Building Physics

6. Fire Safety

ir. A.C. van der Linden, AaCee Building & Environment, Delft

based on material of
ing. T.A.J. Selten, moBius consult b.v., Driebergen
ir. R.H.P. van Herpen, Nieman Raadgevende Ingenieurs, Zwolle.

Klimapedia, August 2022

13

Fire safety

R.H.P. van Herpen; A.C. van der Linden; T.A.J. Selten

In order to be able to construct fireproof buildings and to use buildings safely, first it has to be determined what 'safe' is. Constructing buildings 'even more safe' is not always achievable. Limiting factors can be the costs involved, but also the ease of use, flexibility and durability. What, then, is sufficiently safe and which measures must be taken to ensure this? Which ones are worth considering and which go 'too far'? After all, fire hazards are always present in buildings, leaving aside unused and therefore empty bunkers. The trick is to curtail these hazards sufficiently.

This chapter deals with how fire safety is regulated in the Netherlands, what fire means exactly and what the points of departure are for protecting people, offering means of escape and preventing fire damage.

In the Netherlands, building owners are the ultimate party responsible for the safety situation in the building. They therefore also have a duty of care for fire safety. Building regulations of course provide for basic requirements for fire safety, but designers and consultants have to work out the exact performance requirements and the ideas in respect of fire safety for each individual case.

The rules and regulations address the limitation of risk of casualties with regard to the users of the building, emergency and medical workers, and bystanders and the limitation of damage to the environment. Damage control to buildings or inventory is a matter for the owner and users of the building.

Fire safety is of such complexity that prescribing individual measures is not sufficient. The aim of this chapter is to provide a first introduction to fire safety. In practice, fire safety construction has developed into Fire Safety Engineering. Here, use is made of physics models of how a fire develops and models for simulating escape routes for people in a building. There is, after all, no standard fire and no standard response of people and structures to a fire. Based on the results of these studies, i.e. the risk analyses, the evaluating authorities can decide whether the proposed provisions meet the functional requirements laid down in the rules and regulations. For further information regarding Fire Safety Engineering, visit www.klimapedia.nl.

13.1 Fire safety in rules and regulations

Rules and regulations differ from one country to another and also develop in time. At a European level a general framework is available and several directions and standards exist for testing separate materials and structures for fire resistance.

Limiting fire spreading

In the Netherlands, a building is divided into fire compartments no larger than 1000 m^2 floor area. This should limit the speed with which fire can spread. Resistance against fire penetration and fire spreading from one compartment to the next must therefore take at least 60 minutes. If a sprinkler installation is present which is activated automatically in case of fire, it is not necessary to divide a building into compartments in order to remain in control of the fire. For existing buildings, and in particular in case of their renovation or adaptation, explicitly specified (limited) exceeding of the compartment size is allowed.

Safe use of the building and possibilities of escape

In order to make it possible to make use of a building in a fire safe way, attention must also be paid to fire safety installations (fire and smoke detectors), accessibility of the building by emergency services and of course to the lay-out of the building. This includes special precautions such as for the storage of hazardous materials.
Providing safe escape routes is also of major importance. The escape routes must be properly accessible and it must be made impossible to become locked in. This means that there must always be two possibilities of escape. Additionally, the escape route must offer plenty of resistance against fire in the surrounding area and must be sufficiently smoke free. Rules and regulations specify minimum requirements for these matters and sometimes even certain solutions.

13.2 How a fire originates

Combustion is oxidation of a material at high temperatures, releasing heat. This is called an exothermic reaction.
Combustion requires:

- the presence of fuel;
- sufficient supply of air for the required oxygen;
- fuel at combustion temperature;
- environmental conditions which keep the fire going as a progressive chain reaction.

If one of these conditions is missing, the fire will die: these are the principles on which fire prevention and firefighting are based.

Fuels can be divided into the following categories:

- solids (for example wood, fabric, carpet, asphalt, synthetic materials);
- liquids (for example oil, petroleum, methylated spirits, alcohol);
- gases (for example natural gas, mine gas, carbon monoxide);
- aerosols or dust particles (for example sawdust, soot).

The products created by combustion are:

- heat (flames);
- combustion gases (CO_2, CO, H_2O, SO_2, etc.);
- smoke in the event of incomplete combustion (soot, aerosols).

Smoke hinders vision and can be dangerous, because you will no longer be able to find your way around. Combustion gases (including smoke) are suffocating and generally hot. Any carbon monoxide present will bind with red blood cells and hinder oxygen uptake.

In the course of the fire the following phases can be distinguished:

- the smouldering phase (before the fire turns in to actual open flames);
- the creation of the fire (at time t = 0);
- the development phase of the fire until the moment of flash-over at the location of the fire;
- the completely developed fire created after the flash-over;
- the dying down phase which occurs after time has elapsed as a result of fuel deficiency or active withdrawing of fire capacity (extinguishing).

The first phase is called a fuel-controlled fire. There is no shortage of oxygen and with enough fuel, the fire will spread in all directions with equal speed. At the top of the entire space, a hot zone develops which heats the space in its entirety. The temperature in the room increases until all combustible materials in the room catch fire spontaneously, regardless of the distance to the seat of fire. This phenomenon is called flash-over. This causes the local fire to change into a compartment fire with all available combustible fuel taking part. From this moment on, the fire capacity is determined by the amount of oxygen which can gain access to the compartment via windows, doors or other openings. There is usually not enough air supply to let the fire burn unrestrainedly. Due to lack of oxygen, there is no complete combustion causing partially burned, combustible gases to be produced. When these partially burned gases are released from the compartment they will catch fire because of the oxygen present outside the compartment and the released gases are so hot that they contain enough energy for spontaneous combustion. This combustion phenomenon creates a conflagrant fire. When the fuel runs out, the dying down phase sets in. In the dying down phase the fire capacity reduces to zero and this is what determines the entire duration of the fire. The fire compartment has of course not yet cooled down to the starting phase (environment temperature). Depending on the structural features of the fire compartment, this will take some considerable cooling down time.
Figure 13.1 shows the course of the temperature during the entire fire.

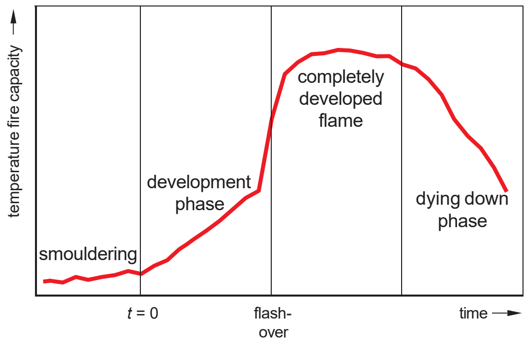

Figure 13.1 Example of a fire process in the case of fire in a room

13.3 Fire penetration, fire spread and strength of buildings during fire

Fire always seeks a way outside and in doing so, tends to move sideways and upwards. Another feature is that it is able to spread itself by moving through small openings.

The term WBD (*Weerstand tegen BrandDoorslag*, Resistance to Fire Penetration) refers to the level of fire spread resistance of a partition between two adjacent rooms (see figure 13.2). The term WBO (*Weerstand tegen BrandOverslag*, Resistance to Fire Spread) refers to the level of resistance against fire spreading via the outside air. In general, this concerns the spread of fire as a result of flames breaking out.

The WBDBO (*Weerstand tegen BrandDoorslag and BrandOverslag*, Resistance to Fire Penetration and Fire Spread) is the total resistance against the spread of fire between two rooms, via both the partition constructions in the building and the outside air. If a wall has a WBDBO of 60 minutes, this means that the wall (the partition construction) is able to resist fire for 60 minutes.
The WBDBO of materials and constructions can be determined in a laboratory fire experiment. To be able to create clearly defined parameters when determining fire-resistant qualities, the so-called standard fire curve is used (standardised fire). It is not only the time needed for the flames to penetrate the partition (the flame density) that is looked at during the test, but for example also the temperature of the partition construction during a fire.
With walls that are subject to a WBDBO requirement, extra attention should be paid to holes and openings for air channels, electricity and data cables, pipes and so on. These openings can affect the WBDBO and should all be fitted with fire-resistant elements. For air channels this should be a fire flap, and in the case of holes used for cables and so on, some sort of fire-resistant material should be considered. Without taking these measures there would be no point in having a fire-resistant wall, as a fire will always seek the route of least resistance in order to spread. Considering that the temperature of the centre of a fire can get as high as around 1100 °C, it hardly needs stating that the relevant fittings must be properly designed and installed. As far as the actual work is concerned, it is sensible to have the supplier issue a completion certificate, which can be used subsequently to

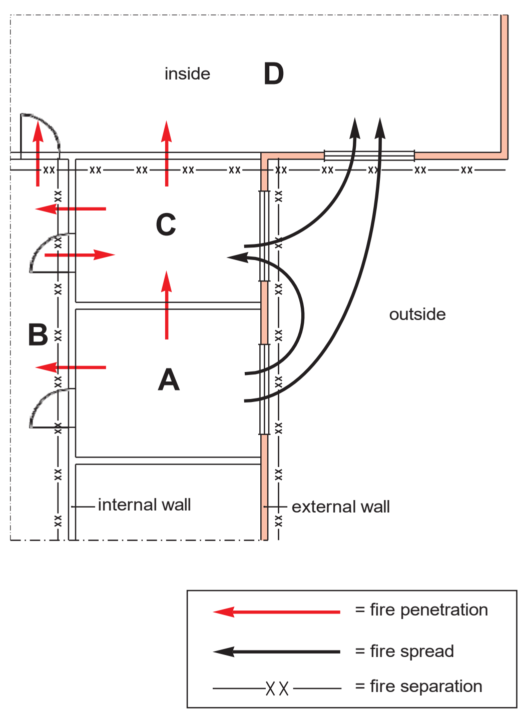

Figure 13.2 Fire penetration and fire spread

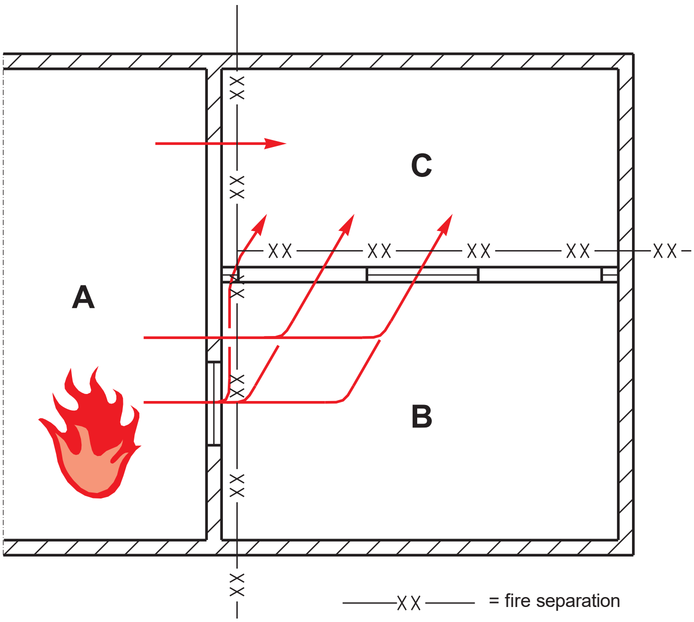

Figure 13.3 Influences in determining the WBDBO

show that the conditions have been met. Whenever fire doors are fitted, the supplier must always issue a completion certificate. The WBDBO between two rooms can be calculated.
Figure 13.3 has a diagram showing the routes and components that need to be borne in mind when calculating the WBDBO between room A and C.

Risk of fire spreading

The greater the distance from the fire, the smaller the risk that it will spread. It can be compared to a campfire situation. The level of radiation reduces, the further the distance from the fire. The limit to the intensity of the heat radiation that is used for determining the risk of fire spreading is 15 kW/(m². As an illustration, the level of total heat radiation in direct sun (UV, visible light and infrared) on a hot summer's day is about 0.8 kW/(m².

Based on the general rules of thumb, the following distances can be taken (see figure 13.4):

- Within a total in-between distance of 5 m, flame contact will occur and fire-resistant measures are necessary.

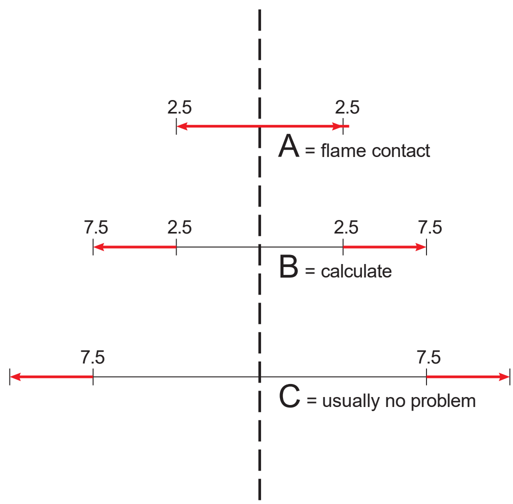

Figure 13.4 Influence of the total in-between distance on the risk of fire spreading

- Within a total in-between distance of between 5 and 15 m the fire spread risk has to be calculated based on methods given in standards. Software programs are available for this.
- If the total distance is greater than 15 m, then there is in principle no risk of fire spreading.

Mirror symmetry

The legal regulations include a method for defining, at the design stage, the risk of fire spreading in cases where no information is available about any other constructions on adjacent plots of land. This method is known as mirror symmetry and assumes that a mirror image of the same design of building is present on the boundary of the neighbouring plot of land. If, for example, a building is erected along the outer edge of its plot of land, it should have a total WBDBO of 60 minutes. However, according to the mirror symmetry method, this total can be divided over both future buildings that may be put up on either side of the boundary, in which case a WBDBO of 30 minutes will suffice. By building say, 7.5 m from the edge of the site boundary (and therefore 15 m from a mirror symmetry point of view), the chance of fire spreading through radiation is virtually impossible and no extra measures will be necessary.

Strength of buildings during fire

A building has to be able to remain standing for a period of time when it catches fire, as any collapse would represent an additional danger to any people still present, and to fire fighters. The requirements with regard to the strength of a building during fire are aimed at the main load-bearing structure. This comprises structural components that, when they give way, can cause the building (or part of it) to suffer a progressive collapse (see figure 13.5). An example of a progressive collapse is that of the Twin Towers in New York. Because the main load-bearing structure was weakened, both buildings collapsed.
The requirements set for the capacity of the load-bearing construction in the event of fire depend on the height of the building. The strength of a high rise residential building will have to be such that an entire floor can burn down, while the load-bearing construction remains intact. The duration that the load-bearing construction must remain intact during a fire varies from 30 to 120 minutes.
Of equal relevance to the requirements relating to the main load-bearing construction is the permanent fire load of the building. This is the amount of heat that is released for every m² of floor surface when the materials that were used in the construction of the building, burn. Some requirements for buildings that contribute little to the permanent fire load may be reduced. The limit is a permanent fire

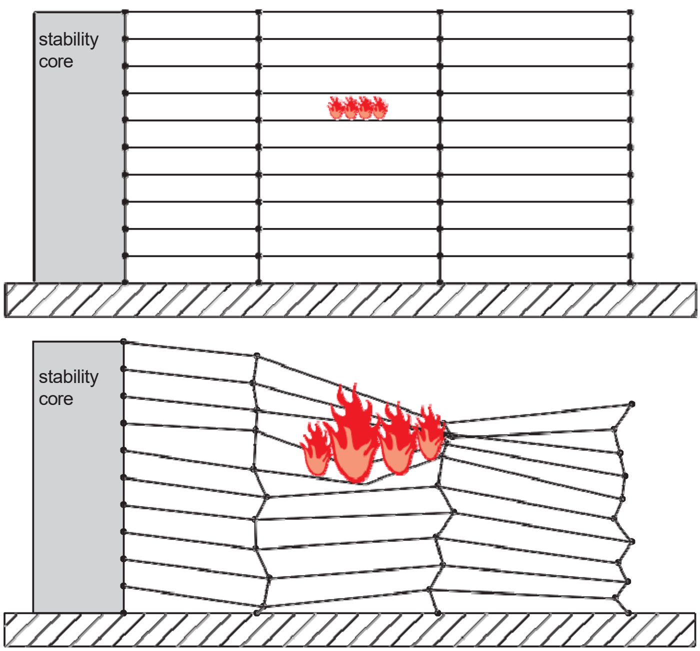

Figure 13.5 Progressive collapse of the main load-bearing construction

load of 500 MJ/m². If this is exceeded, then a reduction of the requirements is not permitted.
The fire load is often expressed in kg/m² pine equivalent. In this case, 1 kg/m² is equal to 19 MJ/m². A fire load of 500 MJ/m² as an example equals 25 kg pine wood per m².
A permanent fire load of less than 500 MJ/m² corresponds with a construction primarily made of concrete, stone and steel. As soon as wood or other flammable material is used in wall units or load-bearing elements, the limit of 500 MJ/m² is quickly exceeded. Another area of attention here is the fire load of the roof covering.

13.4 Fire compartmentalisation and escape routes

The first aspect to be looked at when it comes to fire safety is that of fire compartmentalisation. Apart from the odd exception, a fire compartment may not be any larger than 1000 m². This means that on premises where two buildings are situated with a surface area of 400 m², no separate fire compartmentalisation is necessary, as the maximum of 1000 m² would not be exceeded.
The WBDBO between fire compartments should be 60 minutes, though it may be possible to reduce this if the building is no higher than two storeys. If that is the case, the WBDBO can be lowered to 30 minutes.
When designating the fire compartments, it is important they do not include any smoke and fireproof escape routes. In addition, only self-closing doors may be installed in internal, fire-resistant partitions. The use of doors held open by electronic magnets is allowed as long as the power to the magnet is cut by the fire alarm when activated, causing the door to close automatically.

Fire sub-compartments

A next step on from fire compartmentalisation is that of fire sub-compartmentalisation. This is a sub-division within a fire compartment and is used in buildings where people sleep, but who are not able to bring themselves to safety, or who are dependent on others for doing so. The extra level of protection that this sub-division produces is intended to strictly limit the opportunities a fire has of spreading, in relation to how the building is used. Containing the fire even more rigorously means there are more possibilities for people to escape or for putting the fire out.

Escape possibilities and smoke compartmentalisation

The second aspect concerns the evacuation of people from a threatened area to a safe location. It is well known that most casualties in a fire are caused by suffocation due to the expulsion of oxygen by smoke. For that reason, criteria have been drawn up to judge whether a person is able to escape in time from an environment threatened by smoke. The general rule of thumb is that people can hold their breath for 30 seconds and cover a distance of 30 m, walking at a speed of 1 m per second, to the exit of a so-called smoke compartment, from which point they should be able to escape via a smoke and fireproof emergency exit route.

A smoke compartment is always situated in a fire compartment. A fire compartment can contain one smoke compartment, but also two or more. The boundary of a smoke compartment must be smoke resistant. The smoke resistance of a construction is 1.5 times its fire resistance, so that a WBDBO of 20 minutes is equivalent to a smoke resistance level of 30 minutes.
Smoke compartmentalisation for public buildings can be done on the basis of general regulations. The maximum allowed length of the escape route depends on the occupancy factor of the building. In most cases, 30 m per partitioned room applies. For areas that are not sub-divided (such as an open-plan office), this value should be divided by a factor of 1.5. The maximum length of the emergency escape route would then be 20 m.
For open-plan offices and other rooms that are not sub-divided, it is easy to establish whether

the requirements are being met by ‘drawing’ a circle with a 20-metre radius from the access point to a smoke compartment. This will make clear quite quickly if the basic structure creates any bottlenecks. In applying this method, it should be borne in mind that people will have to walk round construction features, and that mezzanines are not accessible.
Design bottlenecks tend to occur where there are corridors that do not lead anywhere, or when there is only one escape route available. Additional legal requirements apply in such a situation. By working on the basis that a building has two escape routes as standard, it is much easier to comply with safety requirements. For the construction of houses it is important to ensure that the room that is furthest from an emergency escape door is located no more than 15 m away. Also, the rooms through which the escape route passes must have fire alarms connected to the mains.

Escape routes

An escape route must be safe enough for people to be able to escape by. The escape route runs from the point at which it is accessed from the smoke compartment to when it reaches a public highway. In principle, it should be possible to escape in two directions, or there should be two separate escape routes available from any smoke compartment. If this is not the case, then the rules allow for exceptions – with corresponding restrictions – whereby use can be made of escape routes that coincide.
Should there be just one stairwell that will be used by more than 25 people, then it must be smoke and fireproof. This also applies to stairwells higher than 8 m. A feature of a smoke and fireproof stairwell is that it should have a WBDBO of 60 minutes in relation to the rooms in the building.
Separate rules apply to doors. A door can open in three directions: in the same direction as the escape route, against the flow of those escaping, or sideways (as a sliding door). No more than 25 people may be situated behind a door that opens against the flow of people escaping. If there are more people than this, there is a danger that the door cannot be opened because of the sheer numbers pushing forward in their panic to escape. A sliding door that is used on a daily basis can be considered as a door that opens in the same direction as the escape route, as the people present will be familiar with the door. Escape route doors that are only used in emergencies may not be sliding doors.

13.5 Measures for limiting and fighting fire

In this section we will discuss the measures which relate to limiting the development of a fire and fighting already developed fires. The latter mainly concerns the accessibility of the seat of the fire for the fire brigade and the possibilities of firefighting.

Restricting the fire and smoke

Depending on their specific location, structural components should be such that they do not help the fire spread in any significant way. The degree by which materials enable fire to spread is divided into five categories. Category 1 materials are those that make a very minor contribution to the spread of fire, while those in category 5 contribute very strongly.
There are also requirements relating to smoke. Clearly, materials used in the construction of smoke-proof or smoke and fireproof escape routes are subject to more stringent requirements than the materials used in rooms, offices, etc.
The requirements also make a distinction between structural components on the exterior and interior of the building. In the case of the former, extra requirements apply with regard to the fire spread category from a height of 13 m upwards, as the average fire engine hose will not reach beyond this height (see also figure 13.6).

Because of the risk of vandalism, the first 2.5 m of the outer walls of buildings with a floor (where people live or work) higher than 5 m must be constructed with material from category 1 (i.e. those that hardly contribute to the spread of fire). This prevents high buildings from catching fire on the outside as a result of the actions of arsonists.

Naturally, fire safety installations play an important role in the safe use of a building. This applies especially to fire detection and fire alarm installations, which have to ensure a timely alarm and start of the firefighting. It is remarkable that no requirements are included in the rules and regulations for active fire control installations (such as a sprinkler system) and active smoke detection. The reason for this is that active fire and smoke control installations are generally not necessary. Rules and regulations assume passive (structural) solutions for controlling fire and smoke. Only in the event of large fire and/ or smoke compartments, active fire and smoke control installations can be applied as equivalent safety measures. The rules and regulations do, however, ask for regular inspection of the provisions.

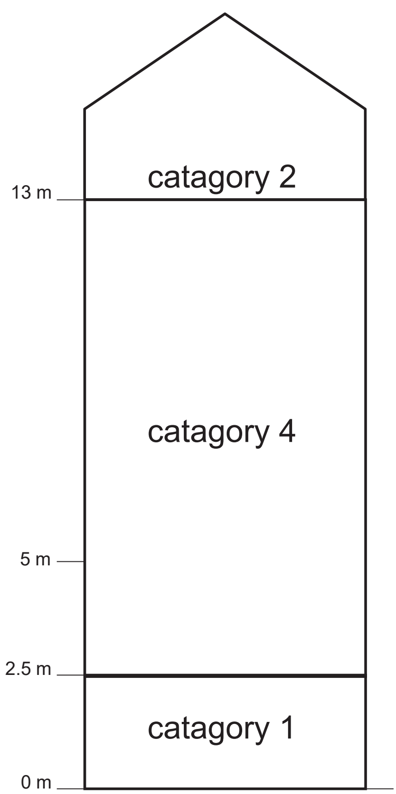

Figure 13.6 Fire-spreading category requirements of outdoor construction materials

It is also of great importance that it is clear to everyone what type of building they are dealing with and where certain provisions are located in the building. This is not just important for evaluating the safety situation in advance, but also for emergency services. This concerns the following general matters:

- the size of the plot, the construction and the locations;
- specification of the gross volume and the gross surface area of the building;
- the purpose of the building (designated uses) and the corresponding surface area;
- the designated use of each room (populated areas, populated rooms, functional area, functional room, control room, etc.);
- number of people for each room and the escape route;
- drawings (maps, facades, cross-sections and details) along with dimensions.

With regard to fire safety the following must additionally be indicated:

- accessibility of the building, the location of water for fire extinguishing and location for fire trucks (for large plots);
- the combustion properties of used materials;
- the (sub)compartmentalisation (including the WBDBO: 20, 30 or 60 minutes);
- the fire resistance of the construction;
- the direction in which the movable construction parts rotate (in relation to the escape route);
- drawings and/or calculations of specific measures and constructions in the building.

With regard to installation components the following must be specified:

- the location of dry risers and connection points;
- the location of fire hose reels;
- the location of fire brigade lifts;
- the escape route signs;
- the emergency lighting.

Dealing with fire

When a fire is starting it is important that action can be taken quickly. If fire hose reels have been installed, people who are on the spot will be able to combat a fire in its early stages.

To ensure that fire fighters can perform their tasks properly, requirements are in place for the design of buildings higher than 20 m:

- In order to be able to quickly tackle a fire that is high up, the fire service has to have a fire lift at their disposal. Additionally, the walking distance from the lift and an escape stairwell to a smoke compartment or smoke sub-compartment should be limited in order to enable the fire fighters to do their work quickly.
- In order that no time is lost pulling fire hoses up to great heights, so-called dry risers must be installed. These are pipes that run vertically from the ground floor to the higher floors which can be used by fire fighters for pumping water upwards. They can then attach their hoses to the pipes.