance.**

The most important part is the structure of the building i.e. columns, beams, and load bearing walls. The criterion to define the value of $f_s$ is: when will the structure collapse under the effect of a "normalised" fire?

The fire rating can be defined by calculation or by an estimate based on the tables that are found in building codes and standards like the Eurocodes.

Unprotected steel structures will have a rating of not more than R15, masonry and concrete structures will have R60 up to R120 fire resistance. Wood structures will have values from 0 to R60 according to type of construction, and the type of fire proof treatment that was applied to the beams and columns.

- **The other parts of the construction.**

It is not allowed to use higher values for the fire rating of the outside walls, the roof or ceiling and the inner walls than that of the structure: It is only logical that if the building would collapse under the effect of the fire, the roof and walls would not give any protection, whatever fire rating they have.

This is particularly true for some types of industrial buildings where prefabricated light concrete slabs are used for the roof and the facades, fixed to a steel structure. The concrete elements may have a fire rating of 60 minutes or more; the structure will have at the best R15, unless extra protection is provided.

The combined rating for the fire resistance will be usually lower that of the structure alone, as non-structural elements have often lower fire ratings. This approach makes the distinction between large buildings with or without internal separations, e.g. warehouses compared with hotels. In those buildings without internal separations, the inner walls shall be rated at zero, what results in a lower average fire rating.

- **Outside walls, roofs and ceilings.**

The second part of the average fire rating is the rating of the outside walls. The fire resistance of the outside walls (of the compartment) helps the fire fighting in two ways: it reduces the possibility to spread the fire to adjacent buildings and to other compartments, and it protects the fire fighters for the radiation heat of the fire. The structural and non-structural elements of the walls must be considered, and the weakest element will define the rating.

A special aspect of the facades are the windows: less than 5 % windows can be neglected in otherwise fire resistant facades (e.g. brickwork), but for offices and residential buildings, zero fire rating for glass is the rule, unless special glass is used.

The third part of the fire rating is the roof or ceiling rating. Consider the bearing elements, the covering and the insulation, and the weakest element from below will define the overall rating. Roofs and ceilings with combustible insulation on the lower side should always have zero ratings.
F.R.A.M.E.

As already mentioned above, some consideration can be given for a sprinkler system protecting a non-combustible roof covering on non-fireproofed beams and girders.

A limited quantity of openings (maximum 5 %) can be accepted in a roof when they will improve smoke and heat evacuation.

- Inside partitions.

The last element for the average rating will be the rating of inside partitions. To be taken into account, these partitions should divide the compartment in fire areas, none of them should be more than 25 % of the compartment, and no area should be larger than 1000 m². Compartments that are not divided in fire areas of less than 1000 m² should have a zero rating for the inner walls. The most common situations where a rating for inner walls is justified are non-industrial buildings such as offices and housing.

THE ESCAPE FACTOR U.

The escape factor U indicates in which way the escape from the fire is secured by special measures. These can broadly be divided into two types: those that speed up the evacuation, and those that slow down the development of the fire.

The group of measures that speed up the evacuation includes automatic fire detection, protected evacuation paths, and evacuation planning.

The group of measures that slow down the fire includes smoke venting, automatic protection, and fire fighting.

The fire escape factor U is calculated in the same way as the special protection factor by adding all the bonuses given for those elements that exist and using the number in an exponential formula:

\[ U = 1.05^u \text{ and } u = \sum u_i \]

- Automatic fire detection and alarm.

Automatic fire detection is only considered when there is a guaranteed connection to the fire brigade. The bonuses given for automatic detection are the same as for the special protection, which is logical as the benefit of early detection works in both cases in the same way.

Bonuses are given for fire detection and alarm systems that a specifically aimed at the occupants’ safety:
- Partial detection system, only in areas critical for people safety
- Evacuation alarm with spoken messages by voice communication system (added in FRAME v.3)

There is an additional bonus when the number of persons that will respond to the signal is less than 300. This is the number of persons that can be evacuated through one door in 5 minutes, corresponding with a building evacuated before the arrival of the fire brigade.
F.R.A.M.E.

Automatic detection and alarm

- By sprinklers
- By thermal (heat) detectors
- By smoke or flame detectors
- By smoke alarm units
- With electronic supervision of the system
- With individual identification of small fire zones
- Partial detection in areas of high risk
- Not more than 300 persons to be warned
- Evacuation alarm with spoken messages by voice communication system

Exit path marking.

One of the most effective measures to speed up the evacuation, is a clear signalisation: Take away any doubt in the minds of the people of how they should get out of the building: a clear and complete evacuation plan, adequate signalling through pictograms and emergency lighting will give an extra bonus of 4 points.

Vertical evacuation paths.

For multiple storey buildings, evacuation stairways are an essential part of the evacuation path. They should have straight runs and be adequately designed for the exits they serve. Some types of stairway construction give already some protection on the way to ground level: outside stairways, enclosed and smoke protected internal stairways, and enclosed stairways.

- Outside stairways give the best protection as far as they are constructed with the weather conditions in mind.
- Internal enclosed and smoke protected stairways are separated from all the compartments by firewalls and fire doors, have provisions for emergency lighting and are protected against smoke intrusion. This can be either by a smoke vent at the top of the staircase, by a sash at each entrance, or by a pressurisation system.
- When the stairways are only separated from the compartments by firewalls but lack the provisions for smoke intrusion, they are classified as enclosed stairways.

For the first and second level above ground level in smaller buildings used for housing children, the use of toboggans to the ground floor can be accepted as an alternative for stairways.

FRAME gives a table with various combination of vertical exit paths, each of them gives a related bonus for escape protection.

<table>
<thead>
<tr>
<th>No stairs used for exit</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Open inside stairs</td>
<td>0</td>
</tr>
<tr>
<td>2. Single enclosed inside stair</td>
<td>1</td>
</tr>
<tr>
<td>3. More than one enclosed inside stair</td>
<td>2</td>
</tr>
<tr>
<td>4. At least one enclosed and smoke protected inside stair</td>
<td>3</td>
</tr>
<tr>
<td>5. More than one enclosed and smoke protected inside stair</td>
<td>4</td>
</tr>
<tr>
<td>6. Inside stair(s) and 1 outside stair</td>
<td>6</td>
</tr>
<tr>
<td>7. Inside stair(s) and more than 1 outside stair</td>
<td>8</td>
</tr>
<tr>
<td>8. Inside stair and outside toboggan or ladders for 1st / 2nd floor</td>
<td>2</td>
</tr>
</tbody>
</table>

Compartmentation.

In hospitals and similar buildings with people who need help to evacuate, it is not a good idea to try to evacuate everybody through the stairs. Such buildings can be constructed in a way that there are always two compartments on each level, which communicate through openings.
protected by fire doors. It becomes then possible to evacuate people "horizontally", i.e. to a protected area at the same level. When this horizontal egress capacity is available for at least half of the occupants, a bonus will be provided.

Compartmentation reduces the number of people that will have to be evacuated and puts barriers in the way of the fire. Some buildings are divided in smaller fire zones by the inside walls, because of the use of the building or even by code requirements, as can be the case for hotels, schools or hospitals. When the compartment is divided in fire zones of less than 1000 m² a bonus is given for inside walls with fire ratings of 2 points for EI30 separation and of 4 points for EI60 separations.

- Smoke venting.

The main threat to the occupants comes from the smoke, less from heat. It is the smoke that kills people. Smoke contains also large quantities of small particles, and the visibility is rapidly reduced in a room with smoke. It is a proven advantage for the evacuation to have the smoke removed as quick and as much as possible. Smoke venting will also reduce the quantity of unburned gases above the fire and thereby the risk of flashover is diminished. For the safety of the people, smoke venting is a positive measure.

When this is done with a smoke venting system actuated by automatic detection, a bonus of 3 points is awarded.

- Automatic fire protection and fire fighting.

It's also evident that the best way to reduce the threat of a fire is to extinguish it, and thus that sprinklers make a valuable contribution to human safety. Sometimes, the fire hazard is concentrated in a small area in a compartment, e.g. the kitchen in a restaurant. In such cases, it is useful to install localised automatic fire protection or to provide a partial sprinkler protection in this area alone, which will reduce the probability that a fire there will grow beyond the area of origin. Bonuses are given for partial automatic protection and for sprinklers.

<table>
<thead>
<tr>
<th>Automatic protection</th>
<th>U₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinklers only in areas with increased fire risk</td>
<td>5</td>
</tr>
<tr>
<td>Sprinklers full protection</td>
<td>10</td>
</tr>
<tr>
<td>Other automatic extinguishing systems</td>
<td>4</td>
</tr>
</tbody>
</table>

The last element in the escape factor calculation is the status of the responding fire station.

<table>
<thead>
<tr>
<th>Responding fire station</th>
<th>U₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Full time station 24h/24 7d/7</td>
<td>8</td>
</tr>
<tr>
<td>2. Professional crewed station (day time crewed, night time retained) Private fire brigade</td>
<td>6</td>
</tr>
<tr>
<td>3. Retained station (part time professionals)</td>
<td>4</td>
</tr>
<tr>
<td>4. Volunteer crewed station</td>
<td>2</td>
</tr>
<tr>
<td>5. Industrial fire brigade (part-time or full-time)</td>
<td>4</td>
</tr>
</tbody>
</table>

**THE SALVAGE FACTOR Y.**

The salvage factor Y reckons with those elements that can reduce the growth of a fire in critical areas and those that can limit the consequences of the fire. The calculation is made in a similar way as for the special protection factor S and the escape factor U by adding bonus
points for all existing protection elements and transforming them into the value of the salvage factor by an exponential formula:

\[ Y = 1.05^y \text{ and } y = \sum y_i \]

The elements that are generally effective to reduce the consequential losses of a fire are the protection of vulnerable areas, disaster planning and splitting up the activities over different locations.

- Protecting vulnerable areas.

One way to reduce the consequential losses of a fire is to protect the vulnerable areas more than the rest of the building. Compartmentation is one of these techniques, as it is possible to install locally automatic detection, sprinklers or any other automatic protection in critical areas. A typical example for this was the use of inert gas systems to protect computer rooms.

Bonus points for separating critical areas or for local protection are only given when there is no overall protection of the same kind. However, it is possible that, in a totally sprinklered building, there is an additional automatic detection in some areas, as it is possible to have sprinklers installed in a part of a building. Whether these systems contribute to the protection of the activities depends from what is happening in that area, and the bonus should be added only if the area houses a critical part of the activity.

<table>
<thead>
<tr>
<th>Physical protection</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub compartmentisation in fire areas of max.1000 m² EI30</td>
<td>2</td>
</tr>
<tr>
<td>Sub compartmentisation in fire areas of max.1000 m² EI60</td>
<td>4</td>
</tr>
<tr>
<td>Partial automatic detection in critical areas</td>
<td>3</td>
</tr>
<tr>
<td>Partially sprinklers (in critical areas)</td>
<td>5</td>
</tr>
<tr>
<td>Other automatic extinguishing system in critical areas</td>
<td>4</td>
</tr>
</tbody>
</table>

- Disaster planning.

One of the best ways to cope with the aftermath of a fire is to be prepared. Starting up a business after a fire is very much a question of knowing what to do:

- Will the economic and financial data such as computer programs, models and patterns, client and suppliers lists, available after the fire, because they are duplicated and stored in a safe location?
- Has the factory or administration easy access to spare parts or replacement machinery, so that repairs can be made in a short time?
- Has the organisation the possibility to make the repairs by themselves with only minimal help from suppliers or machinery manufacturers?
- Are there agreements made with others that provide space, capacity or any other means to relocate the activities elsewhere on a temporary basis?
- Can the loss of production capacity be compensated at other production centres, e.g. by additional shift work in an other location?

These organisational measures are rewarded with bonus points in factor \( Y \).

<table>
<thead>
<tr>
<th>Organisation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Safeguarded financial and economical data</td>
<td>2</td>
</tr>
<tr>
<td>Easy access to spare parts and replacements</td>
<td>4</td>
</tr>
<tr>
<td>Repairs possible with minimal help</td>
<td>2</td>
</tr>
<tr>
<td>Relocation agreements</td>
<td>3</td>
</tr>
<tr>
<td>Multiple production capacity</td>
<td>3</td>
</tr>
</tbody>
</table>
THE ORIENTATION POINT Ro

Once the Potential Risks and the Acceptable Risk Levels are calculated, there is a wide choice possible of fire protection systems: manual protection, automatic detection, sprinklers, special local protection systems, private fire brigades, etc.

In the search for a good overall solution for the fire protection, “FRAME” offers the possibility to make a preliminary choice based on the orientation point Ro, the Initial Risk.

The Initial Risk indicates which level of protection can be already be obtained from the built-in safety measures, such as compartmentation, risk separation, smoke venting, and fire proofing. Most of these elements are already considered when calculating P, the Potential Risk and A, the Acceptable Risk Level for the building. Only one more value has to be calculated: Fo, the structural fire resistance factor, by the formula:

\[ F_o = 1 + \frac{f_s}{100} - \frac{f_s^{2.5}}{10^6} \]

This formula uses \( f_s \), the fire resistance of the structural elements, i.e. columns, beams, and load bearing walls, expressed in minutes as defined by tests based on ISO R 834.

Remark: use as a guideline:
- Unprotected steel structures: R15
- Masonry and concrete structures: R60
- With extra fire proofing: R90 - R120
- Light timber structure: 0
- Heavy timber construction on masonry walls: R60 - R90

Selecting the recommended fire protection

The value of the Initial Risk Ro is then:

\[ R_o = \frac{P}{(A*F_o)} \]

Comparing this value with the following scale will give a good guideline to choose an adequate fire protection system:

According to the value that has been obtained for Ro, the following choices are worth trying:

1) The value of Ro is below 1.0:
Go for a fire protection system with manual fire fighting means, such as extinguishers and hose stations, backed up by an intervention of the public fire brigade, providing that the water supply is adequate. It might be necessary to add protection for the occupants or for the activities.
2) The value of $R_o$ is between 1.0 and 1.6:  
Go for a general automatic fire detection system to obtain an early warning and a quick response from the fire brigade. Adequate water supplies are necessary and some additional protection can still be required to safeguard the human lives and the activities.

3) The value of $R_o$ is between 1.6 and 4.5:  
Go for sprinkler protection. If $R_o$ is also higher than 2.7, then it will be even necessary to improve the reliability of the water supplies. In most cases there will be no requirements for additional protection for the occupants, but it might be necessary to have more protection for the activities.

4) The value of $R_o$ is above 4.5: reduce the risk by preventive measures.

- How to reduce the risk

Looking at the values of the individual factors of $P$ and $A$ will give an indication how to proceed.

A typical situation in industry is the presence in one compartment of machinery and storage. Building a firewall between the production facility and the storage is a logical and often applied risk reduction measure:

- On one side of the wall there will be the storage area with a high fire load, but a low quantity of ignition sources.
- On the other side one will find the production area with a lower fire load but a higher number of fire sources.

The FRAME principle of one calculation per compartment requires then to make two calculations, one for the production compartment, and one for the storage compartment.

In the production area, the Potential Risk will be lower as the fire load factor $q$ and the area factor $g$ will be smaller, but the Acceptance Level $A$ will be normally the same. The Initial Risk for the production area will be lower.

In the storage area the Potential Risk will be lower as the area factor $g$ is smaller, but often the fire spread factor $i$ is also reduced, as the average dimension of stored goods is generally larger than that of goods in production. The Acceptable Risk Level $A$ will be higher as there are only a limited number of fire sources in storage areas. Therefore, the Initial Risk will also be lower for the storage areas.

Compartmentation is one of the most economic risk reduction measures, and its influence is calculated through a reduction of the area factor $g$. Compartmentation can also reduce the total monetary loss caused by a fire, what you will find back in a lower value for the content factor $c$.

Other risk reducing measures, which will influence the Potential Risk, are smoke venting and access improvement.

Values of 1.1 or more for the venting factor $v$ indicate that the smoke will hamper the fire fighting operations. Adding smoke venting systems with an aerodynamic venting area of 1 to 2 % of the floor area will reduce the value of $v$ by 10 to 20 %, and thus also the Potential Risk.

When the access factor $z$ is higher than 1, especially for large single storey buildings, it is recommended to have a road around the building to give the fire brigade a better access to the building. The existence of such an access road is reflected in the value of $Z$, the number of access directions.
Risk reduction measures to improve the Acceptable Risk Level are separation of fire sources and improving the evacuation method. Compartmentation improves the evacuation as it shortens the evacuation path, but it is also possible to add exits (increases factor x), to install emergency lighting to reduce the risk of panic, and to provide a clearly conceived evacuation scheme. This will reduce the evacuation time and factor t.

Locating hazardous activities such as heating, painting, welding or woodwork in a separate room with a fire door is just common sense and is reflected in the FRAME calculation by lower values for the activation factor a.

In residential and other buildings with a low fire load, it is possible to improve the risk by avoiding combustible materials for the construction and decoration. In the method this results in lower values for M, the flame propagation class. This will reduce the Potential Risk by reducing the value of the fire spread factor i, and increase the Acceptable Risk Level \( A_1 \) as the value of the environment factor \( r \) will be lower.
SYMBOLS LIST.

A Acceptable Risk Level for the property (building and content)
   A₁: for the occupants  A₂: for the activities
B Business share
D Protection level for the property (building and content)
   D₁: for the occupants  D₂: for the activities
E Level number
F Fire resistance factor
F₀ Structural fire resistance factor
H Vertical distance to access level (H⁺ above ground, H⁻ below ground)
K Number of exit directions
M Flame propagation class
N Normal protection factor
O number of exits to open air
P Potential Risk for the property (building and content)
   P₁: for the occupants  P₂: for the activities
Qᵢ, Qᵦ Mobile Fire Load
R Fire Risk for the property (building and content)
   R₁: for the occupants  R₂: for the activities
R₀ Initial Risk
S Special protection factor
T destruction temperature
U Escape factor
V Monetary value of the building and its content
W Water supply factor
X Number of persons to evacuate
Y Salvage factor
Z number of access directions
a activation factor
b equivalent width
c value factor (sub factors c₁ and c₂)
d dependency factor
e level factor
f average fire resistance
   fₛ : structural fire resistance  fₘ : fire resistance of outside walls
   f₃ : fire resistance of roof or ceiling  fᵢ : fire resistance of inner walls
g area factor
h ceiling height
i spread factor
k venting ratio
l theoretical length
m average dimension of the content
n number of penalty points for normal protection
p mobility factor
q fire load factor
r environmental factor
s number of bonus points for special protection
t evacuation time factor
u number of bonus points for egress protection
v venting factor
w number of penalty points for water supplies
x number of exit units
y number of bonus points for salvage measures
z access factor

97
SIMILAR METHODS.

A number of fire risk evaluation methods have a similar approach as FRAME.

**Gretener, SIA 81, TRBV 100.**

FRAME has been developed from the Swiss Gretener method. This method had basically two variants, the original made by Max Gretener around 1968 and a revised version published in 1981 by the SIA.

This method is well accepted in Switzerland as well as in several other countries. It has been recommended as a rapid assessment to evaluate the fire risk of alternative concepts for large buildings. The method is one of the most important fire risk ranking methods because of its acceptance for insurance rating and code enforcement.

The latest Swiss version of the Gretener method is described in the VKF/ AEAI document 115-03 of Swiss VKF – AEAI Vereinigung Kantonaler Feuerversicherungen.

In French: [http://bsvonline.vkf.ch/PDF/Erläuterungen/BSE115/115-03f.pdf](http://bsvonline.vkf.ch/PDF/Erläuterungen/BSE115/115-03f.pdf)

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The Austrian version of the Gretener method is the TRVB A 100 Technische Richtlinien Vorbeugender Brandschutz, Brandschutzeinrichtungen Rechnerischer Nachweis. This document has included a graphical solution to combine the fire hazard B with the available fire resistance F and the corresponding special protection S.

The CEPRÉVEN organisation has published a Spanish translation of the SIA method as DT15 Evaluación del Riesgo de Incendio, Método de Cálculo Gretener and descriptions of the Gretener method can also be found on the Internet in several languages such as, German, French, Spanish, Portuguese, Swedish.

Essentially, these methods lack the risk assessment for persons and activities which is included in FRAME and have not been updated for a number of years.

**DIN 18230 Baulicher Brandschutz im Industriebau.**

In Germany, the set of DIN 18230 standards was written for the structural fire protection in industrial buildings, which should be used in relation to the German “Musterbaurichtlinie Industriebau”.

The is composed of three standards:

- DIN 18230-1 : Rechnerisch erforderliche Feuerwiderstandsdeuer (Analytically required fire resistance time)
- DIN 18230-2 : Ermittlung des Abbrandverhaltens von Materialien in Lageranordnung : Werte für den Abbrandfaktor m (Determination of combustion behaviour of materials in storage arrangement, combustion factor m). This standard describes the test method to define the combustion factor m to be used in the method.
- DIN 18230-3 Rechenwerte (values for calculation). This standard gives a set of already defined values for the combustion factor m and the specific heat release and fire load density of a number of common materials.

The DIN 18230-1 methodology has a lot in common with FRAME, although the purpose is different. The Vornorm DIN V 18230, Ausgabe 9/87 and Normentwurf E 18230, Ausgabe 1996 have been used for the development of FRAME version 2.
The basis of the German regulations, such as the Musterbaurichtlinie, is that an industrial building shall have an adequate structural fire resistance, defined by the duration of a large fire. DIN 18230-1 allows then to calculate the equivalent fire duration and the required fire resistance, given the specific conditions for that building, such as fire load density, ventilation conditions, available fire protection systems and others.

The equivalent fire duration is the time by which a "natural fire" has the same effect as a "standard fire" according to DIN 4102-2, which uses the ISO 834 standard fire curve. (see also at the factor q explanation).

The formulas used by DIN18230-1 are:

\[ t_{\text{eq}} = q_R \cdot c \cdot w \]

\[ t_{\text{req}} = t_{\text{eq}} \cdot \gamma \cdot \alpha_L \]

- \( t_{\text{eq}} \) = equivalent fire duration
- \( q_R \) = calculated fire load density in kWh/m²  Note 1kWh/m² = 3.6 MJ /m²
- \( c \) = calculation factor in min.m² / kWh
- \( w \) = heat evacuation factor

and:

- \( t_{\text{req}} \) = required fire resistance
- \( \gamma \) = compartment size factor
- \( \alpha_L \) = protection factor factor.

The fire load density factor \( q_R \) is calculated in the usual way by the total heat of combustion released by the materials in the building, divided by the floor area.

The total heat of combustion is calculated by a formula that uses for each type of material in the building, the heat of combustion, the quantity available and a combustion factor \( m \).

The combustion factor \( m \) is defined, either by the test described in DIN 18230-2 or by the tables of DIN 18230-3. These tables give a combination of the type of material and the size of the objects. For example, wood slats of 40 mm x 40 mm have factor \( m = 1 \), while wood beams of 200 mm x 200 mm have factor \( m = 0.3 \).

A similar approach is found in FRAME for the determination of the fire spread factor \( i \), where the type of material is defined by sub-factor \( T \) and the size of the objects by sub-factor \( m \).

DIN 18230-1 proposes also detailed rules for areas with unevenly distributed fire loads and for "Geschützte Brandlasten in geschlossenen Systemen" or protected fire loads in closed systems. The latter allows the use of a lower fire load density for closed process systems that contain flammable or combustible liquids in metal equipment.

A similar approach to reduce the impact of the fire load is used in FRAME with the "reaction to fire" sub-factor \( M \), a process environment with metal equipment would be evaluated with \( M= 0 \) in the factor \( i \) calculation.

Factor \( c \) is used to transform the value of the fire load density into "minutes of fire resistance". 3 values are used: 0.15 for poorly insulated buildings, 0.2 for moderate insulated buildings and 0.25 for highly insulated buildings.
The distinction is based on observations for smaller rooms where the thermal action more severe in a room where the heat is accumulated inside. It is questionable whether the impact is equally important in large industrial buildings aimed by Din 18230. It appears more as a concession to lower the fire resistance requirements for simple steel sheeted buildings which do not retain the heat inside. FRAME does not use a similar distinction.

Factor w changes the fire duration in function of the heat ventilation capacity of the building. It varies between 0.5 for a partially open building and 2.4 for an almost airtight one.

The value of w can be calculated by formulas or defined on a graph in function of $a_v$, $a_h$ and $\alpha_w$.

The factor $a_v$ is the ratio between the vertical openings in the walls and the floor area. It defines essentially the supply capacity for fresh air.

Factor $a_h$ is the ratio between the horizontal openings in the roof and the floor area. It defines essentially the exhaust capacity.

And factor $\alpha_w$ is a correction for the height of the building.

The graph for $w_o$ shows that, when the vertical openings are less than 2.5 %, there is no effect on the factor w.

The standard also indicates, when there are no openings in the roof, $a_v$ shall only be calculated with at most 2 times the area of the openings in the upper half of the walls.

The calculated value for $w_o$ is corrected by factor $\alpha_w$ for high or low buildings (see next graph)
FRAME has a similar approach to evaluate the smoke and heat venting capacity. Only the vertical openings in the upper third of the walls are taken into account, which fact this limits the application to factor values below 0.05: FRAME is thus more conservative than DIN 18230-1.

The horizontal openings in the roof are used in the FRAME formula for sub-factor v as well as the average height of the ceiling.

The required fire resistance is calculated with two correction factors $\gamma$ for the compartment size protection and $\alpha_L$ for the available protection.

DIN 18230 uses 3 safety classes $\text{SK}_b$ for the building elements in relation to the correction factor $\gamma$. $\text{SK}_b$ 3 are those elements with high structural requirements, such as compartment walls, structural bearing elements (beams and columns) and all other that are part of a fire separation. $\text{SK}_b$ 2 elements are non-bearing elements and roof structure whose failure in case of fire will not be followed by the collapse of the building. $\text{SK}_b$ 1 elements are secondary elements of the roof and non-bearing walls.

The correction factor $\gamma$ is then defined by the safety class, the size of the compartment and the number of floors in the building. This is somehow similar to what is done in FRAME with the sub-factors $g$ and $e$, and with the combination of sub-factors by the calculation of the fire resistance factor $F$.

The protection correction factor $\alpha_L$ reduces the value of the required fire resistance when there are fire detection systems, sprinklers and private fire brigades on the premises. This is similar in what is done in FRAME with the special protection factor $S$.

Although DIN 18230 and FRAME have been developed separately, some test calculations show that the impact of the influence factors is broadly in the same range in both methods.

FRAME simplifies some of the approaches found in DIN 18230 but does not have the limited scope of industrial buildings only.
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