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PERFORMANCE-BASED FIRE-SAFETY ENGINEERING

Abstract: This paper present an overview of a common procedure to follow in a performance-based fire-safety engineering process. The concepts of performance-based codes and fire-safety engineering are described, together with the associated procedure to follow during fire-safety design. The procedure consist of a fire strategy, a quantitative analysis of time to critical conditions and total evacuation of a particular building, together with a following comparison of the solution against the requirements. An international approach is selected and often used acceptance criteria for visibility, thermal radiation, smoke free height, toxical gases, oxygen levels etc., with respect to human safety, are thoroughly described and values of these are given in the paper.

Key words: Fire-safety engineering, performance-based design, design procedure, qualitatively analysis, fire strategy, acceptance criteria, human safety.

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1. INTRODUCTION

Concepts of performance-based codes and Fire-safety Engineering

The concepts of performance-based codes and fire-safety engineering are very closely connected. Fire-safety engineering is a term used for the process that include analysis and documentation of the fire safety of a building.

The principle of performance-based codes is the establishment of a few general requirements for the performance of a given building during a fire. Through fire-safety engineering of the building it is verified whether the proposed solution complies with the codes.

Performance-based codes and fire-safety engineering are therefore necessary prerequisites for each other. It makes no sense to develop performance-based codes, if fire-safety engineering, which demonstrates that the proposed fire solution complies with the performance-based codes, is not subsequently implemented. Conversely, fire-safety engineering cannot be implemented (including the actual fire-safety analysis) if a set of code-specifications has not previously been defined that the proposed solution can be compared against.

There is no universal method or procedure for fire-safety engineering. However, a few different guides have been prepared on how such a design can be implemented. Common to virtually all of these guides is the general content and the overall structure of fire-safety engineering. In contrast, the guides differ slightly in terms of the specific approach towards design.

The following describes the structure and the typical content of fire-safety engineering. The method described here is from [1] and is a combination of a variety of Danish and especially foreign guides.

Levels of design

Before a fire-safety solution can be determined, a design-level has to be selected. The majority of buildings are so conventional in their design that they may be constructed in complete accordance with so-called Collated Examples. A design that only follows these can be called a level 1 design. This type of design is not mentioned in detail. Refer to the literature.

A level 2 design is actually fire-safety engineering by analysis. This kind of design should be used in situations where, to a greater or lesser extent, there is a deviation from Collated Examples. Fire-safety engineering or level 2 designs would typically be relevant to assess fire safety in complex buildings, such as those with very large or high rooms, unconventional design-solutions or construction materials, and in buildings where many people are gathered. However, for each case, it should be decided which level is best suited for the design of fire safety in that specific building.

It should be mentioned here that for both level 1 and level 2 designs, the overlaying codes are performance-based. The levels are just different ways to design the fire safety, but both ways must fulfil the performance criteria. The Collated Examples used in level 1 give examples of fire safety solutions, which are pre-accepted by the authorities.

In many cases it will be possible to combine the levels, so a building mainly satisfies the Collated Examples, but where one element of fire safety, such as the escape routes, is designed by means of calculation. However, extreme care should be taken with these combined solutions. One fire security subsystem should not affect the other subsystems negatively in relation to the overall fire safety of the building. An example of an inappropriate combination is if some parts of an escape route system, such as the corridor widths, are designed based on fire-safety engineering, and other parts, such as the corridor lengths, are designed according to traditional prescriptive solutions.

A level 2 design can be based either on impact analysis (impact-based fire-safety engineering) or risk analysis (risk-based fire-safety engineering). Typically, there will be a combination of these, especially for the largest and most complex building projects.

There are design methods that have been specifically developed for special building types and application, and these may be better suited than the more general methods. The developer and their consultants should therefore always ensure that the best methods for the current building are used. In addition, any fire-safety engineering should be complemented with a thorough and professional assessment (quality control) by persons with sufficient experience of fire-safety engineering.

In connection with fire-safety engineering, computer simulations can be a good tool, but they must never stand alone as the basis for the choice of fire solution. The validity of computer models, and their field of application, must always be documented.

The accuracy of the physical and mathematical models that underlie the software must be documented and it should be ensured with sufficient precision and certainty, that they can be applied in that particular case. Detailed user-manuals and descriptions of each applied theory can, along with experiments, confirm the validity and accuracy of the computer model and be the basis for a sound application of computer simulations.

Methods of Fire-safety engineering

This proposed method of fire-safety engineering consists generally of four elements. It is characteristic of level 2 designs (fire-safety engineering) that, in terms of fire behaviour, they have no prescriptive set of rules that the fire solution must meet except from a set of acceptance criteria. For this reason, it is necessary first to formulate specific fire-safety requirements for the building. The basis for the overall fire-safety engineering is thus established in the first part of the method, which is the fire strategy report. This is the result of a qualitative analysis of the building, people, fire behaviour and potential fire solutions, as well as the choice of calculation tools.

The term “fire solution” covers a combination of active and passive fire protection measures that together will give a building sufficient fire safety. The proposed fire solution is a given combination that, according to the designer's assessment, will satisfy fire requirements for the building.

Based on the overall decisions taken in the fire strategy in the next point, a quantitative analysis is carried out of the fire safety of the building in relation to the proposed fire solutions. To enhance the clarity, the quantitative analysis can be divided into a number of sub-analyses, each related to either a specific stage of fire behavior or specific fire protection measures. The quantitative analysis is discussed in generally terms in this paper.

In the third point of fire-safety engineering, a comparison is made between the acceptance-criteria, set out in the fire strategy, and the results of fire-safety calculations.
It is examined to demonstrate whether the proposed fire solution produces the desired level of fire safety. As long as the fire solution satisfies the requirements to a reasonable extent, it proceeds to the fourth and final element, which is the drawing up of the fire-safety documentation of the building.
The documentation is basically a collection of the previous three points:

- Fire strategy report,
- quantitative analysis and the
- comparison between the achieved and desired level of fire safety.

In addition, it also includes the definitive descriptions and requirements of operation-related conditions for the building. The fire-safety documentation is outlined briefly in this paper. If the comparison shows that the proposed fire solution is not sufficient to achieve the desired level of fire safety, then a new solution must be put forward and the entire fire-safety engineering is implemented, using this new, improved solution. The procedure is repeated until there is a fire solution that provides a satisfactory level of fire safety.

Figure 1 provides a graphical depiction of the proposed procedure for fire-safety engineering and Table 1 provides an overview of the overall contents for fire-safety engineering.

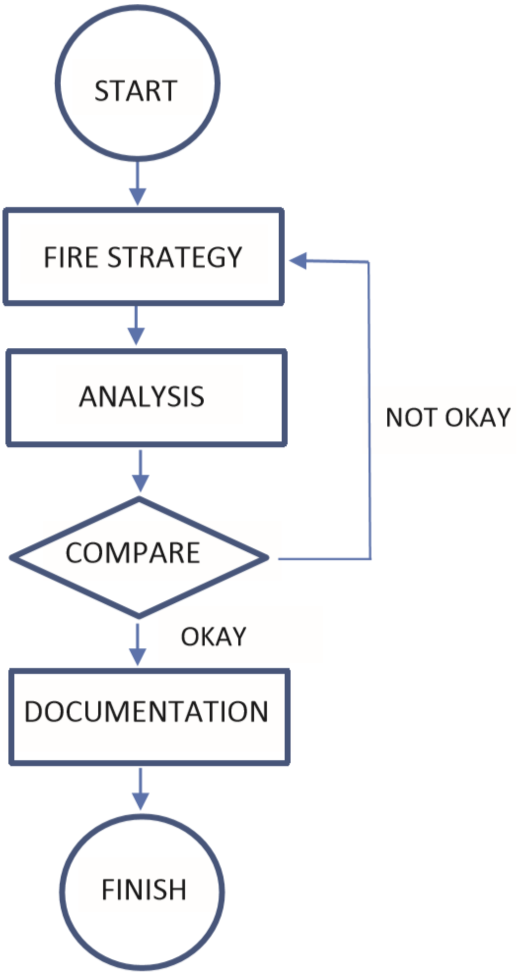

Figure 1 – Flowchart of proposed procedure for Fire-safety Engineering [1] (Sørensen, 2014)

Table 1- Overall contents for Fire-safety engineering

Overall contents of fire-safety engineering
1. Fire strategy report:
• Presentation of the basis for fire safety (building presentation).
• Selection of fire safety level in the form of acceptance criteria.
• Suggestion of fire solutions (based on calculations).
2. Fire analysis:
• Analysis of the building's total evacuation time (result presentation).
• Analysis of critical times in relation to the parameters where acceptance criteria is set (result presentation).
• Determination of how good/bad the various proposed fire solutions are.
3. Comparison:
• Fire solution's performance versus fire requirements (results versus acceptance criteria).
• Assessment of whether the fire solution satisfies the fire strategy's requirements.
4. Reporting:
• Preparation of a so-called fire manual, which summarizes the above points and the operating instructions, whereby all fire-safety documentation for the building is gathered in one place.

Qualitative Analysis (Fire stratety report)

The first item of fire-safety engineering, as mentioned, is the preparation of a *fire strategy report*. The aim is to establish a broad framework for the design. Everyone involved obviously wants and has requirements for the building's use, design, layout, etc. The developer has an application aim of the building, and probably also some ideas for the building's design and layout. Consultants also have ideas for design and layout, just as they have suggestions on possible design and technical installation solutions. The building authority, and possibly the fire authority, makes a number of requirements to be met in order for the building to be approved. Finally, insurers and other stakeholders might have requirements or wishes.

To gather the threads, and thereby identify possible areas of conflict between the parties, a central report (Fire Strategy Report) will be prepared, which describe these factors. This establishes a common starting point for further work. A multi-disciplinary group should be set up, whose task is to draw up the fire strategy report. It is important that all parties are represented in the group. Participants can therefore be the developer, architect, civil engineer, the developer's fire-safety advisor, representatives of the building

and fire approval authorities, the building's future users, the parties`insurance companies, etc.
In relation to the overall fire-safety documentation, the fire strategy report represents the "legislative" part, since the authorities' fire safety requirements for approval of the building are included in the report, so that it presents the building's local and specific "building regulations" in terms of fire behaviour. At any subsequent renovations or extensions, as well as any significant changes in building's use, means the building has to be reapproved by the building and fire authorities. Here the original fire strategy report – in its capacity as the local "building regulations"–is extremely necessary.

Renovations and extensions must in fire-safety terms be in accordance with the plans, requirements and solutions that are approved in the fire strategy report. The same applies to major changes in the building's use. Finally, the fire strategy report is an indispensable tool for fire inspectors in performing fire inspections, i.e. regular fire-safety inspections of the building. They can use the fire strategy report (which they themselves have approved) together with the other fire-safety documentation, including final plans for operation and maintenance as a basis for the inspection.

Table 2 gives a list of the factors to be highlighted in the fire strategy report. The list is not necessarily comprehensive, as there may be special circumstances in a particular building project that has to be included in the fire strategy report. In the following subsections each point is discussed further.

Table 2- Factors to be highlighted in a fire strategy report

Factors
Building description, including use and the report's sphere of application
People factors, including application category
Basis for approval, including the goal of fire safety
Basis for setting fire scenarios
Basis for estimating the evacuation process
Active fire protection, including proposed solution(s)
Passive fire protection, including proposed solution(s)
Operational factors

Building description

Fire safety is inextricably linked to the building's construction and design. These factors form the basis for the entire fire safety system and a *basic description* of the building should be available at the beginning of the fire strategy report. Ideally, it is the architect and possibly the engineer, who will present the building in the form of plans and descriptions. Emphasis should of course be put on design-related factors of particular interest in relation to fire and evacuation.

It should be stated explicitly, which prospectus is used for the analysis of fire and evacuation factors, as well as potential active and passive fire protection systems. It should clearly illustrate and describe which parts, if any, of the building will be designed according to the Collated Examples and which parts come under fire safety engineering. In this way it is clearly determined which parts of the building are covered by the fire strategy report, by which the report's sphere of application is also defined.

Building description may include the following elements:

- local geographic location, i.e. local authority, address, maps,
- area category, refer to local plans (industrial, commercial, residential, centre, etc),
- the use the building is to be approved for,
- building's location on the site, and in relation to buildings on their own land and neighbouring land,
- building design, overall building dimensions and plan solutions,
- load bearing structures (location, materials, design, etc),
- loads on bearing structures, determined according to the structure standards,
- sectional view, facades, exterior and interior surfaces,
- access conditions, exterior working areas, as well as water supplies for the emergency services.

People factors and application category

The building's use – and therefore the people in the building – is crucial to what the fire safety requirements are to be. Firstly, there must be adequate personal safety. To model the evacuation situation as detailed as possible and with as high regard for the specific local conditions in the building as possible, it is essential that you have qualified estimates of the people-related parameters.

For the sake of the evacuation strategy and the pertaining calculations, it is necessary to conduct an analysis of the factors. It is important to know how many people are in the building or the number of people the building is to be approved for, and therefore assumptions can be made of the building. It will also be important to have a qualified estimate of people distribution in the building, and some thought should be given to assumptions of the physical condition that people could be in, i.e. whether they will be able to get to safety in case of a fire by their own means.

In this context it is also important to identify peoples' general state of awareness, vigilance, determination, mutual relationships and knowledge of the building and its fire/evacuation procedure.

In view of the building and people description, it will be possible to place the building or sections of the building, in an application category. The building regulation`s application categories are defined by three factors, which have overall importance for a building's personal safety during a fire, namely:

1) Is the building designed for day occupation, night occupation or possibly both?
2) Do people know the building's escape routes?
3) Are people able to independently get to safety?

Basis for approval

An essential element of the fire strategy report is to provide the relevant basis for approval of the building's fire safety, i.e. the fire safety requirements that the fire safety solution has to comply with. In practice, this is done by upholding the acceptance criteria for personal safety and the safety of valuable items as required for the basis in the design of the building's fire solution.

In Denmark there now exists official certified acceptance criteria for selected parameters; they are not statutory, but only instructive. This means that acceptance criteria should be reviewed each time, perhaps amended and submitted to the fire approval authority, so the building's fire safety is not designed on an incorrect and unapproved basis. However, using the (instructive) official acceptance criteria would of course be approved without further persuasion.

Initially you should identify what the goals are with fire safety. Personal safety is a minimum requirement, but goals may also be set for [4]:

• max. accepted damage to a number of objects.
• max. accepted fire damage to a section of the building.
• max. accepted time frame for reconstruction.

An acceptance criterion for a parameter is given by the parameter value that is believed to mark the boundary between critical and uncritical conditions to people in the building. In order to ensure uncritical conditions to people in the building during the time when evacuation takes place, you need to impose requirements on the parameters that are crucial to peoples' possibilities of escape.

For some parameters, relatively objective acceptance criteria can be set. For example, for respiration it is necessary to have a concentration of oxygen in the inhaled air, which is relatively well-defined, in purely clinical terms. For other parameters, the choice of acceptance criterion is more subjective, for example, necessary visibility.

The following describes the parameters that acceptance criteria are usually formulated on.

Visibility

When an evacuee must leave a burning building – sometimes under chaotic conditions – orientation is of course crucial, which makes the parameter"visibility" very significant. There are numerous examples of fatal fires where rescue crews have found people dead far away from the exits, because they were not able to orient themselves, and therefore got "lost" in the building.

Most of the guides to fire-safety engineering use two different visibility criteria, depending on room size. The boundary between a "large room" and a "small room" is often defined as 150 m2. To exemplify a 150 m2 room you can think of a classroom at 10x15 m2.

A visibility of 10 m is hardly critical in a room with those dimensions and it will probably not be critical in a room double the size, provided that each person in the room is familiar with the layout. This will usually be the case if they have entered the room, or have passed through it before the fire started. In contrast, during evacuation if they should go through a room, i.e. an escape route, if the layout is *not* known in advance, reasonable visibility is much more necessary. Therefore, visibility criterion is not just related to room size, but also whether the room is part of an escape route, i.e. when an escape route passes through the room.

It significantly helps people's orientation if they can clearly assess the layout of the room. Not all people act rationally, especially in a fire situation, but people who have to find their way out of a smoke-filled room that they do not know, will ideally follow a wall they can see because the way out of the room must lead through an opening in the wall. Therefore, in principle the definition of acceptance criteria for visibility must take into account that people should be able to see at least one wall in the room they are in. In practice it may be appropriate to impose some standardized visibility criteria.

If you wish to maintain the division between small and large rooms by 150 m2, the following acceptance criteria is suggested for visibility:

Visibility V > 3 m in a small room (up to 150 m2)
Visibility V > 5 m in a small room (up to 150 m2), if part of an escape route
Visibility V > 8 m in a large room (over 150 m2)
Visibility V > 12 m in a large room (over 150 m2), if part of an escape route.

This means that a non-escape route room can be approx. 250 m2 before we are no longer able to see at least one wall and an escape route room may equivalently be approx. 575 m2. In most cases, a room which is part of an escape route would hardly have such large dimensions (for example, a lobby or another large entrance), without people having knowledge of it in advance, as they would typically have entered the building that way.

Incidentally parameter visibility is not used directly in guidelines. Instead the parameter optical density [dB/m] is used, which is inversely proportional to visibility.
The relationship between visibility and optical density is usually:

$$V = 10\text{dB}/OD \qquad (1)$$

Therefore, the above acceptance criteria for visibility can be converted to the following acceptance criteria for optical density. Note the proportionally determined change from > to <.

Table 3- Acceptance criteria for optical density (visibility). Large rooms > 150 m^2

Condition	Acceptance Criterion	Comments
Optical density, OD, in small rooms	OD < 3.33 dB/m OD < 2.00 dB/m	When the room is part of an escape route
Optical density, OD, in large rooms	OD < 1.25 dB/m OD < 0.83 dB/m	When the room is part of an escape route

Radiation intensity

Thermal radiation is a quantity that may be difficult to relate to purely in quantitative terms. Nevertheless, it is a very important parameter in relation to direct physical, critical conditions for people.

We all know about the sun's radiation. In winter, when the air is ice cold, radiation is very clearly felt. If you sit behind a window you are protected from the cold air from outside, while the sun's rays penetrate directly through the window and provide warmth. In summer, it is radiation that burns the skin by sunburn. Solar radiation, whose effects we are all so familiar with, is in the range of 0.67 kW/m2 [2].

In comparison, a fire that develops into flashover leads to a radiation intensity in the order of 20 kW/m2, which is intolerable for humans. This illustrates why it is so important to define criteria for how high radiation intensity should be while evacuation is in progress.

It is customary to specify thermal radiation as 10 kW/m2 as the upper limit for what people may be exposed to. In most sources the exposure time is indicated as a maximum of 4 seconds. This is not a sufficient requirement, precisely because the tolerable intensity depends on exposure time – the higher the intensity, the shorter time we can tolerate exposure. Therefore it is necessary to also set a specific limit on the maximum permissible radiation dose, i.e. product of radiation intensity and exposure time. It is convenient to separate acceptance criteria for radiation intensity into two sub-criteria, therefore requiring that both the maximum permissible radiation intensity and maximum permissible radiation dose are set.

The overall acceptance criterion can for example, be as shown in Table 4:

Table 4- Acceptance criteria for radiation

Condition	Acceptance Criterion	Comments
Radiation intensity, q	$q \leq 10$ kW/m^2	Maximum of 4 seconds
Radiation dose, qt	$qt \leq 40$ kWs/m^2 = 40 kJ/m^2	when q is larger than 1.5 kW/m^2 and less than 10 kW/m^2
Radiation intensity, q	$q \leq 1.5$ kW/m^2	Tolerated throughout the evacuation time

<u>Inhalation temperature</u>

Another important physical parameter in relation to personal safety is the temperature of the air the evacuee inhales when escaping. The more water vapour the air contains, the lower the temperature is tolerable for people. This is because a person exposed to heat stress will try to regulate their body temperature by, amongst other things, perspiration (sweating). The temperature-lowering effect occurs when sweat evaporates. However, it is a precondition for evaporation to take place that the ambient air is able to absorb water vapour. It is not possible for a person's sweat to evaporate, who is in water-saturated hot air, whereby the body temperature cannot be reduced as necessary, which can prove fatal.

There is general agreement that 60°C is the maximum limit for hot *saturated* air that people can breathe without receiving internal burns. With lower water vapour content in air, a higher temperature can be tolerated. Therefore, to be on the safe side, 60°C is used as the acceptance criterion. In [Informationen] it is indicated that 80°C is an acceptance criterion for temperature, which seems to be high. Just with radiation intensity, it is also relevant to focus here on the relationship between exposure and time, for instance, the product of temperature and exposure time. The time an "average person" can tolerate inhaling air at a given temperature can be expressed as given in [3], and showed in Table 5:

Table 5- Acceptance criteria for inhalation temperature, normally measured 2 m above floor

Factor	Acceptance criteria	Remarks
Temperature below the smoke layer * (inhaling temperature), T_{inh}	$T_{inh} \leq -36.6 \ln\left(\frac{t_m}{179}\right)$	Inverse formula: $t_m \leq 179 \cdot e^{-T_{inh}/36.6}$
	$T_{inh} \leq 60$℃	

The time-independent requirement for a maximum of 60°C corresponds to an exposure time, and therefore a maximum evacuation time of approx. 35 minutes. An occupancy time of 35 minutes in a fire room, or an escape route, may seem like a relatively long time, but it may be realistic. Even under controlled conditions, it can be extremely difficult to maintain orientation, when you cannot see anything, and it is obviously not helped when, as an evacuee, you are in a stressful situation and have difficulty breathing, and you are in a large and often totally dark room, and exposed to excessive heat, etc. As previously mentioned, there are many examples of people, who have attempted to escape from a burning building, and have been found by rescue crews far from the exits. Firemen will typically be deployed into a building shortly after the emergency services (fire) arrive; normally after approx. 10-20 minutes. Based on this, an evacuation time of 30-35 minutes is not unrealistic.

Smoke-free height above floor level

The height of the “cool” lower air layer in a 2-zone air stratification room, i.e. the air layer between the floor and the hot fumes, must have a certain size to provide evacuees with reasonable escape conditions. Most people would refuse to pass through a room filled with smoke. It cannot always be avoided, but to achieve a quick, efficient evacuation, it must be assumed that the evacuee can escape in a fairly upright position.

The most common limit between acceptable and critical factors concerning height of the smoke-free air layer is 1.6 m + 0.1·room height. Almost all guidelines for fire-safety engineering recommend this as the minimum acceptable smoke-free height above floor level.

It is difficult to imagine rooms of less than 2 metres in height that are intended for people, leaving a smoke-free height above the floor level of 1.8 m. Fire-safety engineering will often involve a new building. According to the building regulations, the room height of new buildings in Denmark must be at least 2.5 m. This results, in accordance with the above acceptance criterion, of a requirement for a smoke-free height of 1.85 m, which is considered appropriate for ensuring safe evacuation conditions.

Table 6- Acceptance criterion for smoke-free height above floor level

Factor	Accept criterion
Smoke-free height above floor level, H_∞	$H_\infty \geq 1{,}6$ m + 0,1 · H

Oxygen concentration

It is a known fact that the human body needs oxygen (O2) as fuel for metabolic processes. Atmospheric air contains approx. 21% O2. As combustion processes, and therefore fires, consume oxygen, in a fire situation it could result in the oxygen level in the air falling below 21%. This may become critical for people who find themselves there. If inhaled air contains too little oxygen, muscles and vital organs do not receive enough fuel, so their performance is reduced or completely disappears, which obviously can be fatal. The limit for when critical conditions occur is around 15%.

The vast majority of fire victims die from what is called “smoke inhalation”. In reality it is often suffocation due to the low level of oxygen in inhaled air. It is therefore very important to set a criterion for the minimum permissible level of oxygen in inhaled air.

Table 7- Acceptance criterion for the oxygen concentration of inhaled air

Factor	Accept criterion
Oxygen concentration, C_{oxygen}	$C_{oxygen} \geq 16\%$

You can possibly express the requirement for oxygen as a factor of exposure time, similar to the influence of radiation intensity and temperature. For example, we are not choked by taking a single breath with too little oxygen.

<u>Toxicological factors</u>

Besides oxygen, it also has great significance which toxic fumes are produced during the fire, and are therefore present in the inhaled air. The composition of smoke is very complex and depends, amongst other things, on the chemical composition of the burning material. Any combustion process produces water/water vapour (H2O) and carbon dioxide (CO2). With incomplete combustion processes, in practice all fires, it also produces carbon monoxide (CO), which we know is highly toxic.

The red blood cells that normally bind oxygen from inhaled air, and distribute it around the body, absorb carbon monoxide 411 times easier than oxygen. This means that if the air contains CO that is what is mainly absorbed into the blood instead of O2. There also arises an unfortunate synergy when both CO and CO2 are present.

Inhalation of carbon dioxide increases a person’s breathing frequency, resulting in the inhalation of yet more CO.

Besides CO and CO2, there often occurs a number of other dangerous gases, with the most common being hydrogen cyanide, hydrogen chloride, Sulphur dioxide and nitrous gases. Table 8 shows an overview of the gases, their origin materials at fire sites, and their effect on people.

Finally, it may also be relevant to establish acceptance criteria for various irritants – substances which are not directly toxic, but have some undesirable properties in relation to people. It must be taken into account that several of the compounds may occur simultaneously. A person’s total exposure partly consists of the sum of the concentrations and partly of the total doses (products of concentrations and exposure times).

Table 8- Occurrences of gases and impact on people

Gas	Source materials at fire site	Effects on humans
Carbon monoxide (CO)	organic material, always occurs	Binds to the blood at the expense of oxygen (O_2)
Carbon dioxide (CO_2)	organic material, always occurs	Increases breathing rate
Nitrous gases (NO og NO_2)	ammonia, NPK fertilizer, plastic products (e.g. polyamide)	Can cause difficulty breathing and pulmonary oedema
Sulphur dioxide (SO_2)	sulphur vulcanized rubber products (e.g. car tires)	Can cause acute pulmonary oedema
Hydrogen cyanide (HCN)	plastic products (e.g. polyurethane)	Impaired sense of smell, convulsions and unconsciousness. Can be fatal after only a few minutes
Hydrogen chloride (HCl)	plastic products (e.g. PVC and Neoprene)	Acute pulmonary oedema

Table 9- Acceptance criteria for concentrations of toxic fumes

Factor	Acceptance criteria	Remarks
CO concentration, C_{CO}	$C_{CO} \leq 0.10\%$	*
CO_2 concentration, C_{CO2}	$C_{CO2} \leq 4.0\%$	*
HCN concentration, C_{HCN}	$C_{HCN} \leq 0.005\%$	*
SO_2 concentration, C_{SO2}	$C_{SO2} \leq 0.003\%$	*
NO_2 concentration, C_{NO2}	$C_{NO2} \leq 0.002\%$	*
HCl concentration, C_{HCl}	$C_{HCl} \leq 0.10\%$	*
HBr concentration, C_{HBr}	$C_{HBr} \leq 0.02\%$	*
HF concentration, C_{HF}	$C_{HF} \leq 0.012\%$	*
Acrolein concentration, $C_{acrolein}$	$C_{acrolein} \leq 0.0002\%$	*

Refer to [1] for a continuing description of the fire safety design process, i.e.

- fire strategy
- quantitative fire analysis (simulation of critical conditions, time to evacuation)
- the comparison of the proposed fire solution against the requirements (including the acceptance criteria)
- fire-safety documentation.

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QUESTIONS

1. Could fully performance-based fire codes be introduced in Serbia now?
2. Which pros and cons does performance-based fire-safety engineering have, compared to traditional prescriptive codes?
3. Could performance-based codes also be utilized on other disaster risk disciplines than fire (for instance on flood preventing)?
4. Should the application of new construction materials be controlled by authorities on an overall level, or could/should fire safety experts be allowed to judge them?
5. Where do you see Europe/EU with respect to fire-safety engineering in the future. Do we need a harmonized "standard procedure" to follow in performance-based fire-safety engineering?
6. Suggest an overall vision for a more fire safe Europe, and propose some action points to follow for such a development.